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EFFECTS OF IRRIGATION AND SHADING ON FRUIT YIELD AND QUALITY IN MANGO

By

Gugulethu Jay Mthembu

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Supervisor Dr. E.W. Pavel
Co-Supervisor Prof. P.J. Robbertse

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Abstract

Mangifera indica L. cv. Kent trees were subjected to five irrigation treatments during the 2000/2001 growing season with the aim of assessing the effects of irrigation on tree productivity and fruit quality. Two progressively reduced irrigation treatments (75 and 50 % of the amount of irrigation water applied to the control), a control (100% field capacity), a regulated deficit irrigation (RDI) treatment and a farm control were compared with each other. Fruit yield, number and mean fruit weight were not significantly influenced by the different irrigation treatments. Peel colour and storage potential were improved in the reduced irrigation treatments. The RDI treatment improved the total soluble solids concentration (TSS) of fruits but increased the occurrence of split pit. Fruit firmness was not significantly influenced by the different irrigation treatments. In the second experiment, 'Kent' trees were covered with white shade netting of four mesh densities (50, 75, 100 and 125 g m^{-2}) on a long-term basis, while control trees remained uncovered. During the 2000/2001 growing season, light shading (50 g m^{-2}) increased the yield and fruit numbers above that of control trees, while, heavier shading decreased the yield and fruit number below that of the control with the most dense net (125 g m^{-2}) having the greatest affect. Peel colour, firmness and total soluble solids (TSS) at harvest were not affected by shading while the heaviest shade (125 g m^{-2}) reduced storage potential of the fruit. Shading improved the appearance of fruits through the reduction of split pit, sunburn and wind damage. No fruit damage caused by bacterial black spot was observed in any of the shade treatments or the control.

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1. General Introduction

The mango fruit (*Mangifera indica* L.) is one of the highly demanded fruits in the world as a result of its attractive colour, delicious taste and excellent nutritional properties (Mitra and Baldwin, 1997). The rapid increase of the mango industry in the world (Mitra and Baldwin, 1997) calls for increased knowledge and skills in the production of this crop for growers to keep or find a place in the market.

Consumers are increasingly becoming aware of the quality of products they spend their money on. Quality can be viewed as an absence of defects (Shewfelt, 1999), a degree of excellence or suitability for a particular use (Abbot, 1999). Because of the quality-conscious consumer, the production of fruits needs to shift from 'quantity production' to 'quality production'. Producing tons of poor quality fruits could mean a great loss for the producer. It is for this reason that producers need to improve their knowledge and skills of growing fruits. Most horticultural produce is sold by weight (Jones and Tardieu, 1998). Water as the major component of fruits (Kaufmann, 1972) contributes to a large extent to their weight. Water is the most important commodity in fruit production and the production of other agricultural products. Water is, however, increasingly becoming very scarce and thus very expensive. There is therefore a great demand for irrigation scheduling methodologies that are precise in order to minimise the cost of production (Castel and Buj, 1990). Determining optimal reductions of irrigation water is needed to sustain tree development, yields and fruit quality and can contribute to lower production costs with minimum effects on yield (Torrecillas et al., 1993). Deficit irrigation, whether through complete withholding irrigation for a certain period or the replacement of a certain amount of evaporated water, has been used in saving water (Chalmers et al., 1981, 1986; Mitchell et al., 1984, 1986; Irving and Drost 1987; Kilili et al., 1996a, 1996b). Through the use of deficit irrigation, water savings of 35.3 (Strabbioli, 1992), 15 (Stern and Gazit, 1993), 8 (Caspari et al., 1994) and 30% (Domingo et al., 1996) in peach, litchi, pears and lemon, respectively, have been reported. Minimising water use not only reduces production costs but also helps in reducing the leaching of nutrients into groundwater (Mills et al., 1994). Li et al. (1989) among others have found that reduced irrigation can be useful in reducing the vigour of trees with no or very little effect on yield and fruit quality. Short periods of water deficits could be applied successfully without any adverse effects on mango trees, since they are considered drought tolerant (Schaffer et al., 1994).

