Effect of permanent shade netting on 'Nadorcott' mandarin tree phenology and productivity

By

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Thesis presented in partial fulfilment of the requirements for the degree of Master of Science

in Agriculture (Horticultural Science) at the University of Stellenbosch

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March 2018

DECLARATION

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Date: 28/02/2018

ACKNOWLEDGEMENTS

I am indebted to the following people and institutions for their various contributions to the successful completion of this study:

My Heavenly Father, for giving me the courage, wisdom, and strength to complete this study.

My supervisor, Dr. Paul Cronjé, for his expert guidance, constructive criticism, invaluable advice, and the industry exposure, which made this study both enjoyable and challenging.

My co-supervisor, Jakkie Stander, for encouraging me to pursue a career in citrus, his expert guidance, invaluable advice and innovative thinking, which made this study both enjoyable and challenging.

Dr. Willem Hoffmann for his expert guidance and contributions towards the completion of the budget model.

My parents, Robert and Anneke, for encouraging me to pursue my dreams, and teaching me that anything is possible through humbleness, respect, dedication and perseverance.

My team-citrus partners, Du Toit Prins and Johané Botes, for all the encouragement and orchard conversations.

Jade North and all the lab staff, for their technical assistance with my trials.

Citrus Research International, for the financial support.

Mouton citrus and Conrad Vorster, for providing the trial site and the willingness to assist with field work.

SUMMARY: Effect of permanent shade netting on 'Nadorcott' mandarin tree phenology and productivity

Permanent shade netting in citrus (*Citrus* spp.) is implemented to protect high-value fruit and trees from damaging natural elements. However, the use of the technology accompanies inevitable changes in orchard microclimate that impacts on the physiology and phenology of a citrus tree. In this study a 20% white permanent shade netting treatment was evaluated for its effects on citrus tree phenology, its impact on the efficacy of chemical fruit thinning agents, and the long-term profitability of the technology in a young 'Nadorcott' mandarin (*C. reticulata* Blanco) orchard. Shade netting did not enhance the growth of individual vegetative shoots but did increase tree volume over time. In general, flowering was not affected by the shade net treatment, but during the second season, flowering intensity on summer vegetative shoots was higher in the shade net treatment. Fruit set, fruit yield and fruit internal quality were not affected by the shade net treatment, but fruit diameter was increased in the second season. Shade netting did not influence the ability of uniconazole soil-drench treatment to reduce vegetative growth. The shade net treatment did not influence the efficacy of synthetic auxin fruit thinning agents to thin fruit. The synthetic auxin fruit thinning treatments increased the concentration of selected mineral elements in fruit, and treatments resulted in a shift in fruit size distribution, with higher number of large, premium-sized fruit per tree. The effect on fruit size distribution was more pronounced in the shade net treatment. Apart from fruit size, a combination of shade netting and chemical fruit thinning treatments had no effects on other important fruit quality attributes. From the budget model generated in this study, it can be concluded that 20% white permanent shade netting resulted in increased orchard profitability, despite a high establishment cost and increase in production costs. It can therefore be concluded that under typical Mediterranean-type production conditions, 20% white permanent shade netting increased the productivity and profitability of a 'Nadorcott' mandarin orchard.

The use of the technology can be recommended in areas that experience extensive yield losses due to climatic conditions and possibly also permit citrus production in non-traditional areas.

OPSOMMING: Die effek van permanente skadunet op die fenologie en produktiwiteit van 'Nadorcott' mandaryn

Die implementering van permanente skadunet-strukture om vrugtegewasse teen nadelige natuurlike elemente te beskerm geniet wêreldwyd toenemende aandag. Die tegnologie gaan ongelukkig gepaard met 'n onafwendbare verandering in boord mikro-klimaat, wat kan lei tot fisiologiese en fenologiese veranderinge in die sitrusboom. Om hierdie rede is die impak van 'n 20% wit, permanente skadunet op die fenologie en die doeltreffendheid van chemiese vruguitdunning in 'n model mandaryn kultivar, 'Nadorcott' ondersoek, sowel as die winsgewendheid van die tegnologie oor die langtermyn. Die skadunet behandeling het nie vegetatiewe groei van individuele lote bevorder nie, maar wel boomvolume verhoog. Opvolgblom in die lente was oor die algemeen nie beinvloed deur die skadunet behandeling nie, maar in die tweede seisoen het die skadunet blomintensiteit verhoog op lote wat in die voorafgaande somer ontwikkel het. Die finale vruggrootte is verhoog deur die skadunet in die tweede seisoen, maar vrugset, oeslading en interne vrugkwaliteit is nie beinvloed in enige van die seisoene nie. Die effektiwitiet van unikonasool as 'n grondtoediening om lootgroei te inhibeer is nie geaffekteer deur die skadunet behandeling nie. Die doeltreffendheid van blaarbespuitings van sintetiese ouksiene as chemiese uitdunmiddels is nie geaffekteer deur die skadunet behandeling nie. Daar is ook gevind dat die ouksien behandelings die konsentrasie van sekere minerale nutriente in die behandelde vrugte verhoog het, en gelei het tot meer vrugte in die groter kommersiële vrugklasse. Die skadunet behandeling het hierdie effek van die sintetiese ouksiene op vruggrootte bevorder, en geen effek op die interne vrugkwaliteit gehad nie. Die begrotingsmodel wat saamgestel is het getoon dat 'n 20% wit, permanente skadunet die vermoë het om die wingewendheid van 'n mandaryn boord te verhoog, ten spyte van die hoë insetkoste en verhoogde produksiekoste. Deur gebruik te maak van 'n 20% wit, permanente skadunet kan die produktiwiteit en winsgewendheid van 'n 'Nadorcott' mandaryn boord dus verhoog word in ‘n tipiese Meditereense-tipe klimaat, en kan hierdie praktyk aanbeveel word in areas waar ongure klimaatstoestande tot grootskaalse oesverliese lei.

This thesis is a compilation of chapters, starting with a literature review, followed by three research papers. The first two research papers were prepared as scientific papers for submission to Journal of the American Society for Horticultural Science. Repetition or duplication between papers might therefore be necessary. The third research paper was prepared as an agricultural economics research paper, and the style therefore differs from the scientific papers.

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1. General Introduction

Global trade and production of citrus (*Citrus* spp.) fruit is ever increasing and consumers are becoming progressively demanding in terms of fruit external appearance, internal fruit quality and production efficiency. In addition to fruit external appearance, one of the most important fruit internal quality attributes is seedlessness, especially in production of high-value mandarin (*C. reticulata* Blanco) cultivars. To meet the increasing demand for fresh citrus fruit, producers have to adapt and implement new cultural practices to increase production volume and efficiency.

Considering the impact of external damage of citrus fruit, the control of those environmental factors responsible, as well as those of insects and pathogens, should ideally be managed to reduce losses in production. Environmental factors accounting for external fruit damage include climatic extremities such as temperature, wind, and hail, amongst others. Pests and disease damage can be controlled to a certain extent within an orchard, but annually, sunburn, hail, and high seed counts account for major financial losses, unless modern technologies such as permanent shade netting are implemented.

During the past decade, the use of permanent shade netting in citrus has been found to be effective in reducing both high seed counts and fruit cosmetic damage. The use of permanent shade netting, however, accompanies inevitable changes in orchard microclimate such as reduced radiation and wind speed, while relative humidity and ambient temperature are increased (Perez et al., 2006; Stamps, 1994; Wachsmann et al., 2014). In citrus, shade netting increases vegetative growth, fruit set and fruit yield (Raveh et al., 2003; Wachsmann et al., 2014). These results have been reported for different cultivars and under various coloured netting, but the influence of a standard 20% white permanent shade netting structure on the vegetative growth, flowering and fruit set of 'Nadorcott' mandarin (*C. reticulata* Blanco) is not known and needs to be quantified.

Furthermore, the impact of shade netting on cultural practices such as the foliar application of plant growth regulators (PGRs) such as chemical fruit thinning agents to adjust crop load and improve fruit quality, has not been elucidated (Guardiola and García-Luis, 2000; Mesejo et al., 2003). Since permanent shade netting alters important environmental factors that affects the uptake of foliar applied substances (Bukovac, 1972), the efficacy of PGR applications may be altered by shade netting.

The use of permanent shade netting is an effective tool to increase production efficiency and to minimize risk, but to what extent the phenology of a citrus tree and other associated cultural practices would be influenced, is unknown. The aim of this study was therefore to determine the effect of 20% white permanent shade netting on the phenology of ‘Nadorcott’ mandarin trees over a period of two seasons. The following aspects were specifically addressed in this study:

1) A comprehensive literature study focussed on the possible impacts of shade netting on citrus phenology;
2) An evaluation of the effects of permanent shade netting on tree phenology over a period of two seasons;
3) A determination of the effects of shade netting on foliar applied synthetic auxin fruit thinning agents, 2,4-dichlorophenoxy propionic acid and 3,5,6 trichloro-2-pyridiloxyacetic acid;
4) The evaluation of the financial impact of permanent shade netting under South African production conditions, to determine the long-term profitability of this capital-intensive technology.

This study forms part of a larger project in which the impacts of shade netting on orchard microclimate, tree carbohydrate assimilation, and fruit quality were also quantified and documented.

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2. Literature review – Citrus phenology influenced by shade netting

Permanent shade netting structures are becoming an increasingly popular cultural practice in the global citrus industry. The effect of shade netting on the phenology of a citrus tree is however a new field of study, and the efficacy of cultural practices such as foliar application of plant growth regulators may be influenced. This review was conducted to study available information on citrus phenology, relating it to the effect of shade netting and to hypothesize on how this technology will possibly influence the phenology of a citrus tree.

2.1 Citrus phenology

2.1.1 Root growth phenology

In general, the citrus root system consists of a taproot forming a primary axis, which is flanked by lateral roots. Although this is the general structure of the citrus root system, root architecture may vary according to different cultivation and irrigation practices. According to Castle (1987), root systems of citrus trees acquire a bimorphic structure with time, which refers to the lateral roots forming two horizontal layers in the soil, with the first layer being a fibrous mat of lateral roots close to the soil surface, responsible for rapid uptake of nutrients and water. The second layer occurs deeper in the soil and acts as a buffer for water uptake during prolonged dry periods (Spiegel-Roy and Goldschmidt, 1996), while also being responsible for uptake of minerals that leached through the first layer of the lateral roots. Root growth patterns may also be influenced by irrigation, as secondary roots in drip irrigated orchards grow a pot-like structure under the dripper (Bravdo et al., 1992).

Citrus root growth occurs in two to three major cycles per annum (Crider, 1927; Marloth, 1949). The growth flushes of citrus roots are tightly controlled by shoot growth, soil water content and soil temperature (Bevington and Castle, 1985). At optimum soil temperature and soil water content, shoot growth is the major factor influencing root growth. In deciduous fruit trees, shoot and root growth occurs in alternate cycles, which indicates that the rate of root growth declines while shoots are growing actively (Head, 1967). In evergreen citrus trees, a similar pattern exists, viz. as the rate of shoot growth increases, root growth rate decreases. Root growth will remain inactive until the cessation of shoot growth, and will commence immediately thereafter (Bevington and Castle, 1985). In contrast with these findings of alternate growth, concurrent root and shoot growth in citrus has also been reported under mild subtropical, summer rainfall conditions (Marloth, 1949).

Soil temperature is a crucial factor determining citrus root growth and according to Spiegel-Roy and Goldschmidt (1996), the minimum soil temperature for active root growth, also referred to as the biological zero, is 13°C. Limited root growth occurs between 18°C to 22°C, while root elongation mainly occurs between 22°C and 28°. Optimum root growth is experienced at soil temperatures higher than 29°C (Bevington and Castle, 1985), while temperatures reach an optimum at 36°C, where after root growth will successively be restricted.

Other factors influencing root growth is soil water content and fruit load. If water stress occurs, root growth will cease and will only commence after irrigation, if all other conditions are favourable (Bevington and Castle, 1985). In studies done on alternate bearing citrus trees, it was found that high crop load restricted root growth, due to possible competition and depletion of tree carbohydrates (Goldschmidt and Golomb, 1982; Jones et al., 1975).

2.1.2 Vegetative growth phenology

Citrus shoot growth occurs in distinctive waves or “shoot growth flushes”, which generally occurs in a series of two to five intense shoot growth waves per annum (Bain, 1949; Iwasaki and Owada, 1960). Shoot growth flushes mainly occur during spring, summer and autumn. The spring flush is the most important for reproductivity as it consists of both reproductive and vegetative shoots. Furthermore, the main flush responsible for the vegetative development of the tree is the summer flush, which will become increasingly important for vegetative development as the tree matures, as the spring flush will tend to become solely reproductive with tree age (Spiegel-Roy and Goldschmidt, 1996). The spring flush is the longest in duration (Cooper et al., 1963), although contradicting evidence was found by Krishnamurti et al. (1960) who found that the main summer flush occurred over a longer period. In tropical climates, such as Florida USA, citrus shoot growth is known to occur in a continuum, all year round, with no definite flushes. With regard to flowering and reproductivity, all flushes in the current season are important, as these will serve as the reproductive shoots for the following fruiting season (Spiegel-Roy and Goldschmidt, 1996).

Bud sprouting in citrus occurs without a definite cold requirement and dormancy, as required in deciduous fruit trees (Stathakopoulos and Erickson, 1966). However, it was found that heat plays a crucial role, and that bud sprouting occurred only when soil temperatures exceeded 12°C (Mendel, 1969). These new shoots normally emerge from axillary buds close to the shoot tip with a slight angle to the previous, and is normally soft with a triangular form, and rounds off with secondary growth (Spiegel-Roy and Goldschmidt, 1996). Axillary buds occur along the shoot in the axil of every leaf and may be accompanied by thorns in juvenile or vigorously growing trees or cultivars, while the leaves are normally arranged in spiral phyllotaxy (Spiegel-Roy and Goldschmidt, 1996).

2.1.3 Factors influencing citrus vegetative growth

The main environmental factors influencing shoot growth are temperature, light, and relative humidity (RH), with RH being a minor influencing factor. Temperature exerts a crucial regulatory role in shoot growth, and extremes in temperature may inhibit shoot growth completely. The optimum temperature for citrus shoot growth is 23°C to 34°C, with the minimum temperature being 13°C. The maximum temperature above which citrus shoot growth ceases, ranges between 37°C and 39°C (Bain, 1949; Webber, 1943). In an enclosed shade netting structure, as used to prevent pollination, the ambient temperature tends to be higher than the outside environment (Pérez et al., 2006; Stamps, 1994). This may be beneficial for shoot growth early during the growing season when temperatures are low but can also serve to restrict shoot growth during hot summer conditions. Stamps (1994) also confirmed that the relative humidity under shade netting is higher, which is beneficial for vegetative growth and photosynthesis (Jifon and Syvertsen, 2001). Furthermore, Cooper et al. (1963) reported that elevated temperatures with high RH will stimulate increased shoot growth activity.

The intensity and the quality of radiation also has a direct influence on shoot growth. The properties of light quality that influence shoot growth is the red to far-red ratio (Piringer et al., 1961) as well as the UV content. Light intensity however, shows an inverse relationship with shoot growth in citrus, thus, higher irradiation leading to less shoot growth (Piringer et al., 1961). Shade netting is known to reduce radiation (Monselise, 1951), thus Piringer et al. (1961) hypothesized that shade netting will favour citrus shoot growth with decreasing light intensity.

From reviewing the factors influencing shoot growth, it can be hypothesized that citrus shoot growth will be enhanced by shade netting.

2.1.4 Vegetative growth of fruit crops as influenced by shade netting

In this section, the effect of shade netting on various other fruit crops will be explored as background to relate to, and explore the possible effects on citrus. One of the first noticeable effects reported when producing fruit crops under shade netting, is the change in the vegetative growth response. For most fruiting crops, shade netting is reported to enhance vegetative growth, however, the response is dependent on the colour of the net (Stamps, 2009). In peach (*Prunis persica v. Hermosa)*, Shahak et al. (2004) reported that shade netting resulted in increased vegetative growth with blue, grey, pearl and yellow (30% shade factor) as well as for a 12% white shade net. In contrast, in a study conducted in Southern Italy it was found that blue shade netting decreased the vegetative growth in kiwi (*Actinidia deliciosa* cv. Hayward), compared to the no-net and red net treatments (Basile et al., 2008), while blueberry (*Vaccinium* cv. Berkely) vegetative growth under black shade nets was higher, while white, red, and grey nets had no significant effect on vegetative growth (Retamales et al., 2008).

In studies done on citrus shade netting, similar trends were reported. In a study in three-year-old, de-fruited 'Murcott' mandarin (*C. reticulata* Blanco) grown in Israel, three treatments were carried out under highly reflective aluminized shade netting. Two of the treatments were in shade tunnels and the third under 60% flat shade net, with the 30% tunnel treatment showing a significant increase of 34% in tree height after only three months (Raveh et al., 2003). Wachsmann et al. (2014) evaluated the difference in canopy volume in 5-year-old 'Orri' mandarin after being covered for two years by different coloured shade netting. In this experiment, trees grown under 25% red nets had the largest canopy (43 m^3), followed by trees under 24% yellow netting (42 m^3). However, trees under clear and 18% white shade netting differed significantly from the red treatment with volumes of 35 m^3 and 31 m^3 respectively. The control trees, grown in the open, had significantly smaller canopy volumes of 25 m^3, compared to all the other netting treatments.

Most of the research on fruit crops, except for kiwi, suggests that shade netting increases vegetative growth, with the intensity depending on the colour of shade netting. This could be beneficial for young tree canopy development and filling allocated in-row space in the orchard, but could result in additional pruning costs as the trees mature.

2.2 Reproductive phenology of citrus: Flowering and fruit set

2.2.1 Flowering: General phenology

Flowering and fruit development is an annual event for citrus grown in sub-tropical areas (Davenport, 1990). In sub-tropical areas, flowering occurs in response to inductive cool winter temperatures. These winter inductive temperatures are followed by the spring flush, which consists of flowers for the entire crop cycle (Davenport, 2000; Guardiola et al., 1982; Valiente and Albrigo, 2004). In tropical growing regions, lacking cold winter temperatures, citrus is known to flower all year round, but can however be manipulated by irrigation after a period of drought stress (Bain, 1949; Schneider, 1968).

In citrus, flowering occurs on the previous season's vegetative flush shoots (Spiegel-Roy and Goldschmidt, 1996), and the axillary buds on these shoots differ in their ability to sprout (Guardiola, 1981). The factors determining the ability of a bud to flower include bud age and bud position. (Krajewski and Rabe, 1995). The position of the bud refers to its position on the bearing unit i.e. proximal to distal, and Valiente and Albrigo (2004) reported that buds in proximal positions flowered more readily. Older buds (≥12 months) are known to flower less readily than buds between 5 and 8 months of age (Guardiola, 1981; Guardiola et al., 1982; Lovatt et al., 1984). Krajewski and Rabe (1995) also reported that buds between 5 and 8 months flowered more readily, concurring with other studies that showed that only buds younger than one-year contribute to flowering (Guardiola, 1981; Lovatt et al., 1984). Furthermore, shade conditions (low PAR) perceived by bearing units inside the tree canopy will tend to break and flowers less readily (Lewis and McCarthy, 1973), which suggests that bud break and flowering may be negatively affected by shade netting. Fruit originating from these shaded flowering units will also tend to have reduced colour development and increased susceptibility to rind disorders due to lower transpiration and subsequent nutrient levels (Cronjé, et al., 2011). Shoots that exhibit strong flowering are usually situated towards the outer parts of the tree canopy and grows in a distinctly vertical pattern (Krajewski and Pittaway, 2000).

The main flowering period for citrus occurs in the spring. During this stage, three different types of shoots develop i.e. vegetative, pure reproductive (leafless inflorescence), and mixed reproductive (leafy inflorescence) (Davenport, 1990). Vegetative shoots, bearing only leaves, are partially responsible for the flower bearing units in the next season, and tend to be the longest of the spring sprouts (Spiegel-Roy and Goldschmidt, 1996). Pure reproductive shoots are the shortest, exclusively bears flowers, and named leafless inflorescence, whereas mixed shoots consist of flowers and leaves and are referred to as leafy inflorescence (Davenport, 1990). The terminal flower buds sprout first (Guardiola et al., 1982) and leafy inflorescence tend to dominate at these terminal positions, while buds at the lower lateral positions tend to sprout leafless inflorescence (Valiente and Albrigo, 2004).

2.2.2 Flower development: Induction, initiation and development

Citrus flower development is a complex set of events that occur inside the flower bud before anthesis in the spring (sub-tropical climates). Flower development in citrus occurs during the quiescent phase of the tree, i.e. during the winter in sub-tropical climates or during periods of drought stress in summer rainfall areas (Spiegel-Roy and Goldschmidt, 1996) and is divided into three phases, viz. floral induction, floral initiation and evocation or floral differentiation (Davenport, 1990).

Flower induction occurs when an activating or depressing mechanism within the buds interacts with exogenous and endogenous factors. This commits the meristematic tissue of the bud to either a reproductive or vegetative state (Davenport, 1990). Nishikawa (2013) described induction as a phase when a newly synthesized protein is present in the tree, which initiates the induced state in the buds. For several decades citrus was thought to have a quiescent phase for induction to occur. However, in molecular studies done by Komeda (2004) and Pin and Nilsson (2012), flowering related genes were discovered for citrus. This gene became known as the FLOWERING LOCUS T (FT) and was subsequently also found in deciduous fruit trees (Kotoda et al., 2010) and in citrus (Nishikawa et al., 2007).

The identification of Citrus FLOWERING LOCUS T (CiFT) lead to an improved understanding of floral induction and Nishikawa et al. (2007) stated that CiFT increases concurrently with inductive conditions. Physiological studies identified inductive conditions as prolonged water stress (Davenport, 1990) and low temperatures (<15°C) (García-Luis et al., 1992), which subsequently increase the expression of CiFT in the leaves, buds and stems (Nishikawa et al., 2007; Nishikawa, 2013). This increase of CiFT leads to the transcription of CiFT m-RNA, which encode for the CiFT protein (Florigen) (Nishikawa, 2013). The protein product or the CiFT itself is then transported via the phloem to the buds where it commits the bud to become reproductive (Nishikawa, 2013).

After flower induction, floral initiation occurs, which is the physiological and biochemical events occurring in the bud involving the molecular transition of the meristematic tissue from vegetative to reproductive in reaction to sufficient amounts of FT- protein in the bud (Davenport, 1990; Nishikawa, 2013). Flower differentiation is the final stage of floral development where histological and morphological manifestation takes place in the form of cell division and organ development (Davenport, 1990). This stage will only occur after a prolonged period of chilling or water stress (García-Luis et al., 1992). Conditions favourable for bud sprouting then leads to flower differentiation and development (Furr and Armstrong, 1956; Randhawa and Dinsa, 1947).

2.2.3 Fruit set

Fruit set is the most important step determining final yield (Ruiz et al., 2001), and is defined as the process after fertilization, where the flower ovary adheres and develop into a mature fruit. Citrus exhibits three types of ovary fertilization namely, self-compatible, self-incompatible/facultative parthenocarpy and true parthenocarpy (Iglesias et al., 2007). Self-compatible cultivars like the sweet orange (*C. sinensis* cv. Pineapple), need ovaries to be pollinated, as these ovaries will arrest growth and abscise if unpollinated (Ben-Cheikh et al., 1997). These ovaries will abscise due to a lack of re-activation of cell division and gibberellin (GA) synthesis after bloom if not fertilized (Ben-Cheikh et al., 1997), thus fertilization through pollination is key for cultivars in this category. Self-incompatible cultivars such as 'Nules Clementine' grow seeded fruit when cross-pollinated, but also exhibit weak parthenocarpy. Self-incompatible fruit set can however be manipulated with gibberellic acid (GA_3) application in the absence of a source of cross-pollination (Iglesias et al., 2007). True parthenocarpy refers to cultivars of citrus such as Satsuma mandarin *(C. unishiu Marc.)* and Navel sweet orange, as these cultivars exhibit gametic sterility and endogenous signals have replaced all pollination and fertilization requirements (Frost and Soost, 1968). Due to the gametic sterility, cultivars that exhibit parthenocarpy will always set seedless fruit (Iglesias et al., 2007).

Citrus fruit set is a complex process which is controlled by a composite set of regulatory factors including carbon status, plant hormones, nutrients, irrigation and bearing unit type. Fruit set is generally expressed as a percentage of the initial flowers that develop to actively growing fruit, and is generally between 0.1 to 10% (Goldschmidt and Monselise, 1977). Fruit set is evaluated a few weeks after anthesis, after the period of physiological fruit drop [November drop for Southern hemisphere (SH)] (Agustí et al., 1982). Citrus has two known fruit drop waves determining final fruit set, with the first fruit drop period during flowering or after petal drop, and the second wave approximately 60 days after full bloom, also called physiological fruit drop or November drop in the SH (Agustí et al., 1982).

During the first wave of fruit/flower abscission, the plant hormones GA, abscisic acid (ABA) and 1-aminocyclopropane-1-carboxylic acid (ACC), a precursor of ethylene, interact to affect abscission (Iglesias et al., 2007), with GA playing the crucial role (Talon et al., 1990). Self-compatible, parthenocarpic and facultative parthenonocarpic cultivars exhibit a lack in sufficient endogenous GA levels in the ovaries during flowering if not pollinated (Iglesias et al., 2007). This lack of sufficient GA causes the levels of ABA to rise, which activates an increase in ACC and finally ethylene synthesis, and subsequent abscission of the ovary (Ben-Cheikh et al., 1997; Iglesias et al., 2007). However, exogenous foliar application of GA_3 can replace deficient internal GA levels in facultative and truly parthenocarpic cultivars (Iglesias et al., 2007) and induce fruit set. This does however not hold true for unpollinated self-compatible cultivars (Ben-Cheikh et al., 1997).

Carbohydrate supply is a major fruit set determinant during the second wave of fruit abscission as it supplies the necessary energy to facilitate this final stage of fruit set (Goldschmidt and Monselise, 1977; Iglesias et al., 2003; Iglesias, et al., 2007; Rivas et al., 2006; Ruan 1993; Schaffer et al., 1985). The second wave of fruit abscission is often referred to as a natural self-thinning mechanism where the tree adjusts its fruit load according to its carbohydrate status. Experiments conducted with various techniques such as girdling (Rivas et al., 2006), direct tree sucrose supplementation, defoliation (Iglesias et al., 2003), and darkening (Ruan, 1993), all confirmed that increased carbohydrate status exhibits a positive correlation with fruit set. During fruit set, carbohydrates are mainly metabolized from stored reserves and depends on the photosynthetic capacity of old leaves (Iglesias et al., 2003), as young leaves will only start contributing when leaf maturity is reached (after 1-2 months) (Moss et al., 1972). A carbohydrate shortage during this stage will lead to the triggering of hormonal fruit drop which will in this case be activated by deficient auxin levels from the fruitlet and will lead to fruitlet abscission and a intensefied physiological fruit drop (Iglesias et al., 2007).

Other factors regulating fruit set during the second abscission wave include mineral nutrient supply, bearing unit type, and temperature. Foliar nitrogen applications during the winter pre-bloom and full bloom periods enhances fruit set (Lovatt, 1999), while studies on bearing units found that leafy inflorescences exhibit stronger fruit set than leafless inflorescences (Lovatt et al., 1984). Furthermore, Reuther (1973) examined the behaviour of citrus in reaction to climate, and found that extreme heat waves during the time of fruit set can lead to devastating fruit drop intensities due to plant stress and the activation of the hormonal abscission pathway.

2.2.4 Flowering and fruit set of fruit crops as influenced by shade netting

To date, very little research has been done on the effect of shade netting on flowering intensity of fruit crops. In Italy it was found that Kiwi flowering was reduced under shade net treatments, compared to control (Basile et al., 2008). Shahak et al. (2004) however found that 12% white shade net as well as red, pearl blue and yellow netting, all with 30% shading, increased flowering of peach trees. For Cripps Pink and Braeburn apples *(Malus domestica* Borkh.*)*, covered with 20% black nets resulted in a higher percentage reproductive buds under shade nets (Smit, 2007), concurring with the results found on peaches.

Shahak et al. (2004) reported that red and white shade netting which reduced PAR with 20%, increased fruit set on ‘Smoothee Golden Delicious’ apple. Wachsmann et al. (2014) reported that ‘Orri’ mandarin also showed an increase of 23% and 29% fruit set under 18% white and 13% transparent nets, respectively.

2.3 Reproductive phenology of citrus: Fruit growth

2.3.1 Fruit growth

One of the main fruit quality attributes affecting the economic value of citrus, is fruit size, with fruit growth rate being the physiological process that affects final fruit size. Fruit growth in citrus is a complex process consisting of various phases, with many factors influencing the rate thereof. A ground-breaking study by Bain (1958) found that citrus fruit growth can be divided into three distinct phases and that fruit growth follows a sigmoidal curve, with phase I being the slow growth, phase II exponential growth, and phase III the maturation phase (Bain, 1958).

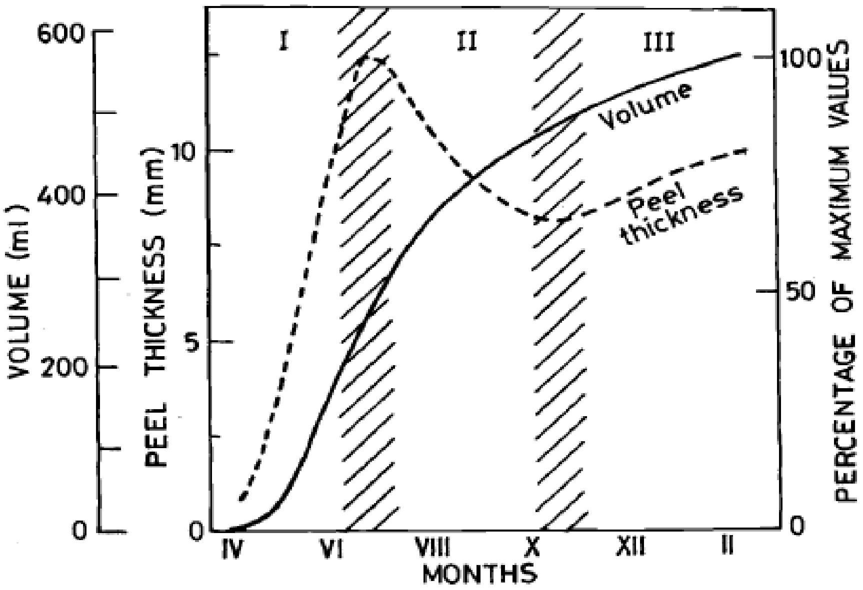

Fig. 2.1. Fruit growth of 'Valencia' orange. Volume and peel thickness during the developmental stages I, II and III (Bain, 1958), adapted from Spiegel-Roy and Goldschmidt (1996).

Stage I of fruit growth is the cell division stage and commences directly after or during anthesis, with a duration of two to three months (± 75 days) depending on cultivar and climatic conditions, but normally lasts until physiological fruit drop (Bain, 1958). During this phase, a slow increase in fruit diameter is experienced due to cell division and can mainly be ascribed to an increase in rind thickness (Spiegel-Roy and Goldschmidt, 1996), with the rind reaching its maximum thickness at or just after the end of stage I in grapefruit (Bain, 1958) as well as in mandarin (Kuraoka, 1962).

Stage II of fruit growth is the phase of rapid cell and fruit enlargement. The increase in size during this stage is mainly due to pulp growth which can last for approximately 29 weeks in oranges (Bain, 1958). During stage II juice sacs fill the fruit locules as water accumulates in the pulp (Iglesias et al., 2007), while the rind stretches to accommodate the extra volume (Bain, 1958). Fruit growth is arrested at the end of phase II, with the onset of colour change in the rind, from green to yellow. The change in rind colour is accompanied by sugar accumulation and a reduction in acidity (Spiegel-Roy and Goldschmidt, 1996).

The last fruit developmental phase, stage III, is characterized as the phase of fruit maturation. During this stage, the total soluble solids of the pulp increases, which is accompanied by a decrease in citric acid content and the change in rind colour (Bain, 1958). Bain (1958) also found that during this phase, fruit growth may resume, and if pulp growth does not keep up with the peel it can lead to a condition known as peel-puffiness (Kuraoka, 1962).

2.3.2 Factors influencing fruit growth

Several factors influence citrus fruit growth and thus final fruit size. Thus, it is crucial to have a clear understanding of these factors and how they influence each other. Factors influencing fruit growth are divided into various categories, but for this study they will be reviewed as either climatic (uncontrollable), or horticultural (controllable).

Reuther (1973) investigated the behaviour of the citrus tree and fruit in reaction to a change in climate, and found that the climatic components influencing fruit size are the following: air temperature, radiation, rainfall, day length as well as wind and humidity. Several studies were done on temperature effects on fruit growth, and from these studies, it is apparent that temperature and radiation have different effects on fruit size during the respective stages of fruit growth. It was found that during the pre-bloom period, higher day and night temperatures resulted in bigger fruit at harvest, although a decline in fruit growth is experienced at temperatures above 30°C for prolonged periods during stage II of fruit growth (Du Plessis, 1982; Reuther, 1973). During the fruit set period, however, elevated temperatures may lead to extensive fruit drop, resulting in reduced yield per tree and big fruit at harvest (Gilfillan, 1987). In addition, high wind speeds can contribute to fruit stress, and when accompanied by low soil temperatures on hot days, the roots may not keep up with transpiration, leading to water stress and an intensified fruit drop (Gilfillan, 1987). It was also found that dry winds associated with low humidity (as low as 4%) had an irreversible negative effect on fruit size (Erickson, 1968). These climatic conditions, however, can be manipulated with shade netting.

Unlike climatic factors, horticultural factors are controllable and can be manipulated to a certain extent. The first action in manipulating fruit size is selecting the rootstock and scion combination. Some citrus cultivars are prone to grow smaller fruit than others (Gilfillan, 1987). Vigorous rootstocks such as Rangpur lime (*C. limonia* Osbeck) and Rough lemon (*C. jambhiri* Lush*)* tend to grow bigger fruit than their less vigorous counterparts, such as Carrizo and Troyer citrange (Wutscher, 1979). However, deciding on a rootstock is more complex, and attributes such as water stress -, salinity-, and disease tolerance should also be considered, as they can have a secondary negative effect on tree health and thus fruit size (Gilfillan, 1987). Root viruses, rot diseases and nematodes are all factors that should be kept to a minimum for optimum fruit size, as these will all impede the overall fitness of the tree and can ultimately lead to less total tree carbohydrates and smaller fruit (Hamid et al., 1985; Olson, 1969).

Other factors influencing fruit size include mineral nutrition, irrigation and crop load. Studies on mineral nutrition found that potassium and nitrogen correlates positively with fruit size when applied as foliar sprays on 'Nules Clementine' and certain sweet orange cultivars (Lovatt, 2013). Furthermore, irrigation and timing thereof are key for fruit size, as it was found that deficit irrigation of 25% and 50% on 'Nules Clementines' during stage II of fruit growth, led to a 11% and 25% decrease in fruit size as early as in autumn already (Gonzalez-Altozano and Castel, 1999). Water stress during stage I of fruit growth will result in decreased fruit set, but water stress during stage II will significantly impede fruit size (Du Plessis, 1986), as this is the stage of rapid fruit cell expansion and water accumulation (Bain, 1958). High fruit load is the final, and probably the most important factor that influences fruit growth, and it is due to increased competition for carbohydrates between fruits. High fruit load can however be manipulated in several ways, and will be explored later in this review (Goldschmidt, 1999).

2.3.3 Fruit growth and yield of fruit crops as influenced by shade netting

As previously mentioned, fruit size is directly influenced by crop load, and conclusions drawn about one of these factors should always be done in relation to the other. In plants, fruits are a major sink and competes for assimilates with roots and shoots (Kozlowski, 1992). The obvious conclusion can therefore be made that the higher the number of sinks on a plant, the less assimilates each sink will receive. Thus, high fruit load will lead to smaller fruit due to source dilution, except for when the photosynthetic capacity of the source is up-regulated (Taiz et al., 2015).