Light interception within fruit trees plays a very important role in the production of maximum yields and high quality fruits (Kappel, 1989; Kappel and Neilsen, 1994). Insufficient or excess light striking the plant and/or product can result in alterations in product appearance (Kays, 1999) which could render the product unfit for sale. Shading by shade nets is used as a management technique, for example to reduce frost damage, decrease water consumption or delay fruit maturity (Israeli et al., 1995). Furthermore, fruit trees can be covered with shade netting to avoid damage caused by hail, sunburn or wind. Shading, however, reduces the absorption and utilisation of photosynthetically active radiation (PAR). This results in the low potential for photosynthesis which limits yield productivity as a result of a reduced supply of current assimilates to the fruit (Lionakis et al., 1997; Kappel, 1989). Rom (1990) reported 30% full sunlight as being the critical threshold value for maximum photosynthetic activity and carbohydrate production by apple fruit trees. Any decrease in photosynthate availability will therefore decrease fruit quality (Roper and Loescher, 1987). Bacterial black spot (BBS), caused by *Xanthomonas campestris pv. mangiferaeindicae,* is the most serious disease of mango in Asia and Africa (Manicom, 1986) lowering yields due to premature fruit drop and strongly impairing fruit quality (Pruvost et al., 1993). In windy areas, this disease accounts for more than 50% loss in cultivars such as "Keitt" and "Kent"(Boshoff et al., 1999). Doidge (1915) observed that the disease not only spread in the direction of prevailing winds but its severity was also correlated with rainfall. Copper sprays are most commonly used as measures of control for BBS but have been found to be inadequate and are becoming uneconomical (Boshoff et al., 1999). The use of shade nets has been found to result in the reduction of rain penetration (Lawson et al. 1994) and wind velocity (Freeman, 1976). These findings suggest that shade nets might reduce the occurrence of the disease. A degradation of pigmentation will occur when fruits are exposed to excess solar energy and if the duration of exposure or intensity is sufficiently high, cellular death and collapse of the tissues follows resulting in what is known as sunscald (Kays, 1999). Shading, whether natural or artificial, might represent a management practice to reduce incidences of such disorders.

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2. Effects of irrigation on fruit yield and quality in mango

2.1. Introduction

The successful application of deficit irrigation seems to be dependent on the time of the season at which stress is imposed, on the species and on the duration and intensity of the stress (Bradford and Hsiao, 1982; Peng and Rabe, 1996). The end product required, however, will influence decisions taken about the timing, duration and intensity of stress. One would expect deficit irrigation strategies adopted for fruits destined for processing to be different from those applied to fruits destined for the fresh produce market. For instance, fruit size is more important for table olives compared to oil olives and the former would therefore require adequate water supply during the entire season (Michelakis, 1990).

The effectiveness of two types of deficit irrigation strategies were investigated in this study, that is regulated deficit irrigation (RDI) and progressively reduced irrigation. According to Chalmers et al. (1981) RDI is an irrigation strategy based on limiting non-beneficial water losses and applying water so that plant water deficits are controlled during times of the season when adverse effects on productivity are minimised. However, opinions about when to apply RDI differ. In this study, progressively reduced irrigation is defined as the continuous reduction of irrigation water applied to plants throughout the entire season.