Keeping the above mentioned in mind, it was found that shade netting increased apple fruit size and yield, even if the nets were applied after bloom (Shahak et al., 2008), while blueberry yield was increased under 50% white nets, while 35% white nets had no significant effect (Retamales et al., 2008). In contrast, shade netting of kiwi vines reduced fruit yield, but led to an increase in fruit size, resulting in a crop of the same economic value (Basile et al., 2008). Shahak et al. (2004) found that peach fruit size was improved under nets, while a study on pear (*Pyrus communis* L.*)* under pearl netting also reported increased fruit size (Shahak, et al., 2008). Studies on citrus show that 'Orri' mandarin yield was increased under 18% white and 13% transparent nets (Wachsmann et al., 2014), which contradicts with results found by Cohen et al. (2005) who found that aluminized netting with shade percentages of 30% and 60% had a negative impact on grapefruit *(C. paradisi* L.*)* yield.

2.4 Citrus physiology: Hormones in Citrus

Plant hormones exert a crucial role in citrus fruit production and are highly influential during the processes of flowering (Guardiola, et al., 1982; Iglesias et al., 2007), fruit set (Talon et al., 1990), fruit abscission (Iglesias et al., 2007) and vegetative growth (Spiegel-Roy and Goldschmidt, 1996). Hormones differ in their effect on citrus physiology and phenology, and some may exhibit interactions. In terms of plant growth regulators in citriculture, it is key to understand the effects of endogenous hormones and their interactions. The main endogenous hormones involved in citrus growth are gibberellin (GA), Auxin (IAA), cytokinin (CK) and abscisic acid (ABA) and will be explored in the following section.

2.4.1 Auxin (IAA)

The first studies on IAA were done in the nineteenth century by Charles Darwin, who investigated the influence of light on the bending of coleoptiles during seedling growth. However, he could not identify the responsible compound, and studies by Frits Went in 1926 found that this same substance transmitted from growing tips of seedlings induced elongation of coleoptile sections. This growth promoting substance was named auxin, from the Greek word *auxein*, which means to "grow" or to "increase" (Taiz et al., 2015). In the mid 1930's, endogenous auxin was eventually identified to be indole-3-acetic acid (IAA), and while several other forms of auxin exist in higher plants, IAA is by far the most abundant (Kögl et al., 1933). The first studies on citrus however, suggested that the compound found in citrus fruits was not IAA, but a compound specific to citrus referred to as "citrus auxin" (Khalifah et al., 1963). However, after the 1960's the evidence mounted against the hypothesis of the so called "citrus auxin", and in the 1970's IAA was isolated from vigorously growing lemon and orange shoots, at very low concentrations [<1µ/g fresh weight] (Goldschmidt et al., 1971; Goldschmidt, 1976).

IAA is assumed to be synthesised at low levels in all parts of the plant. However, the tissues responsible for high IAA synthesis are generally associated with rapid dividing cells and growing plant tissues such as apical regions of growing shoots, young leaves and actively growing fruit and seeds (Taiz et al., 2015). These sites of IAA synthesis are similar for citrus and were found to be synthesized in young vigorously growing shoots of orange and lemon (Goldschmidt et al., 1971), in young growing fruit (Yuan et al., 2003), and in in developing ovaries (Goren and Goldschmidt, 1970). Although young ovaries and young fruit showed high IAA activity, maximum fruit IAA content of 'Satsuma' mandarin was observed about 10 days after full bloom (dafb.) from where after it declined to undetectable levels about 40 dafb. (Takahashi et al., 1975). Concurring results were found in 'Valencia' orange fruit, where higher export and levels of IAA were found for young developing fruit in stage I of fruit growth, than during stage II and III (Yuan et al., 2003).

Transport of IAA in higher plants is more complex than that of other hormones, as IAA is the only hormone that is known to be transported in a polar cell-to-cell fashion (Muday and DeLong, 2001). The mechanism of polar IAA transport became known when studies identified the shoot apex as the primary source of IAA for the rest of the plant, and that a gradient of IAA concentration exists from the shoot to the root tip (Taiz et al., 2015). Polar IAA transport occurs in a cell to cell fashion and not via the apoplast (in between cell walls) or symplast (through cell walls). It diffuses into the cell on one side, undergoes a change in form inside the plasma lamella (from IAAH to IAA^-), and exits the cell again through the plasma membrane on the other side of the cell. This process of polar IAA transport is an active process and consumes energy in the form of ATP and proton extrusion (Friml and Palme, 2002). In higher plants IAA is transported basipetally from the sites of synthesis (shoots) to the roots along the polar pathway (Muday and DeLong, 2001), while recent evidence indicates that a significant amount of IAA is present in the phloem, suggesting that this is the primary pathway for IAA to be transported to the root tip (Baker, 2000). Muday and De Long (2001) also state the more complex IAA transport in roots, where acropetal (to root tip) IAA movement occurs through the central parts of the root, while basipetal (from root tip upwards) IAA transport occurs in the outer layers of the root.

IAA plays a crucial role in several plant responses and processes such as shoot elongation, apical dominance, vascular differentiation, senescence, abscission, and cell enlargement. For this review, only the abscising and cell enlargement effect of IAA will be discussed. IAA plays a crucial role in abscission, which is a major determinant of final yield as mentioned earlier in this review. Abscission of leaves and fruitlets is regulated through a hormonal balance between IAA originating from fruits/leaves and ABA stimulating abscission (Taiz et al., 2015). This hormonal balance is crucial, as fruit drop can be manipulated by altering this balance. Internal fruit IAA content is at a maximum 10 dafb., where after levels decline. Further studies showed that ten days after this maximum IAA concentration in fruit, abscission of fruit started and that the maximum peak of abscission occurred 10 days after the minimum IAA content (Takahashi et al., 1975). The influence of IAA on abscission during this stage of fruit growth, is important for manipulating crop load by means of plant growth regulators (PGR's) and will be discussed later in the PGR section. Exogenous application of synthetic auxins was also found to reduce preharvest drop of oranges (Gardner et al., 1950), by to upregulating endogenous IAA levels and thereby inhibiting fruit abscission.

IAA also stimulates cell enlargement by acidifying the cell walls, thereby activating cell wall loosening enzymes, which results in cell enlargement mediated by the internal turgor pressure of the cell (Vanderhoef and Dute, 1981). In citrus fruit, IAAs are known to stimulate cell enlargement rather than cell division, and foliar applications of synthetic auxin at the onset of fruit growth stage II are known to stimulate cell elongation and fruit growth, whereas application during stage I induces fruitlet abscission (Iglesias et al., 2007).

2.4.2 Gibberellin (GA)

Gibberellins were initially isolated in 1926 from the fungus *Gibberella fujikuroi* by the scientist Eiichi Kurosawa while studying the "foolish seedling" disease in rice (Buchanan et al., 2000). The discovery of GA in citrus, however only came a while later, with the isolation of GA_1 in 'Satsuma' water sprouts by Kawarada and Sumiki in 1959. GA's found in citrus are mainly members derived from the 13-hydroxylation pathway, eventually leading to GA_1, the bioactive form of GA in citrus (Zeevaart et al., 1993).

The production of endogenous GA in citrus is well understood but the source of synthesis is however never clearly stated. Considering plant physiology as a whole, convincing evidence can be found on synthesis and transport of GA as an endogenous growth substance. In plants, the highest concentration of GA is found in apical tissues, young seeded fruit, young leaves and in apical regions of the root (Taiz et al., 2015). These findings however also seem to hold true for citrus, where GA was found in shoots (Goldschmidt, 1976; Poling and Maier, 1988). Fruit set studies found that GA levels of developing fruitlets are significantly higher than in other plant tissues (Goldschmidt, 1976; Talon et al., 1990), with seeded fruit exhibiting the highest GA content, which suggests that seeds are a major source of GA (Iglesias et al., 2007). Spiegel-Roy and Goldschmidt (1996) suggested that roots are also a site of endogenous GA synthesis in citrus, as low soil temperatures and drought restricts GA supply to the aerial parts of the tree, because of root growth restriction.

Research on the mode of transport of GA in citrus is vague, however in all plants GA or intermediates synthesized in apical tissues can be transported via the phloem to other tissues to affect a response or to be further metabolized (Hoad and Bowen, 1968). However, research on citrus indicates that flower induction is inhibited by high fruit load and subsequent endogenous GA production by citrus fruit (Guardiola et al., 1982; Monselise and Halevy, 1964; Plummer et al., 1988), which suggests that GA is also transported via the phloem in citrus. However, Goldschmidt (1976) also states that GA produced in the roots can be transported to the canopy via the xylem.

Being one of the major hormones in citrus, GA plays a crucial role in many physiological aspects of the tree. The role of endogenous GA is an extensively researched field and the influence on the inhibition of flower induction in citrus has been proven by several studies (Guardiola et al., 1982; Koshita et al., 1999; Monselise and Halevy, 1964; Plummer et al., 1988). This is due to heavy fruit loads producing high levels of GA (Plummer et al., 1988), which results in poor return bloom. This suggests that endogenous GA translocation from fruit, inhibits flower bud induction in the current season, which may lead to sparse flowering in the following season. This was confirmed in studies with exogenous GA_3 application during the time of flower bud induction in non-fruiting trees, which also inhibited flower induction, and lead to a decreased flowering reaction the following season (Guardiola et al., 1982; Koshita et al., 1999; Monselise and Halevy, 1964).

GA plays a pivotal role in developing ovaries during the fruit set period, and Soost and Burnett (1961) found that fruit set could be significantly increased by foliar GA_3 application in parthenocarpic fruit set of self-incompatible citrus cultivars, such as ‘Nules Clementine’. In seeded cultivars, there is a definite rise in the ovary GA content after pollination, which is thought to reinitiate cell division and fruit growth (Ben-Cheikh et al., 1997; Iglesias et al., 2007). In parthenocarpic and self-incompatible cultivars this rise in GA after pollination is however less pronounced or absent, resulting in a weakened fruit set response during the initial stages of ovary growth (Ben-Cheikh et al., 1997). The weakened fruit set in these cultivars can however be enhanced by exogenous gibberellic acid (GA_3) application, which acts as a substitute for the lack of seed derived GA, which confirm the crucial role that GA exerts on fruit set during the first stages of fruit growth (Iglesias et al., 2007).

2.4.3 Cytokinin (CK) & Abscisic acid (ABA)

Cytokinin (CK) are universally known as the hormone promoting cell division and can be found in either bound or free form in all plant tissues. CK are primarily synthesized in the root apical meristems (RAM) undergoing active growth (Aloni et al., 2006) and accumulates in mature leaves (Hendry et al., 1982; Van Staden, 1976). Root derived CK along with water and minerals are transported to the aboveground canopy via the transpiration stream in the xylem (Kudo et al., 2010). This was confirmed by studies showing that conditions impeding root growth, such as water stress, reduced the xylem CK content (Itai and Vaadia, 1971). The RAM seems to be the major site of CK synthesis, however, other plant tissues such as young leaves and fruit (Taiz et al., 2015), flowers and ovaries (Goldschmidt, 1976) and seeds (Khalifah and Lewis, 1966), also have the ability to synthesize cytokinin. However, it was found that cytokinin content in fruit of seedless cultivar ‘Salustinia’ was similar to that of the seeded ‘Blanca comuna’ fruit (Hernandez Minana et al., 1989), suggesting that citrus fruit tissues are the major site of synthesis, and not seeds.

The various citrus tissues exhibiting CK activity suggests that CK is highly influential in citrus growth and development. In citrus ovaries and young fruit, CK levels are relatively high from anthesis until 10 to 20 mm fruit diameter (Hernandez Minana et al., 1989), which supports the hypothesis that CK plays an influential role during the cell division phase of fruit growth. Exogenous CK application after petal drop significantly increases fruit set (Moss, 1972), although this practice is not used commercially. CK is also involved in new vegetative growth in citrus, as Hendry et al. (1982) found that during active shoot growth levels of CK in mature leaves decreased as it is utilized by new vegetative growth to stimulating cell division.

Abscisic acid (ABA) is generally known as the "stress" hormone that regulates stomatal conductance, the root:shoot growth balance, and organ abscission in plants (Taiz et al., 2015). ABA is synthesized in all plant organs that perceive stress signals i.e. leaves and roots but is also found in citrus fruit during fruit development (Goldschmidt, 1976). Levels of ABA are particularly high in citrus trees during periods of water stress, extreme temperatures, and low relative humidity (Iglesias et al., 2007). For this review, the role of ABA during fruit abscission is important, as is ethylene (Goren, 1993). The two stages during early fruit development where ABA content is high, coincides with petal fall and the physiological fruit drop period, which marks the periods of intense fruitlet abscission (Iglesias et al., 2007). The decline of ABA concentration in citrus fruit maintains a stable state after the initial fruit drop stages but exhibit a stable rise as maturity approaches (Goldschmidt, 1976). This is the change in hormonal balance which leads to the well-known pre-harvest drop or "hartseerval", the well-known and perfectly describing Afrikaans term.

2.5 Plant growth regulator (PGR) manipulations in citrus

2.5.1 Vegetative growth

Citrus vegetative growth manipulation is an effective tool to manipulate carbohydrate partitioning within the tree during phases where it may be critically needed in other processes, such as fruit set or fruit growth, rather than for shoot elongation. Recent literature reporting on citrus shade netting, found an increase in vegetative growth in reaction to reduced light levels, which indicates that vegetative growth control may become an increasingly important practice as the use of shade netting increases (Wachsmann et al., 2014). Various practices can be used to manipulate vegetative growth, however, for the purpose of this study, only vegetative growth control by means of PGR's will be reviewed.

The mode of action of these PGR's are related to endogenous GA synthesis of the tree. Most of the known growth retardants reduce vegetative growth by disrupting the pathways of GA synthesis, thus partially retarding the stimulating effect of GA on cell elongation and vegetative growth (Smeirat and Qrunfleh, 1988). Various growth retardants have been investigated in citrus and other fruiting crops, however most of these substances proved to have inconsistent and unreproducible results (El-Otmani et al., 2000). Later research on citrus and avocados indentified the triazoles paclobutrazol, uniconazole, and prohexadione-calcium as the gibberillin-biosynthesis inhibitors producing the best results (Greenberg et al., 1992; Le Roux and Barry, 2010; Penter and Stassen, 1998).

Greenberg et al. (1992) found that PB sprays and soil application during autumn increased the number of flowering shoots sprouting in the spring, accompanied by a reduced number of vegetative shoots. The influence of PB on shoot elongation evaluated in this study, showed that the spring and early summer PB treatments on 'Minneola' tangelo gave the best results in reducing excess elongation of summer shoots. The tree height was also evaluated with 'Minneola' tangelo trees topped to similar height before the PB treatments. After six months it was found that the 1000 ppm PB treated trees were roughly 400 mm shorter than the control trees, confirming the effect of PB on retarding vegetative growth of citrus trees (Greenberg et al., 1992).

Uniconazole and prohexadione-calcium (ProCa) research on vegetative growth of potted 'Eureka' lemon nursery trees showed that 1000ppm uniconazole returned the best results for retarding shoot growth, followed by ProCa at 800ppm (Le Roux and Barry, 2010). Interestingly, the number of nodes on the longest shoot did not differ from the control, while the node length differed significantly, with ProCa and uniconazole having the shortest nodes (Le Roux and Barry, 2010). This indicates that these two growth retardants did not reduce shoot length by altering the number of nodes, but rather by reducing the internodal length. This suggests that the number of nodes, from which inflorescence can sprout in the following season, was not reduced.

Increased fruit size and flowering were reported for avocado and citrus, respectively in reaction to the application of growth retardants (Greenberg et al., 1992; Penter and Stassen, 1998), thus resulting in higher crop value. However, Greenberg et al. (1992) found that on citrus, early spring and summer PB sprays had a negative effect on fruit development by shifting the fruit size distribution to a smaller average fruit size. Contradicting results were found for uniconazole on avocados, where inhibition of the shoot growth flushes during the fruiting season lead to an increase in average fruit size (Penter and Stassen, 1998).

According to literature, uniconazole, ProCa and paclobutrazol produced the best results in retarding vegetative growth, however it is unlikely that paclobutrazol will be registered commercially on citrus due to the negative imapact on fruit size and its persistance in the enviroment and the plant (Le Roux and Barry, 2010).

2.5.2 Fruit set

Fruit set in citrus is a tightly regulated physiological process, which is regulated by numerous factors such as carbohydrate status, endogenous GA’s, bearing unit quality and other cultural practices (Talon et al., 1990). In commercial citriculture however, the best results in enhancing fruit set is obtained with exogenous GA_3 application during full bloom (Krezdorn, 1969).

The mechanism behind the promoting effect of GA_3 on citrus fruit set is an intensively researched field and some of the first results indicated that it is responsible for enhancing early fruit growth which leads to an inhibition of fruit abscission and thus an increase in fruit set (El-Otmani et al., 1992). García-Martínez and Garcia-Papi (1979) however reported that foliar application of GA_3 resulted in increased mineral nutrient translocation to the developing fruitlets, while Mauk et al. (1986) reported that the application of foliar GA_3 sprays increased the sink strength of developing ovaries resulting in increased carbohydrate translocation and a transient increase in fruit set.

Application of GA_3 during full bloom is inevitable in the production of parthenocarpic and self-incompatible cultivars (low endogenous ovary GA levels), and in areas where decreased fruit set is experienced (García-Martínez and Garcia-Papi, 1979). GA_3 applications is especially important in areas producing ‘Clementine’, as this cultivar is prone to high ovary abscission during the post bloom period (El-Otmani et al., 2000). El-Otmani et al. (1992) also did extensive research on the timing and concentration of GA_3 as a foliar application to increase ‘Clementine’ fruit set and final yield. To ensure maximum coverage of as many ovaries as possible it was concluded that during sparse flowering seasons GA_3 should be applied twice, at lower concentrations during early bloom to petal drop. However, in seasons with a shorter bloom period, single sprays with increased dosage, showed promising results.

When GA_3 is applied to increase fruit set, the best results are obtained when a wetting agent is added, and the spray covers the tree until the point of runoff (El-Otmani et al., 2000). However, on hot days with high evaporative potential and mixtures with high concentrations, should be avoided as cases of new shoot dieback and leaf drop have been reported (El-Otmani et al., 2000).

2.5.3 Fruit thinning and fruit size

Fruit size is an important factor determining final crop value. This section will explore the different methods of increasing fruit size using PGR's, which is mainly done using synthetic auxins (Rabe, 2000). Synthetic auxins enhance fruit size via two pathways, one being the thinning of fruit, thereby reducing inter-sink competition, and the other an enhancement of fruit sink strength (Guardiola, 1997).

When considering the profitability of a citrus orchard, the two main factors influencing monetary returns are yield and fruit quality (Agustí et al., 1996). During the last three decades, markets saw an increase in consumer preference for larger sized fruit, and currently, fruit size is arguably the most important fruit quality parameter, followed by colour, seedlesness, a blemish free rind and good internal quality. Mandarins is a high value crop due to many consumer-friendly attributes, however, they tend to produce high crop yields consisting of small fruits with low market value (El-Otmani et al., 1996; Guardiola and Lázaro, 1987), which calls for additional measures to enhance fruit size and increase returns.

Another problem influencing fruit size in mandarins, is alternate bearing. Alternate bearing is a characteristic of several mandarin and mandarin hybrid species and is characterized by trees that exhibit a cycle of "on" and "off" years. During this cycle, the "on" years refer to years of heavy crops with small fruit, which leads to carbohydrate depletion. The "on" year is followed by a so called "off" year, with almost no flowers and while the few flowers that set grow into oversized fruit (Monselise et al., 1981). One practice used to control this cycle of alternate bearing is chemical fruit thinning during “on” years, thus reducing the number of fruit and increasing fruit size (Guardiola and García-Luis, 2000). This reduction in fruit number, thus total sinks, will result in more carbohydrates being available for storage and return bloom, as shown in hand thinning experiments done by Stander and Cronjé (2016). The increase in stored carbohydrates will lead to a more intense return bloom and possibly the breaking of an alternate bearing cycle.

Studies done on the *mode of action* of synthetic auxins showed that success depends on several factors, such as timing of application, cultivar, and concentration (Guardiola, 1997; Guardiola and García-Luis, 2000). Results from these studies also showed that synthetic auxins have two mechanisms to affect an increase in citrus fruit size, either acting as a fruit thinner or by inducing an increase in fruit sink strength without reducing fruit numbers.

Synthetic auxins as *fruit thinners*. When a high crop load or an “on” year of alternate bearing is identified after flowering, the intended use of synthetic auxin application is to remove the smaller fruit and to reduce the number of fruit per tree. As the number of fruit per tree are inversely related to final fruit size, this will result in a higher average fruit size at harvest, decreased carbohydrate utilization and increased profitability.

When applied during the cell division stage of fruit growth, before physiological fruit drop, synthetic auxins have a thinning effect, and induces fruitlet abscission (Guardiola, 1997). Fruitlet abscission occurs through two mechanisms during this stage, one being a direct effect and the other being an auxin induced ethylene abscission (Guardiola, 1988). Abscission at the calyx is regulated by the auxin/ethylene concentration and abscission is induced by reduced auxin produced by fruit, with a subsequent increase in ethylene sensitivity (Ortolá et al., 1997). The decrease in fruitlet derived auxin in reaction to synthetic auxin application is due to a recently suggested temporal impairment of photosynthetic photosystem electron flow, which results in decreased metabolite availability and translocation to fruitlets, after which smaller fruit abscise as a result of increased ethylene sensitivity at the calyx (Mesejo et al., 2012). Ortolá et al. (1997) found that fruitlets of 10 to 15 mm diameter showed the highest susceptibility to ethylene induced abscission in reaction to NAA sprays. However, for ethylene induced thinning, synthetic auxin sprays must be done before the end of physiological fruit drop, as fruitlets will become insensitive for all auxin induced ethylene abscission after this stage (Guardiola, 1997). During stage I of fruit growth, synthetic auxins can also have a direct abscising effect. This effect is brought by as the bigger fruitlets, already a stronger sink than smaller ones, becomes a stronger sink after the application of synthetic auxins (Guardiola, 1997). These then outcompete the smaller ones for metabolites, which leads to the starvation and abscission of smaller fruitlets.

Synthetic auxins as *fruit growth promoters*. Synthetic auxin application after or during the end of physiological fruit drop only has a minor or no thinning effect (Agustí, et al., 1994; Guardiola, 1997; Guardiola and García-Luis, 2000), and have a direct effect on increasing fruit size by stimulating fruit to become stronger sinks. (Guardiola and García-Luis, 2000). Almost all literature on application of synthetic auxins after physiological fruit drop, agrees that fruit size is increased with no thinning effect. However, Guardiola (1997) stresses the fact that fruit size will not be enhanced by late auxin application if the fruit load is excessive, and that fruit growth will always be limited by corbohydrate supply. The direct effect of synthetic auxins is supported by findings that fruit penducle diameter was increased by synthetic auxin application to citrus fruit, which indicates that solute transport to the fruit is enhanced through increased vascular capacity, resulting in increased final fruit diameter (Bustan et al, 1995; Mesejo et al., 2003).

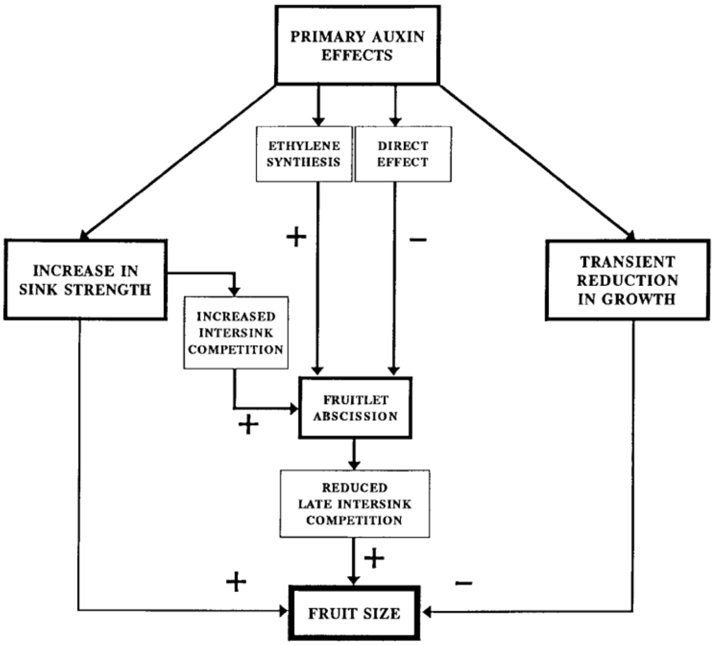

Fig. 2.2. Illustration of the different pathways of synthetic auxin applications on fruit growth and fruit abscission. Adapted from Guardiola (1988).

Commercial use. Synthetic auxins are widely used to enhance fruit size in citrus, and while a few formulations have been tested and used, only two are still being used commercially. In a review done by Rabe (2000) the main formulations of chemical thinning agents are compared which consists of ethephon, ethychlozate, NAA (naphethalene acetic acid), 2,4-D (2,4-dichlorophenoxyacetic acid), 2,4-DP (2,4- dichlorophenoxy propionic acid) and 3,5,6-TPA (trichloro-2- pyridyl-oxyacetic acid). However, in several studies it was found that some of these compounds would never be used commercially as they were ineffective in increasing fruit size or had erratic, inconsistent thinning results. For this review however, only the compounds currently used in commercial citrus production will be investigated which are 2,4-DP and 3,5,6- TPA (Agustí, et al., 1994; Agustí, et al., 2002; El-Otmani, et al., 1996; Guardiola and García-Luis, 2000; Rabe, 2000).

2,4-DP has been extensively researched and proves to be one of the most reliable and consistent forms of synthetic auxin to increase fruit size in citrus (Rabe, 2000). When applied during stage I of fruit growth, 2,4-DP exhibits acceptable fruit thinning, and in a study by Koch et al. (1996) it was found that in South Africa on ‘Clementine’, early sprays (5 to 7 mm fruit size) reduced yield and increased fruit size. However, contradicting results were found for thinning when it was sprayed at a later stage (22-24 mm fruit size), where less fruit thinning was accompanied by enhanced yield, while the increase in fruit size was less pronounced. For fruit thinning with 2,4-DP, it should be noted that if reduction in fruit number does not exceed 20%, it will always be outweighed by the increase in fruit size, and yield will be unaffected (Rabe, 2000).

Agusti et al. (1994) evaluated the efficacy of 2,4-DP on ‘Satsuma’ mandarin to increase fruit size if sprayed after physiological fruit drop. In this study, it was found that 2,4-DP application after physiological fruit drop was effective to significantly increase fruit size, without altering the number of fruit per tree. This finding suggests that 2,4-DP has the ability to stimulate cell enlargement as no cell division occurs during stage II of citrus fruit growth (Bain, 1958). From literature, it can be concluded that 2,4-DP can increase fruit size either through a fruit thinning effect during stage I of fruit growth, or by enhancing fruit sink strength during the later stage II of fruit growth, without altering fruit number and yield. According to Koch et al. (1996) the optimum timing for 2,4-DP application for increasing fruit size was during the final period of stage I in fruit growth.

Another synthetic auxin used commercially is *3,5,6-TPA*. This compound has proven to be successful in increasing fruit size of several cultivars such as ‘Satsuma’ mandarin (Agustí et al., 2002) and ‘Nules Clementine’ (El-Otmani et al., 1996). This synthetic auxin exhibits a stronger thinning effect than 2,4-DP, and if applied before physiological fruit drop, severe, unwanted thinning may occur (Agustí et al., 1994). The use of 3,5,6-TPA is therefore not recommended before physiological fruit drop, which is supported by findings of Agustí et al. (1995), who stated that it may have a thinning effect even after physiological fruit drop.

As 3,5,6-TPA is such an aggressive thinning agent, it is almost solely used to enhance fruit sink strength and increase fruit size, rather than to thin fruit. Agustí et al. (2002) focussed on the ability of this compound to enhance sink strength and evaluated carbohydrate accumulation in ‘Satsuma’ mandarin fruit if sprayed during the cell enlargement period. It was found that carbohydrates were higher in the treated fruit, which suggested that the there was a fruit sink strength promotion in the treated trees. These findings are supported by an earlier study stating that the increase in fruit size by 3,5,6-TPA, occurred irrespectively of the number of fruit per tree, which also suggests that sink strength is promoted (Agustí et al., 1994).

In the study by El-Otmani et al. (1996) the effect of 3,5,6-TPA was evaluated on fruit growth as well as vegetative growth. During this research an interesting finding was made, which was that the 3,5,6-TPA treatment increased the leaf size of treated trees, which supposedly increased the photosynthetic capacity of the tree. This finding opens a new field of thought, which is that besides increasing fruit sink strength, this compound may lead to increased tree assimilate production. Considering fruit size, 3,5,6-TPA also showed the best results compared to 2,4-DP when applied at the end of physiological fruit drop.

It can thus be concluded that although 3,5,6-TPA tends to have more severe results in terms of fruit thinning, it seems to be more effective in increasing fruit size compared to 2,4-DP. However, particular care should be taken determining the time of application, as significant yield reductions occur if applied before the end of the physiological fruit drop period.

2.5.4 Factors influencing the uptake of foliar applied substances

Bukovac (1972) explored factors which could influence the uptake and efficacy of plant growth regulators by leaves. These factors, viz. ambient temperature, relative humidity and leaf properties such as the leaf cuticle, are known to be affected by shade netting and as a result could influence the foliar uptake of PGR’s (Bukovac, 1972; Edgerton and Haesler, 1959; Stover and Greene, 2005).

High temperatures in orchards were found to increase foliar uptake, but as to what extent this is influenced by structural changes in the cuticle is still unclear (Unrath, 1981). Increased RH generally favours foliar uptake of foliar applied substances (Hull, 1970). This increase is due to an extended drying time of spray droplets, keeping the cuticle in a hydrated state for a longer period favouring uptake. Furthermore, Edgerton and Haesler (1959) reported that apple leaves preconditioned in a low light environment, showed increased absorption in comparison with leaves preconditioned at normal light intensities.

These studies suggest that the altered microclimate under shade netting may affect the uptake of foliar applied agro-chemicals such as plant growth regulators, which may influence the efficacy if applied at the same dosage as in open orchards.

2.6 Conclusion

The ability of shade netting to enhance the productivity and profitability of citrus is a breakthrough for the global citrus industry. However, inevitable changes in orchard microclimate occur when permanent shade netting is erected over an orchard. These changes include a rise in ambient air temperature, increased RH and decreased radiation, to mention only a few. Changes in all these variables could favour vegetative growth in citrus trees under shade netting. Citrus vegetative growth under shade netting has been quantified on a whole tree level i.e. increase in tree volume, however to what extent shade netting would influence shoot growth of the respective flushes have not been quantified.

Furthermore, the flowering response of citrus trees in reaction to shade netting has not been a research focus. Contradicting results exists on other fruit crops, however most research reports an increased flowering response under shade netting. Citrus fruit set was found to be increased by shade netting, concurring with reports from other fruit crops. Fruit growth also seems to be enhanced by shade netting and several studies reported an increased fruit size, however the fruit growth rate and size of mandarin fruit has not been quantified under shade netting. Contradicting results exist on the effect of shade netting on yield of fruit crops, while on citrus increased yield was reported for mandarins under shade netting.

No research has been done to determine the efficacy of citrus plant growth regulators under shade netting. The efficacy of foliar applied PGR’s is dependent on several climatic, morphological and physiological factors which would be influenced by shade netting and may enhance the efficacy of foliar applied PGR’s.

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3. Paper 1. The impact of permanent shade netting on the phenology of ‘Nadorcott’ mandarin trees

Abstract. The use of permanent shade netting to protect high value citrus (*Citrus* spp.) crops is gaining support globally. The use of this technology, however, is inevitably accompanied by changes in orchard microclimate, which may sway the growth balance of a tree away from reproductivity. In this study, the effects of 20% white permanent shade netting were evaluated on citrus phenology in a model mandarin cultivar, ‘Nadorcott (*C. reticulata* Blanco), in a commercial orchard located in Citrusdal, South Africa. Vegetative phenology, flowering, and fruit set of each of the three main vegetative shoot flushes were evaluated over a period of two seasons, in addition to shade net effects on tree volume, fruit yield and internal fruit quality. Vegetative growth was not enhanced by the shade netting at shoot level, but tree volume was increased significantly over two seasons. Overall, flowering was not affected by the shade netting, but flowering intensity on summer vegetative shoots was higher during the second season. Fruit set, fruit yield and internal fruit quality were not affected, while final fruit diameter was enhanced by the shade netting in the second season. The ability of uniconazole to reduce vegetative growth of the three respective vegetative shoot flushes was not influenced by shade netting, while the uniconazole treatments had no effects on shoot growth overall. It can be concluded that the use of 20% white permanent shade netting increased vegetative growth of ‘Nadorcott’ mandarin without impeding reproductive development and yield parameters, and can thus be recommended as a commercial practice in areas where external fruit damage and high seed content necessitates the practice.

3.1 Introduction

Damage to fruit crops during fruit development causes major financial losses in orchards worldwide. Principal factors accounting for these include sporadic climatic extremes such as sunburn, wind, and hail and freeze damage caused by spells of frost. In recent years the use of protective permanent shade netting has become an increasingly popular agricultural practice to protect high-value fruit crops against such damage. Apart from protection of fruit, the use of shade netting has also been widely implemented to successfully prevent cross-pollination and produce seedless fruit in various citrus cultivars.

An inevitable response to permanent shade netting, however, is subsequent changes in the orchard microclimate that accompanies the use of the technology, i.e. reduced irradiation and air flow, lower plant-surface temperatures, higher ambient temperatures, and an increase in relative humidity (Pérez et al., 2006; Stamps, 1994; Wachsmann et al., 2014). These changes in orchard micro-climate have significant effects on the physiology of a tree and its various phenological events. In peach (*Prunus persica* cv. Hermosa) (Shahak et al., 2004), blueberry (*Vaccinium* cv. Berkely) (Retamales et al., 2008) and apple (*Malus domestica* Borkh. cv. Braeburn) (Smit, 2007), for example, shade netting increased vegetative growth. The opposite was reported in kiwi (*Actinidia delicosa* cv. Hayward) (Basile et al., 2008). In citrus, 30% and 60% aluminized shade netting increased vegetative growth in ‘Murcott’ mandarin (*Citrus reticulata* Blanco) (Raveh et al., 2003), and a similar response was reported for red, yellow and white shade netting treatments in ‘Orri’ mandarin (Wachsmann et al., 2014). Shade netting increased flowering intensity and fruit set in peach (Shahak et al., 2004) and apple (Shahak et al., 2004; Smit, 2007). In citrus, 18% white, and 13% transparent shade netting treatments increased fruit set in ‘Orri’ mandarin by 23% and 29%, respectively (Wachsmann et al., 2014).

Shade netting increased fruit size and yield in apple (Shahak et al., 2008) and peach (Shahak et al., 2004), while only increasing yield in blueberry (Retamales et al., 2008) and kiwi (Basile et al., 2008). In citrus, Wachsmann et al. (2014) reported higher fruit yields for shade netting treatments in 'Orri' mandarin, but lower fruit yield was reported for reflective aluminized shade netting treatments in grapefruit (*Citrus paradisi* Macf.) (Cohen et al., 2005).

Increased vegetative growth is reported for most fruit crops that are grown under shade netting, which may become problematic in terms of tree reproductivity. Management of unwanted vegetative vigour will therefore become increasingly important as the use of shade netting in citrus increases. Promising results with the use of vegetative growth retardants such as the triazoles, paclobutrazol and uniconazole, and prohexadione-calcium were reported in citrus (Greenberg et al., 1992; Le Roux and Barry, 2010), and could offer viable options to manage vegetative vigour in citrus trees grown under shade netting. Although the use of uniconazole was effective in reducing shoot length in 'Eureka' lemon (*C. limon* L. Burm. F.) nursery trees (Le Roux and Barry, 2010), this chemical has not been adequately evaluated for potential as standard practice in citrus production, and even less so for use in trees grown under shade netting.

The effects of different coloured non-permanent and permanent shade netting treatments have been reported on different fruiting crops, but it is not clear to what extent a 20% white permanent shade netting treatment would affect the balance between vegetative and reproductive growth in citrus under representative Mediterranean-type climatic conditions.

The objective of this study was to determine the impact of permanent, 20% white shade netting on the balance between vegetative and reproductive growth compared with an untreated control, using the late maturing mandarin cultivar 'Nadorcott' (*C. reticulata*) as a model crop. Important vegetative and reproductive phenological events were recorded, and the intensities were measured and compared over a period of two seasons. The hypothesis is that the permanent 20% white shade netting treatment will increase vegetative growth, and therefore have a negative effect on flowering and fruit set. In addition, the plant growth regulator, uniconazole, was evaluated for its efficacy on vegetative growth control, both under and outside the shade netting during the second season.

3.2 Materials and methods

3.2.1 Plant material and experimental site

The experiments were conducted in a commercial orchard of 5-year-old ‘Nadorcott’ mandarin (*C. reticulata*) trees budded onto ‘Carrizo’ [*C. sinensis* (L.) Osbeck x *Poncirus. trifoliata* (L.) Raf.] rootstock in Citrusdal (lat. 32°32’31”S, long. 19°0’42”E) in the Western Cape province of South Africa. The area experiences a Mediterranean-type climate: summer occurs from December to February, autumn from March to May, winter from June to August and spring from September to November. The orchard is orientated in a North-to-South row-direction and trees are planted at a spacing of 5.5 x 2.5 m (727 trees per hectare). The experiments were conducted over a period of two seasons, viz. 2015/16 (season 1) and 2016/17 (season 2).

3.2.2 Experimental design and treatments

Experiment 1: The experiment was set up in a randomized complete block design and consisted of an untreated control, i.e. open (without shade netting), and a 20% white, permanent shade netting treatment. Each treatment consisted of four replicates (n=4) and two data trees per replicate located in the middle of each block. An orchard was selected in 2015 and divided into eight uniform 25 x 75 m blocks. A 20% white shade net was randomly erected over four of the eight blocks at a height of 5.5 m above the orchard floor prior to anthesis in 2015.

Experiment 2: The experiment was set up in a split-plot, randomized complete block design. The main factor comprised two factors, i.e. an untreated control (open), and a 20% white, permanent shade netting treatment. The sub-factor consisted of the following treatments that were applied separately to individual trees: 1) Untreated control; 2) $0.25 g \cdot L^{-1}$ uniconazole [Sunny 50 SC®; Philagro South Africa (Pty) Ltd, Somerset West, South Africa; containing 50 $g \cdot L^{-1}$ active ingredient] soil drench in Aug. 2016; 3) $0.25 g \cdot L^{-1}$ uniconazole soil drench in Dec. 2016, and 4) $0.25 g \cdot L^{-1}$ uniconazole soil drench in Feb. 2017. The treatments were applied to two data trees per replicate and targeted the spring, summer and autumn vegetative shoot flushes, respectively. The treatments were applied with a measuring cup in solution with 1 L water around the trunk of each replicate tree, after scraping away all leaf debris.

3.3 Data collection: Experiment 1

3.3.1 Vegetative phenology

Five non-bearing, vegetative shoots were randomly selected on each data tree at a height of 1 to 2 m above the orchard floor during full bloom in October for the spring flush, in January for the summer flush, and in April for the autumn flush. The phenology of each shoot was followed, and during winter, the number of nodes, leaves and final length of each shoot were recorded.

After winter, the trunk circumference of each data tree was measured at a marked height directly above the bud union. The canopy volume (V, m^3) of each tree was determined by measuring the canopy height and the in-row and across-row dimensions. Canopy volume was calculated using the following formula of Burger et al. (1970):

$$V = R^2 (\pi h - 1.046R)$$

Where:

R = canopy radius $[(\frac{(\text{in}-\text{row width}+\text{across}-\text{row width})}{2})/2]$

h = canopy height

Canopy volume measurements and calculations were repeated on the same trees in the following seasons to calculate the change in canopy volume.

3.3.2 Reproductive phenology

Flowering and fruit set. Return bloom was evaluated during full bloom, on the same shoots that were used to determine vegetative growth and phenology. For each shoot, the total number of flowers per shoot, the number of flowers on leafy inflorescences, the number of flowers on leafless inflorescence, and the number of purely vegetative shoots were recorded. After physiological fruit drop in December, fruit set percentage (%) was determined by counting the number of fruit that persisted on the same shoots, and dividing it by the number of flowers per shoot.

Fruit growth. Five fruitlets were selected and tagged on each replicate tree in December. Initial fruitlet diameter was measured using an electronic caliper (CD-6” C; Mitutoyo Corp, Tokyo, Japan) and subsequent fruit diameter measurements were conducted at monthly intervals until commercial harvest in July. The fruit diameter measurements were used to calculate the treatment effects on fruit growth rate, (in $\text{mm}\cdot\text{day}^{-1}$), and to generate fruit growth curves representing the change in fruit diameter over time. The fruit growth rate was calculated using the following formula:

$$\text{Fruit growth rate } = \frac{\text{Fruit size current month} - \text{Fruit size previous month}}{\text{No. days between measurements}}$$

3.3.3 Fruit yield and quality

Fruit yield. Data trees were stripped of all fruit to determine the treatment effects on total fruit yield (in kg fruit per tree) at time of commercial harvest. From each data tree, the diameter of 50 randomly distributed fruit was measured to calculate the fruit size distribution per tree. The total fruit yield, fruit size distribution, and average mass of different sized fruit were used to estimate the total number of fruit per tree.

Fruit quality. From each replicate, ten fruit were sampled to determine effects on fruit quality parameters. Rind colour was evaluated using a Citrus Research International (CRI) colour chart for soft citrus (no.36, 2004). Rind colour was scored on a scale from 1 to 8, with 1 being a fully coloured orange fruit, and 8, a fruit with a dark green colour. An electronic caliper was used to measure average fruit diameter for each sampled fruit. For evaluation of treatment effects on internal quality, fruit were cut open along the longitudinal plane and rind thickness was measured on opposite sides of each fruit using an electronic caliper. Each fruit was juiced with a citrus fruit juicer (Sunkist®, Chicago, USA). The mass of the juice was divided by the total fruit mass to calculate the treatment effects on juice percentage (%). Thereafter, the juice was used to analyse the percentage total soluble solids (TSS) (PR-32 Palette, Atago Co, Tokyo, Japan) expressed as °Brix, and the titratable acidity (TA) (888 Titrando, Metrohm, Switzerland) as the citric acid concentration. The sugar:acid ratio was calculated by dividing the °Brix value by the citric acid concentration (°Brix:TA).

3.4 Data Collection: Experiment 2

Data collection for this experiment focussed on evaluating the efficacy of uniconazole in reducing vegetative shoot growth compared to an untreated control, in both the open and shade netting treatments. For this purpose, 5 shoots were tagged at a height of 1 to 2 m on each replicate tree per treatment, after cessation of each respective vegetative shoot flush in spring, summer, autumn, respectively. Shoot phenology was followed, and various events recorded on each shoot, similar to experiment 1.

3.5 Statistical analysis

For experiment 1, a randomized-block analysis of variance (ANOVA) and a repeated measures ANOVA was carried out using Statistica data analysis software (Dell Inc. 2015, Dell Statistica, version 13.software.dell.com). In experiment 2, a split-plot ANOVA was used. Fisher's least significant difference (LSD) test was used to separate means at the 5% level.

3.6 Results

3.6.1 Experiment 1

Trunk circumference and tree canopy volume. Trunk circumference increased over time, but no differences were recorded between the open and shade net treatments over the three respective seasons (Table 3.1).

Initial tree canopy volume did not differ between treatments (m^3), but was higher for the shade netting treatment in both seasons (Table 3.2). The tree canopy volume increased significantly as the experiment progressed, indicating that the trees had not yet reached full maturity, and were still developing.

Shoot growth. In season 1, no differences were recorded for shoot length, number of nodes or leaves, between open and netting treatments (Table 3.3). Differences were found between the length of the respective vegetative shoots that developed in the different shoot growth flushes, with the summer shoots having a higher shoot length than that of the spring and autumn flush shoots. Shoot length of the spring and autumn flush shoots did not differ from each other (Table 3.3). The number of nodes and leaves per shoot followed the same trend as shoot length, and the open and shade net treatments did not differ from each other. The summer flush shoots had significantly more nodes and leaves compared to the spring and autumn flush shoots, which did not differ from each other (Table 3.3).

In season 2, neither shoot length, nor the number of nodes and leaves per shoot of the open and shade net treatment differed from each other (Table 3.4). Significant differences for shoot length, and the number of nodes and leaves per shoot were however recorded between the different shoots that developed in the respective shoot growth flushes. The summer flush shoots were longer and had more nodes and leaves per shoot compared to shoots from the spring and autumn flushes, with the spring flush shoots having significantly higher values than the autumn flush shoots for length, the number of nodes and leaves per shoot (Table 3.4).

Flowering. During season 1, total flowers per shoot did not differ between treatments. Differences in flower number were however recorded for shoots that originated from the different vegetative flushes, with shoots from the summer flush having significantly more flowers than shoots from the spring flush. Shoots from the autumn flush, however, showed no difference compared to the summer and spring shoots (Table 3.5). The total number of flowers on leafy inflorescence did not differ between treatments. Shoots from the summer flush had more leafy flowers compared to the spring flush, while shoots from the autumn flush showed no significant differences for leafy flowers compared to summer and spring shoots (Table 3.5). The total number of leafless flowers and vegetative sprouts per shoot did not differ between treatments or the respective shoot growth flushes.

In season 2, open and shade net treatments interacted with the respective shoot growth flushes (Table 3.6). Total flowers and leafy inflorescence from the open and shade net treatment of the spring and autumn flushes did not differ between treatments or shoot growth flushes. The summer flush shoots under the shade net treatment had the highest number of flowers per shoot, which was ±70% higher compared to summer shoots from the open treatment. The total number of leafy flowers per shoot showed the same trend as that of total flowers, with the summer flush in the shade net treatment having the highest number of leafy flowers (Table 3.6). The number of vegetative sprouts per shoot was the highest for the shoots from the summer and autumn flush in the open treatment. The summer flush shoots in the open had significantly more vegetative sprouts than the shade net treatment. However, for the spring and autumn flush, no differences occurred (Table 3.6). No interaction was recorded for the number of leafless flowers, however the number of leafless flowers were higher for the summer flush, compared to the autumn, and did not differ from the spring flush (Data not shown).

Fruit set percentage. Fruit set (%) in season 2 did not differ between the open and shade net treatments (Table 3.7) and no differences were recorded between the respective shoot growth flushes for fruit set % (Data not shown).

Fruit growth and size. Fruit growth rate was slightly higher for the net treatment during both seasons, but the differences were not significant (Table 3.8 A). Final fruit diameter did not differ between the open and net treatments during season 1. In season 2, final fruit diameter of the shade net treatment was higher compared to the open, but the difference was just not significant at the 95% confidence interval (P=0.056). (Table 3.8 B).

Fruit yield and quality. In both seasons the shade net treatment had no effect on fruit yield (Table 3.9). Fruit size distribution for season 1 showed no significant differences between treatments. However, the percentage (%) of fruit in the commercial fruit size count (SC) 1XX (72-77mm) was 7% higher for the shade net treatment compared to the open (Figure 3.1). For season 2, significant differences between treatments were found for the % fruit in SC 1XXX

(78-86mm) and SC 1 (64-67mm). The shade net treatment yielded 4% more fruit in SC 1XXX, while having 3% less fruit in SC 1 (Figure 3.2). No differences were found between the open and shade net treatments for titratable acidity (TA), TSS (^{o}Brix) or sugar:acid (^{o}Brix:TA) ratio in both seasons. In season 1, the shade net treatment reduced the fruit juice content significantly compared to the open (Table 3.10).

3.6.2 Experiment 2

Vegetative growth. No differences were found between the open and shade net treatments, or for the uniconazole treatment compared to the control, for the length of shoots that developed from the spring vegetative shoot flush. The number of nodes per shoot showed concurring results, and no differences occurred between the open and shade net treatments, or between the uniconazole and control (Table 3.11). For the summer flush, no differences were found between the open and shade net treatments for shoot length or the number of nodes per shoot. The uniconazole treatment reduced shoot length by 17% compared to the control, but the difference was, however, not significant at the 95% confidence interval (P=0.067). No differences were recorded between the control and uniconazole treatment for the number of nodes per shoot (Table 3.12). There were no differences between the open and shade net treatments, or the uniconazole and control, for shoot length and the number of nodes per shoot in the autumn flush (Table 3.13).

Flowering. *Spring shoots.* No differences were recorded between the open and shade net treatments for the total flowers, total leafy flowers, total leafless flowers, or pure vegetative sprouts per shoot (Table 3.14). Total flowers per shoot differed significantly for the uniconazole treatment, with the uniconazole treatment having 38% more flowers per shoot compared to the control. The total leafy flowers, leafless flowers, and pure vegetative sprouts per shoot did not show any differences for the uniconazole treatment compared to the control (Table 3.14).

Summer shoots. Significant interaction was found between the open and shade netting and uniconazole treatments for return bloom on the summer flush shoots. Both the total flowers and total leafy flowers were more for the control trees under the net treatment, but for the shaded trees this was reversed. No differences were recorded between treatments for the total leafy flowers per shoot. The total pure vegetative sprouts per shoot was significantly higher for the control in the open treatment compared to all other treatments (Table 3.15).

3.7 Discussion

The 20% white permanent shade netting treatment increased vegetative growth and fruit size in 'Nadorcott' mandarin, but had no effects on flowering intensity, fruit yield and fruit quality.

Shade netting had no effect on trunk circumference after two seasons, but the increased vegetative growth manifested in a significant increase in tree canopy volume for the shade net treatment over the course of the study. This concurs with Wachsmann et al. (2014) who reported a similar response in 'Orri' mandarin trees grown under shade netting. Increased tree height was also reported by Raveh et al. (2003) in 'Murcott' mandarin trees grown under shade netting, while shade netting also increased vegetative growth in other fruiting trees such as peach (Shahak et al., 2004) and apple (Smit, 2007).

Climatic factors such as temperature (Bain, 1949; Webber 1943), relative humidity (Cooper et al., 1963), and light intensity (Piringer et al., 1961) all tightly regulate vegetative growth in citrus, and permanent shade netting has conclusively been shown to alter all these factors in favour of vegetative growth (Perez et al., 2006; Stamps, 1994; Wachsmann et al., 2014). Measurements of vegetative growth revealed that shade netting had no effect on shoot length of any of the three-main vegetative shoot growth flushes evaluated in this study, but it could have increased the quantity of vegetative growth flushes occurring throughout a season, which subsequently resulted in the cumulative increase in tree canopy volume. Increased shoot sprouting may be a response of the tree to an altered microclimate under the shade netting, since vegetative shoot flushes in citrus trees that are grown under warm, tropical climates, often occurs uninterrupted and in a continuum (Mendel, 1969; Spiegel-Roy and Goldschmidt, 1996). In addition, average soil temperatures during spring and summer were slightly higher under the shade net treatment in this study (Prins, 2018), which could have stimulated increased root growth activity and subsequently also resulted in more vegetative shoot growth flushes (Bevington and Castle, 1985).

In general, shoots that developed from the summer vegetative flush were the longest and had more leaves and nodes per shoot compared to shoots that developed in any of the other vegetative shoot flushes. Furthermore, shoots that developed from the spring vegetative flush in season 2 were longer than the autumn flush and had more nodes and leaves. These results concur with previous reports that in citrus, summer vegetative shoot flushes produce the longest shoots (Mendel, 1969; Spiegel-Roy and Goldschmidt, 1996), and is an important finding, since shoots that arise from summer and autumn vegetative flushes account for crucial flower bearing units in the subsequent spring (Guardiola, 1981; Guardiola et al., 1982; Krajewski and Rabe, 1995; Lovatt et al., 1984). Flowers sprout more readily from buds between the age of five to eight months, and the summer and autumn vegetative shoot flushes therefore serve as the main bearing units for flowers in the following season (Guardiola et al., 1982; Krajewski and Rabe, 1995; Lovatt et al., 1984). Indeed, in this study, the majority of flowers developed on shoots that sprouted from the summer vegetative shoot flush, followed by shoots from the autumn flush. In addition, the number of flowers per node was slightly higher for the summer and autumn flushes in both seasons, compared to the spring flush (Data not shown).

The quality and intensity of light that reaches the tree canopy exerts a key regulatory effect on citrus flowering. Lewis and McCarthy (1973) found that shoots located towards the inside of the tree canopy flowered less readily due to a lower amount of photosynthetically active radiation (PAR) that reaches these potential flowering sites. Krajewski and Pittaway (2000) concurred, and concluded that flower bearing units on the outside of the tree canopy received higher levels of PAR, and subsequently exhibited a stronger flowering response. Shade netting is well-documented to reduce PAR levels (Stamps, 2009), and since the shade net treatment in this study also increased tree density (personal observation), it was theorised that the increased vegetative growth that resulted from the shade net treatment could be detrimental to the tree's flowering potential. In this experiment, however, shade netting had no influence on the flowering intensity of individual bearing units during return bloom of season 1, compared to the control. In fact, in season 2, flowering intensity on summer vegetative shoots was higher for the shade net treatment. Furthermore, most of these flowers developed from leafy inflorescences, which are well-documented to have a higher likelihood to set, as opposed to flowers that develop from leafless inflorescences (Lovatt et al., 1984). These results illustrate that the reproductive potential of trees was not negatively impacted by shade netting and concurs with other studies in citrus (Wachsmann et al., 2014), as well as in other fruiting crops such as the deciduous peach (Shahak et al., 2004) and apple (Smit, 2007) trees.

Fruit set did not differ between open and shade netted trees in this study, which contradicts with findings by Wachsmann et al. (2014), who reported an increase in fruit set by 23% and 29% for white and transparent shade net treatments, respectively. Factors such as availability of carbohydrates (Goldschmidt and Monselise, 1977; Rivas et al., 2006), mineral nutrients (Lovatt, 1999), the type of bearing unit (Lovatt et al., 1984) and climate (Reuther, 1973) all affects fruit set. It is therefore hypothesized that fruit set was not influenced by carbohydrate availability, mineral nutrient concentration or the changed microclimate under the shade net treatment, as no differences were found between treatments for inflorescence type.

There was no difference in fruit yield between the open and shade net treatments over two seasons. Fruit diameter was slightly higher for the shade net treatment in season 2 (P=0.056). The result, however, could have a significant commercial impact, as it increased the percentage of fruit in the three largest fruit size counts viz. SC 1XXX, SC 1XX and SC 1X, and reduced those in smaller size counts. Goldschmidt (1999) suggested that carbohydrate availability is the major determinant of fruit growth in citrus. In this experiment, a larger tree canopy volume, supporting a similar flower and fruit number in the shade net treatment compared to the open, resulted in a higher leaf-to-fruit ratio, and increased fruit size in season two. This effect of shade netting on fruit diameter concurs with studies in apple (Shahak et al., 2008), kiwi (Basile et al., 2008), peach (Shahak et al., 2004), pear (Shahak et al., 2008) and grapefruit (Cohen et al., 2005). The increase in fruit diameter for kiwi and grapefruit under shade netting, was however on trees with a lower fruit load, while data from studies on apple showed increased fruit diameter under shade netting despite higher fruit loads.

Shade netting had no effects on the TA, TSS and rind thickness of fruit, and contradicts results of Jifon and Syvertsen (2001) and Cohen et al. (2005). It should however be noted that the latter studies were conducted on sweet orange and grapefruit trees that were grown under nets with high shade percentages, viz. between 30% and 60%.

In an attempt to provide a viable practice to manage vegetative growth in citrus trees grown under shade netting, the vegetative growth inhibitor, uniconazole, was evaluated for its effects in ‘Nadorcott’ mandarin. The control of vegetative growth with plant growth regulators is achieved by temporarily inhibiting gibberellin biosynthesis (Rademacher, 1991; Smeirat and Qrunfleh, 1988). In this study, the 20% white shade net treatment did not affect the efficacy of uniconazole on any of the growth flushes. The uniconazole treatment reduced the length of the summer flush shoots by 17%, but not the number of nodes, which concurs with results from studies in 'Eureka' lemon (Le Roux and Barry, 2010). The difference between treatments, however, was not statistically significant (*P*=0.067), but it may be useful in future research to evaluate timing and concentrations of uniconazole treatments.

In shoots treated with uniconazole during the previous spring, flower number was higher during return bloom, but the shade net treatment had no effect on this result. An earlier study by Greenberg et al. (1992) showed that application of paclobutrazol, a triazole and vegetative growth inhibitor similar to uniconazole, during autumn, increased flowering in 'Shamouti' sweet orange trees in the subsequent spring. Since the cultivar, the timing and dosage of application, as well as the type of chemical that was used differs from this study, future follow-up studies are necessary to adequately interpret the results obtained in this experiment in terms of flowering.

To conclude, a 20% white permanent shade net treatment increased the total vegetative growth in 'Nadorcott' mandarin trees, but not at the expense of reproductive growth. Individual shoot length did not differ between open and shade net treatments, which suggests that the increase in tree canopy volume may be due to more shoot growth flushes per annum, rather than length growth. Flowering and fruit diameter were increased by the shade net treatment in season 2, and fruit yield and internal fruit quality were unaffected by the treatment. Uniconazole treatments had no effects on vegetative growth in any of the treatments, but a soil drench treatment in spring may affect intensity of flowering during return bloom in the subsequent spring. Flowering and fruit set were unaffected, and the hypothesis that the increased vegetative growth of 'Nadorcott' mandarin trees under 20% white shade netting will shift the phenological balance away from reproductive, is rejected. While novel phenological findings are reported in this study, the underlying reasons for increased vegetative growth and flowering may be useful in future studies on the effects of permanent shade netting in citrus.

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Table 3.1. Trunk circumference of 'Nadorcott' mandarin (*C. reticulata*) trees as measured above the graft union, in a 20% white permanent shade netting (net) treatment and an untreated control (open) (n=4), in Citrusdal in the Western Cape Province of South Africa.

Treatment	**Trunk circumference (cm)**		
	2015	**2016**	**2017**
Open	18.75^{ns}	22.94^{ns}	25.79^{ns}
Net	20.38	24.73	27.40
P-value	*0.1494*	*0.1138*	*0.1524*

^{ns} No significant differences within column.

Table 3.2. Tree volume of 'Nadorcott' mandarin (*C. reticulata*) trees in a 20% white permanent shade netting treatment (net) and an untreated control (open) (n=4) in Citrusdal in the Western Cape Province of South Africa. Values of 2015 represent initial tree volume, before the shade netting treatment was applied.

Treatment	**Tree volume (m^3)**		
	2015	**2016**	**2017**
Open	3.57 d[z]	8.22 c	11.30 b
Net	5.44 d	10.73 b	15.10 a
P-value	*0.0504*	*0.0101*	*0.0002*

[z] Means with a different letter within a column differ significantly at the 5% level (LSD).

[ns] No significant differences within column.

Table 3.3. Final shoot length, no. of nodes, and no. of leaves per shoot, for the three main vegetative shoot growth flushes in 'Nadorcott' mandarin (*C. reticulata*) trees in a 20% white permanent shade netting treatment (net) compared to an untreated control (open) (n=4), for season 1 (2015/16), in Citrusdal in the Western Cape Province of South Africa.

Factor	**Shoot growth**		
	Shoot length (cm)	**No. of nodes**	**No. of leaves**
Treatment (TMT)			
Open	15.55[ns]	8.89[ns]	8.08[ns]
Net	17.07	9.91	9.29
Shoot growth flush (Flush)			
Spring	15.68 b[z]	8.41 b	7.15 b
Summer	19.88 a	11.81 a	11.36 a
Autumn	13.35 b	7.98 b	7.54 b
P-values			
TMT	*0.3813*	*0.2596*	*0.1975*
Flush	*<0.0001*	*<0.0001*	*<0.0001*
TMT*Flush	*0.7139*	*0.4339*	*0.4568*

[z] Means with a different letter within a column differ significantly at the 5% level (LSD).

[ns] No significant differences within column.

Table 3.4. Final shoot length, no. of nodes, and no. of leaves per shoot, for the three main vegetative shoot growth flushes in ‘Nadorcott’ mandarin (*C. reticulata*) trees in a 20% white permanent shade netting treatment (net) compared to an untreated control (open) (n=4), for season 2 (2016/17), in Citrusdal in the Western Cape Province of South Africa.

Factor	**Shoot growth**		
	Shoot length (cm)	**No. of nodes**	**No. of leaves**
Treatment (TMT)			
Open	16.39[ns]	8.91[ns]	7.89 [ns]
Net	16.64	9.59	8.33
Shoot growth flush (Flush)			
Spring	15.08 b[z]	8.86 b	7.13 b
Summer	26.51 a	13.27 a	12.34 a
Autumn	7.96 c	5.62 c	4.86 c
P-values			
TMT	*0.7807*	*0.2533*	*0.3408*
Flush	*<0.0001*	*<0.0001*	*<0.0001*
TMT*Flush	*0.7135*	*0.2124*	*0.0513*

[z] Means with a different letter within a column differ significantly at the 5% level (LSD).

[ns] No significant differences within column.

Table 3.5. Total flowers, total leafy flowers, total leafless flowers, and total vegetative sprouts per shoot for shoots from each flush of 'Nadorcott' mandarin (*C. reticulata*) trees in a 20% white permanent shade netting treatment (net) compared to an untreated control (open) (n=4), for the respective vegetative shoot flushes in season 1 (2015/16), in Citrusdal in the Western Cape Province of South Africa. Bearing units were the same that were used for evaluation of parameters of vegetative growth.

Factor	**Flowering**			
	Total flowers per shoot	**Leafy flowers per shoot**	**Leafless flowers per shoot**	**Vegetative sprouts per shoot**
Treatment (TMT)				
Open	12.82^{ns}	11.67^{ns}	1.15^{ns}	0.99^{ns}
Net	13.36	12.40	0.95	1.08
Bearing shoots (Flush)				
Spring	9.03 b^{z}	8.04 b	0.98^{ns}	0.81^{ns}
Summer	17.13 a	15.73 a	1.40	1.27
Autumn	13.11 ab	12.33 ab	0.78	1.04
P- values				
TMT	*0.8145*	*0.7301*	*0.5223*	*0.7838*
Flush	*0.0135*	*0.0105*	*0.1821*	*0.3387*
TMT*Flush	*0.7417*	*0.6808*	*0.8743*	*0.8634*

^{z} Means with a different letter within a column differ significantly at the 5% level (LSD).

^{ns} No significant differences within column.

Table 3.6. Total flowers, total leafy flowers, and total vegetative sprouts per shoot for shoots from each flush of 'Nadorcott' mandarin (*C. reticulata*) trees in a 20% white permanent shade netting treatment (net) compared to an untreated control (open) (n=4), for the respective vegetative shoot flushes in season 2 (2016/17), in Citrusdal in the Western Cape Province of South Africa. Bearing units were the same that were used for evaluation of parameters of vegetative growth.

Bearing shoot (Flush)	**Treatment (TMT)**	**Flowering**		
		Total flowers per shoot	**Leafy flowers per shoot**	**Vegetative sprouts per shoot**
Spring	**Open**	8.55 c[z]	5.98 c	0.52 bc
	Net	9.34 c	3.93 c	0.47 bc
Summer	**Open**	22.99 b	18.72 b	1.56 a
	Net	39.22 a	30.06 a	0.15 c
Autumn	**Open**	3.41 c	3.13 c	1.22 ab
	Net	8.04 c	5.85 c	0.56 bc
P-values				
TMT		*0.0652*	*0.0796*	*0.0875*
Flush		*<0.0001*	*<0.0001*	*0.2492*
TMT*Flush		*0.0259*	*0.0038*	*0.0425*

[z] Means with a different letter within a column differ significantly at the 5% level (LSD).

[ns] No significant differences.

Table 3.7. Fruit set percentage (%) of ‘Nadorcott’ mandarin (*C. reticulata*) in a 20% white permanent shade netting treatment (net) compared an untreated control (open) (n=4) for season 2 (2016/17), in Citrusdal in the Western Cape province of South Africa. Fruit set evaluations was done on the same shoots that were used for evaluations of return bloom.

Treatment	**Fruit set %**
Open	23.90^{ns}
Net	27.06
P-value	*0.6167*

^{ns} No significant differences at the 5% level (LSD).

Table 3.8. Growth rate (mm·day^{-1}) (A), and final diameter (mm) (B) of 'Nadorcott' mandarin (*C. reticulata*) fruit from trees in a 20% white permanent shade net treatment (net) compared to an untreated control (open) (n=4), in Citrusdal in the Western Cape province of South Africa.

A

Treatment	**Fruit growth rate (mm·day^{-1})**	
	2015/16	**2016/17**
Open	0.19^{ns}	0.20^{ns}
Net	0.20	0.21
P-value	*0.2437*	*0.1432*

^{ns} No significant differences at the 5% level (LSD).

B

Treatment	**Final fruit diameter (mm)**	
	2015/16	**2016/17**
Open	60.57^{ns}	64.92^{ns}
Net	62.50	70.30
P-value	*0.3438*	*0.0563*

^{ns} No significant differences at the 5% level (LSD).

Table 3.9. Fruit yield (kg· tree^{-1}) and number of fruit per tree (fruit·tree^{-1}) for 'Nadorcott' mandarin (*C. reticulata*) trees in a 20% white permanent shade net treatment (net) compared to an untreated control (open) (n=4), at time of commercial maturity, in Citrusdal in the Western Cape Province of South Africa.

Treatment	**2016**		**2017**	
	Fruit·tree^{-1}	**Kg·tree^{-1}**	**Fruit·tree^{-1}**	**Kg·tree^{-1}**
Open	367^{ns}	31.98^{ns}	550^{ns}	55.31^{ns}
Net	432	40.19	526	58.69
P-value	*0.3894*	*0.2183*	*0.7908*	*0.7125*

^{ns} No significant differences at the 5% level (LSD).

Table 3.10. Effect of 20% white permanent shade netting (net) on internal fruit quality parameters of 'Nadorcott' mandarin (*C. reticulata*) trees, compared to an untreated control (open) (n=4), in Citrusdal in the Western Cape province of South Africa.

Year	**Treatment**	**TA^x**	**ºBrix**	**ºBrix/TA**	**Juice content (%)**
2016	Open	1.37^{ns}	12.68^{ns}	9.24^{ns}	52.87 a^z
	Net	1.53	12.93	8.51	48.50 b
	P-value	*0.1631*	*0.60418*	*0.0815*	*0.0096*
2017	Open	1.11^{ns}	11.53^{ns}	10.40^{ns}	40.45^{ns}
	Net	1.05	11.43	11.03	38.30
	P-value	*0.5004*	*0.2522*	*0.4956*	*0.3404*

^{x} Titratable acidity.

^{z} Means with a different letter within a column differ significantly at the 5% level (LSD).

^{ns} No significant differences.

Table 3.11. Parameters of spring vegetative shoot growth in 'Nadorcott' mandarin (*C. reticulata*) trees in reaction to a 250 ppm uniconazole soil drench treatment, applied 30 days before bud sprouting, in a 20% white permanent shade net treatment (net) and an untreated control (open) (n=4), in Citrusdal in the Western Cape province of South Africa.

Factor	**Spring uniconazole shoot growth (2016/17)**	
	Shoot Length (cm)	**No. of nodes**
Treatment (TMT)		
Open	15.24^{ns}	8.98^{ns}
Net	15.28	8.86
Plant growth regulator (PGR)		
Control	15.27^{ns}	8.86^{ns}
Uniconazole	15.25	8.99
P-values		
TMT	*0.9520*	*0.6491*
PGR	*0.9802*	*0.6195*
TMT*PGR	*0.1806*	*0.3305*

^{ns} No significant differences at the 5% level (LSD).

Table 3.12. Parameters of summer vegetative shoot growth in ‘Nadorcott’ mandarin (*C. reticulata*) trees in reaction to a 250 ppm uniconazole soil drench treatment, applied 30 days before bud sprouting, in a 20% white permanent shade net treatment (net) and an untreated control (open) (n=4), in Citrusdal in the Western Cape province of South Africa.

Factor	**Summer uniconazole shoot growth (2016/17)**	
	Shoot length (cm)	**No. of nodes**
Treatment (TMT)		
Open	24.85^{ns}	12.68^{ns}
Net	24.35	12.80
Plant growth regulator (PGR)		
Control	26.57^{ns}	13.27^{ns}
Uniconazole	22.63	12.22
P-values		
TMT	*0.8216*	*0.8909*
PGR	*0.0675*	*0.1906*
TMT*PGR	*0.4487*	*0.0893*

^{ns} No significant differences at the 5% level (LSD).

Table 3.13. Parameters of autumn vegetative shoot growth in 'Nadorcott' mandarin (*C. reticulata*) trees in reaction to a 250 ppm uniconazole soil drench treatment, applied 30 days before bud sprouting, in a 20% white permanent shade net treatment (net) and an untreated control (open) (n=4), in Citrusdal in the Western Cape province of South Africa.

Factor	**Autumn uniconazole shoot growth (2016/17)**	
	Shoot length (cm)	**No. of nodes**
Treatment (TMT)		
Open	7.14^{ns}	4.83^{ns}
Net	7.62	5.60
Plant growth regulator (PGR)		
Control	8.10^{ns}	5.62^{ns}
Uniconazole	6.67	4.81
P-values		
TMT	*0.6516*	*0.2208*
PGR	*0.1388*	*0.1157*
TMT*PGR	*0.4400*	*0.7745*

^{ns} No significant differences at the 5% level (LSD).

Table 3.14. Flowering parameters of the spring vegetative shoot flush in 'Nadorcott' mandarin (*C. reticulata*) trees in reaction to a 250 ppm uniconazole soil drench treatment, applied 30 days before bud sprouting, in a 20% white permanent shade net treatment (net) and an untreated control (open) (n=4), in Citrusdal in the Western Cape province of South Africa.

Factor	**Spring flush uniconazole flowering (2016/17)**			
	Total flowers per shoot	**Leafy flowers per shoot**	**Leafless flowers per shoot**	**Vegetative sprouts per shoot**
Treatment (TMT)				
Open	10.03^{ns}	6.52^{ns}	3.51^{ns}	0.45^{ns}
Net	11.23	4.41	6.82	0.37
Plant growth regulator (PGR)				
Control	8.94 b	4.95^{ns}	3.99^{ns}	0.49^{ns}
Uniconazole	12.32 a	5.98	6.34	0.33
P-values				
TMT	*0.5022*	*0.1386*	*0.0925*	*0.7443*
PGR	*0.0437*	*0.3393*	*0.0973*	*0.4339*
TMT*PGR	*0.7961*	*0.9594*	*0.7339*	*0.9104*

[z] Means with a different letter within a column differ significantly at the 5% level (LSD).

[ns] No significant differences within column.