Mitchell et al. (1984) applied RDI on pear trees during the stage of rapid vegetative growth until about 60 days before full bloom. Ninety-two, 46 and 23% of evaporated water calculated over the planting square (Eps) was applied for the period of RDI. A decline in shoot and frame growth in proportion to water deficits was observed. Fruit growth in the 46% treatment during RDI tended to be slower than the 23% treatment and similar to the 92% Eps treatment. However, RDI did not decrease final fruit size or yield but, as mentioned earlier, reduced vegetative growth. Following the period of full irrigation, fruit growth was initially faster in the RDI treatments compared to non-stressed trees resulting in marginally increased yields in the RDI treatments. Mitchell et al. (1984) also found that trees receiving RDI in the previous season had increased flowering in the following season compared to non-stressed trees. The application of water deficits in apples during growth stage I (about six weeks after full bloom) until the end of shoot growth led to a terminal shoot growth reduction of 37% (Irving and Drost, 1987). The water stress imposed on the trees did not significantly affect fruit growth. Irving and Drost (1987) observed an increased number of cracked fruits when water deficits were imposed during stage I compared to non-stressed trees. Fruits from stressed trees had higher soluble solids compared to fruits from non-stressed trees. Mitchell et al. (1986) also observed increased gross yields in 'Bartlett' pears when RDI was applied during the rapid vegetative growth stage until the end of this stage. During the subsequent rapid fruit growth stage all trees were irrigated. During the first year of the study, RDI treatments increased gross yields by increasing fruit set and fruit size. However, increased fruit numbers in the second year resulted in smaller average fruit size in the RDI treatments. Nevertheless, RDI trees still had higher yields compared to the non-stressed trees in both years (Mitchell et al., 1986). When RDI was imposed early in the season until terminal bud set in apple trees, RDI trees were found to have similar or less vegetative growth and similar or higher yield efficiency than the non-stressed trees (Ebel et al., 1995). Although fruit growth rate was slowed during RDI, a recovery upon re-watering was observed resulting in yield efficiency similar to or better than that of non-stressed trees. Greater volumes of fruits in stressed trees than non-stressed trees as a consequence of accelerated growth or 'growth jump' after the removal of water stress has also been observed in pears (Chalmers et al., 1986) and in citrus (Huang et al., 2000). Behboudian et al. (1994) also observed smaller diameters when water stress was applied early in the season in Asian pears with differences ceasing to be statistically significant after re-watering. Kilili et al. (1996a, 1996b) found that mean apple fruit weight was significantly reduced when irrigation was withheld early in the season [from full bloom to 104 days after full bloom (DAFB)]. Ginestar and Castel (1996) also observed decreased yield in citrus when water stress was imposed early in the season with the most sensitive phenological stages being the flowering and fruit set periods. The yield reduction occurred mostly as a result of fewer fruit as the final fruit size was not significantly reduced by stress. A heavy fruit drop was the cause for the reduction in fruit number.

Late withholding of irrigation from 104 DAFB until harvest at 194 DAFB did not have any negative effect on the mean fruit weight of apple trees (Kilili et al., 1996a, 1996b). At harvest these stressed fruits had a more yellow background colour compared to non-stressed fruits or those from trees stressed early in the season. Increases in total soluble solids (TSS) and flesh firmness were also observed in apple fruits from late season deficit irrigated trees compared to fruits from early season stressed and non-stressed trees. Ginestar and Castel (1996) showed late season deficit irrigation to be favourable to citrus fruit quality with stressed trees producing fruits of increased peel thickness, TSS and acid contents. Similar improvements in fruit quality resulting from late season deficit irrigation were observed in apple (Mills et al., 1994) and peach (Li et al., 1989). Water deficits during the final fruit growth phase can therefore improve fruit quality and storage capacity and reduce premature fruit drop.

Kilili et al. (1996a, 1996b) observed decreased mean fruit weight when irrigation was withheld during the entire growing season of apple trees. Increased TSS, flesh firmness and skin pigmentation were however observed. According to the results of Kilili et al. (1996a, 1996b) deficit irrigation during the entire season was apparently favourable to fruit quality. It could, however, be very detrimental to tree productivity especially if water stress occurs during flowering and fruit set (Behboudian and Mills, 1997), since these two periods have been found to be most sensitive to water stress (Ginestar and Castel, 1996).