Table 3.15. Flowering parameters of the summer vegetative shoot flush in ‘Nadorcott’ mandarin (*C. reticulata*) trees in reaction to a 250 ppm uniconazole soil drench treatment, applied 30 days before bud sprouting, in a 20% white permanent shade net treatment (net) and an untreated control (open) (n=4), in Citrusdal in the Western Cape province of South Africa

Factor		**Summer flush uniconazole flowering (2016/17)**			
		Total flowers per shoot	**Leafy flowers per shoot**	**Leafless flowers per shoot**	**Vegetative sprouts per shoot**
Treatment (TMT)	**Plant growth regulator (PGR)**				
Open	Control	22.99 b^{z}	18.72 b	4.28^{ns}	1.56 a
	Uniconazole	34.74 ab	26.34 ab	8.40	0.18 b
Net	Control	39.22 a	30.06 a	9.16	0.15 b
	Uniconazole	28.11 ab	19.74 ab	8.37	0.45 b
	P-values				
	TMT	*0.4133*	*0.5530*	0.3417	0.1827
	PGR	*0.9499*	*0.7089*	0.4463	0.0353
	TMT*PGR	*0.0343*	*0.0195*	0.2659	0.0021

[z] Means with a different letter within a column differ significantly at the 5% level (LSD).

Table 3.16. Flowering parameters of the autumn vegetative shoot flush in 'Nadorcott' mandarin (*C. reticulata*) trees in reaction to a 250 ppm uniconazole soil drench treatment, applied 30 days before bud sprouting, in a 20% white permanent shade net treatment (net) and an untreated control (open) (n=4), in Citrusdal in the Western Cape province of South Africa

Factor	**Autumn flush uniconazole flowering (2016/17)**			
	Total flowers per shoot	**Leafy flowers per shoot**	**Leafless flowers per shoot**	**Vegetative sprouts per shoot**
Treatment (TMT)				
Open	3.25^{ns}	2.95^{ns}	0.30^{ns}	1.25^{ns}
Net	8.08	5.47	2.61	0.47
Plant growth regulator (PGR)				
Control	5.73^{ns}	4.49^{ns}	1.23^{ns}	0.89^{ns}
Uniconazole	5.61	3.93	1.68	0.83
P-values				
TMT	*0.0513*	*0.1058*	*0.0698*	*0.0920*
PGR	*0.9308*	*0.6149*	*0.5999*	*0.8252*
TMT*PGR	*0.8785*	*0.8542*	*0.6258*	*0.6727*

^{ns} No significant differences within column.

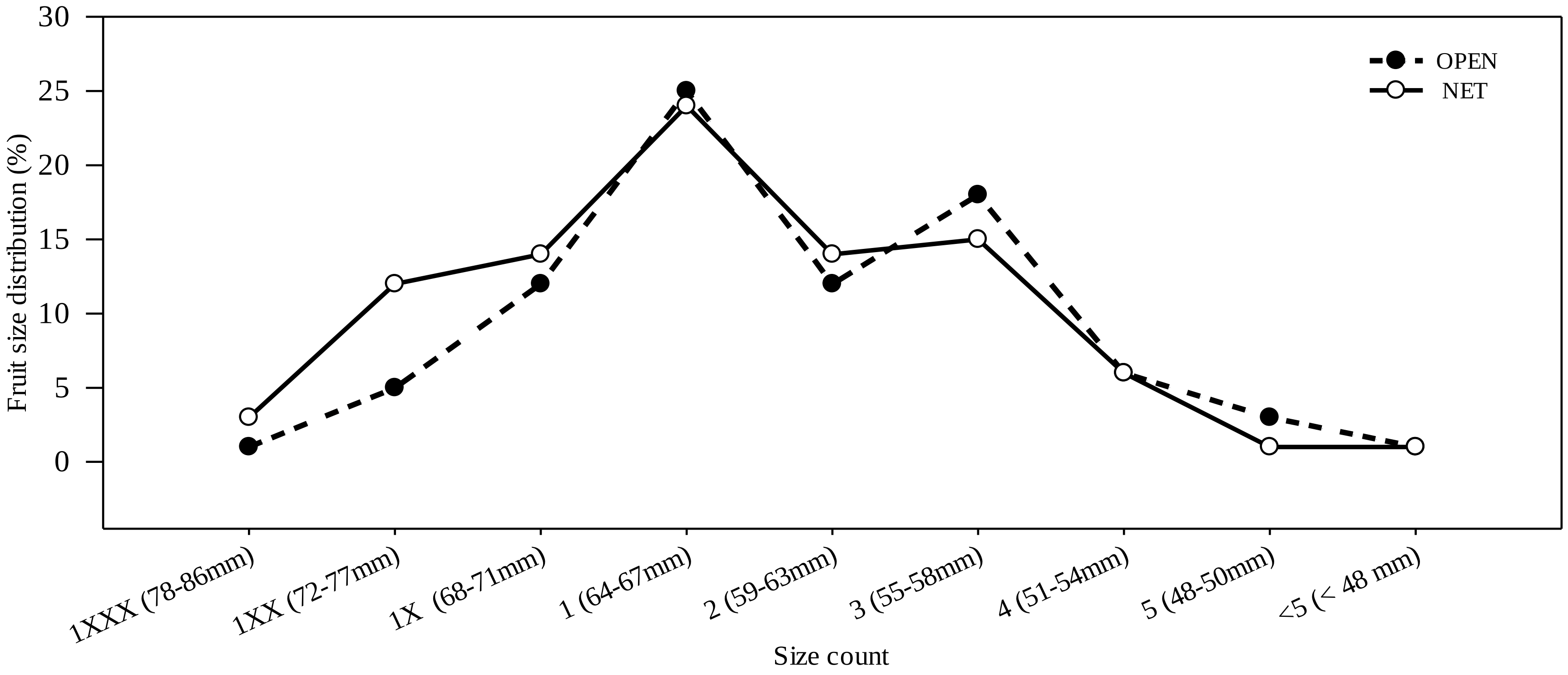

Fig. 3.1. Fruit size distribution (%) of 'Nadorcott' mandarin (*C. reticulata*) in a 20% white permanent shade net treatment (net) and an untreated control (open) (n=4), in Citrusdal in the Western Cape province of South Africa. No significant differences were recorded at the 5% level.

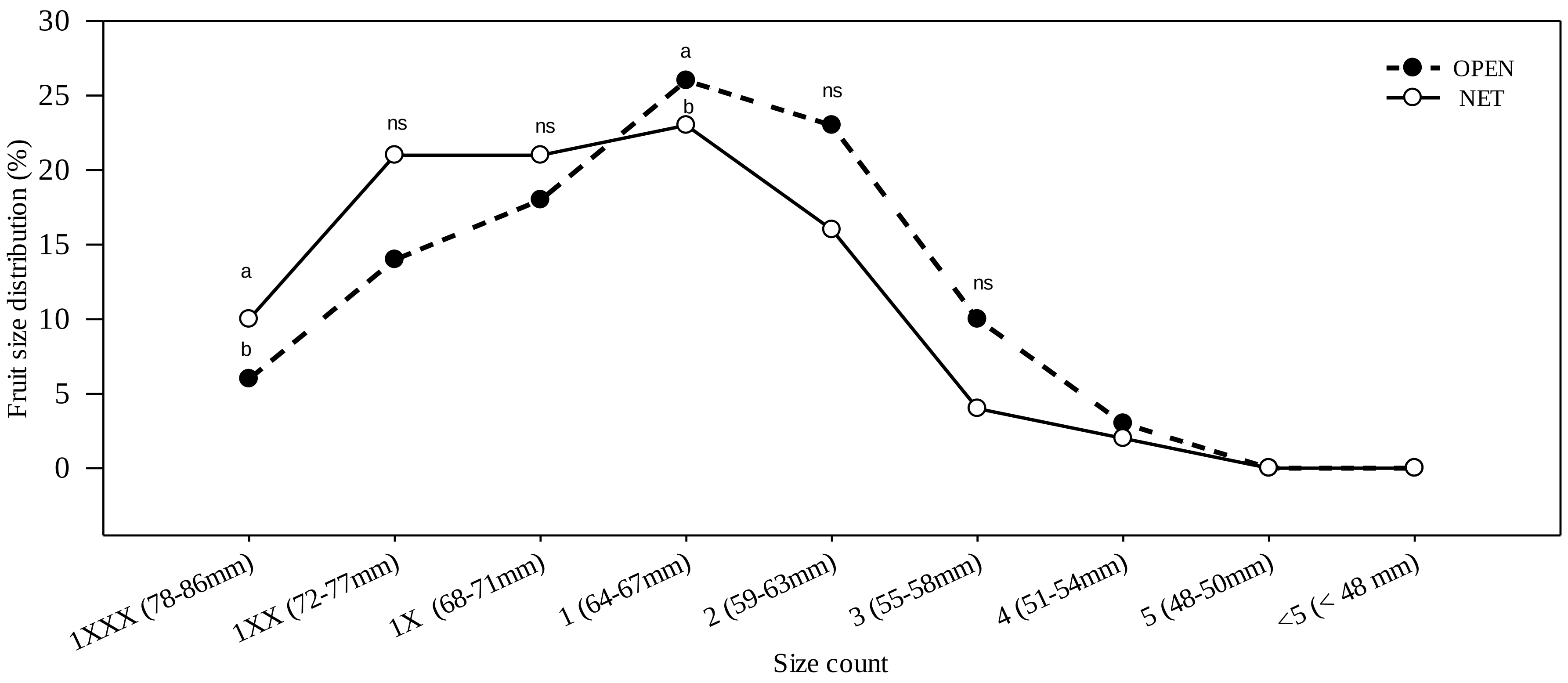

Fig. 3.2. Fruit size distribution (%) of 'Nadorcott' mandarin (*C. reticulata*) in a 20% white permanent shade net treatment (net) and an untreated control (open) (n=4), in Citrusdal in the Western Cape province of South Africa. Means with a different letter within a size count differ significantly at the 5% level. ^{ns} No significant differences.

4. Paper 2. The influence of permanent shade netting on the efficacy of chemical fruit thinning agents in 'Nadorcott' mandarin

Abstract. The use of permanent shade netting in citrus (*Citrus* spp.) is gaining support globally. The use of this technology, however, is inevitably accompanied by changes in orchard microclimate, which might have a significant impact on the efficacy of foliar applied plant growth regulators such as chemical fruit thinning agents. In this study, the effects of 20% white permanent shade netting on foliar applied chemical fruit thinning agents, viz. the synthetic auxins 2,4-dichlorophenoxy propionic acid (2,4-DP) and 3,5,6 trichloro-2-pyridiloxyacetic acid (3,5,6-TPA), were evaluated in a model cultivar, 'Nadorcott' mandarin (*C. reticulata* Blanco), in a commercial orchard in Citrusdal in South Africa. Treatments were evaluated for effects on fruit growth, fruit yield, fruit quality, and fruit mineral nutrient concentration. Overall, synthetic auxin treatments resulted in a higher number of large, premium sized fruit per tree, and a lower number of small fruit. These effects were more pronounced in the shade netting treatment. The shade netting treatment did not affect the synthetic auxins' efficacy to thin fruit, but did enhance their effects on fruit size. Apart from fruit size, the shade netting and chemical thinning treatments had no effect on other important fruit quality attributes. The concentration of selected mineral elements in fruit was enhanced by the chemical thinning agents. The application of 2,4-DP and 3,5,6-TPA to 'Nadorcott' mandarin under 20% white permanent shade netting resulted in successful fruit thinning and increased fruit size, and can therefore be recommended as commercial combination of treatments.

4.1 Introduction

The use of plant growth regulators (PGRs) as chemical fruit thinning agents is a common cultural practice in commercial citrus (*Citrus* spp.) production to adjust alternate bearing cycles, increase fruit size, and enhance other important fruit quality attributes (Guardiola and García-Luis, 2000; Mesejo et al., 2003). For these purposes, two formulations of synthetic auxins, viz. 2,4-dichlorophenoxy propionic acid (2,4-DP) and 3,5,6 trichloro-2-pyridiloxyacetic acid (3,5,6-TPA) are extensively used in citriculture (Agustí et al., 1994; Agustí et al., 2002; El-Otmani et al., 1996; Guardiola and García-Luis, 2000; Rabe, 2000). The 2,4-DP formulation is known to be a less aggressive fruit thinning agent compared to the latter, and is generally applied during phase I of fruit growth, before the end of the physiological fruit drop period [from full bloom until the end of November, for the Southern hemisphere (SH)] (Koch et al., 1996; Rabe, 2000). On the other hand, 3,5,6-TPA results in a very strong fruit thinning response and should ideally be applied during the end of, or after the physiological fruit drop period (or November drop, for the SH). When 3,5,6-TPA is applied before the end of physiological fruit drop, excessive fruit thinning and unwanted yield losses may occur (Agustí et al., 1994). Although citrus differs in its sensitivity to different synthetic auxins, these PGRs are generally rapidly absorbed and translocated in the phloem to young meristematic tissue, upon which it accumulates in young leaves, flowers, or fruitlets, and stimulates cell expansion and regulates abscission events (Aloni, 2001, Ashton and Monaco, 1991; Borroto et al., 1981; Goren, 1993; Mitchell, 1961).

Chemical fruit thinning agents are normally applied in a tank-mixture with surfactants to increase surface coverage and plant uptake, but apart from these practical considerations, uptake and effectivity of foliar applied PGR's have also been proven to be highly dependent on various environmental conditions, most notably the level of irradiation, wind speed, temperature and relative humidity (RH) (Bukovac, 1972). In apple (*Malus domestrica* Borkh.), for example, Edgerton and Haeseler (1959) reported that leaves pre-conditioned to low light levels absorbed foliar applied naphthaleneacetic acid more effectively than leaves pre-conditioned to high light levels. In cherry (*Prunis avium* L.), elevated ambient temperatures increased ethylene production by leaves in reaction to foliar ethylene treatments, and resulted in an increased fruit thinning response (Unrath, 1981). Furthermore, high RH generally favours penetration of foliar applied substances over hydrophobic leaf surfaces, due to a prolonged droplet drying and thus absorption time of the active ingredient on the leaf (Bukovac, 1972).

The use of permanent shade netting has become an increasingly popular agricultural practice to protect fruit crops against damaging natural elements, but apart from protection of fruit, shading of trees is also known to change the immediate orchard microclimate. In citrus, shade netting reduces irradiation and air flow, lowers plant-surface temperatures, and increases RH (Perez et al., 2006; Stamps, 1994; Wachsmann et al., 2014). Application of chemical fruit thinning agents during spring and early summer – a time of high temparatures and generally low RH, might therefore be significantly influenced by the commercial use of shade netting, and result in a different plant physiological response than desired, perhaps at the expense of profitable commercial fruit production.

The precise effect of 20% white, permanent shade netting on the uptake and efficacy of chemical fruit thinning agents in citrus, is unknown. Considering the above-mentioned effects of shade netting on the orchard micro-climate, it may be hypothesized that shade netting will increase the uptake and efficacy of foliar applied PGRs. Without any quantitative analyses, however, any assumptions would be speculative.

The objective of this study was to evaluate the influence of a permanent, 20% white shade netting treatment, on the efficacy of chemical fruit thinning agent treatments with two different synthetic auxins, viz. 2,4-DP and 3,5,6-TPA in ‘Nadorcott’ (*C. reticulata* Blanco), a model mandarin cultivar in which chemical fruit thinning is a standard commercial practice and the use of shade netting is becoming increasingly popular. In addition to the effects on fruit yield, important fruit growth and developmental events were recorded, and results compared over a period of two seasons.

4.2 Materials and Methods

4.2.1 Plant Material and experimental site

The experiments were conducted in a commercial orchard of 5-year-old ‘Nadorcott’ mandarin trees budded onto ‘Carrizo’ [*C. sinensis* (L.) Osbeck x *Poncirus trifoliata* (L.) Raf.] rootstock in Citrusdal (lat. 32°32’31”S, long. 19°0’42”E), in the Western Cape province of South Africa. The area experiences typical Mediterranean-type climatic conditions: summer occurs from December to February, autumn from March to May, winter from June to August and spring from September to November. The orchard is orientated in a North-to-South row-direction and trees are planted at a spacing of 5.5 x 2.5 m (727 trees per hectare). The experiments were conducted over a period of two seasons, viz. 2015/16 (season 1) and 2016/17 (season 2).

4.2.2 Experimental design and treatments

Season 1. Experiments were set up in a split-plot randomized complete block design. The main factor comprised an untreated control (open) and a 20% white, permanent shade netting treatment. The sub-factor consisted of three treatments: 1) an untreated control, 2) a 38 $mg \cdot L^{-1}$ 2,4-DP foliar spray treatment ± 45 days after full bloom (DAFB) at an average fruitlet diameter of 10 to 12 mm, and 3) a 10 $mg \cdot L^{-1}$ 3,5,6-TPA foliar spray treatment ± 65 DAFB at an average fruitlet diameter of 16 to 20 mm (after physiological fruit drop). Each treatment consisted of four treatment replicates (n=4) and two data trees per replicate.

Season 2. Experiments were set up in a split-plot randomized complete block design. The main factor comprised an untreated control (open), and a 20% white, permanent shade netting treatment. The sub-factor consisted of five treatments: 1) an untreated control, 2) a 38 mg·L^{-1} 2,4-DP foliar spray treatment ± 45 days after full bloom (DAFB) at an average fruitlet diameter of 10 to 12 mm, 3) a 10 mg·L^{-1} 3,5,6-TPA foliar spray treatment ± 65 DAFB at an average fruitlet diameter of 16 to 20 mm (after physiological fruit drop), 4) a 10 mg·L^{-1} 3,5,6-TPA treatment ± 45 DAFB at an average fruitlet diameter of 10 to 12 mm (before physiological fruit drop), and 5) a 19 mg·L^{-1} (0.5X) 2,4-DP foliar spray treatment ± 45 DAFB at an average fruitlet diameter of 10 to 12 mm (before physiological fruit drop). Each treatment consisted of four replicates (n=4) and two data trees per replicate.

4.2.3 Spray material and application method

Two synthetic auxin formulations, 2,4-DP [Corasil® P; Nufarm Agriculture (Pty) Ltd, South Africa; 25 g·L^{-1} active ingredient] and 3,5,6-TPA [Maxim®; Arysta LifeScience South Africa (Pty) Ltd, La Lucia Ridge, South Africa; 100 g·kg^{-1} active ingredient] were applied as foliar sprays. All the foliar sprays were applied in a tank mixture with a non-ionic wetting agent [Break- Thru®; Villa Crop Protection, Kempton Park, South Africa] containing the active ingredient polyether-polymethylsiloxane-copolymer (1000g·L^{-1}) at a rate of 5 mL per 100 L spray solution. Spray applications of both chemicals were made using a mist blower [Stihl® SR430; Andreas Stihl (Pty) Ltd, Pietermaritzburg, South Africa] until point of runoff, at ≈ 4L per tree. Control trees received no spray application. Buffer trees were left untreated between treated and control trees in the same row, and buffer rows between different rows to avoid the influence of drift. Trees uniform in canopy size and crop load were selected for the foliar treatments of each season.

4.3 Data collection

4.3.1 Fruit growth

Directly after the final foliar treatments were applied, five fruit were randomly selected and tagged on all data trees at a height of 1 to 2 m above the orchard floor. Initial fruit diameter was measured using a caliper (CD-6" C; Mitutoyo Corp, Tokyo, Japan), and subsequent measurements were done in monthly intervals until commercial harvest. The fruit development data were used to calculate the fruit growth rate (expressed as mm·day$^{-1)}$, and generate fruit growth curves for each treatment. The fruit growth rate was calculated using the following formula:

$$\text{Fruit growth rate } = \frac{\text{Fruit size current month} - \text{Fruit size previous month}}{\text{No. days between measurements}}$$

4.3.2 Fruit yield and quality

At time of commercial harvest, trees were stripped of all fruit to determine the total fruit yield in kg fruit per tree. In each data tree the diameters of 50 randomly distributed fruit were measured to calculate the fruit size distribution for each treatment. The total fruit yield, fruit size distribution measurements and average mass of different sized fruit were used to estimate the total number of fruit per tree.

Fruit quality. From each replicate, ten fruit were randomly sampled to determine treatment effects on fruit quality parameters. Rind colour was evaluated using a Citrus Research International (CRI) colour chart for soft citrus (no.36, 2004). Rind colour was scored on a scale from 1 to 8, with 1 being a fully coloured orange fruit, and 8, a fruit with a dark green colour. An electronic caliper was used to measure average fruit diameter for each sampled fruit. For evaluation of treatment effects on internal quality, fruit were cut open along the longitudinal plane and rind thickness were measured on opposite sides of each fruit using an electronic caliper. Each fruit was juiced with a citrus fruit juicer (Sunkist®, Chicago, USA). The mass value of the juice and that of the pulp were divided to calculate the treatment effects on juice percentage (%). Thereafter, the juice was used to analyse the total soluble solids (TSS) content (PR-32 Palette, Atago Co, Tokyo, Japan) expressed as °Brix and the titratable acidity (TA) (888 Titrando, Metrohm, Switzerland) as the citric acid content. The sugar:acid ratio was calculated by dividing the °Brix value by the citric acid content (°Brix:TA).

Fruit mineral nutrient concentration. A representative sample consisting of ten fresh fruit from each replicate of the control, 2,4-DP and 3,5,6-TPA treatments, was sent to a commercial analytical laboratory for mineral analysis [Bemlab (Pty) Ltd., Strand, South Africa] to determine the mineral nutrient concentration of all the macro- and important micro-elements. Briefly, a volume of 50 ml solution containing fresh sample tissue was analysed on the nitric/hydrochloric total acid digestion, using an inductively coupled plasma-optical emission spectrometer (ICP–OES) (Varian PRX–OEX, Varian, Inc. Corporate, Palo Alto, CA, USA) against suitable standards. The values of the macro-elements nitrogen (N), phosphorous (P), potassium (K), calcium (Ca), and magnesium (Mg) are expressed as $mg \cdot 100\ g^{-1}$ fresh weight (FW), while that of the micro-elements sodium (Na), manganese (Mn), iron (Fe), copper (Cu), zinc (Zn) and boron (B) are expressed as $mg \cdot kg^{-1}$ FW.

Maximum residue levels. A representative fresh fruit sample consisting of ten fruit from each replicate of the control, 2,4-DP and 3,5,6-TPA treatments were sent to an accredited analytical laboratory (Hearshaw and Kinnes; Cape Town, South Africa) for residue analysis in fruit. Samples were macerated, and extracts were analysed with liquid chromatography mass spectrometry (LCMS/MS; Agilent 6410, Agilent Technologies Inc., Santa Clara, CA, USA) and alkaline hydrolysis. The concentration of 2,4-DP and 3,5,6-TPA are expressed as $mg \cdot kg^{-1}$ fruit weight.

4.4 Statistical analysis

A split-plot two-way factorial analysis of variance (ANOVA) and two-way factorial repeated measures (RM) ANOVA was carried out using Statistica data analysis software (Dell Inc. 2015, Dell Statistica version 13. software.dell.com). Fisher's least significant difference test (LSD) was used to separate means at the 5% level.

4.5 Results

Fruit growth and size

In season 1, the fruit growth rate of the chemical fruit thinning agent treatments did not differ from each other, while both 3,5,6-TPA and 2,4-DP increased fruit growth rate significantly compared to the control (Table 4.1). Interaction was found for fruit growth rate between the main treatment (open and net) and time (month) during the first season, due to the fruit growth rate (mm· day^{-1}) being higher for the shade netting treatment throughout all the months, except for June (Fig. 4.1).

In season 2, no interaction was found for fruit growth rate between the open and shade netting and chemical fruit thinning treatments. The fruit growth rate of the open and shade netting treatments did not differ from each other, but significant differences occurred between the chemical fruit thinning agent treatments. The fruit growth rate of the early 3,5,6-TPA treatment was significantly higher than the control, while the 0.5X 2,4-DP treatment reduced fruit growth rate. Significant differences were recorded between months, since fruit growth rate was highest during stage II (cell enlargement) of fruit growth (Jan.- Mar.) (Table 4.2).

During season 1, no interaction was found for final fruit diameter between the open and shade netting, and chemical fruit thinning agent treatments. Final fruit diameter did not differ between the open and shade netting treatments. The 3,5,6-TPA treatment increased the final fruit diameter, while 2,4-DP had no effect compared to the control (Table 4.3). During season

2, significant differences were recorded between the open and the shade netting treatments. The shade netting treatment increased final fruit diameter of the chemical thinning agent treatments significantly compared to the open. Furthermore, the early 3,5,6-TPA treatment increased final fruit diameter compared to the control, while the 0.5X 2,4-DP treatment reduced final fruit diameter. No differneces were found between the control and standard 2,4-DP and 3.5,6-TPA treatments (Table 4.4).

Yield and fruit per tree

During season 1, no interactions were found between treatments for yield or no. of fruit per tree. Yield was increased by the shade netting treatment, while the shade netting had no effect on the number of fruit per tree. The chemical fruit thinning treatments had no significant effect on either the number or kg of fruit per tree (Table 4.5). During season 2, no differences were found in yield or fruit per tree between the open and shade netting treatments. Both 3,5,6-TPA treatments reduced the number of fruit per tree compared to the control, while only the 0.5X 2,4-DP and early 3,5,6-TPA treatments reduced total fruit yield per tree (Table 4.6).

Fruit size distribution

During season 1, no interactions were found between treatments for fruit size distribution. The shade netting treatment had a lower number of fruit in the commercial size count (SC) 3 (55-58 mm), but no differences occurred in any other size counts. The 3,5,6-TPA treatment significantly increased the number of fruit in SC 1XXX (78-86 mm) compared to the control and 2,4-DP treatment. In SC 3, the control trees had significantly more fruit, compared to the chemical fruit thinning agents (Table 4.7).

During season 2, no interactions were found between treatments. The net treatment had more fruit in SC 1XXX but less in SC 2 (59-63 mm). The chemical fruit thinning agent treatments showed multiple significant differences. In SC 1XXX and SC 1XX (72-77mm), both the 3,5,6-TPA treatments increased the amount of fruit significantly compared to the control, which was to the expense of SC 1, 2, 3 and 4 where the 3,5,6-TPA and early 3,5,6-TPA had significantly less fruit. The 2,4-DP treatments had no effect on the fruit size distribution (Table 4.8).

Fruit quality

During season 1, no interactions were found between treatments for fruit quality. Neither the open and shade netting, nor the chemical fruit thinning agents had significant effects on TA, ^{o}Brix or the ^{o}Brix:TA ratio, with only the juice % of fruit treated with the chemical fruit thinning agents being reduced by the shade netting (Table 4.9). Rind colour and rind thickness did not differ between the open and shade netting, or the chemical fruit thinning agent treatments (Data not shown).

During season 2, no interactions were found between treatments. The open and shade netting treatments had no effect on any internal fruit quality attributes, however the early 3,5,6-TPA treatment reduced the TA and TSS content of the fruit significantly compared to the control and 2,4-DP treatment. The late 3,5,6-TPA treatment also reduced the TSS content significantly, compared to the control. The early 3,5,6-TPA treatment was the only to increase the ^{o}Brix:TA ratio significantly (Table 4.10). Both the 2,4-DP treatments and the normal 3,5,6-TPA treatment increased the juice percentage significantly compared to the control. Rind colour and rind thickness did not differ between any of the open and shade netting or chemical fruit thinning agent treatments (Data not shown).

Fruit mineral nutrient concentration

In season 1, no interactions were found between treatments for fruit mineral nutrient concentration. The open and shade netting treatments had no effect on the concentration of any element in fruit, but both the 2,4-DP and 3,5,6-TPA treatments reduced the Na concentration compared to the control (Table 4.11).

During season two, interactions were found between treatments for fruit P and Fe concentration. Fruit P concentration was significantly lower in the open control fruit, compared to all the other treatment combinations. The fruit Fe concentration of the 2,4-DP and 3,5,6-TPA treatments in the open were lower compared to the open control (Table 4.12 B).

For the other nutrient elements, no significant interactions were found between treatments, and the open and shade netting treatments had no effect on the concentration of any mineral nutrient in fruit. The K and Mg concentration in fruit was significantly higher for the 2,4-DP and 3,5,6-TPA treatments compared to the control. The Ca concentration was increased significantly by the 3,5,6-TPA treatment, while B concentration was significantly increased by the 2,4-DP treatment, compared to the control, but did not differ from the 3,5,6-TPA treatment (Table 4.12 A).

Residue analysis in fruit

No synthetic auxin residues were detected in any fruit treated with 2,4-DP or 3,5,6-TPA, in either the open or the shade netting treatments (Data not shown).

4.6 Discussion

The foliar application of synthetic auxins as chemical fruit thinning agents was effective in increasing final fruit diameter and improving fruit size distribution. The efficacy of chemical fruit thinning agents to thin fruitlets was not influenced by shade netting, but the shade netting increased fruit diameter and fruit size distribution of fruit treated with chemical fruit thinning agents in season 2. Shade netting had no influence on the effects of chemical fruit thinning agents on fruit yield and quality, while no residues of the synthetic auxins were detected in fruit at time of commercial maturity.

The thinning efficacy of the chemical fruit thinning agents was not altered by the shade netting, as no significant interactions were recorded between treatments. The 3,5,6-TPA treatments, however, reduced the number of fruit per tree significantly in season 2, which concurs with reports that 3,5,6-TPA is an erratic chemical fruit thinning agent when applied before, or during the final stages of physiological fruit drop (Agustí et al., 1996; Rabe, 2000). During this period, citrus is known to be highly susceptible to auxin-induced fruitlet abscission. Although applied before the end of the physiological fruit drop period, the 2,4-DP treatment had no thinning effect, which concurs with findings that this type of synthetic auxin is a less aggressive chemical fruit thinning agent compared to 3,5,6-TPA (Koch et al.,1996; Rabe, 2000).

The increase in fruit yield for the synthetic auxin treatments in the shade netting treatment during season 1, however, should be ascribed to an increase in fruit size, since no differences were recorded between treatments for fruit number. The chemical fruit thinning agent treatments had no effects on fruit yield, except for the early 3,5,6-TPA treatment that was applied before physiological fruit drop, and 0.5X 2,4-DP, which reduced yield significantly in season 2. Fruit yield, however, was unaffected for all other chemical thinning agent treatments that were applied at the recommended timing and concentrations. This concurs with Guardiola (1997) and Rabe (2000) who reported that fruit yield will be unaffected if less than 20% of fruitlets are removed, and that the increased fruit size will compensate for the reduction in fruit number.

Concurring with the results on final fruit diameter, the shade netting also improved the fruit size distribution of the chemical fruit thinning agent treatments. Furthermore, 3,5,6-TPA treatments showed the best results and successfully shifted the fruit size distribution towards the larger fruit size counts. These results concur with findings from El-Otmani et al. (1993) who reported that synthetic auxin chemical fruit thinning agent treatments improved fruit size distribution in mandarin. Shade netting was found to further enhance this effect in this study, which is of commercial significance, since improved fruit size distribution are linearly correlated with higher monetary returns when exporting fruit to markets with a preference for larger sized fruit.

Shade netting had no effect on the internal quality of fruit treated with chemical fruit thinning agent treatments. Generally, the chemical thinning treatments also had no effect on internal fruit quality parameters, except for the 3,5,6-TPA treatments, which reduced the fruit TA and TSS content during season 2. This reduction can be ascribed to increased fruit size for these treatments, since Agustí et al. (1996) found lower levels of TA in larger fruit, as a result of a dilution effect prevalent in larger fruit. Jifon and Syvertson (2001) reported a similar effect for TSS, which may be the underlying reason for the reduced TSS levels in fruit from the 3,5,6-TPA treatment in this study.

The ability of chemical fruit thinning agents to increase citrus fruit size is partly due to a subsequent increase in fruit sink strength. This increase in sink strength may also have an effect on fruit mineral nutrient concentration, as previous studies by Agustí et al. (1996) reported that fruit from synthetic auxin treated trees showed an increase in resistance to post harvest physiological rind disorders, such as rind pitting. This disorder is primarily related to the general condition and mineral nutrient concentration in the rind, especially in relation to potassium (K), magnesium (Mg) and calcium (Ca) (Cronjé et al., 2011). In this study the 2,4-

DP and 3,5,6-TPA treatments increased the K and Mg levels in the fruit, while only the 3,5,6-TPA treatment enhanced the fruit Ca concentration.

Previous studies showed that synthetic auxin treated fruit are known to transport the auxin basipetally towards the peduncle, which in turn leads to increased cambial activity and vascular development (Aloni, 2001; Bustan et al., 1995). This results in subsequent increased xylem capacity and peduncle diameter, which will lead to increased transport of metabolites, water and mineral nutrients towards the fruit (Bustan et al., 1995; Mesejo et al., 2003). Furthermore, synthetic auxin treatments are known to increase fruit sink strength (Agustí et al., 1994; Agustí et al., 2002; El Otmani et al., 1996; Guardiola and García-Luis, 2000; Rabe, 2000), which, in addition to increased vascular capacity of the fruit peduncle, may be responsible for the elevated fruit K, Mg and Ca levels in the chemical thinning treatments.

Results obtained in this study, suggests that shade netting did not affect the fruit thinning efficacy of foliar applied chemical fruit thinning agents, but did enhance the final diameter of fruit treated with chemical fruit thinning agents. Considering that shade netting generally reduces radiation levels and wind speed, and increases relative humidity and ambient temperatures (Stamps, 1994; Wachsmann et al., 2014) the uptake efficiency of foliar applied substances should be enhanced by shade netting (Bukovac 1972; Edgerton and Haeseler, 1959; Stover and Greene, 2005; Unrath, 1981), and therefore also that of synthetic auxin thinning agents. Increased efficacy of chemical fruit thinning agents was however not the case in this study.

The reason why the chemical fruit thinning agent efficacy was not enhanched by the shade netting may be related to the mode of action of these substances to induce fruitlet thinning. In a recent study on the mode of action of 3,5,6-TPA, it was found that 3,5,6-TPA treatments applied before the end of the physiological fruit drop period, caused a reduction in leaf photosynthetic capacity by temporarily impairing photosystem II, for 13 to 20 days

(Mesejo et al., 2012). This results in a lower rate of leaf photosynthesis, a reduction in available photosynthate, and reduced fruitlet growth rate. A reduction in fruit growth rate then triggers the hormonal sequence for fruitlet abscission at the calyx, which eventually results in shedding of the smaller fruitlets (Mesejo et al., 2012). If uptake of the synthetic auxins was indeed enhached by the permanent shade netting treatment in this experiment, a higher rate of leaf photosynthesis and increased carbohydrate status for trees under the shade nets (Jifon and Syvertson, 2003; Prins, 2018) could have masked the mode of action of chemical fruitlet thinning as proposed by Mesejo et al. (2012) and various other studies (Agustí et al. 1996; Guardiola and García-Luis, 2000; Iglesias et al., 2007). It could also be that in this experiment the microclimate under the shade netting was not altered to such an extent that the uptake of the chemical fruit thinning agents was enhanced. This should, however, be clarified in future studies.

Considering the various commercial advantages of shade netting and the application of synthetic auxins as chemical fruit thinning agents, these cultural practices could be of immense importance as combination treatments. Results from this study showed that the shade netting enhanced fruit size of the chemical fruit thinning agent treatments. In addition, the chemical fruit thinning agents enhanced the fruit mineral nutrient concentration of selected elements, while fruit yield, internal fruit quality, and residue levels of treatments in fruit were not influenced by shade netting. This suggests that the combination of shade netting and chemical fruit thinning results in fruit of higher market value, while the elevated fruit mineral nutrient concentration may lead to additional advantages such as increased resistance to post-harvest physiological rind disorders.

To conclude, the efficacy of the synthetic auxins 2,4-DP and 3,5,6-TPA to thin fruitlets, when applied at the recommended timing, was not affected by the shade netting. The shade netting enhanced the diameter of fruit in the chemical fruit thinning agent treatments compared to the open, while it had no effect on internal fruit quality parameters, or fruit yield. The chemical fruit thinning agent treatments increased the concentration of selected mineral nutrient elements in fruit, an effect that was also not altered by the shade netting. Furthermore, the shade netting had no effect on residue breakdown of the chemical fruit thinning agents as no chemical residues were detected at the time of commercial harvest. The hypothesis that shade netting will enhance the efficacy of synthetic auxin fruit thinning agents is thus rejected, and it can be concluded that 20% white permanent shade netting had no effect on the thinning efficacy of synthetic auxin chemical fruit thinning agents in ‘Nadorcott’ mandarin.

4.7 Literature cited

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Table 4.1. Fruit growth rate (mm·day^{-1}) of 'Nadorcott' mandarin (*C. reticulata*) during season 1 (2015/16), in reaction to synthetic auxin fruit thinning agent treatments, in a 20% white permanent shade net treatment (net) and an untreated control (open) (n=4), in Citrusdal in the Western Cape province of South Africa. TMT*Month interaction illustrated in Fig. 4.1.

Thinning agent (PGR)	**Fruit growth rate 2015/16 (mm·day^{-1})**
Control	0.20 b[z]
2,4-DP	0.21 a
3,5,6-TPA	0.22 a
P-values	
TMT	*0.1425*
PGR	*0.0006*
Month	*<0.0001*
TMT*PGR	*0.3752*
TMT*Month	*0.0001*
PGR*Month	*0.5291*
TMT*PGR*Month	*0.8456*

[z] Means with a different letter within a column differ significantly at the 5% level (LSD).

Table 4.2. Fruit growth rate (mm·day^{-1}) of 'Nadorcott' mandarin (*C. reticulata*) during season 2 (2016/17), in reaction to synthetic auxin fruit thinning agent treatments, in a 20% white permanent shade net treatment (net) and an untreated control (open) (n=4), in Citrusdal in the Western Cape province of South Africa.

Factor	**Fruit growth rate 2016/17 (mm·day^{-1})**
Treatment (TMT)	
Open	0.21^{ns}
Net	0.22
Thinning agent (PGR)	
Control	0.21 bc^{z}
2,4-DP	0.21 bc
3,5,6-TPA	0.21 b
0.5X 2,4-DP	0.20 c
Early 3,5,6-TPA *	0.23 a
Month	
Jan	0.29 ab^{z}
Feb	0.29 a
Mar	0.28 b
Apr	0.22 c
May	0.19 d
June	0.08 f
July	0.13 e
P-values	
TMT	*0.0880*
PGR	*<0.0001*
Month	*<0.0001*
TMT*PGR	*0.7199*
TMT*Month	*0.0719*
PGR*Month	*0.2488*
TMT*PGR*Month	*0.8387*

^{z} Means with a different letter within a column differ significantly at the 5% level (LSD).

^{ns} No significant differences within column.

* Sprayed at same phenological stage as Corasil treatments (Before physiological fruit drop).

Table 4.3. Final fruit diameter (mm) of ‘Nadorcott’ mandarin (*C. reticulata*) during season 1 (2015/16), in reaction to synthetic auxin fruit thinning agent treatments, in a 20% white permanent shade net treatment (net) and an untreated control (open) (n=4), in Citrusdal in the Western Cape province of South Africa.

Treatment (TMT)	**Final fruit diameter 2015/16 (mm)**
Open	62.34^{ns}
Net	65.65
Thinning agent (PGR)	
Control	61.53 b^{z}
2,4-DP	63.74 b
3,5,6-TPA	66.71 a
P-values	
TMT	*0.1001*
PGR	*0.0075*
TMT*PGR	*0.6495*

^{z} Means with a different letter within a column differ significantly at the 5% level (LSD).

^{ns} No significant differences within column.

Table 4.4. Final fruit diameter (mm) of ‘Nadorcott’ mandarin (*C. reticulata*) during season 2 (2016/17), in reaction to synthetic auxin fruit thinning agent treatments, in a 20% white permanent shade net treatment (net) and an untreated control (open) (n=4), in Citrusdal in the Western Cape province of South Africa.

Treatment (TMT)	**Final fruit diameter 2016/17 (mm)**
Open	67.73 b[z]
Net	71.75 a
Thinning agent (PGR)	
Control	67.61 bc[z]
2,4-DP	68.75 bc
3,5,6-TPA	70.77 b
0.5X 2,4-DP	66.70 c
Early 3,5,6-TPA *	74.60 a
P-values	
TMT	*0.0269*
PGR	*0.0004*
TMT*PGR	*0.8143*

[z] Means with a different letter within a column differ significantly at the 5% level (LSD).

* Sprayed at same phenological stage as Corasil treatments (Before physiological fruit drop).

Table 4.5. Total fruit per tree (fruit·tree^{-1}) and yield (kg·tree^{-1}) of 'Nadorcott' mandarin (*C. reticulata*) during season 1 (2015/16), in reaction to synthetic auxin fruit thinning agent treatments, in a 20% white permanent shade net treatment (net) and an untreated control (open) (n=4), in Citrusdal in the Western Cape province of South Africa.

Treatment (TMT)	**Yield 2015/16**	
	Fruit·tree^{-1}	**Kg·tree^{-1}**
Open	373.25^{ns}	33.40 b^{z}
Net	398.67	39.65 a
Thinning agent (PGR)		
Control	399.00 ^{ns}	36.08 ^{ns}
2,4-DP	371.13	34.32
3,5,6-TPA	387.75	39.17
P-Values		
TMT	*0.4337*	*0.0453*
PGR	*0.7312*	*0.3933*
TMT*PGR	*0.3527*	*0.1189*

^{z} Means with a different letter within a column differ significantly at the 5% level (LSD).

^{ns} No significant differences within column.

Table 4.6. Total fruit per tree (fruit·tree^{-1}) and yield (kg·tree^{-1}) of 'Nadorcott' mandarin (*C. reticulata*) during season 2 (2016/17), in reaction to synthetic auxin fruit thinning agent treatments, in a 20% white permanent shade net treatment (net) and an untreated control (open) (n=4), in Citrusdal in the Western Cape province of South Africa.

Treatment (TMT)	**Yield 2016/17**	
	Fruit· tree^{-1}	**Kg· tree^{-1}**
Open	445.70^{ns}	47.65^{ns}
Net	410.95	50.01
Thinning agent (PGR)		
Control	537.88 a^{z}	56.00 a
2,4-DP	456.63 ab	49.58 ab
3,5,6-TPA	405.25 b	51.78 ab
0.5X 2,4-DP	454.38 ab	47.02 bc
Early 3,5,6-TPA *	287.50 c	38.75 c
P-values		
TMT	*0.4673*	*0.5284*
PGR	*0.0001*	*0.0103*
TMT*PGR	*0.2095*	*0.2579*

^{z} Means with a different letter within a column differ significantly at the 5% level (LSD).

^{ns} No significant differences within column.

* Sprayed at same phenological stage as Corasil treatments (Before physiological fruit drop).

Table 4.7. Fruit size distribution (%) of 'Nadorcott' mandarin (*C. reticulata*) during season 1 (2015/16), in reaction to synthetic auxin fruit thinning agent treatments, in a 20% white permanent shade net treatment (net) and an untreated control (open) (n=4), in Citrusdal in the Western Cape province of South Africa.

	Size Count (% per tree)								
Factor	**1XXX** (78-86mm)	**1XX** (72-77mm)	**1X** (68-71mm)	**1** (64-67mm)	**2** (59-63mm)	**3** (55-58mm)	**4** (51-54mm)	**5** (48-50mm)	**<5** (< 48 mm)
Treatment (TMT)									
Open	2 ^{ns}	7 ^{ns}	14 ^{ns}	25 ^{ns}	28 ^{ns}	15 a	6 ^{ns}	2 ^{ns}	1 ^{ns}
Net	4	14	18	26	22	9 b	4	1	1
Thinning agent (PGR)									
Control	2 b^{z}	8 ^{ns}	13 ^{ns}	24 ^{ns}	27 ^{ns}	16 a	6 ^{ns}	2 ^{ns}	0 ^{ns}
2,4-DP	2 b	9	18	24	27	11 b	5	2	0
3,5,6-TPA	6 a	14	17	27	20	9 b	4	1	0
P-values									
TMT	*0.0762*	*0.0557*	*0.2208*	*0.4972*	*0.1936*	*0.0478*	*0.2269*	*0.0985*	*0.7519*
PGR	*0.0115*	*0.2382*	*0.0696*	*0.4379*	*0.1207*	*0.0385*	*0.3490*	*0.0822*	*0.5787*
TMT*PGR	*0.2385*	*0.9286*	*0.5494*	*0.5156*	*0.6299*	*0.4586*	*0.2492*	*0.8351*	*0.5787*

^{z} Means with a different letter within a column differ significantly at the 5% level (LSD).

^{ns} No significant differences.

Table 4.8. Fruit size distribution (%) of ‘Nadorcott’ mandarin (*C. reticulata*) during season 2 (2016/17), in reaction to synthetic auxin fruit thinning agent treatments, in a 20% white permanent shade net treatment (net) and an untreated control (open) (n=4), in Citrusdal in the Western Cape province of South Africa.

Factor	**Size Count (% per tree)**								
	1XXX (78-86mm)	**1XX** (72-77mm)	**1X** (68-71mm)	**1** (64-67mm)	**2** (59-63mm)	**3** (55-58mm)	**4** (51-54mm)	**5** (48-50mm)	**<5** (< 48 mm)
Treatment									
Open	12 b[z]	19[ns]	20[ns]	20[ns]	19 a	6[ns]	2[ns]	1[ns]	0[ns]
Net	19 a	22	18	18	13 b	4	1	0	0
Thinning agent (PGR)									
Control	8 b	17 c	19[ns]	25 a	20 a	7 a	3 a	1[ns]	0[ns]
2,4-DP	10 b	19 bc	19	23 a	18 a	6 a	2 a	1	0
3,5,6-TPA	22 a	23 ab	19	16 b	12 b	3 b	1 bc	0	0
0.5X 2,4-DP	9 b	17 bc	21	22 a	21 a	8 a	2 ab	1	0
Early 3,5,6-TPA *	28 a	27 a	18	11 c	8 c	2 b	1 c	0	0
P-values									
TMT	*0.0365*	*0.1504*	*0.4447*	*0.1883*	*0.0113*	*0.1013*	*0.3224*	*0.5999*	*0.7608*
PGR	*<0.0001*	*0.0010*	*0.8766*	*<0.0001*	*<0.0001*	*0.0003*	*0.0172*	*0.4732*	*0.3983*
TMT*PGR	*0.8199*	*0.5313*	*0.2677*	*0.9548*	*0.0515*	*0.3119*	*0.3878*	*0.7137*	*0.0573*

[z] Means with a different letter within a column differ significantly at the 5% level (LSD).

[ns] No significant differences.

* Sprayed at same phenological stage as Corasil treatments (Before physiological fruit drop).

Table 4.9. Internal fruit quality of 'Nadorcott' mandarin (*C. reticulata*) during season 1 (2015/16), in reaction to synthetic auxin fruit thinning agent treatments, in a 20% white permanent shade net treatment (net) and an untreated control (open) (n=4), in Citrusdal in the Western Cape province of South Africa.

Factor	**Titratable acidity (TA)**	**TSS^y**	**Sugar:Acid (ºBrix:TA)**	**Juice %**
Treatment (TMT)				
Open	1.40^{ns}	12.88^{ns}	9.26^{ns}	52.24 a^z
Net	1.45	12.73	8.84	47.90 b
Thinning agent (PGR)				
Control	1.45^{ns}	12.80^{ns}	8.88^{ns}	50.69^{ns}
2,4-DP	1.43	13.13	9.20	50.34
3,5,6-TPA	1.38	12.49	9.08	49.17
P-values				
TMT	*0.3060*	*0.4188*	*0.1179*	*0.0337*
PGR	*0.6785*	*0.2180*	*0.6261*	*0.5145*
TMT*PGR	*0.2886*	*0.3024*	*0.5058*	*0.8709*

[z] Means with a different letter within a column differ significantly at the 5% level (LSD).

[y] Total soluble solids (ºBrix).

[ns] No significant differences.

Table 4.10. Internal fruit quality of ‘Nadorcott’ mandarin (*C. reticulata*) during season 2 (2016/17), in reaction to synthetic auxin fruit thinning agent treatments, in a 20% white permanent shade net treatment (net) and an untreated control (open) (n=4), in Citrusdal in the Western Cape province of South Africa.

Factor	**Titratable acidity (TA)**	**TSS^y (°Brix)**	**Sugar:Acid (°Brix:TA)**	**Juice %**
Treatment (TMT)				
Open	1.08^{ns}	11.32^{ns}	10.58^{ns}	43.70^{ns}
Net	1.03	11.28	11.07	44.85
Thinning agent (PGR)				
Control	1.08 ab^z	11.48 a^z	10.71 b^z	39.37 b^z
2,4-DP	1.14 a	11.68 ab	10.29 b	46.37 a
3,5,6-TPA	1.04 b	10.86 c	10.53 b	46.53 a
0.5X 2,4-DP	1.13 a	11.86 a	10.58 b	47.55 a
Early 3,5,6-TPA *	0.88 c	10.61 c	12.02 a	41.57 b
P-values				
TMT	*0.1675*	*0.6999*	*0.1544*	*0.3907*
PGR	*<0.0001*	*<0.0001*	*0.0023*	*0.0001*
TMT*PGR	*0.9690*	*0.2408*	*0.9653*	*0.0783*

^{z} Means with a different letter within a column differ significantly at the 5% level (LSD).

^{ns} No significant differences.

^{y} Total soluble solids.

* Sprayed at same phenological stage as Corasil treatments (Before physiological fruit drop).

Table 4.11. Fruit mineral nutrient concentration consisting of macro-elements (N, P, K, Ca, Mg) and micro-elements (Na, Mn, Fe, Cu, Zn, B), of ‘Nadorcott’ mandarin (*C. reticulata*) during season 1 (2015/16), in reaction to synthetic auxin fruit thinning agent treatments, in a 20% white permanent shade net treatment (net) and an untreated control (open) (n=4), in Citrusdal in the Western Cape province of South Africa

Fruit Nutrients 2015/16											
Factor	**Macro - elements (mg·100g^{-1})**					**Micro - elements (mg·kg^{-1})**					
	N	**P**	**K**	**Ca**	**Mg**	**Na**	**Mn**	**Fe**	**Cu**	**Zn**	**B**
Treatment (TMT)											
Open	224.25[ns]	15.48[ns]	191.50[ns]	57.65[ns]	14.80[ns]	16.90[ns]	2.19[ns]	6.78[ns]	0.41[ns]	1.68[ns]	3.48[ns]
Net	230.42	15.11	194.29	57.15	14.97	18.19	1.46	5.91	0.33	1.97	3.59
Thinning agent (PGR)											
Control	231.56[ns]	15.01[ns]	201.19[ns]	55.25[ns]	14.05[ns]	20.38 a[z]	1.66[ns]	6.33[ns]	0.39[ns]	1.99[ns]	3.62[ns]
2,4-DP	224.81	15.62	198.81	56.00	14.52	16.60 b	1.71	6.03	0.38	1.69	3.83
3,5,6-TPA	225.63	15.24	178.69	60.94	16.08	15.65 b	2.11	6.68	0.33	1.79	3.16
P-values											
TMT	*0.6538*	*0.6151*	*0.8373*	*0.9240*	*0.8780*	*0.5136*	*0.1319*	*0.1886*	*0.1454*	*0.3263*	*0.7429*
PGR	*0.8667*	*0.7512*	*0.3059*	*0.5971*	*0.1972*	*0.0403*	*0.5436*	*0.6017*	*0.2431*	*0.5984*	*0.1419*
TMT*PGR	*0.6497*	*0.4551*	*0.4508*	*0.8777*	*0.9062*	*0.1962*	*0.9274*	*0.5901*	*0.3307*	*0.5049*	*0.6216*

[z] Means with a different letter within a column differ significantly at the 5% level (LSD).

[ns] No significant differences.

Table 4.12. (A) Fruit mineral nutrient concentration and (B) fruit mineral nutrient concentration interactions, consisting of macro-elements (N, P, K, Ca, Mg) and micro-elements (Na, Mn, Fe, Cu, Zn, B) in 'Nadorcott' mandarin (*C. reticulata*) during season 2 (2016/17), in reaction to synthetic auxin fruit thinning agent treatments, in a 20% white permanent shade net treatment (net) and an untreated control (open) (n=4), in Citrusdal in the Western Cape province of South Africa

A

Factor	**Macro elements (mg·100g^{-1})**				**Micro-elements (mg·kg^{-1})**				
	N	**K**	**Ca**	**Mg**	**Na**	**Mn**	**Cu**	**Zn**	**B**
Treatment (TMT):									
Open	218.50[ns]	215.08[ns]	47.33[ns]	17.45[ns]	28.63[ns]	1.33[ns]	0.38 [ns]	1.59[ns]	2.91[ns]
Net	207.92	212.33	43.03	17.60	32.18	1.23	0.34	1.50	2.70
Thinning agent (PGR)									
Control	208.00[ns]	204.00 b[z]	40.25 b	16.21 b	32.55[ns]	1.23[ns]	0.40[ns]	1.49[ns]	2.63 b
2,4-DP	216.25	217.88 a	44.81 b	17.70 a	31.85	1.24	0.35	1.55	2.94 a
3,5,6-TPA	215.38	219.25 a	50.46 a	18.66 a	26.80	1.36	0.33	1.60	2.85 ab
P-values									
TMT	*0.1316*	*0.2367*	*0.1263*	*0.7360*	*0.2021*	*0.6941*	*0.3534*	*0.2981*	*0.0932*
PGR	*0.3842*	*<0.0001*	*0.0054*	*0.0012*	*0.1033*	*0.6937*	*0.0878*	*0.4740*	*0.0307*
TMT*PGR	*0.7450*	*0.2066*	*0.4718*	*0.1462*	*0.5841*	*0.1824*	*0.6610*	*0.6289*	*0.3506*

[z] Means with a different letter within a column differ significantly at the 5% level (LSD).

[ns] No significant differences.

B

		Nutrient	
Treatment	**Thinning agent**	**P (mg·100g^{-1})**	**Fe (mg·kg^{-1})**
Open	Control	18.15 b[z]	5.08 a
	2,4-DP	21.41 a	3.38 b
	3,5,6-TPA	22.35 a	3.43 b
Net	Control	21.37 a	3.45 ab
	2,4-DP	20.86 a	3.78 ab
	3,5,6-TPA	20.83 a	4.80 ab
P-value			
TMT*PGR		*0.0261*	*0.0434*

[z] Means with a different letter within a column differ significantly at the 5% level (LSD).

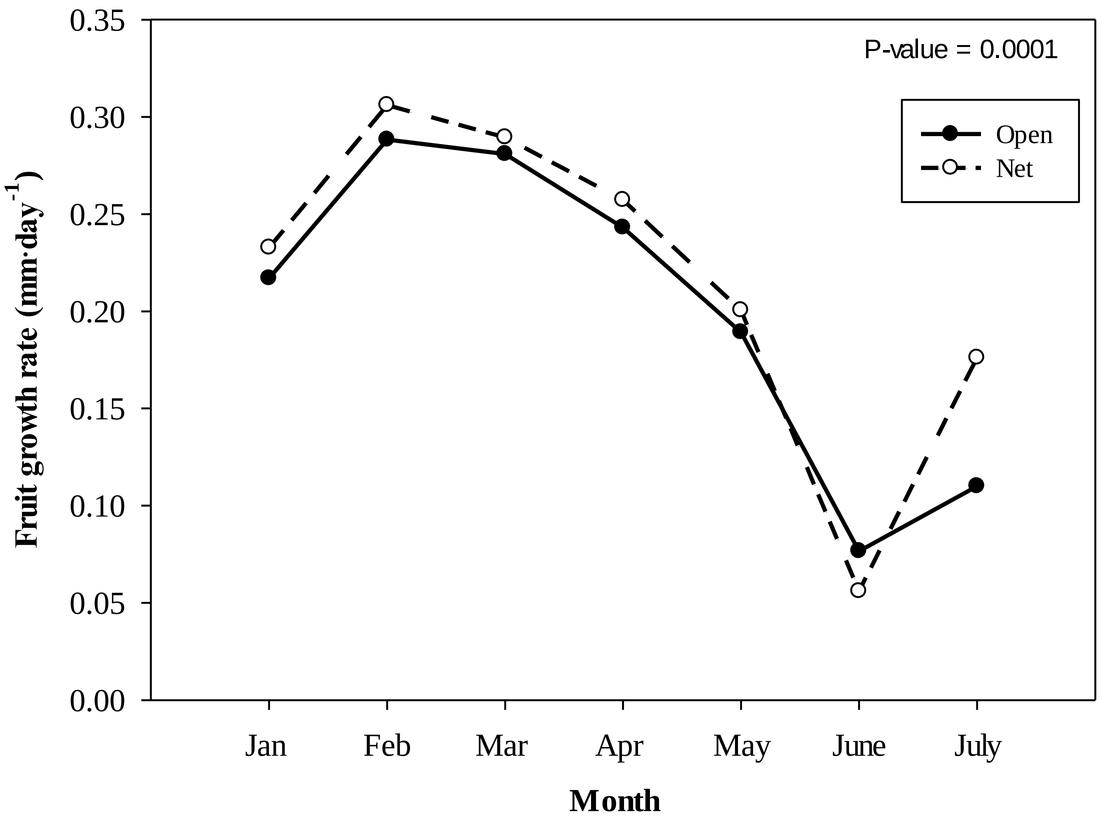


Fig. 4.1. Fruit growth rate (mm·day^{-1}) and month interaction of 'Nadorcott' mandarin (*C. reticulata*) during season 1 (2015/16), in reaction to synthetic auxin fruit thinning agent treatments, in a 20% white permanent shade net treatment (net) and an untreated control (open) (n=4), in Citrusdal in the Western Cape province of South Africa. Interaction illustrated as showed in Table 4.1.

5. Paper 3. Citrus shade netting: A 15-year budget model quantifying the influence of permanent shade netting on ‘Nadorcott’ mandarin orchard profitability

Abstract. Pressure to produce commodities with increased efficiency is perceived by agricultural sectors worldwide. To achieve this goal, the global citrus industry is turning towards the technology of permanent shade netting in orchards. Permanent shade netting structures in citrus orchards has many benefits and can assist in buffering climatic extremities and preventing cross pollination, however at production level there are some disadvantages associated therewith. The establishment of permanent shade structures is a capital-intensive exercise, and in addition the orchard microclimate is altered, and subsequently pest and disease pressure are increased. This study was conducted to identify all known advantages and disadvantages of citrus shade netting, to quantify the impact thereof on the profitability of a high value ‘Nadorcott’ mandarin orchard. Financial evaluations were done by compiling an enterprise budget model based on standard accounting principles. The model was compiled in a spreadsheet programme, allowing for multiple assumptions and integrated calculations. All parameters and values assumed in the model are based on weighted averages from a South African citrus shade netting industry survey, in addition to information gathered in scientific studies in this project at the Department of Horticultural Science, Stellenbosch University. From the budget model it can be concluded that 20% white shade netting resulted in an 10% increase in production costs per hectare, while gross income was 28% higher under shade netting. The result was a gross margin increase of 32% per annum for the shade netted orchard, during full bearing potential. It can thus be concluded that 20% white shade netting increased the productivity and profitability of a ‘Nadorcott’ mandarin orchard, under South African production conditions.

5.1 Introduction

The use of shade netting in citrus orchards is increasing globally, however a lack of knowledge exists on the effect that shade netting has on the physiological and phenological parameters of a citrus tree, and more so on the effect of these changes on commercial citrus production. Much speculation exists on the farm-level economic impact of citrus shade netting, however without scientific based studies to support arguments. This study forms part of a larger horticultural research project and will take an agricultural economic approach, creating and utilizing an enterprise budget model based on standard accounting principles, to assess the effect of citrus shade netting on orchard level economics and revenue.

To evaluate return on investment, orchard level income and expenses needed to be quantified. These are directly linked to production advantages and disadvantages, linked to the use of citrus shade netting. Firstly, these advantages and disadvantages thus need to be identified. To evaluate the advantages and disadvantages of shade netting in the South African citrus industry, a study by Stander and Cronje (2016) was consulted. In addition, a citrus shade netting industry survey (CNIS) which was conducted during this research project, in which information was gathered. The CNIS focussed on two South African production areas, the Western Cape and Limpopo – a winter and a summer rainfall area, respectively. Producers currently making use of shade netting in these areas were identified and interviewed. The survey focussed on identifying and quantifying changes in production practices under shade netting for high value mandarin cultivars such as ‘Nadorcott’ (*Citrus reticulata* Blanco), and the costs and savings associated therewith.

Growers indicated possible advantages such as increased young tree growth, 20 to 30% savings on irrigation, a 10 to 20% increase in fruit pack-out percentage (mainly due to reduced sunburn and wind blemishes), in addition to increased fruit size, which results in an improved fruit size distribution (Stander & Cronje. 2016). Results from the CNIS concurred, viz. a 10 to 20% increase in fruit pack-out, and a 10 to 25% saving on irrigation under shade netting. Additional advantages identified in the CNIS included reduced time until full bearing potential, an increase in Class 1 fruit pack-out percentage due to reduced fruit surface blemishes, a 20 to 40% saving on orchard sanitation, and tree and fruit protection against damaging hail. Hail storms have the potential to eliminate a full crop if the orchard is not covered, and in production areas where this climatic extremity is inevitable, e.g. Ohrigstad and Marble Hall (Limpopo province, South Africa), the use of protective shade netting is a necessity. Some of the above-mentioned results were confirmed by the scientific experiments presented in Paper 1 of this study, viz. increased fruit size, improved fruit size distribution, increased pack out percentage, and increased vegetative growth of 'Nadorcott' mandarin.

From the above mentioned, it seems that there are mostly advantages associated with production of citrus under shade netting, but sight must not be lost as to the negative effects associated with this cultural practice. The main disadvantage of shade netting, and particularly enclosed netting structures is increased pest and disease pressure (Stander and Cronje, 2016; CNIS, 2017), and a rapid increase in pest population once present (CNIS, 2017). This will lead to increased costs for pest and disease management, and if the producer is not proactive, a loss in yield may occur due to extensive fruit damage. Although increased vegetative growth under shade netting is an advantage during early tree growth, this may result in increased expenditure on pruning practices after tree canopies has filled the allocated space.

The above-mentioned summarises the influence of shade netting on citrus production, but a study to which extent these changed parameters influence the returns of a mandarin orchard over a prolonged period, has not been done. The objective of this chapter was to develop an enterprise budget model to project 15-year budgets for two scenarios: 1) a mandarin orchard under shade netting, and 2) a standard commercial mandarin orchard without shade netting. Shade netting is a capital-intensive practice, but it is hypothesized that it will increase the gross margin income of a mandarin orchard.

5.2 Technique

Creating an enterprise budget model for a scenario such as shade netting of a citrus orchard is a highly integrated process as it should account for various physical-biological and socio-economical parameters and assumptions. The main benefit of financial models is that it integrates the physical farm practices with the financial outcome, which is achieved through a sequence of equations that adhere to standard accounting principles. Budget models are normally created as a farm-model, including whole-farm assumptions and values. For this study however, an enterprise budget model was constructed for a specific orchard and calculation outputs will show orchard gross margins for both scenarios.

5.2.1 The multi-period enterprise model

A typical multi-period farm budget model is the ideal tool to evaluate the effect of shade netting on a citrus orchard and it will focus on expressing the effect of shade netting on orchard income over a prolonged period. This is because some of the differences in gross margin may only become significant with time. Furthermore, it is important to note that the parameters used in this study are for a typical mandarin orchard under South African production conditions.

Farm models are popular research tools due to its practicality, and it is easily comprehended by a wide audience. It is described as a simple representation of real world scenarios based on an ordered set of values and assumptions (Knott, 2015). Creating a farm model consists of three distinct phases viz. model construction, model validation and model utilization (Hoffmann and Kleynhans, 2011). Constructing a budget model typically involves the use of a spreadsheet programme, integrating the physical-biological farming system with the socio-economical facet, through standard accounting principles.

In addition to model construction, multi period farm budget models consist of three distinct components, viz. inputs, calculations, and outputs (Mugido, Kleynhans and Hoffmann, 2011). Data inputs include farm gate producer prices, yield, pack-out percentages (inflow variables), and the variable costs (outflow variables). Calculations include gross margin (GM) calculations; GM consists of subtracting establishment - and production costs (allocatable variable cost) from gross production value for each scenario. This budget model will evaluate the financial implications of different cultural practices (Open and Net) applied within a specific enterprise (mandarins). The appropriate measurement of the output for this specific model will be gross margin, thus excluding overhead farm costs.

Several types of models exist within budget models, and can be classified as stochastic or deterministic models, with the latter being the type utilized in this study. When taking a systematic approach to modelling, using known input values, a deterministic model is best suited, and risk could be dealt with by creating scenarios. Stochastic modelling is generally used when probabilities and random variables are used. The main objective or focus of a study should determine what approach should be used in a model, i.e. positive or normative. For this budgeting model, where historic and current values are used to measure the financial implications of a certain cultural practice, a positive approach to modelling was used.

5.3 Financial analysis of permanent shade netting of a mandarin citrus orchard

5.3.1 Processing and formulation of trial data

The main objective in developing this budget model was to determine the financial impact of shade netting if used on a mandarin orchard. Two scenarios are compared throughout the model, viz. 1) a standard open orchard (Open) and 2) an orchard covered with permanent 20% white shade netting (Net).

Assumptions and values used in the model consist of current and historical data. The two sources from which the model data were obtained are MSc trials presented in Paper 1, and the CNIS. The CNIS was done by visiting farmers producing mandarin fruit under shade netting and conducting a questionnaire with each (Appendix 3, CNIS questionnaire). Candidates were identified in the Limpopo and Western Cape production regions of Southern Africa, after which the survey was done (Appendix 2, List of producers that took part in CNIS). The data from these two sources were used in the model construction and phases, as to where it was applicable. The detail concerning the allocation of data in the model, is discussed in the model development section.

After the final model was constructed, validation was done by presenting the model to a panel of experts in the South African citrus industry which consisted of:

Dr. Paul Cronje, CRI-SA, University of Stellenbosch
Mr. Jakkie Stander, CRI-SA, University of Stellenbosch
Dr. Hoppie Nel, CRI-SA
Mr. Hannes Bester, CRI-SA
Mr. Steve Turner, Core Fruit South Africa
Mr. Ballie Wahl, Private Consultant
Mr. Rynhardt Nel, Goede Hoop Citrus
Mr. Hans la Grange, Private Consultant
Mr. Mark Fry, Private Consultant

Validation was done to ensure that the model is sufficiently thorough in terms of each aspect and that the values used in the model falls within industry specifications.

5.4 Model Development

The budget model was developed in a spreadsheet programme, Microsoft® Exel®. The programme also allows user-friendliness, and the model can be adjusted and used for other cultivars and areas according to specific parameters. Each spreadsheet of the budget model is displayed in Appendix 1. This section will describe the calculations for each spreadsheet in the budget model, followed by a description of the assumptions that were accepted for each sheet, as well as the results. For each scenario (Open and Net), a budget model with an outline such as in Figure 4.1, was compiled. The model was constructed to measure the financial implications of shade netting at gross margin level

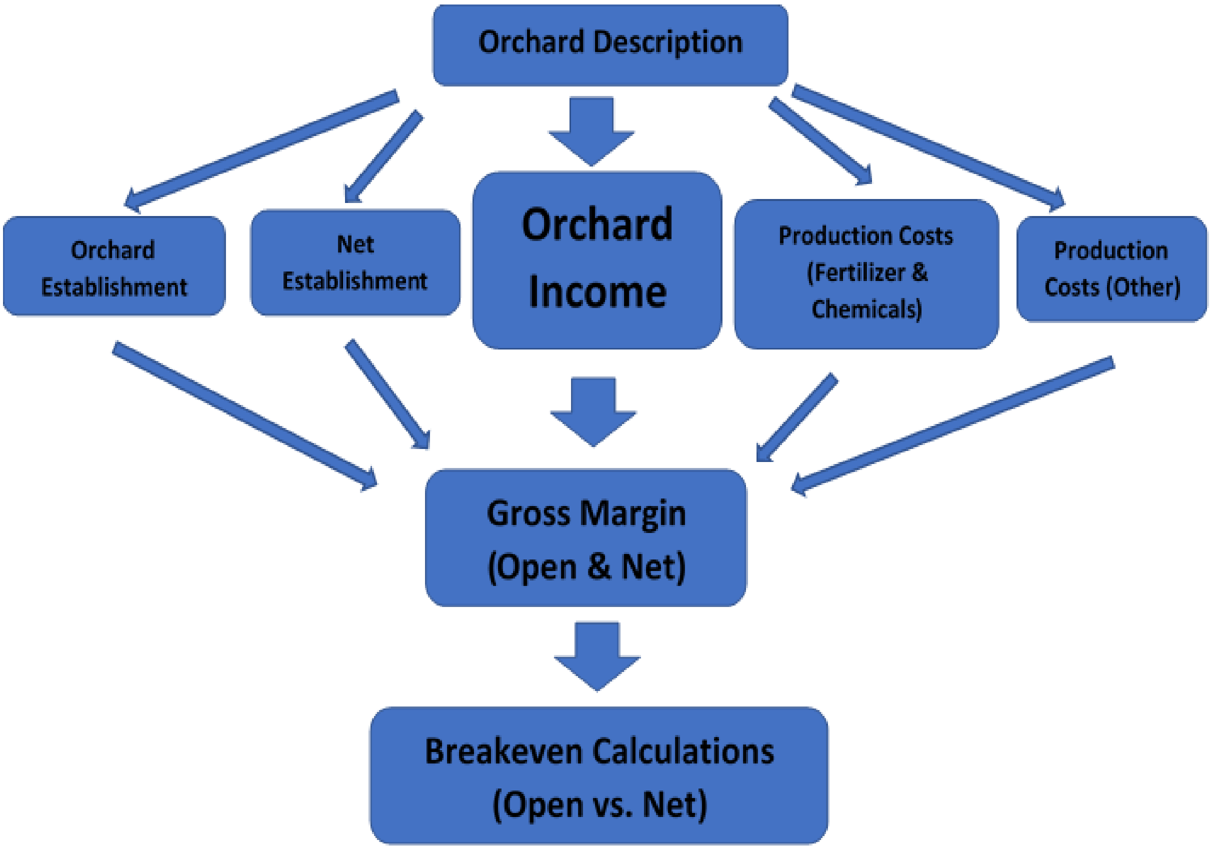


Fig. 5.1. Flow diagram illustrating the structure and flow of the spreadsheets and values within the enterprise budget model.

5.4.1 Orchard description - Spreadsheet 1

Calculation description

The first step of compiling a budget model is to define the physical dimensions, which is the orchard description in this instance. The spreadsheet consists of selectable drop-down menus (yellow), to allow user friendliness. Each parameter is specified from a list of pre-set values. Cultivar selection is the first selectable, followed by the size of the orchard in hectares (ha). The selected orchard size will impact on all sheets calculating values for the total orchard. Tree spacing is specified by selecting in-row and between-row values in meters (m) and will calculate trees per hectare accordingly. Ideal yield (ton/ha) should be selected according to the orchard's full bearing potential and will impact on several calculations throughout the model. If the orchard or cultivar is prone to alternate bearing, an average yield figure representing "on" and "off" years should be selected. The last parameter on the sheet is orchard age, and will impact on the orchard yield level and costs during the first few years of production, if a newly established orchard is modelled.

Parameter assumptions

A 'Nadorcott' orchard of 20 ha, with a spacing of the experimental orchard and a cultivar benchmark yield of 60 ton/ha (CNIS), was modelled. An orchard age of one year was selected to illustrate the ability of the model to increase yield levels, income and production costs automatically, according to orchard age. The parameters selected on this sheet will be used for both the open and netted scenarios, as an orchard of the same cultivar, size and age is compared.