Johnson et al. (1992) observed decreased vegetative growth in peach trees when postharvest water deficits were applied. The stress did not lead to yield and fruit size reductions or a progressive decline in the vigour and health of trees. The total withholding of irrigation at postharvest did, however, result in the increased occurrence of double fruits leading to increased time and expense spent in removing these fruits from the trees with the result of low yields.

Assaf et al. (1974, 1975) applying progressively reduced irrigation in apple observed that the application of less water throughout the season produced small fruits of increased TSS and flesh firmness. The ‘wet’ (receiving an average of 1190 mm per season) treatment was found to be inferior, in terms of TSS concentration, to the ‘dry’ (receiving an average of 617 mm per season) treatment since the former had a shallow root system composed of thin roots only.

Very little, if any, work has been done on the irrigation of mango (Mostert and Hoffman, 1996) compared to other tree crops such as apples, peaches and pears. The objective of this study was therefore to assess the effects of deficit irrigation (with the goal of saving water) on fruit yield and quality of mango.

2.2. Materials and Methods

The study was carried out during the 2000/2001 season in a commercial orchard of the Westfalia Estate Mariepskop situated in Hoedspruit, South Africa (longitude 34°, latitude, 25°).

Five-year old mango (*Mangifera indica* L. cv. Kent) trees, grown on 'Sabre' rootstock and planted at a density of 1.5 x 6m, were used for this experiment. The following four irrigation treatments with four replications per treatment (randomised block design) in a 1 ha orchard were applied:

- T0 – Full irrigation, 100% field capacity (control)
- T1 – Progressively reduced irrigation, ≈ 75% of T0
- T2 – Progressively reduced irrigation, ≈ 50% of T0
- T3 (RDI)- amount of irrigation water applied like T0 except that water was withheld for 3-4 weeks during May/June 2000 and during December 2000/January 2001

A farm control (Co-F) was also included to compare differences in the effects of the different treatments with normally followed farm procedures. Irrigation scheduling was conducted according to weekly soil moisture readings using neutron probes. Cultural practices such as pest control, pruning and fertilisation conducted according to commercial practices on the farm were not altered.

At harvest trees were stripped (all fruits harvested) and the fresh weight of each fruit taken. For each of the three quality assessments of the experiment, 8 x 4 fruits were taken per treatment. Normal harvesting procedures were followed. The fruits were dipped in water immediately after harvest (to prevent any damage from the latex) and protected from direct sunlight. Yield, fruit number and size (weight) and sunburn damage were determined. Fruits destined for the local and export market were washed and waxed in the pack house as normally done when fruits are being prepared for the export market.

Quality evaluations were made immediately after harvest (referred to as 'at harvest'). Fruits destined for the local market (referred to as 'shipping control') were stored at room temperature (21-25°C) and their quality was assessed as soon as they reached ripeness. Shipping conditions were simulated for fruits destined for export (referred to as 'shipping') by storing them in darkness for 28 days at 11°C in a climatised chamber. Following the shipping simulation, fruits were allowed to ripen at room temperature (21-25°C) and their quality was then evaluated.

Fruit firmness was measured using a penetrometer (FT 327, Southtrade, Italy), total soluble solids (TSS) with a refractometer (N-1E, ATAGO, Japan), and flesh colour using colour charts (South African Mango Growers Association). Peel colour was visually evaluated and rated according to the following classifications:

- 0 = 0% colour change
- 1 = 25% colour change
- 2 = 50% colour change
- 3 = 75% colour change
- 4 = 100% colour change

The weight of fruits destined for the export market (shipping) was taken before and after cold storage to determine the percentage weight loss during storage.

The effects of the various irrigation treatments on fruit yield and quality were evaluated by a one-factorial (irrigation) ANOVA using the SAS programme. Means were compared using the t-test.