5.4.2 Orchard income - Spreadsheet 2

Calculations description

Orchard gross income is a fundamental set of calculations, as shade netting influences these variables to a large extent. In addition to the drop-down cells (yellow), this sheet contains self-fill cells (red), where the user can enter situation specific values.

The first variable of this page, yield (ton/ha), is linked to the [“Orchard description”] sheet. For the netted orchard calculations, an “adjustment factor” is included for all variables. These adjustment values can be manipulated throughout the model according to the extent to which the shade netting influences the specific parameter. The export pack-out percentage represents the number of fruit which is of exportable quality, which is further divided into Class 1 and Class 2, depending on external fruit appearance. This percentage is then used to calculate the ton/ ha fruit destined for each class. The tonnage is then divided into 15kg equivalent cartons, according to the respective fruit size distributions provided for each scenario. Gross income per size count is calculated according to the provided Delivered In Port price (DIP)(ZAR), per 15kg equivalent. The same method is used to calculate the income for Class 2 fruit. The sum of the gross income for both Class 1 and 2 fruit equates to the total gross income for both the open and netted scenarios.

Parameter Assumptions

For orchard income calculations, data from both the CNIS and the scientific experiments were integrated. Data obtained from the CNIS were pooled, from which a weighted average was calculated for each parameter. These parameters include the expected ton/ha, export pack out percentage, Class 1 and 2 pack out percentages and average DIP price per 15kg equivalent carton. The average DIP prices for ‘Nadorcott’ were obtained from a separate survey conducted between several South African citrus export companies.

Data obtained from the scientific trials include the average fruit size distribution over a period of two seasons (2016 and 2017). All fruit from the trial orchard were sent to a commercial pack house where it was packed according to treatment i.e. open and net. This was done to confirm the export pack-out percentages obtained from the CNIS.

The parameters in this calculation which mainly influence the difference in gross income, are the export pack-out percentage and the difference in pack-out of Class 1 fruit for the netted orchard. This increase in export pack-out percentage under shade netting results in more fruit meeting export quality standards, while fruit in Class 1 receive a price premium in export markets.

According to the respective parameters provided in the model, the full production gross income for the open orchard was R788 045 /ha, while it was R1 005 596 /ha for the netted orchard.

5.4.3 Establishment Cost (Orchard) - Spreadsheet 3

Calculations description

If an already established orchard is evaluated in the model, the “New orchard” drop down of this sheet can be set to “No”, and an override function will exclude orchard establishment cost from the budget model. In addition to the drop down (yellow) and self-fill (red) cells, a suggested price for each listed action is provided, as the options is selected in the yellow cells. The user can still enter own price in the “own price/ha” column, as the suggested price will only serve as a “default price” for users that do not have a reference or quotation. The “own price/ha” function was included to lend more flexibility to the model.

When a newly established orchard is modelled the first action is selecting if it will be established on virgin soil or previously planted land. If “Previously planted” is selected, a tree removal cost is applicable. Other soil preparation actions include ripping, tilling, and ridging, with different options in the drop-down cells. Additional actions, unique to a specific farm or orchard, are accounted for in the "Other" section.

The plant material section includes options for either new trees or top working of existing rootstocks. Tree spacing and trees per hectare are linked to the ["Orchard description"] sheet, while the user can enter own tree price, royalties per tree (once-off) or the budding price per tree. Labour cost for top working or planting is included in the plant material section. All "per tree" values in this section are multiplied by the "trees/ha", to calculate the total cost per hectare for plant material.

The irrigation section has an override option if the orchard has an existing irrigation infrastructure. If a new irrigation system is installed, the user can separate the cost of the underground infrastructure (pumps, PVC pipes, taps) and the aboveground infrastructure (micro-sprinklers or drippers). If the "micro sprinkler" option is selected, a specific price is recommended. If a dripper system is selected, the suggested price will be as for a single line drip system. The next step allows for the selection of a double line dripper system which will adjust the price automatically. The last component of the irrigation section is the underground drainage option for orchards with water logged soils.

Trellis systems are generally not used in the South African citrus industry, but the option to incorporate the cost of a trellis system, is included in the model. This section allows an override option, and the trellis system section will be excluded by selecting "No" for "Trellis system usage". This section of the model includes a set of calculations to calculate the cost of poles and wire to establish a trellis system for one hectare, according to selected values and price inputs.

The total orchard establishment cost, per hectare and for the whole orchard is calculated at the end of the sheet.

Parameter assumptions

All the parameters for the orchard establishment cost calculations were obtained from the CNIS. The cost of soil preparation actions (ripping, tillage, and ridging) is an average of the CNIS and average prices obtained through personal communication with heavy machinery contractors. All soil preparation prices that are machine related, includes the operator, machinery, and fuel, and are referred to as the 'wet' price.

For these calculations, a newly established orchard on previously planted soil, was simulated. The soil was cross-ripped, and ridges were made using an excavator. The cost to chip the previous trees, to use as a mulch, was included. The price and royalties of 'Nadorcott' mandarin trees were used, while the orchard was assumed to have received a completely new irrigation system (under – and aboveground), with double line drippers. No drainage and trellis systems were implemented for the simulated orchard.

Table 5.1. Establishment cost allocation of a 'Nadorcott' orchard with a new irrigation system as modelled.

Category	Cost/ha
Soil Preparation	R 24 250,00
Plant material	R 66 181,82
Irrigation	R 46 300,00
Trellis system	R -
Total Cost	**R 136 731,82**

The cost to establish one hectare of 'Nadorcott' trees according to the parameters provided to the model is R136 732 per hectare (Table 5.1), with the most significant cost being the plant material.

5.4.4 Establishment (Net Structure) - Spreadsheet 4

The initial cost of a permanent shade net structure is probably the main reason producers would decide not to use this technology. The CNIS included discussions with contractors who specialize in erecting permanent shade net structures. The cost of these structures can generally be divided into four categories:

1) structure (poles, cables, anchors etc.)

2) labour

3) machinery (tractors, platforms, diggers etc.) and,

4) the shade nets.

Allocating the cost to these four categories generally results in the structure being responsible for approximately two fifths of the cost, while the labour, machinery and netting all contribute to one fifth of the cost respectively.

Calculations description

The first section of this calculations, determines the price of the net. This price, for a structure with open sides, is the input in the “Net price (open sides)” cell. If “Yes” is selected for the “Closed sides” cell, 20% will be added to the price, as sides contribute 20% of total net used per hectare. The implementation of closed sides is normally applicable for producers erecting shade netting to avoid wind blemishes and cross pollination. Lastly, the height selection will impact on the pole length.

The structure of the shade net consists of poles, cables (stay wire), anchors and other smaller components. Stronger poles are used on the outside of the structure, thus, the number of inside and outside poles are calculated separately due to a price difference. The “between row” pole spacing depends on the orchard between row spacing and is linked to the “Orchard description” sheet. The “in row” spacing of the outside poles are subjected to preference, but the same spacing as for the between row is normally used. The number of outside poles is then calculated according to the spacing specifications provided.

The inside pole spacing is normally placed in a staggered (zig-zag) pattern, which uses half the number of inside poles, compared to conventional spacing. The number of inside poles is calculated according to the spacing pattern selected in the "Inside pole spacing pattern" drop down menu. The number of anchors is calculated according to the number of outside poles, adding two extra anchors for each corner of the structure (8 extra). The numbers of anchors and poles are multiplied by the "Own price/unit" which will calculate the cost per hectare. The length of stay wire (cables) is calculated from a per hectare norm. Steel wire is only used in the sides of such an enclosed structure and the cost will only be accounted for if "Yes" is selected for the "Closed sides" option. General material used for the structure is accounted for in the "Other" section.

The last section calculates the cost of the labour and machinery components. The machinery cost is calculated by adding the cost of machinery to dig holes for the anchors and poles, and for transport and platforms. Labour is divided into three categories and is the final component included. The final calculation on this sheet calculates the sum of all the net establishment sections into a total per hectare cost, while a total orchard cost is calculated according to the selected orchard size.

Parameter assumptions

All parameters and prices use in the "Net establishment" sheet were obtained from the CNIS. The sources included own producer records and quotations from several suppliers of shade net structure materials. It should be noted that price assumptions are based on a structure with the aboveground height of six meters, covered with 20% white shade netting. Prices per unit for materials used in the structure are based on an average of four quotations from wholesale suppliers. The costs of the labour and machinery and the allocation thereof were obtained from an average based on values from the CNIS.

Table 5.2. Establishment cost allocation of a 20% white shade net structure with an aboveground height of six meters, as modelled.

Category	Price/ha
Net	R 57 600,00
Structure	R 111 501,67
Machinery	R 21 200,00
Labour	R 56 500,00
Total Cost	**R 246 801,67**

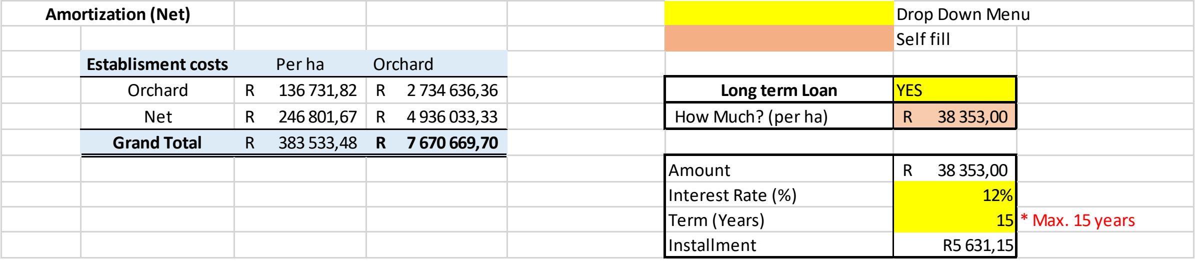
As mentioned earlier, the cost of erecting shade net over an orchard is normally divided into five categories, with the structure accounting for two fifths of the price. This also holds true for the calculations in this section (Table 5.2). According to the parameters and prices provided, erecting a structure with 20% shade netting will equate to R 246 802 per hectare.

5.4.5 Amortizations - Spreadsheet 5 & 6

Calculations description

The option to borrow capital was accounted for in the model, for both the open and net scenarios, in the form of amortization tables. The term amortization refers to the repayment of a loan or a mortgage over a specific period with fixed instalments. For the first payment, the greater percentage of the instalment consists of interest. With each subsequent payment, a smaller percentage of the instalment is allocated towards interest and more to the loan principle.

For the amortization of both scenarios, the total establishment cost is expressed in the "Establishment cost" table of each amortization sheet. For the net scenario, the establishment cost consists of both the orchard and net establishment costs. In the "long-term loan" section, the user can override the amortization tables if no money is borrowed, and it will be excluded from the budget model. When "Yes" is selected in the long-term loan dropdown, the user should specify the amount of money to be borrowed per hectare. This amount will then be shown in the following table. The interest rate, the term of repayment, and borrowed capital amount must be specified, where after the model will calculate a yearly instalment for the loan (Figure 5.2).



Amortization (Net)

Establisment costs	Per ha	Orchard
Orchard	R 136 731,82	R 2 734 636,36
Net	R 246 801,67	R 4 936 033,33
Grand Total	R 383 533,48	**R 7 670 669,70**

🟨	Drop Down Menu
▨	Self fill

Long term Loan	YES
How Much? (per ha)	R 38 353,00

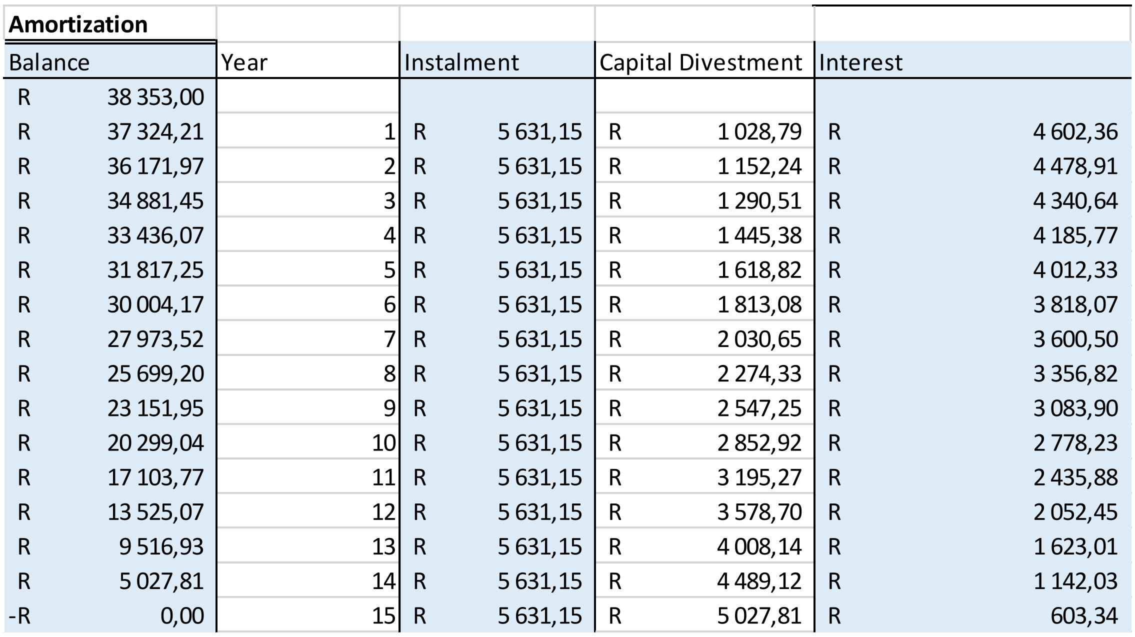
Amount	R 38 353,00	
Interest Rate (%)	12%	
Term (Years)	15	* Max. 15 years
Installment	R5 631,15	

Fig. 5.2. Model representation of information provided for the netted orchard amortization.

The amortization table consists of five columns, which calculate the annual balance, instalment, capital divestment and interest for each consecutive year. The balance column states the outstanding capital amount. The instalment amount consists of the capital divestment and the interest of each year. As the term commences, the portion of instalment allocated towards interest decreases, while the portion allocated towards capital divestment increases until the loan is fully paid, and the balance is zero.

Parameter assumptions

To illustrate the ability of the model to account for borrowed capital an amount of 10% of the establishment cost for each scenario was hypothetically borrowed. Although technically wrong, the instalments of each loan will reflect in the gross margin (GM) calculations of each scenario. This would normally be a factor cost in a whole farm budget model, however it is included in the gross margin as this enterprise model only calculates up until GM.



Amortization				
Balance	Year	Instalment	Capital Divestment	Interest
R 38 353,00				
R 37 324,21	1	R 5 631,15	R 1 028,79	R 4 602,36
R 36 171,97	2	R 5 631,15	R 1 152,24	R 4 478,91
R 34 881,45	3	R 5 631,15	R 1 290,51	R 4 340,64
R 33 436,07	4	R 5 631,15	R 1 445,38	R 4 185,77
R 31 817,25	5	R 5 631,15	R 1 618,82	R 4 012,33
R 30 004,17	6	R 5 631,15	R 1 813,08	R 3 818,07
R 27 973,52	7	R 5 631,15	R 2 030,65	R 3 600,50
R 25 699,20	8	R 5 631,15	R 2 274,33	R 3 356,82
R 23 151,95	9	R 5 631,15	R 2 547,25	R 3 083,90
R 20 299,04	10	R 5 631,15	R 2 852,92	R 2 778,23
R 17 103,77	11	R 5 631,15	R 3 195,27	R 2 435,88
R 13 525,07	12	R 5 631,15	R 3 578,70	R 2 052,45
R 9 516,93	13	R 5 631,15	R 4 008,14	R 1 623,01
R 5 027,81	14	R 5 631,15	R 4 489,12	R 1 142,03
-R 0,00	15	R 5 631,15	R 5 027,81	R 603,34

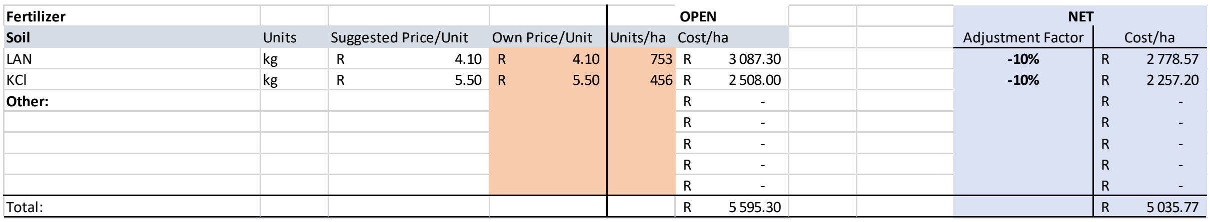
Fig. 5.3. Model representation of the “Net” amortization table.

5.4.6 Production costs (Fertilizer and Chemicals) - Spreadsheet 7

The next phase of the model consists of the variable costs or outflow variables. The first set of outflow variables is the production costs, including; fertilizers, pesticides, fungicides, herbicides, and plant growth regulators. This is an integral part of the budget model as this will quantify the influence of shade netting on fertilizer needs, disease and pest pressure. In future modelling, it is assumed that the use of pesticides and fungicides will be increased as more information on integrated pest management (IPM) practices under shade netting is gathered in commercial and experimental studies.

Calculations description

Production costs are calculated separately for the open and net scenarios, as it is important to quantify the effect of shade netting on these specific parameters. The calculations include the product name, the units of the product (kg or liter), the price per unit, the number of units used per hectare and the total cost per hectare for an open orchard. The cost per hectare for each production practice under shade netting is calculated using the open cost, and adjusting it according to an adjustment factor provided. The adjustment factor is a percentage value which indicates if netting increases (positive value) or decreases the cost (negative value) of each production practice under the shade netting. A suggested price for each product is provided, but "self-fill" cells (red) enable the user to manipulate the price and units per hectare of each product. The total production cost of fertilizer and chemicals as cost per hectare, and for the total orchard, is calculated at the end of the sheet.



Fertilizer					**OPEN**			**NET**	
Soil	Units	Suggested Price/Unit	Own Price/Unit	Units/ha	Cost/ha			Adjustment Factor	Cost/ha
LAN	kg	R 4.10	R 4.10	753	R 3 087.30			**-10%**	R 2 778.57
KCl	kg	R 5.50	R 5.50	456	R 2 508.00			**-10%**	R 2 257.20
Other:					R -				R -
					R -				R -
					R -				R -
					R -				R -
					R -				R -
Total:					R 5 595.30				R 5 035.77

Fig. 5.4. Representation production costs (Fertilizer). Note the adjustment factor to adjust the cost for the shade netting.

Parameter assumptions

Parameters on the ["Production Cost (Fertilizer and Chemicals)"] sheet were obtained from the citrus industry survey, chemical price quotations, and a standard mandarin fertilizer and spray program. The suggested product prices were obtained through communication with two agricultural agents specializing in distributing fertilizer and chemicals (August 2017). The average of each product price was calculated to obtain a trustworthy industry representative value.

The "units/ha" of each product was obtained by consulting product labels and a standard fertilizer and chemical programme for 'Nadorcott' mandarin. Adjustment values used for the netted orchard calculations were obtained from the CNIS, using a weighted average for each production practice. It should however be noted that these adjustment values were subjected to production practices and opinions of a set of producers. Evaluating the adjustment factors obtained from the CNIS, showed that although shade netting influences most production parameters negatively, savings can occur on fertilizers.

Table 5.3. Summary of adjustment factors used for each fertilizer product.

Fertilizer	Adjustment Factor
LAN	-10%
KCl	-10%
Urea	-20%
Copper oxychloride	0%
Manganese Sulphate	0%
Zinc Nitrate	0%
Solubor	0%
Magnesium Sulphate	0%
Potassium Nitrate	0%

Table 5.4. Summary of adjustment factors used for each chemical product.

Insecticides	Adjustment factor
Abamectin (Thrips)	+50%
Confidor (Thrips, Red Scale,Whitefly)	+75%
Buprofenzin (MealyBug)	+50%
Nemesis (Red Scale)	+50%
Runner (FCM)	0%
Helicovir (Bollworm)	0%
Snail Pellets (Charda)	-50%
Fruit Fly (GF-120)	0%
Fungicides	Adjustment factor
Score (Alternaria)	+50%
Dithane (Fungal diseases)	+15%
Herbicides	Adjustment factor
Glyphosate	+20%

According to the information obtained from the CNIS, shade netting decreased the amount of fertilizer applied per annum. This is mainly due to reduction of nitrogen fertilization, in attempts to restrict vegetative growth of mature trees. As mentioned in the introduction, shade netting tends to increase pest and disease pressure, which leads to an increase in cost of chemicals. Adjustment values based on the CNIS information showed that major cost increases were found for the control of red scale, red mite, and thrips, under shade netting. An interesting finding from the CNIS was that shade netting increased the cost of herbicides, due to increased weed growth under these structures.

The total cost calculations for this section indicates that, according to all information provided to the model, shade netting results in an additional R 2738/ha for fertilizer and chemical production costs.

5.4.7 Production costs (Other) - Spreadsheet 8

Production costs other than fertilizer and chemicals were allocated to the [“Production Cost (Other)”] sheet. The costs accounted for in these calculations include production royalties, pruning, orchard sanitation, irrigation, harvesting cost, packing cost, diesel, and net maintenance in the last section.

Calculations description

The calculations on this sheet were similar to the previous [“Production costs (Fertilizer & Chemicals)”] sheet. A suggested price for each production practice is provided for an open orchard. The user can enter values in the “own price/ha” cells and the model will calculate the cost of each practice for the open and net scenarios, according to the adjustment factor provided.

The “Production royalties” section of the sheet consists of a drop-down menu where a selection can be made for royalties, if applicable. If not chosen, the model will override this section. If “Yes” is selected in the drop down, the next drop down specifies the royalty type (per ha or per 15kg carton). If the “Per hectare” option is selected, the appropriate unit price should be provided, and the model will calculate royalties according to the size of the orchard. If “Per carton” is selected the royalties will be automatically calculated according to the total cartons for each scenario, linked to the [“Income”] sheet.

The remainder of the sections are general calculations using the price provided for each production practice and calculating a price per hectare for the open and net scenarios respectively.

Parameter assumptions

All prices and adjustment factors for this sheet were obtained from the CNIS. Royalty calculations in this model were based on ‘Nadorcott’ mandarin and was calculated per carton. Pruning cost was increased for the shade netting due to reported increase in vegetative growth and the fact that mechanical pruning is not possible under shade netting due to the overhead structure. Thus, the adjustment value for “pruning”, is a result of all pruning under netting that must be done by hand. The cost of orchard sanitation is less under shade netting, while harvesting cost is subjected to respective yields specified in the [“Orchard income’] sheet. Packing cost increases proportionally with the number of cartons for each scenario. Diesel cost is higher under shade netting due to increased tractor hours per hectare for spraying. Annual maintenance of the net structure is an additional production cost for the shade netting scenario.

5.4.8 Gross margin calculations - Spreadsheet 9 & 10

GM calculations incorporate all model values to project the GM of each scenario for 15 consecutive years. The GM calculations for each scenario (open and net) are based on their respective income and production cost values. Orchard establishment cost is the same for both.

Calculations description

The first step of setting up GM calculations for a fruit commodity is to establish the yield (“Expected yield %”) over the first years, until full production. This was established through the CNIS for both scenarios, and will adjust automatically according to the orchard age selected in the [“Orchard description”] sheet.

Gross production value is calculated by multiplying the full production income of each scenario with the respective yield percentage of each year, until full bearing potential is reached. To calculate the GM for each scenario, all directly allocatable costs are deducted from gross income. For the open orchard scenario, the first deduction is the orchard establishment cost, while this deduction consists of both the orchard and net establishment costs for the netted orchard scenario.

Fertilizer and chemical costs are directly allocatable variable costs and are deducted as a proportion of the production (Expected yield %) as the orchard yield increases. As the young trees are already sprayed and fertilized in the first year after planting, the fertilizer and chemical costs for year one are based on the expected yield percentage of year two.

The general production section represents the cost of the ["Production cost (Other)"] sheet and unlike the fertilizer and chemicals section, all costs are directly linked to the expected yield percentage on a year to year basis. For the net scenario, net maintenance cost is a fixed amount, and is not linked to production percentage.

Irrigation and diesel are not directly allocatable costs, but during the CNIS a price per hectare for irrigation and diesel was obtained, which represents orchard level expenses. Water and diesel usage on the farm for general purposes are thus not included, resulting in a price per hectare directly allocatable to an orchard, on a per hectare basis.

For the purpose of this model GM is calculated by subtracting the sum of all the production costs and the loan repayment, from the gross income.

Parameter assumptions

All values on the gross margin calculation sheet are linked to the rest of the model except for the expected yield percentage of the two scenarios. The expected yield percentage for each scenario was obtained from the CNIS, after which an average was calculated to be used in the model. The expected yield percentage until full production differs between the two scenarios. This is due to the shade netting that increases the yield percentage for the initial production years, while decreasing the number of years until full production.

GM calculations indicate that the mandarin orchard simulated under 20% white shade netting was more profitable each season from year four onwards, for 11 consecutive years. During the period of year four to six, the shade net orchard was relatively more profitable due to larger trees and production that increased earlier than the open orchard. From year six onwards the orchards of both scenarios were in full production. During this time, the GM of the shade netted orchard is higher due to the constant higher export pack-out percentages under the shade netting. During this time (year six to 15), when both orchards were in full production, the shade netted orchard outperformed the open orchard with a gross margin of R 185 889 /ha per annum.

5.4.9 Break-even projection - Spreadsheet 11

To illustrate the cumulative gross margin including the effect of loan repayment for both scenarios, a break-even calculation was included. This calculation is incorporated to illustrate in which year break-even is reached for each scenario. The result show that the shade net scenario will break-even a year later (year four), than the open scenario. However, from year five onwards, the shade net orchard outperformed the open scenario in each season.

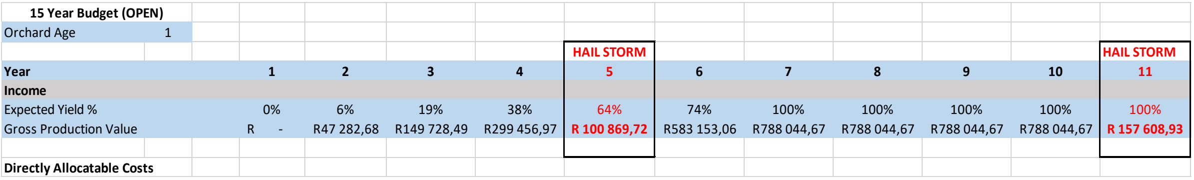
Given that the shade net gross margin was higher for each year after year four, over a 15-year period, the shade netting had a cumulative advantage of R 2 434 695 per hectare over the open scenario, *ceteris paribus*.

5.5 Extreme scenario simulations

In this section, the budget model will be used to simulate two extreme scenarios and the ability of shade netting to protect citrus crops against natural elements, thereby decreasing risk and increasing profitability. The first scenario simulates the effect of shade netting to protect citrus crops against hail damage. Furthermore, when cross pollination occurs between certain mandarin cultivars, seeds can develop in fruit which are otherwise seedless. Seedless fruit receive a price premium in markets worldwide, and the effect of shade netting to prevent cross pollination and seeded fruit, will be evaluated in terms of orchard returns for scenario two.

5.5.1 Scenario 1: Hail storm damage

The initial use of shade netting on fruit crops, was to prevent extensive fruit damage caused by hail storms. These climatic extremities can destroy an entire fruit crop, which inevitably leads to reduced income. For this simulation, the occurrence of two hail storms in a 15-year period, were simulated on 'Nadorcott' mandarin for both an open and netted orchard.



15 Year Budget (OPEN)											
Orchard Age 1											
					HAIL STORM						**HAIL STORM**
Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Income											
Expected Yield %	0%	6%	19%	38%	64%	74%	100%	100%	100%	100%	100%
Gross Production Value	R -	R47 282,68	R149 728,49	R299 456,97	**R 100 869,72**	R583 153,06	R788 044,67	R788 044,67	R788 044,67	R788 044,67	**R 157 608,93**
Directly Allocatable Costs											

Fig. 5.5. The effect of hail two hail events on gross production value per hectare of a 'Nadorcott' orchard. The hail storms were simulated to destroy 80% of the fruit respectively.

The hail storms were assumed to have reduced the exportable fruit of the open orchard by 80%, at an orchard age of five and 11 years, respectively. As the netting will protect the orchard against hail damage, production for the netted orchard was unaffected.

Figure 5.5 illustrates the years in which the hail storms were simulated and the effect thereof on the gross income per hectare for the open orchard. Harvest and packing costs were also reduced by 80% for these two years, while it was assumed that all other production practices were implemented. Figure 5.6 illustrates the effect of shade netting in preventing hail damage on gross margin income, over a 15-year cumulative period. The effect of two hail storms in a period of 15 years resulted in the netted orchard having a R3 254 492 per hectare cumulative advantage over the open orchard, *ceteris paribus*.

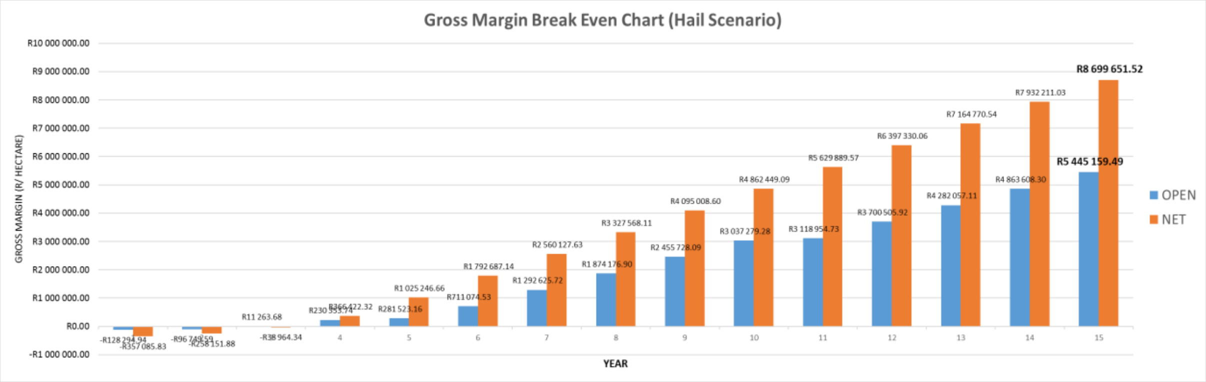
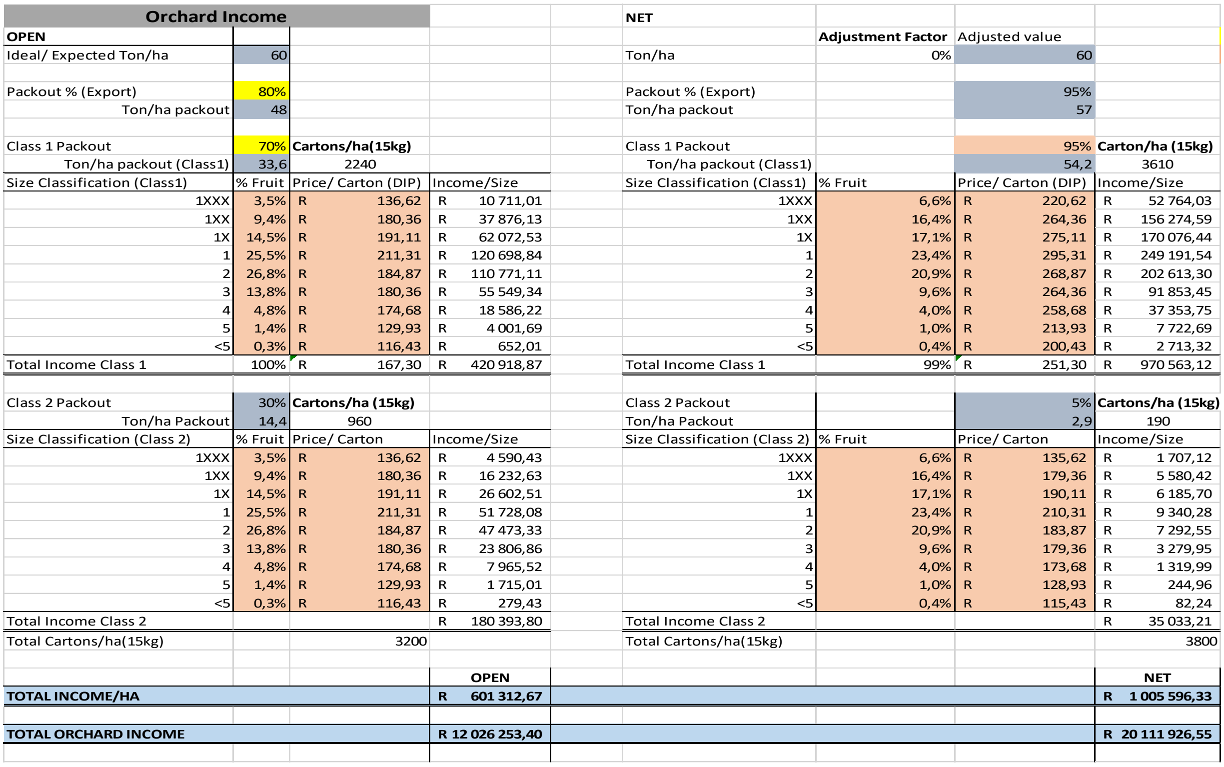


Fig.5.6. The cumulative gross margin effect of two hail storms destroying 80% fruit respectively.

5.5.2 Scenario 2: Prevalence of seeded fruit

Cross pollination between compatible seedless mandarin cultivars can result in the development of seeded fruit. Bees are the main vector responsible for cross pollination between cultivars, and during the last decade citrus producers worldwide opted for enclosed shade net structures to prevent bees from cross-pollinating specific orchards and cultivars.

Throughout this chapter it was assumed that both open and net orchards produced seedless fruit. In this scenario however, the effect of seeded 'Nadorcott' mandarin fruit in the open orchard will be simulated against an orchard under an enclosed net structure with seedless fruit. For this scenario, it was assumed that the seeded fruit in the open orchard received conservatively R80 per 15kg equivalent less (Class 1 & Class 2), than seedless fruit produced under shade netting. The effect of seeded fruit on export price and gross income per hectare is shown in Figure 5.7. The same reduced price was simulated for both Class 1 and Class 2 of the open orchard, with the seeded fruit.



Orchard Income					NET			
OPEN						**Adjustment Factor**	Adjusted value	
Ideal/ Expected Ton/ha	60				Ton/ha	0%	60	
Packout % (Export)	80%				Packout % (Export)		95%	
Ton/ha packout	48				Ton/ha packout		57	
Class 1 Packout	70%	**Cartons/ha(15kg)**			Class 1 Packout		95%	**Carton/ha (15kg)**
Ton/ha packout (Class1)	33,6	2240			Ton/ha packout (Class1)		54,2	3610
Size Classification (Class1)	% Fruit	Price/ Carton (DIP)	Income/Size		Size Classification (Class1)	% Fruit	Price/ Carton (DIP)	Income/Size
1XXX	3,5%	R 136,62	R 10 711,01		1XXX	6,6%	R 220,62	R 52 764,03
1XX	9,4%	R 180,36	R 37 876,13		1XX	16,4%	R 264,36	R 156 274,59
1X	14,5%	R 191,11	R 62 072,53		1X	17,1%	R 275,11	R 170 076,44
1	25,5%	R 211,31	R 120 698,84		1	23,4%	R 295,31	R 249 191,54
2	26,8%	R 184,87	R 110 771,11		2	20,9%	R 268,87	R 202 613,30
3	13,8%	R 180,36	R 55 549,34		3	9,6%	R 264,36	R 91 853,45
4	4,8%	R 174,68	R 18 586,22		4	4,0%	R 258,68	R 37 353,75
5	1,4%	R 129,93	R 4 001,69		5	1,0%	R 213,93	R 7 722,69
<5	0,3%	R 116,43	R 652,01		<5	0,4%	R 200,43	R 2 713,32
Total Income Class 1	100%	R 167,30	R 420 918,87		Total Income Class 1	99%	R 251,30	R 970 563,12
Class 2 Packout	30%	**Cartons/ha (15kg)**			Class 2 Packout		5%	**Cartons/ha (15kg)**
Ton/ha Packout	14,4	960			Ton/ha Packout		2,9	190
Size Classification (Class 2)	% Fruit	Price/ Carton	Income/Size		Size Classification (Class 2)	% Fruit	Price/ Carton	Income/Size
1XXX	3,5%	R 136,62	R 4 590,43		1XXX	6,6%	R 135,62	R 1 707,12
1XX	9,4%	R 180,36	R 16 232,63		1XX	16,4%	R 179,36	R 5 580,42
1X	14,5%	R 191,11	R 26 602,51		1X	17,1%	R 190,11	R 6 185,70
1	25,5%	R 211,31	R 51 728,08		1	23,4%	R 210,31	R 9 340,28
2	26,8%	R 184,87	R 47 473,33		2	20,9%	R 183,87	R 7 292,55
3	13,8%	R 180,36	R 23 806,86		3	9,6%	R 179,36	R 3 279,95
4	4,8%	R 174,68	R 7 965,52		4	4,0%	R 173,68	R 1 319,99
5	1,4%	R 129,93	R 1 715,01		5	1,0%	R 128,93	R 244,96
<5	0,3%	R 116,43	R 279,43		<5	0,4%	R 115,43	R 82,24
Total Income Class 2			R 180 393,80		Total Income Class 2			R 35 033,21
Total Cartons/ha(15kg)		3200			Total Cartons/ha(15kg)			3800
			OPEN					**NET**
TOTAL INCOME/HA			**R 601 312,67**					**R 1 005 596,33**
TOTAL ORCHARD INCOME			**R 12 026 253,40**					**R 20 111 926,55**

Fig. 5.7. The effect of a R80,00 price premium for seedless fruit on orchard gross income.

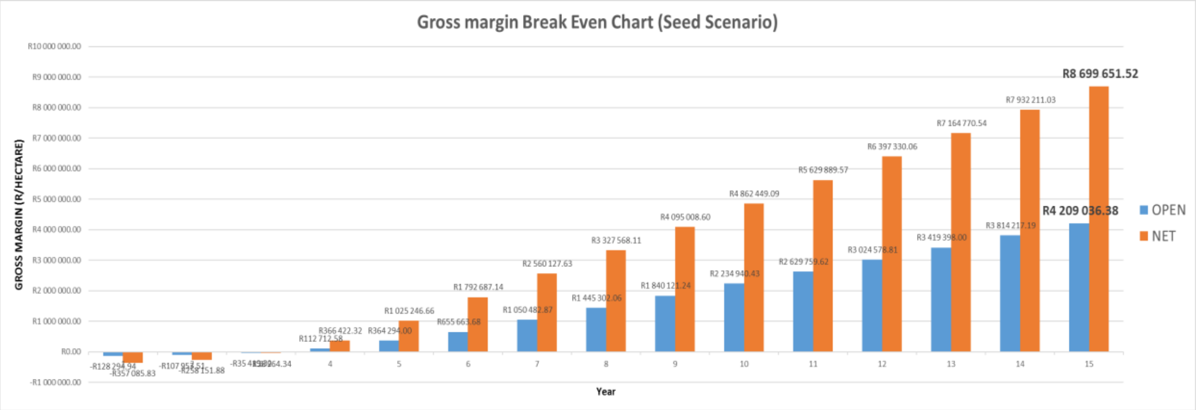


Fig. 5.8. Cumulative gross margin effect of an orchard with seeded fruit (open), compared to an orchard with seedless fruit under shade netting.

The effect on gross margin as a result of seedless fruit are shown in Figure 5.8. The graph illustrates the cumulative effect of this scenario over a period of 15 years. It was assumed that the open orchard produced seeded fruit each year, compared to the seedless fruit of the netted orchard. Over a 15-year period, the gross margin cumulative effect of seedless fruit production under shade netting, showed an R 4 490 615 /ha advantage over the open orchard, *ceteris paribus*.

5.6 Conclusion

Citrus shade netting has become a technology of immense value for the global citrus industry, providing a viable option to increase the efficiency of citrus production. In a world with a rapidly increasing population, thus an increasing demand for fresh produce, production effectivity is becoming a major point of discussion. Resource limitations, such as water and arable land, necessitates the development of cultural practices like shade netting, which could enhance productivity. Permanent shade netting is however a capital-intensive investment and negative effects on some production parameters are reported. To quantify these, the effects thereof was evaluated in terms of the GM income of a citrus orchard. In this budget model, shade netting increased the per hectare production cost of ‘Nadorcott’ mandarin, while the capital investment of erecting the shade net structure was high. However, results from the model created in this study, showed that the gross income per hectare of a ‘Nadorcott’ mandarin orchard, was increased by shade netting under South African production conditions. This increase in gross income is mainly ascribed to increased pack-out percentages and premium quality fruit, rather than to increased yield. In addition, the netted orchard was more profitable from year four, which can be ascribed to the trees under the shade netting that reached full bearing potential earlier.

However, the results obtained for the open scenario in this study, was for an orchard with average pack-out percentages. It should thus be noted that if an orchard is situated in an area where high value citrus fruit are not prone to obtain cosmetic damage, and pack-out percentages are high, shade netting may not have such a significant effect on orchard profitability.

From all information in this research chapter and the budgeting scenarios, it can be concluded that 20% white permanent shade netting increased the production efficiency and profitability of a hypothetically modelled ‘Nadorcott’ mandarin orchard, under South African production conditions.

5.7 Literature cited

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6. General conclusion

In most horticultural industries, the use of permanent shade netting is becoming an increasingly popular cultural practice to protect high value fruit crops against climatic extremities such as wind, sunburn, hail and frost. In addition, enclosed shade netting structures are extensively used in citriculture to prevent cross pollination between susceptible cultivars and subsequent seed development in fruit. However, permanent shade netting is known to alter the orchard microclimate, which may affect tree phenology, the efficacy of foliar applied agro-chemicals like plant growth regulators and therefore impact on orchard profitability. To gain a better understanding on this technology the effect of 20% permanent white shade netting was evaluated for its impact on 'Nadorcott' mandarin tree phenology. Furthermore, the effect of shade netting was also evaluated on the efficacy of plant growth regulators and orchard profitability.

Shade netting was found to increase vegetative growth and fruit diameter, which was however not at the expense of reproductive growth parameters i.e. flowering and fruit set. In an unexpected result, the shoot length of the three main vegetative flushes did not differ between the open and net treatments, suggesting that the increased tree volume found under the shade netting may be due to additional vegetative shoot growth flushes per season. This hypothesis is however speculative and considering reports on increased vegetative sprouting in tropical climates, further studies should clarify if this may be true for shade netting. As this study was conducted on younger trees in a Mediterranean-type climate, it should be noted that the effect of shade netting on tree phenology may be different in mature trees and in other climates, such as in tropical areas with conditions of higher relative humidity prevailing.

The shade netting treatment increased the flowering response and fruit diameter during the second season, while fruit yield or internal quality were unaffected for both seasons. The efficacy of uniconazole, a vegetative growth retarding chemical, was not altered by the shade netting, which suggests that this growth retardant may become a useful cultural practice to control increased vegetative growth of citrus under shade netting. The effect of uniconazole on return bloom under shade netting should however be part of further research.

The thinning efficacy of the foliar applied synthetic auxin fruit thinning agents 2,4-DP and 3,5,6-TPA, applied at the recommended concentration and timing, was not affected by the shade netting. In addition, the shade netting had an additive effect on the final fruit size of the chemical fruit thinning treatments, while having no effects on fruit yield. The chemical fruit thinning treatments increased the fruit mineral nutrient concentration of selected elements, while having no effect on internal fruit quality. The increased fruit diameter in reaction to chemical fruit thinning treatments is well known in citriculture, but the further enhancement thereof by shade netting has not been documented.

It is suspected that the change in microclimate under shade netting should enhance the uptake, thus efficacy of foliar applied chemical fruit thinning agents. These chemicals are known to thin fruit by effecting a temporal reduction in the photosynthetic capacity of the tree. However, the up-regulated photosynthesis and carbohydrate status of trees under shade netting is thought to mask the effect of these chemical fruit thinning agents, as no difference between open and net treatments was recorded in terms of thinning efficacy. This assumption is however hypothetical, and as to what extent permanent shade netting influences the uptake of foliar applied substances, should be a topic for future research. In addition, the photosynthetic rate in reaction to synthetic auxin fruit thinning treatments, should also be evaluated to determine if shade netting has the ability to up-regulate photosynthetic capacity during this stage.

Furthermore, the synthetic auxin fruit thinning treatments increased the fruit potassium (K), magnesium (Mg), and calcium (Ca) concentration during the second season. The increased levels of these nutrients are thought to be related to the increased sink strength and peduncle diameter of citrus fruit in reaction to synthetic auxin treatments. This increase in K, Mg and Ca levels occurred irrespective of the open and shade netting treatments, and in previous studies these elements were proved to be involved in determining fruit susceptibility to post harvest physiological rind disorders, such as rind breakdown. The increased levels of these mineral nutrients in synthetic auxin treated fruit, could therefore be useful in future post-harvest studies, as it may have the potential to increase citrus fruit resistance to post harvest physiological rind disorders.

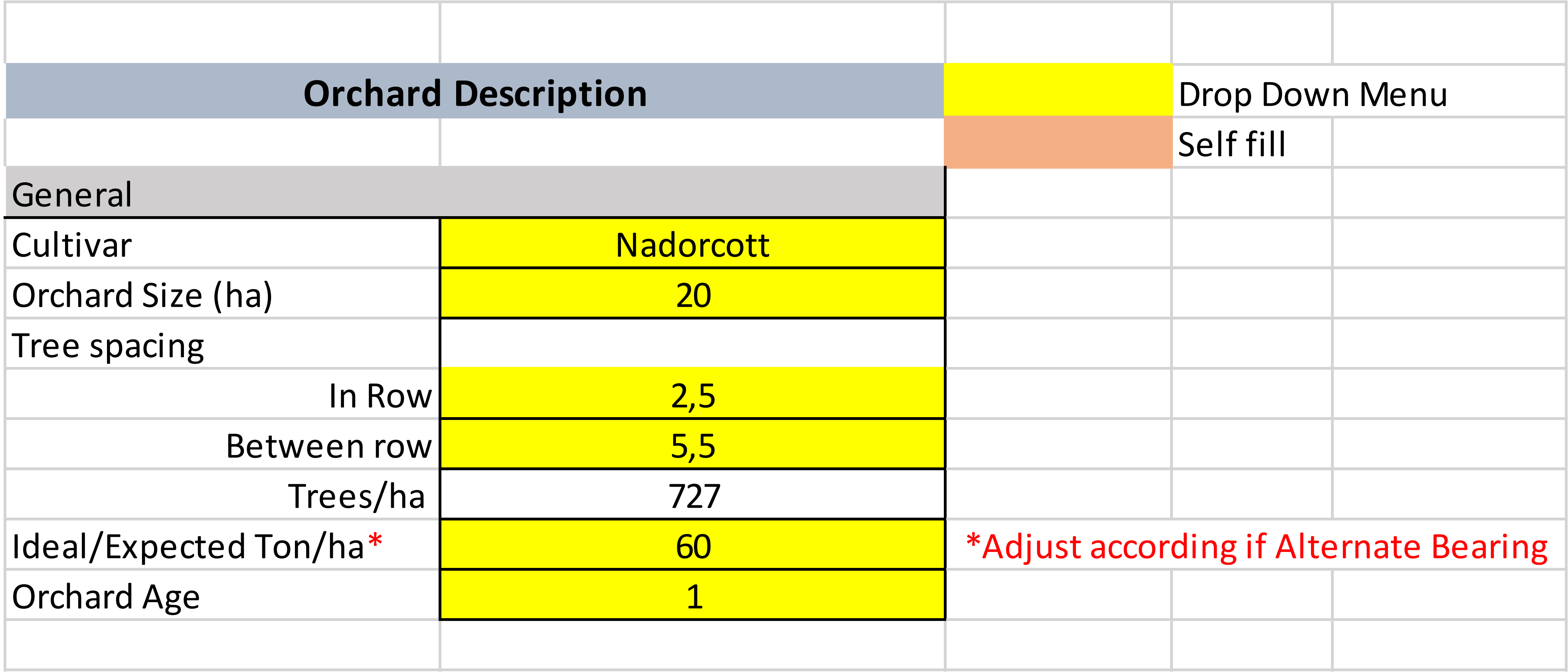
Evaluating the effect of a permanent shade netting on the profitability of a mandarin orchard, under South African production conditions, it was found that returns were increased over a period of 15 years. The cost of erecting a shade netting structure is initially capital-intensive, and in addition, a citrus shade netting industry survey reported increased production costs under these net structures. The increase in production costs are mainly due to higher pest and disease pressure and additional measures to control vegetative growth as the trees mature. However, after constructing an enterprise budget model, and providing it with validated industry information and scientific data, it was concluded that permanent shade netting increased the profitability of a mandarin orchard over a period of 15 years. Despite the high establishment and increased production costs, this increase in profitability under the shade netting was still prevalent. The increased profitability is mainly a factor of increased pack-out percentages, better fruit size distribution, seedless fruit, and the benefit of climatic risk management. Permanent shade netting would however be cautiously recommended in production areas with low climatic risks in which orchards are already producing high pack-out percentages of seedless fruit. In such areas, the profitability margin will not be increased to such an extent, and the shade netting will not be as economically viable as in this study.

Considering the results from this study, the production practices, and specifically crop manipulations, of ‘Nadorcott’ mandarin fruit under permanent shade netting would not differ to a large extent, compared to a standard commercial open orchard. Fruit set evaluations were not affected which indicates the normal gibberellic acid (GA_3) fruit set sprays will still be needed. In addition, the use of chemical fruit thinning agents at the normal timing and concentration, would still be recommended under shade netting for years when high fruit loads are expected. It should however be noted that shade netting may further enhance the effect on fruit size in reaction to these thinning treatments. Furthermore, as the trees under the shade netting exhibited increased vegetative growth, the use of a chemical vegetative growth inhibitors such as uniconazole may be a useful manipulation during spring to restrict excessive growth of the summer shoots. Finally, as the trees reach maturity, additional pruning strategies may be required to prevent dense tree canopies and over shading of potential bearing units, which may lead to decreased productivity and fruit quality.

The main conclusions that can be drawn from this study is that the use of 20% white permanent shade netting, in a Mediterranean-type climate, increased the vegetative growth of ‘Nadorcott’ mandarin without affecting any reproductive parameters. The efficacy of synthetic auxin chemical fruit thinning agents was not altered, while ultimately, shade netting has the ability to increase the effectivity and profitability of mandarin production.

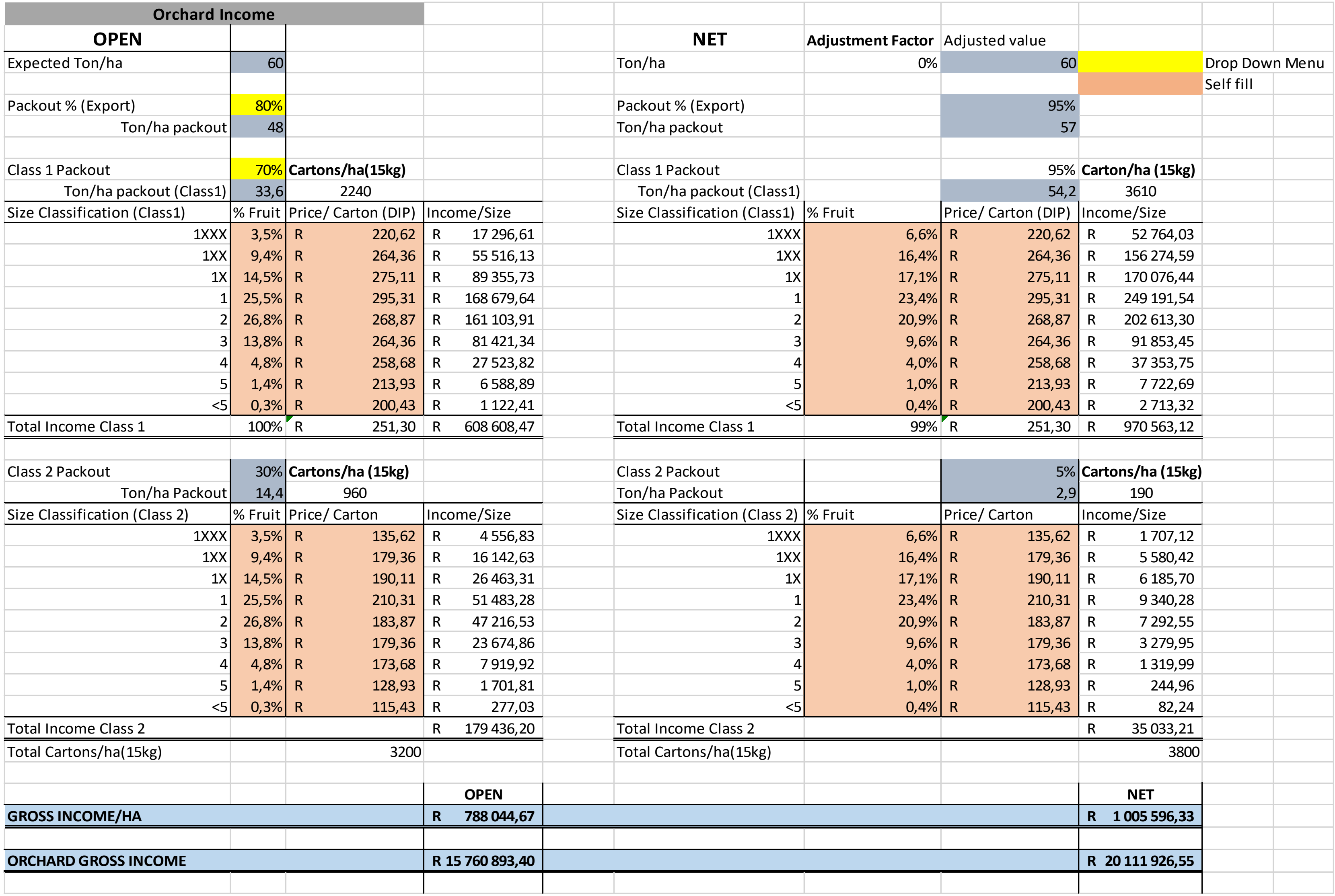
Appendix 1 – Budget model spreadsheets

Spreadsheet 1- Orchard description



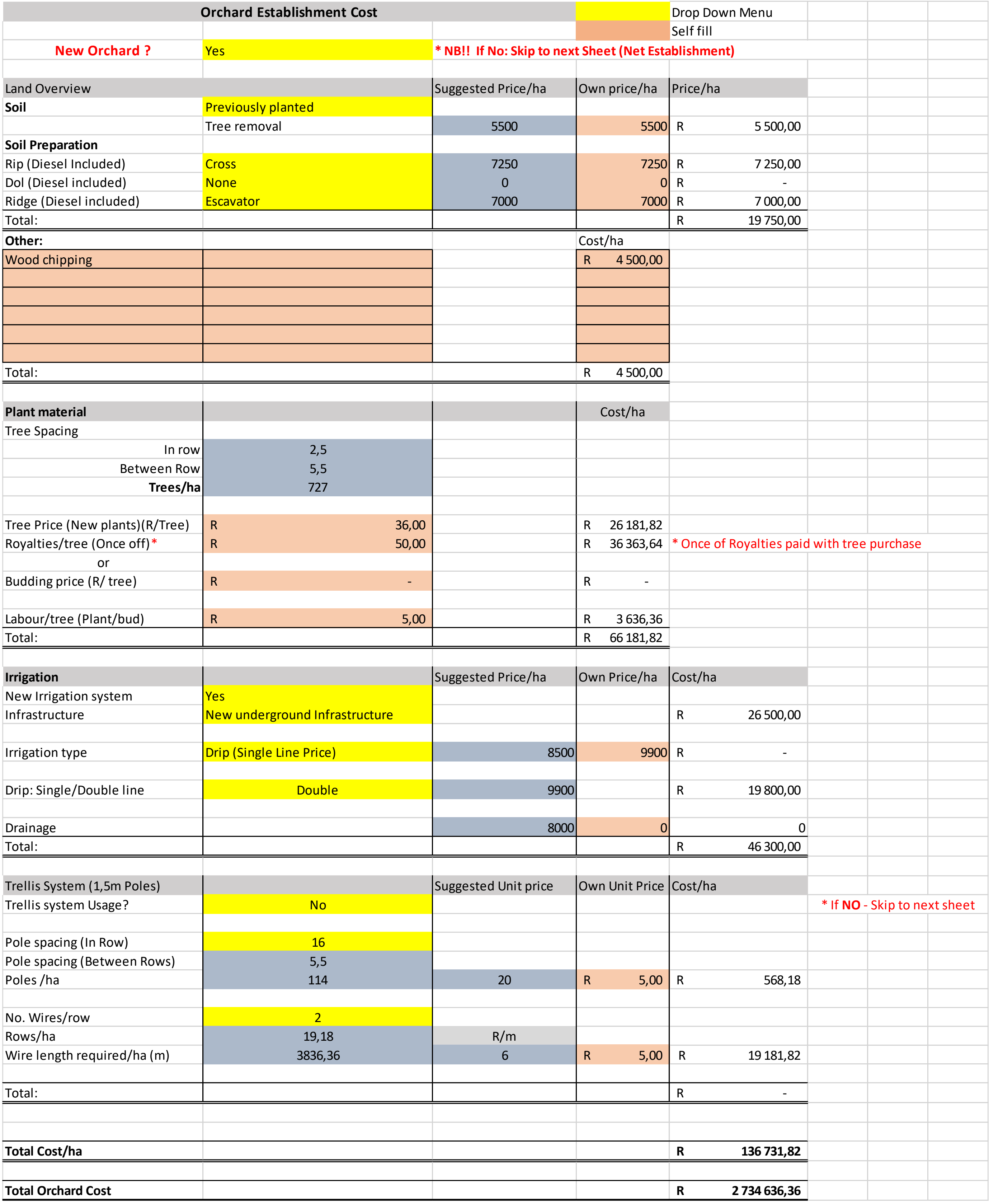
Orchard Description		🟨	Drop Down Menu	
		🟧	Self fill	
General				
Cultivar	Nadorcott			
Orchard Size (ha)	20			
Tree spacing				
In Row	2,5			
Between row	5,5			
Trees/ha	727			
Ideal/Expected Ton/ha*	60	*Adjust according if Alternate Bearing		
Orchard Age	1			

Spreadsheet 2- Orchard gross income



Orchard Income									
OPEN				**NET**	**Adjustment Factor**	Adjusted value			
Expected Ton/ha	60			Ton/ha	0%	60		🟨	Drop Down Menu
								🟧	Self fill
Packout % (Export)	80%			Packout % (Export)		95%			
Ton/ha packout	48			Ton/ha packout		57			
Class 1 Packout	70%	**Cartons/ha(15kg)**		Class 1 Packout		95%	**Carton/ha (15kg)**		
Ton/ha packout (Class1)	33,6	2240		Ton/ha packout (Class1)		54,2	3610		
Size Classification (Class1)	% Fruit	Price/ Carton (DIP)	Income/Size	Size Classification (Class1)	% Fruit	Price/ Carton (DIP)	Income/Size		
1XXX	3,5%	R 220,62	R 17 296,61	1XXX	6,6%	R 220,62	R 52 764,03		
1XX	9,4%	R 264,36	R 55 516,13	1XX	16,4%	R 264,36	R 156 274,59		
1X	14,5%	R 275,11	R 89 355,73	1X	17,1%	R 275,11	R 170 076,44		
1	25,5%	R 295,31	R 168 679,64	1	23,4%	R 295,31	R 249 191,54		
2	26,8%	R 268,87	R 161 103,91	2	20,9%	R 268,87	R 202 613,30		
3	13,8%	R 264,36	R 81 421,34	3	9,6%	R 264,36	R 91 853,45		
4	4,8%	R 258,68	R 27 523,82	4	4,0%	R 258,68	R 37 353,75		
5	1,4%	R 213,93	R 6 588,89	5	1,0%	R 213,93	R 7 722,69		
<5	0,3%	R 200,43	R 1 122,41	<5	0,4%	R 200,43	R 2 713,32		
Total Income Class 1	100%	R 251,30	R 608 608,47	Total Income Class 1	99%	R 251,30	R 970 563,12		
Class 2 Packout	30%	**Cartons/ha (15kg)**		Class 2 Packout		5%	**Cartons/ha (15kg)**		
Ton/ha Packout	14,4	960		Ton/ha Packout		2,9	190		
Size Classification (Class 2)	% Fruit	Price/ Carton	Income/Size	Size Classification (Class 2)	% Fruit	Price/ Carton	Income/Size		
1XXX	3,5%	R 135,62	R 4 556,83	1XXX	6,6%	R 135,62	R 1 707,12		
1XX	9,4%	R 179,36	R 16 142,63	1XX	16,4%	R 179,36	R 5 580,42		
1X	14,5%	R 190,11	R 26 463,31	1X	17,1%	R 190,11	R 6 185,70		
1	25,5%	R 210,31	R 51 483,28	1	23,4%	R 210,31	R 9 340,28		
2	26,8%	R 183,87	R 47 216,53	2	20,9%	R 183,87	R 7 292,55		
3	13,8%	R 179,36	R 23 674,86	3	9,6%	R 179,36	R 3 279,95		
4	4,8%	R 173,68	R 7 919,92	4	4,0%	R 173,68	R 1 319,99		
5	1,4%	R 128,93	R 1 701,81	5	1,0%	R 128,93	R 244,96		
<5	0,3%	R 115,43	R 277,03	<5	0,4%	R 115,43	R 82,24		
Total Income Class 2			R 179 436,20	Total Income Class 2			R 35 033,21		
Total Cartons/ha(15kg)		3200		Total Cartons/ha(15kg)			3800		
			OPEN				**NET**		
GROSS INCOME/HA			**R 788 044,67**				**R 1 005 596,33**		
ORCHARD GROSS INCOME			**R 15 760 893,40**				**R 20 111 926,55**		

Spreadsheet 3- Orchard establishment cost

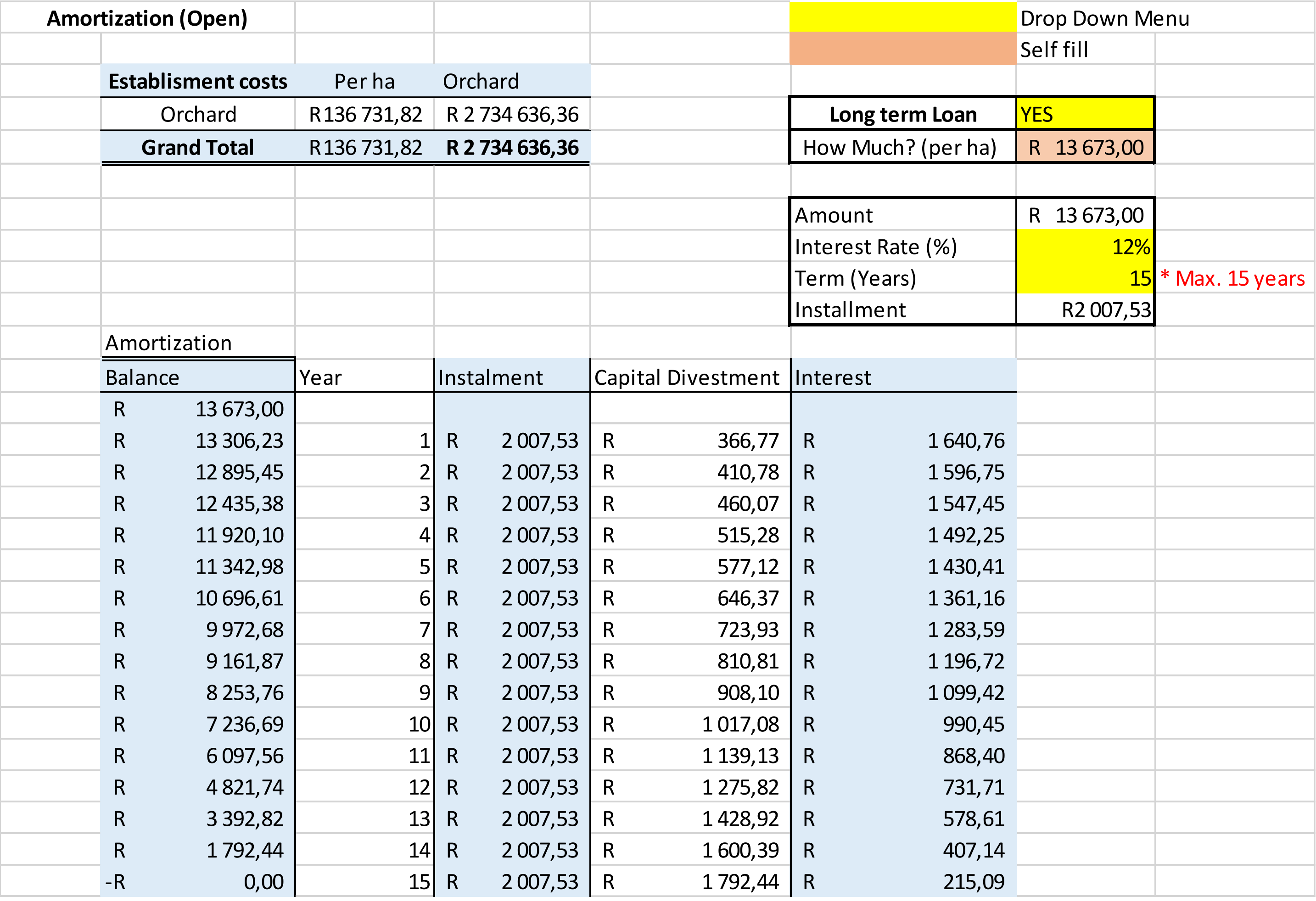


Orchard Establishment Cost			🟨	Drop Down Menu	
			🟧	Self fill	
New Orchard ?	Yes	*** NB!! If No: Skip to next Sheet (Net Establishment)**			
Land Overview		Suggested Price/ha	Own price/ha	Price/ha	
Soil	Previously planted				
	Tree removal	5500	5500	R 5 500,00	
Soil Preparation					
Rip (Diesel Included)	Cross	7250	7250	R 7 250,00	
Dol (Diesel included)	None	0	0	R -	
Ridge (Diesel included)	Escavator	7000	7000	R 7 000,00	
Total:				R 19 750,00	
Other:			Cost/ha		
Wood chipping			R 4 500,00		
Total:			R 4 500,00		
Plant material			Cost/ha		
Tree Spacing					
In row	2,5				
Between Row	5,5				
Trees/ha	727				
Tree Price (New plants)(R/Tree)	R 36,00		R 26 181,82		
Royalties/tree (Once off)*	R 50,00		R 36 363,64	* Once of Royalties paid with tree purchase	
or					
Budding price (R/ tree)	R -		R -		
Labour/tree (Plant/bud)	R 5,00		R 3 636,36		
Total:			R 66 181,82		
Irrigation		Suggested Price/ha	Own Price/ha	Cost/ha	
New Irrigation system	Yes				
Infrastructure	New underground Infrastructure			R 26 500,00	
Irrigation type	Drip (Single Line Price)	8500	9900	R -	
Drip: Single/Double line	Double	9900		R 19 800,00	
Drainage		8000	0	0	
Total:				R 46 300,00	
Trellis System (1,5m Poles)		Suggested Unit price	Own Unit Price	Cost/ha	
Trellis system Usage?	No				* If **NO** - Skip to next sheet
Pole spacing (In Row)	16				
Pole spacing (Between Rows)	5,5				
Poles /ha	114	20	R 5,00	R 568,18	
No. Wires/row	2				
Rows/ha	19,18	R/m			
Wire length required/ha (m)	3836,36	6	R 5,00	R 19 181,82	
Total:				R -	
Total Cost/ha				**R 136 731,82**	
Total Orchard Cost				**R 2 734 636,36**	

Spreadsheet 4- Net establishment cost

Net Establishment Cost			🟨	Drop Down Menu	
			🟧	Self fill	
Net				Cost/ha	
Net Type (Colour & Shade %)	**20% White**				
Closed Sides	Yes				
Aboveground Structure Height	6				
		Net Price (Open sides)			
		R48 000,00		R 57 600,00	
Total:				R 57 600,00	
Structure		UNITS/HA	Suggested Price/unit	Own Price/Unit	Cost/ha
Pole Length (m)	**6,6**				
Outside pole spacing					
Between Row	5,5	38	R 415,00	R 415,00	R 15 920,91
In Row	6	31	R 415,00	R 415,00	R 13 003,33
Inside Pole Spacing Pattern	Staggered				
Pole Spacing					
Between Row	5,5	127,5	R 240,00	R 210,00	R 26 775,00
In Row	12				
Anchors (8 Ton capacity)		78	R 190,00	R 190,00	R 14 762,42
Steel Wire (sides) (m)		140	R 6,00	R 6,00	R 840,00
Staywire (Outside-10mm) (m)		400	R 11,00	R 11,00	R 4 400,00
Staywire (Inside-6mm) (m)		3400	R 4,50	R 4,50	R 15 300,00
Other:	Price/ha				
General material (nails, clamps etc.)	R 20 500,00				R 20 500,00
					R -
					R -
Total:					R 111 501,67
Machinery & Labour		Suggested Price/ha	Own Price/Quote/ha	Cost/ha	
Machinery					
Hole digging (Anchors & Poles)		12000	12000	12000	
Tractors (Transport) & Platforms		9500	9200	9200	
Labour					
Anchor & Pole planting		17500	17500	17500	
Staywire Pull trough		22500	22500	22500	
Net Pull trough & Fasten		16500	16500	16500	
Total:				R 77 700,00	
Total Cost/ha				**R 246 801,67**	
Total Orchard Cost				**R 4 936 033,33**	

Spreadsheet 5- Amortization (Open)



Amortization (Open)

🟨	Drop Down Menu
🟧	Self fill

Establisment costs	Per ha	Orchard
Orchard	R136 731,82	R 2 734 636,36
Grand Total	R136 731,82	**R 2 734 636,36**