2.3. Results and Discussion

2.3.1. Yield, fruit number and weight

Although not significant, fully irrigated trees (T0) had the highest yields followed by the trees of the regulated deficit treatment (T3, RDI) and the farm control (Co-F) trees while the two progressively reduced (T1 and T2) treatments had reduced the final yield (Fig. 2.1.). The percentage of fruits exhibiting export quality was insignificantly higher in T0, T1 and T3 trees accounting for 96.41, 96.27, and 95.04%, respectively, compared to trees of T2 (87.35%) and Co-F (82.50%).

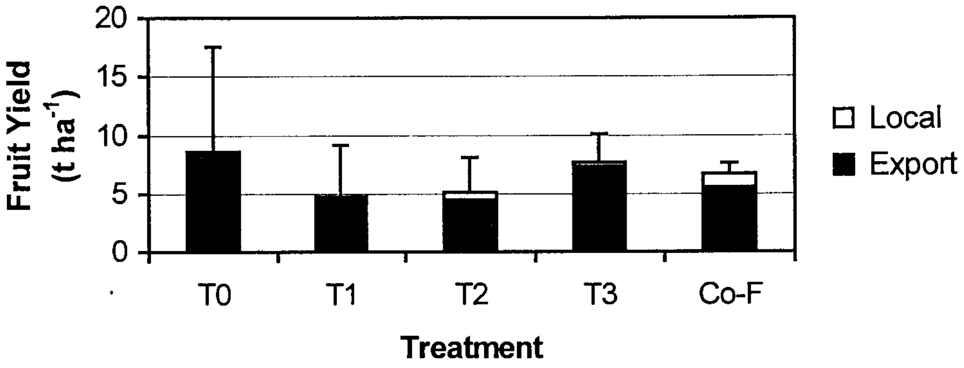

Fig. 2.1. Mean yield of mango trees as influenced by different irrigation regimes at harvest in 2001. Local ( ): fruits < 330 and >776g and export ( ): fruits >330 and <776g. T0 (Full irrigation, 100% - control); T1 (Progressively reduced irrigation, ≈ 75% of T0); T2 (Progressively reduced irrigation, ≈ 50% of T0); T3 (RDI: amount of irrigation water applied like T0 except that water was withheld for 3-4 weeks during May/Jun 2000 and Dec 2000/Jan 2001) and a farm control (Co-F). Each data point represents mean ±SD of 4 replicates of 6 trees.

Co-F trees produced a reduced number of export fruits while T0 trees had more fruits falling between counts 8 and 10 (Fig. 2.2.) which are export market counts (SAMGA guidelines). T1 and T3 treatments on the other hand had more fruits falling between counts 7 and 8, while T2 trees produced more fruits falling between counts 6 and 7. Counts 6 to 12 are export market counts (SAMGA). There were no significant differences in the count distribution of the different irrigation treatments.

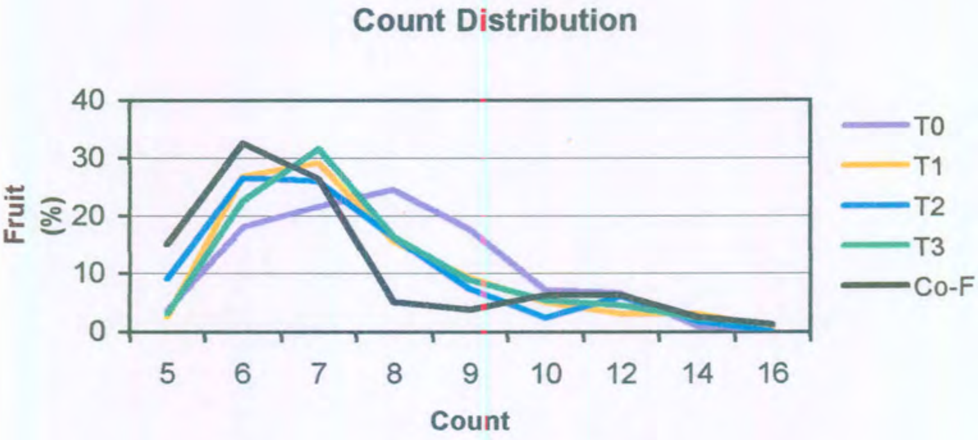

Fig. 2.2. Count distribution of mango fruits as influenced by different irrigation treatments at harvest in 2001. Counts 6 to 12 are for export market whereas counts 13 to 16 are for local market. Each data point represents mean ±SD of 4 replicates of 6 trees. For description of irrigation treatments see legend Fig. 2.1.

Some of the trees included in this study bore little if any fruits and this resulted in large variations occurring between replicates and treatments. This could have been primarily the reason for the results presented here being statistically insignificant. Insignificant differences in the fruit size and yield of fully irrigated trees have, however, also been observed in apple (Irving and Drost, 1987), peach (Strabbioli, 1992; Johnson et al., 1992), citrus (Torrecillas et al., 1993) and pear (Caspari et al., 1994). The yield of the different irrigation treatments (Fig. 2.1.) followed the same trend as the one of fruit numbers per tree (Fig. 2.3.). Differences in mean fruit weight were minor and showed no significant differences between treatments (Fig. 2.4.).

Fruit number (Fig. 2.3.) apparently influenced the final yield of trees rather than fruit weight (Fig. 2.4.).

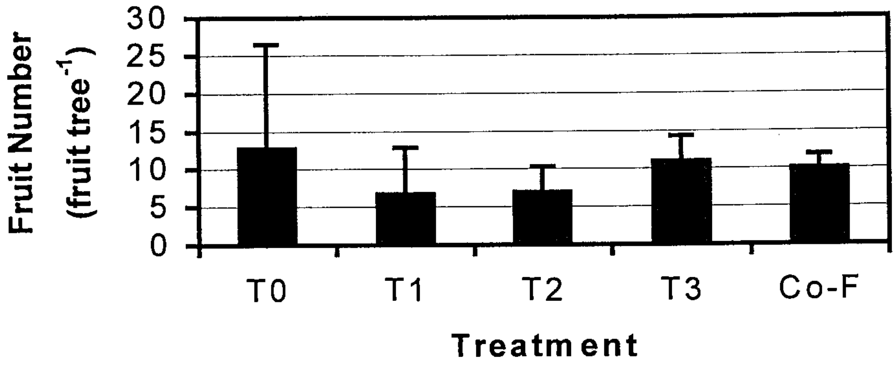

Fig. 2.3. Mean fruit number per tree of mango trees as influenced by irrigation at harvest in 2001. Each data point represents mean ±SD of 4 replicates of 6 trees. For description of irrigation treatments see legend Fig. 2.1.

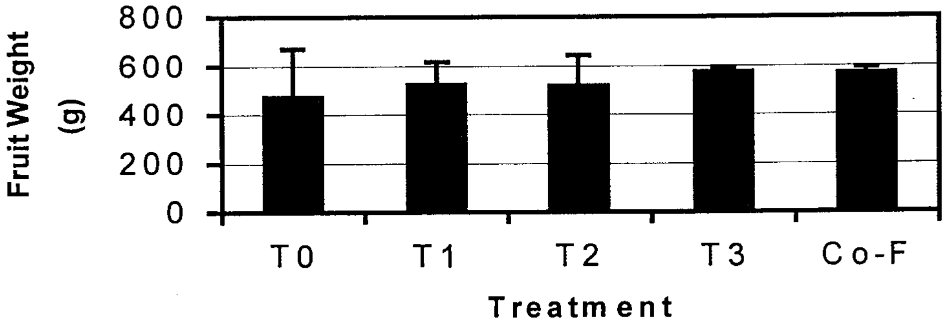

Fig. 2.4. Mean fruit weight of mango trees as influenced by irrigation at harvest in 2001. Each data point represents mean ±SD of 4 replicates of 6 trees. For description of irrigation treatments see legend Fig. 2.1.

Fruit weight did not seem to be affected by