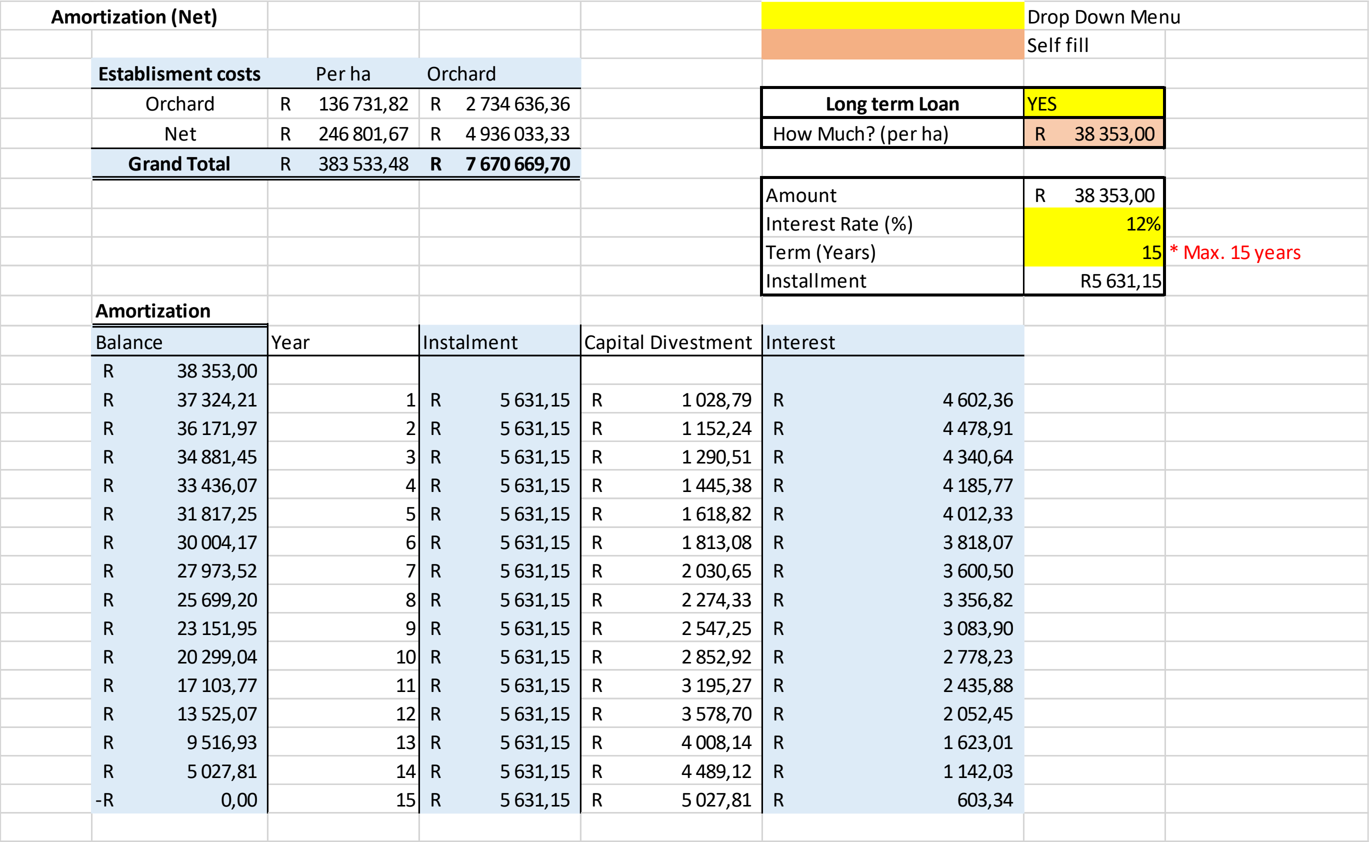
Long term Loan	YES
How Much? (per ha)	R 13 673,00

Amount	R 13 673,00	
Interest Rate (%)	12%	
Term (Years)	15	* Max. 15 years
Installment	R2 007,53	

Amortization

Balance	Year	Instalment	Capital Divestment	Interest
R 13 673,00				
R 13 306,23	1	R 2 007,53	R 366,77	R 1 640,76
R 12 895,45	2	R 2 007,53	R 410,78	R 1 596,75
R 12 435,38	3	R 2 007,53	R 460,07	R 1 547,45
R 11 920,10	4	R 2 007,53	R 515,28	R 1 492,25
R 11 342,98	5	R 2 007,53	R 577,12	R 1 430,41
R 10 696,61	6	R 2 007,53	R 646,37	R 1 361,16
R 9 972,68	7	R 2 007,53	R 723,93	R 1 283,59
R 9 161,87	8	R 2 007,53	R 810,81	R 1 196,72
R 8 253,76	9	R 2 007,53	R 908,10	R 1 099,42
R 7 236,69	10	R 2 007,53	R 1 017,08	R 990,45
R 6 097,56	11	R 2 007,53	R 1 139,13	R 868,40
R 4 821,74	12	R 2 007,53	R 1 275,82	R 731,71
R 3 392,82	13	R 2 007,53	R 1 428,92	R 578,61
R 1 792,44	14	R 2 007,53	R 1 600,39	R 407,14
-R 0,00	15	R 2 007,53	R 1 792,44	R 215,09

Spreadsheet 6- Amortization (Net)



Amortization (Net)

🟨	Drop Down Menu
🟧	Self fill

Establisment costs	Per ha	Orchard
Orchard	R 136 731,82	R 2 734 636,36
Net	R 246 801,67	R 4 936 033,33
Grand Total	R 383 533,48	**R 7 670 669,70**

Long term Loan	YES
How Much? (per ha)	R 38 353,00

Amount	R 38 353,00
Interest Rate (%)	12%
Term (Years)	15
Installment	R5 631,15

* Max. 15 years

Amortization

Balance	Year	Instalment	Capital Divestment	Interest
R 38 353,00				
R 37 324,21	1	R 5 631,15	R 1 028,79	R 4 602,36
R 36 171,97	2	R 5 631,15	R 1 152,24	R 4 478,91
R 34 881,45	3	R 5 631,15	R 1 290,51	R 4 340,64
R 33 436,07	4	R 5 631,15	R 1 445,38	R 4 185,77
R 31 817,25	5	R 5 631,15	R 1 618,82	R 4 012,33
R 30 004,17	6	R 5 631,15	R 1 813,08	R 3 818,07
R 27 973,52	7	R 5 631,15	R 2 030,65	R 3 600,50
R 25 699,20	8	R 5 631,15	R 2 274,33	R 3 356,82
R 23 151,95	9	R 5 631,15	R 2 547,25	R 3 083,90
R 20 299,04	10	R 5 631,15	R 2 852,92	R 2 778,23
R 17 103,77	11	R 5 631,15	R 3 195,27	R 2 435,88
R 13 525,07	12	R 5 631,15	R 3 578,70	R 2 052,45
R 9 516,93	13	R 5 631,15	R 4 008,14	R 1 623,01
R 5 027,81	14	R 5 631,15	R 4 489,12	R 1 142,03
-R 0,00	15	R 5 631,15	R 5 027,81	R 603,34

Spreadsheet 7- Production costs (Fertilizer & Chemicals)

Production Costs (Fertilizer & Chemicals)							
				🟨	Drop Down Menu		
				🟧	Self fill		
Fertilizer				**OPEN**		**NET**	
Soil	Units	Suggested Price/Unit	Own Price/Unit	Units/ha	Cost/ha	Adjustment Factor	Cost/ha
LAN	kg	R 4.10	R 4.10	753	R 3 087.30	**-10%**	R 2 778.57
KCl	kg	R 5.50	R 5.50	456	R 2 508.00	**-10%**	R 2 257.20
Other:					R -		R -
					R -		R -
					R -		R -
					R -		R -
					R -		R -
Total:					R 5 595.30		R 5 035.77
Foliar		Suggested Price/Unit	Own Price/Unit	Units/ha	Cost/ha		
Urea	kg	R 7.37	R 7.37	2	R 14.74	**-20%**	R 11.79
Copper oxychloride	kg	R 58.20	R 58.20	4.5	R 261.90	**0%**	R 261.90
Manganese Sulphate	kg	R 9.79	R 9.79	12	R 117.48	**0%**	R 117.48
Zinc Nitrate	kg	R 15.80	R 15.80	12	R 189.60	**0%**	R 189.60
Solubor	kg	R 32.85	R 32.85	4.5	R 147.83	**0%**	R 147.83
Magnesium Sulphate	kg	R 3.16	R 3.16	24	R 75.84	**0%**	R 75.84
Magnesium Chloride	kg				R -	**0%**	R -
Potassium Nitrate	kg	R 12.72	R 12.72	120	R 1 526.40	**0%**	R 1 526.40
Calcium Nitrate	kg	R 5.05			R -	**0%**	R -
Other:					R -		R -
					R -		R -
					R -		R -
					R -		R -
					R -		R -
					R -		R -
Total:					R 2 333.79		R 2 330.84

Chemicals									
Insectisides	Units	Suggested Price/Unit	Own Price/Unit	Units/ha	Cost/ha				
Abamectin (Thrips)	Liter	R 91,60	R 91,60	0,7	R 64,12			50%	R 96,18
Dicarzol (Thrips)	Liter	R 1 008,95	R 1 008,95	0	R -			50%	R -
Confidor (Thrips, Red Scale,Whitefly)	Liter	R 678,88	R 678,88	6,5	R 4 412,72			75%	R 7 722,26
Hunter (Thrips)	Liter	R 694,07	R 694,07	0	R -			50%	R -
Selecron (MealyBug)	Liter	R 119,00		0	R -			50%	R -
Buprofenzin (MealyBug)	Liter	R 260,00	R 260,00	3,6	R 936,00			50%	R 1 404,00
Applaud (MealyBug)	Liter			0	R -			50%	R -
Nemesis (Red Scale)	Liter	R 233,15	R 233,15	3,6	R 839,34			50%	R 1 259,01
Movento (Red Scale)	Liter	R 1 830,00	R 1 830,00	0	R -			50%	R -
Genesis (Red Scale)	Liter	R 91,40	R 91,40	0	R -			50%	R -
Dursban (FCM)	Liter	R 83,60	R 83,60	0	R -			0%	R -
Coragen (FCM)	Liter	R 1 850,00		0	R -			0%	R -
Runner (FCM)	Liter	R 420,00	R 420,00	6	R 2 520,00			0%	R 2 520,00
Selecron (Bollworm, Whitefly)	Liter	R 119,00		0	R -			0%	R -
Lannate (Bollworm)	Liter			0	R -			0%	R -
Helicovir (Bollworm)	Liter	R 749,22	R 749,22	0,72	R 539,44			0%	R 539,44
Snail Pellets (Charda)	Kg	R 624,35	R 624,35	5	R 3 121,75			-50%	R 1 560,88
Wetting Agent (ClingTight)	Liter	R 166,40	R 166,40	0	R -			40%	R -
Fruit Fly (GF-120)	Liter	R 105,00	R 105,00	1,5	R 157,50			0%	R 157,50
Other:	**Units**								
					R -				R -
					R -				R -
					R -				R -
					R -				R -
					R -				R -
Total:					R 12 590,87				R 15 259,26
Fungicides	Units	Suggested Price/Unit	Own Price/Unit	Units/ha	Cost/ha				
Scope (Alternaria)	Liter	R 182,00	R 182,00	3	R 546,00			50%	R 819,00
Dithane (Downy Mildewl)	Kg	R 57,20	R 57,20	30	R 1 716,00			15%	R 1 973,40
Penconazole (Powdery Mildew)	Liter	R 338,19		0	R -			20%	R -
Sulfur (Sulfostar)	Liter	R 18,11		0	R -			0%	R -
Black Spot				0	R -				R -
Other:					R -				R -
					R -				R -
					R -				R -
					R -				R -
Total:					R 2 262,00				R 2 792,40

Herbicides	Units	Suggested Price/Unit	Own Price/Unit	Units/ha	Cost/ha				
Roundup	Liter	R 24,95	R 51,00	10	R 510,00			20%	R 612,00
Grammaxone	Liter	R 36,40	R 12,00	0	R -			10%	R -
MCPA	Liter	R 44,75		0	R -				R -
Other:					R -				R -
					R -				R -
					R -				R -
					R -				R -
					R -				R -
Total:					R 510,00				R 612,00

PGR's (Hormones)	Units	Suggested Price/Unit	Own Price/Unit	Units/ha	Cost/ha				
ProGibb (GA3)	g	R 6,24	R 6,24	87,5	R 546,00			0%	R 546,00
Corasil (2,4-DP)	Liter	R 608,60	R 608,60	0	R -				R -
Maxim (3,5,6-TPA)	g	R 6,86	R 6,86	0	R -			0%	R -
2,4-D		R 43,70	R 43,70	0	R -				R -
Other:									
Total:					R546,00				R 546,00
					OPEN				**NET**
Total/ha					R 23 837,95				R 26 576,27
Total Orhard Cost					R 476 759,07				R 531 525,41

Spreadsheet 8 - Production costs (Other)

Production Costs (Other)						🟨	Drop Down Menu
						🟧	Self fill
				OPEN		**NET**	
						Adjustment Factor	Cost/ha
Production Royalties	Yes	Own Price		Cost/ha			
Per Carton/Per ha?	Per Carton						
Price per Unit		R 1,60		R 5 120,00		16%	R 5 928,42
Total:				R 5 120,00			R 5 928,42
Pruning	Suggested Price/ha	Own Price/ha		Cost/ha			
Labour	3000	3000		R 3 000,00		150%	R 7 500,00
Machinery	2500	2500		R 2 500,00		-100%	R -
Total:				R 5 500,00			R 7 500,00
Orchard Sanitation	Suggested Price/ha	Own Price/ha		Cost/ha			
Labour	1200	1200		1200		-40%	R 720,00
Total:				R 1 200,00			R 720,00
Irrigation	Suggested Price/ha	Own Price/ha		Cost/ha			
Electricity	3500	3600		3600		-20%	R 2 880,00
Water	1600	0		0		-20%	R -
Total:				R 3 600,00			R 2 880,00
Harvest Costs	Ton/ha	Cost/ton		Cost/ha			
	60	320		19200		0%	R 19 200,00
Total:				R 19 200,00			R 19 200,00
Packing Costs	Cartons/ha	Cost/Carton		Cost/ha			
		45		R 144 000,00			R 171 000,00
				R 144 000,00			R 171 000,00
Diesel	Suggested Price/ha	Own Price/ha		Cost/ha			
	2000	2028		2028		17%	R 2 372,76
Total:				R 2 028,00			R 2 372,76
Other:	Suggested Price/ha	Own Price/ha		Cost/ha			
Net Maintenance	1600	1600		0			R 1 600,00
				0			R -
				0			R -
				0			R -
				0			R -
				0			R -
				0			R -
				0			R -
Total:				R -			R 1 600,00
				OPEN			NET
Total Cost/ha				R 180 648,00			R 211 201,18
Total Orchard Cost				R 3 612 960,00			R 4 224 023,62

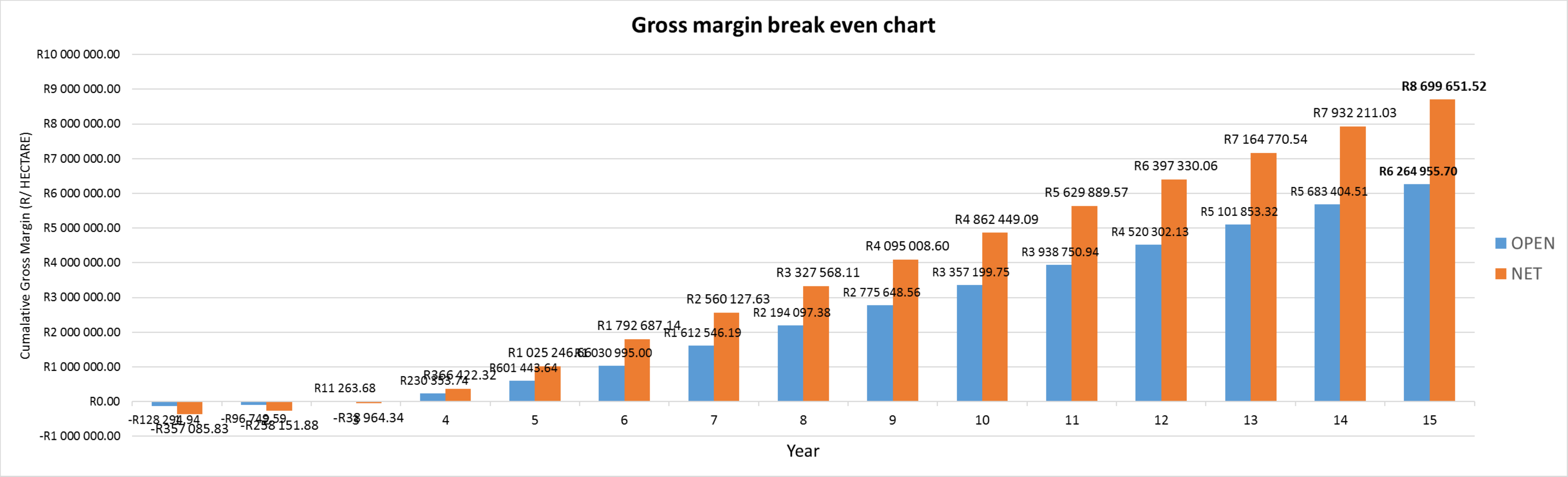
Spreadsheet 9- Gross margin (Open)

Gross Margin (OPEN)																
Orchard Age	**1**															
Year		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Income																
Expected Yield %		0%	6%	19%	38%	64%	74%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Gross Production Value		R -	R 47 282.68	R 149 728.49	R 299 456.97	R 504 348.59	R 583 153.06	R 788 044.67	R 788 044.67	R 788 044.67	R 788 044.67	R 788 044.67	R 788 044.67	R 788 044.67	R 788 044.67	R 788 044.67
Directly Allocatable Costs																
Establishment Cost																
Orchard Establishment		R 123 058.82	R -	R -	R -	R -	R -	R -	R -	R -	R -	R -	R -	R -	R -	R -
Soil preparation		24250.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Plant Material		66181.82	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Irrigation		46300.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Trellis System		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Production Costs																
Fertilizer		R 475.75	R 475.75	R 1 506.53	R 3 013.05	R 5 074.61	R 5 867.52	R 7 929.09	R 7 929.09	R 7 929.09	R 7 929.09	R 7 929.09	R 7 929.09	R 7 929.09	R 7 929.09	R 7 929.09
Soil		335.72	335.72	1063.11	2126.21	3580.99	4140.52	5595.30	5595.30	5595.30	5595.30	5595.30	5595.30	5595.30	5595.30	5595.30
Foliar		140.03	140.03	443.42	886.84	1493.62	1727.00	2333.79	2333.79	2333.79	2333.79	2333.79	2333.79	2333.79	2333.79	2333.79
Chemicals		R 1 947.17	R 1 947.17	R 3 878.04	R 6 700.09	R 10 561.84	R 12 047.12	R 15 908.87	R 15 908.87	R 15 908.87	R 15 908.87	R 15 908.87	R 15 908.87	R 15 908.87	R 15 908.87	R 15 908.87
Insecticides		755.45	755.45	2392.26	4784.53	8058.16	9317.24	12590.87	12590.87	12590.87	12590.87	12590.87	12590.87	12590.87	12590.87	12590.87
Fungiscides		135.72	135.72	429.78	859.56	1447.68	1673.88	2262.00	2262.00	2262.00	2262.00	2262.00	2262.00	2262.00	2262.00	2262.00
Herbicides		510.00	510.00	510.00	510.00	510.00	510.00	510.00	510.00	510.00	510.00	510.00	510.00	510.00	510.00	510.00
PGR's		546.00	546.00	546.00	546.00	546.00	546.00	546.00	546.00	546.00	546.00	546.00	546.00	546.00	546.00	546.00
General		R -	R 10 501.20	R 33 253.80	R 66 507.60	R 112 012.80	R 129 514.80	R 175 020.00	R 175 020.00	R 175 020.00	R 175 020.00	R 175 020.00	R 175 020.00	R 175 020.00	R 175 020.00	R 175 020.00
Royalties		0.00	307.20	972.80	1945.60	3276.80	3788.80	5120.00	5120.00	5120.00	5120.00	5120.00	5120.00	5120.00	5120.00	5120.00
Pruning		0.00	330.00	1045.00	2090.00	3520.00	4070.00	5500.00	5500.00	5500.00	5500.00	5500.00	5500.00	5500.00	5500.00	5500.00
Orchard Sanitation		0.00	72.00	228.00	456.00	768.00	888.00	1200.00	1200.00	1200.00	1200.00	1200.00	1200.00	1200.00	1200.00	1200.00
Harvest Cost		0.00	1152.00	3648.00	7296.00	12288.00	14208.00	19200.00	19200.00	19200.00	19200.00	19200.00	19200.00	19200.00	19200.00	19200.00
Packing Cost		0.00	8640.00	27360.00	54720.00	92160.00	106560.00	144000.00	144000.00	144000.00	144000.00	144000.00	144000.00	144000.00	144000.00	144000.00
Other		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total		R 125 481.74	R 12 924.12	R 38 638.37	R 76 220.74	R 127 649.25	R 147 429.45	R 198 857.95	R 198 857.95	R 198 857.95	R 198 857.95	R 198 857.95	R 198 857.95	R 198 857.95	R 198 857.95	R 198 857.95
Other		R 805.68	R 805.68	R 1 069.32	R 2 138.64	R 3 601.92	R 4 164.72	R 5 628.00	R 5 628.00	R 5 628.00	R 5 628.00	R 5 628.00	R 5 628.00	R 5 628.00	R 5 628.00	R 5 628.00
Irrigation (Electricity & Water)		684.00	684.00	684.00	1368.00	2304.00	2664.00	3600.00	3600.00	3600.00	3600.00	3600.00	3600.00	3600.00	3600.00	3600.00
Diesel		121.68	121.68	385.32	770.64	1297.92	1500.72	2028.00	2028.00	2028.00	2028.00	2028.00	2028.00	2028.00	2028.00	2028.00
Long term Loan		R 2 007.53	R 2 007.53	R 2 007.53	R 2 007.53	R 2 007.53	R 2 007.53	R 2 007.53	R 2 007.53	R 2 007.53	R 2 007.53	R 2 007.53	R 2 007.53	R 2 007.53	R 2 007.53	R 2 007.53
Gross Margin		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Gross Income		R -	R 47 282.68	R 149 728.49	R 299 456.97	R 504 348.59	R 583 153.06	R 788 044.67	R 788 044.67	R 788 044.67	R 788 044.67	R 788 044.67	R 788 044.67	R 788 044.67	R 788 044.67	R 788 044.67
Directly Allocatable Cost		R 126 287.42	R 13 729.80	R 39 707.69	R 78 359.38	R 131 251.17	R 151 594.17	R 204 485.95	R 204 485.95	R 204 485.95	R 204 485.95	R 204 485.95	R 204 485.95	R 204 485.95	R 204 485.95	R 204 485.95
Long term loan		R 2 007.53	R 2 007.53	R 2 007.53	R 2 007.53	R 2 007.53	R 2 007.53	R 2 007.53	R 2 007.53	R 2 007.53	R 2 007.53	R 2 007.53	R 2 007.53	R 2 007.53	R 2 007.53	R 2 007.53
Gross Margin		**-R 128 294.94**	**R 31 545.36**	**R 108 013.27**	**R 219 090.06**	**R 371 089.89**	**R 429 551.36**	**R 581 551.19**	**R 581 551.19**	**R 581 551.19**	**R 581 551.19**	**R 581 551.19**	**R 581 551.19**	**R 581 551.19**	**R 581 551.19**	**R 581 551.19**

Spreadsheet 10- Gross margin (Net)

Gross margin (Net)																
Orchard Age	**1**															
Year		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Income																
Expected Yield %		0%	14%	29%	53%	86%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Gross Production Value		R -	R 139 107.49	R 294 974.92	R 536 318.04	R 864 812.84	R 1 005 596.33	R 1 005 596.33	R 1 005 596.33	R 1 005 596.33	R 1 005 596.33	R 1 005 596.33	R 1 005 596.33	R 1 005 596.33	R 1 005 596.33	R 1 005 596.33
Directly Allocatable Costs																
Establishment Cost																
Orchard Establishment		R 136 731.82	R -	R -	R -	R -	R -	R -	R -	R -	R -	R -	R -	R -	R -	R -
Soil preparation		24250.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Plant Material		66181.82	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Irrigation		46300.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Trellis System		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Net Establisment		R 208 448.67														
General		57600.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Structure		111501.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Labour & Machinery		77700.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Production Costs																
Fertilizer		R 1 019.05	R 1 019.05	R 2 160.87	R 3 928.86	R 6 335.28	R 7 366.61	R 7 366.61	R 7 366.61	R 7 366.61	R 7 366.61	R 7 366.61	R 7 366.61	R 7 366.61	R 7 366.61	R 7 366.61
Soil		696.61	696.61	1477.16	2685.74	4330.76	5035.77	5035.77	5035.77	5035.77	5035.77	5035.77	5035.77	5035.77	5035.77	5035.77
Foliar		322.43	322.43	683.71	1243.11	2004.52	2330.84	2330.84	2330.84	2330.84	2330.84	2330.84	2330.84	2330.84	2330.84	2330.84
Chemicals		R 3 655.15	R 3 655.15	R 6 453.15	R 10 785.55	R 16 682.43	R 19 209.66	R 19 209.66	R 19 209.66	R 19 209.66	R 19 209.66	R 19 209.66	R 19 209.66	R 19 209.66	R 19 209.66	R 19 209.66
Insecticides		2110.86	2110.86	4476.05	8138.27	13122.97	15259.26	15259.26	15259.26	15259.26	15259.26	15259.26	15259.26	15259.26	15259.26	15259.26
Fungicides		386.28	386.28	819.10	1489.28	2401.46	2792.40	2792.40	2792.40	2792.40	2792.40	2792.40	2792.40	2792.40	2792.40	2792.40
Herbicides		612.00	612.00	612.00	612.00	612.00	612.00	612.00	612.00	612.00	612.00	612.00	612.00	612.00	612.00	612.00
PGR's		546.00	546.00	546.00	546.00	546.00	546.00	546.00	546.00	546.00	546.00	546.00	546.00	546.00	546.00	546.00
General		R 1 600.00	R 29 868.20	R 61 542.20	R 110 585.82	R 177 339.64	R 205 948.42	R 205 948.42	R 205 948.42	R 205 948.42	R 205 948.42	R 205 948.42	R 205 948.42	R 205 948.42	R 205 948.42	R 205 948.42
Royalties		0.00	820.10	1739.00	3161.82	5098.44	5928.42	5928.42	5928.42	5928.42	5928.42	5928.42	5928.42	5928.42	5928.42	5928.42
Pruning		0.00	1037.50	2200.00	4000.00	6450.00	7500.00	7500.00	7500.00	7500.00	7500.00	7500.00	7500.00	7500.00	7500.00	7500.00
Orchard Sanitation		0.00	99.60	211.20	384.00	619.20	720.00	720.00	720.00	720.00	720.00	720.00	720.00	720.00	720.00	720.00
Harvest Cost		0.00	2656.00	5632.00	10240.00	16512.00	19200.00	19200.00	19200.00	19200.00	19200.00	19200.00	19200.00	19200.00	19200.00	19200.00
Packing Cost		0	23655	50160	91200	147060	171000	171000	171000	171000	171000	171000	171000	171000	171000	171000
Other		R 1 600.00	R 1 600.00	R 1 600.00	R 1 600.00	R 1 600.00	R 1 600.00	R 1 600.00	R 1 600.00	R 1 600.00	R 1 600.00	R 1 600.00	R 1 600.00	R 1 600.00	R 1 600.00	R 1 600.00
Total		R 351 454.68	R 34 542.39	R 70 156.23	R 125 300.24	R 200 357.35	R 232 524.69	R 232 524.69	R 232 524.69	R 232 524.69	R 232 524.69	R 232 524.69	R 232 524.69	R 232 524.69	R 232 524.69	R 232 524.69
Other		R 1 173.03	R 1 173.03	R 1 540.81	R 2 801.47	R 4 517.37	R 5 252.76	R 5 252.76	R 5 252.76	R 5 252.76	R 5 252.76	R 5 252.76	R 5 252.76	R 5 252.76	R 5 252.76	R 5 252.76
Irrigation (Electricity & Water)		844.80	844.80	844.80	1536.00	2476.80	2880.00	2880.00	2880.00	2880.00	2880.00	2880.00	2880.00	2880.00	2880.00	2880.00
Diesel		328.23	328.23	696.01	1265.47	2040.57	2372.76	2372.76	2372.76	2372.76	2372.76	2372.76	2372.76	2372.76	2372.76	2372.76
Long term Loan		R 5 631.15	R 5 631.15	R 5 631.15	R 5 631.15	R 5 631.15	R 5 631.15	R 5 631.15	R 5 631.15	R 5 631.15	R 5 631.15	R 5 631.15	R 5 631.15	R 5 631.15	R 5 631.15	R 5 631.15
Gross Margin		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Gross Income		R -	R 139 107.49	R 294 974.92	R 536 318.04	R 864 812.84	R 1 005 596.33	R 1 005 596.33	R 1 005 596.33	R 1 005 596.33	R 1 005 596.33	R 1 005 596.33	R 1 005 596.33	R 1 005 596.33	R 1 005 596.33	R 1 005 596.33
Directly Allocatable Cost		R 351 454.68	R 34 542.39	R 70 156.23	R 125 300.24	R 200 357.35	R 232 524.69	R 232 524.69	R 232 524.69	R 232 524.69	R 232 524.69	R 232 524.69	R 232 524.69	R 232 524.69	R 232 524.69	R 232 524.69
Long term Loan		R 5 631.15	R 5 631.15	R 5 631.15	R 5 631.15	R 5 631.15	R 5 631.15	R 5 631.15	R 5 631.15	R 5 631.15	R 5 631.15	R 5 631.15	R 5 631.15	R 5 631.15	R 5 631.15	R 5 631.15
Gross Margin		**-R 357 085.83**	**R 98 933.95**	**R 219 187.54**	**R 405 386.66**	**R 658 824.34**	**R 767 440.49**	**R 767 440.49**	**R 767 440.49**	**R 767 440.49**	**R 767 440.49**	**R 767 440.49**	**R 767 440.49**	**R 767 440.49**	**R 767 440.49**	**R 767 440.49**

Spreadsheet 11- Gross margin – Break-even Chart



Appendix 2 – CNIS participants

Citrus industry survey participants:

Western Cape:

Duppie van Zyl – Dome Citrus, Hexriver Valley

Dewalt Viviers – Indigo Farms (Zandvliet), Ashton

Simon Baty – Unifrutti Farms, Sandveld

Jannie Toerien – Patrysberg Farm, Citrusdal

Limpopo:

Gustav Mallo – Indigo Farms, Burgersfort

Sean Colyn – Mahela, Ohrigstad

Smit le Roux – Le Roux Farms, Ohrigstad

Coenie Scheepers – Ambrosia Estates, Hoedspruit

Arnold van der Walt – Schoonbee Estate, Loskop

Frans Olivier – Schoemann Farms, Loskop

Appendix 3 – CNIS Questionnaire

Citrus netting industry survey - Questionnaire

A- Orchard Description

1. Cultivar under shade netting?

____

____

____

____

____

2. Biggest orchard under shade netting (ha)?

____

3. Tree Spacing for mandarins?
   3.1 0.5 m Increments? __________
   3.2 Spacing
   In row ___________
   Between Row ___________
4. Oldest orchard under net?

____

5. Average lifespan of a typical mandarin orchard?

____

6. Average orchard production from one year after planting?

Year	1	2	3	4	5	6	7	8
Open								
Net								

B- Orchard Income

1. Yield per hectare?

Open:____

Net: ____

2. Export pack out %?

Open:____

Net: ____

3. Class 1 pack out %?

Open:____

Net: ____

4. Equivalent carton weight for price calculations (10/15kg)?

____

5. Difference in price for seeded vs. seedless fruit?

____

____

6. Average ‘Nadorcott’ price per carton according to size counts (Class 1 and Class 2)?

____

____

____

____

____

____

____

____

____

____

C- Orchard Establishment

1. Tree removal
   1.1 Removal and transport cost/ha? ____
   1.2 Cost/ha to chip trees?

   ____

   ____

2. Ripping
   2.1 Different methods used with cost/ha?

   ____

   ____

   ____

   ____

   ____

3. Tilling
   Different methods used with cost/ha?

   ____

   ____

   ____

   ____

   ____

4. Ridging methods and cost/ha?

   ____

   ____

   ____

   ____

5. Soil amendments before planting?

   ____

   ____

6. Drainage cost/ha?

____

____

7. Tree price (Nadorcott)
   7.1 Tree price?

   ____

   7.2 Royalties?

   ____

   7.3 Labour/tree (cost for planting)?

____

8. Budding
8.1 Buds/tree?

____

8.2 Cost per bud?

____

8.3 Labour/tree (Cost per bud)

____

9. Irrigation
9.1 Price/ha for underground infrastructure (Lines & Pumps)?

____

9.2 Micro sprinkler price/ha (aboveground)?

____

9.3 Drip line price/ha (Specify if price is for single or double line)

____

____

10. Trellis system (If applicable)
10.1 Pole length?

____

10.2 In row pole spacing?

____

10.3 Wires per row and cost/m?

____

____

10.4 Anchor cost?

____

10.5 Labour cost/ha for trellis system?

____

D- Net Establishment

1. Hail structure: Extra cost/ha and % extra?

2. Side nets: % shade, extra cost and number of steel wires?

3. Price of 20% white net per hectare?

4. Shade net structure aboveground height?

5. Structure pole length and cost/pole?
   Outside: ______________________________
   Inside: ______________________________
6. In row spacing net poles?
   Outside: ______________________________
   Inside: ______________________________
7. Stay wire: length/ha (m) and cost/ha?

8. Machinery and Labour
   8.1 Machinery cost/ha: Hole digging (anchors & poles)?

   8.2 Machinery cost/ha: Platforms and transport?

   8.3 Labour
   Poles and anchor planting cost/ha?
   ____
   Staywire pull through and tension?
   ____
   Net pull through and tension?
   ____

E- Production Costs (Fertilizer & Chemicals)

Fertilizer

Soil	Units	Price/unit	Units/ha Open	**Adjustment Factor (%)**	Units/ha Net
LAN	kg				
KCl	kg				
Other:					
Foliar		Price/unit	Units/ha Open	**Adjustment Factor (%)**	Units/ha Net
Urea	kg				
Copper oxychloride	kg				
Manganese Sulphate	kg				
Zinc Nitrate	kg				
Solubor	kg				
Magnesium Sulphate	kg				
Magnesium Chloride	kg				
Potassium Nitrate	kg				
Calcium Nitrate	kg				
Other:					
Chemicals					
Insecticides	Units	Price/unit	Units/ha Open	**Adjustment Factor (%)**	Units/ha Net
Abamectin (Thrips)	Liter				
Dicarzol (Thrips)	Liter				
Confidor (Thrips, Red Scale,Whitefly)	Liter				
Hunter (Thrips)	Liter				
Selecron (MealyBug)	Liter				
Buprofenzin (MealyBug)	Liter				
Applaud (MealyBug)	Liter				
Nemesis (Red Scale)	Liter				
Movento (Red Scale)	Liter				

Genesis (Red Scale)	Liter				
Dursban (FCM)	Liter				
Coragen (FCM)	Liter				
Runner (FCM)	Liter				
Selecron (Bollworm, Whitefly)	Liter				
Lannate (Bollworm)	Liter				
Helicovir (Bollworm)	Liter				
Snail Pellets	Kg				
Wetting agent	Liter				
Fruit Fly (GF-120)	Liter				
Fungicides	Units	Price/unit	Units/ha Open	**Adjustment Factor (%)**	Units/ha Net
Scope (Alternaria)	Liter				
Dithane (Downy Mildew)	Liter				
Penconazole (Powdery Mildew)	Liter				
Sulphur	Kg/Liter				
Other:					
Herbicides	Units	Price/unit	Units/ha Open	**Adjustment Factor (%)**	Units/ha Net
Roundup	Liter				
Grammaxone	Liter				
MCPA	Liter				
Other:					
	Units	Price/unit	Units/ha Open	**Adjustment Factor (%)**	Units/ha Net
ProGibb (GA3)	g				
Corasil (2,4-DP)	Liter				
Maxim (3,5,6-TPA)	g				
2,4-D	Liter				

F- Production Costs (Other)

Production Costs (Other)

Royalties		**Open** Cost/ha	**Adjustment Factor (%)**	**Net** Cost/ha
Per Carton/Per ha?				
Price/ carton?				
Pruning		Open Cost/ha		Net Cost/ha
Labour				
Machinery				
Orchard Sanitation		Open Cost/ha	**Adjustment Factor (%)**	Net Cost/ha
Labour				
Irrigation				
Electricity				
Water				
Harvest Costs				
Cost/ton?				
		Open Cost/ha	**Adjustment Factor (%)**	Net Cost/ha
Diesel				
Other:		Open Cost/ha		Net Cost/ha

Notes: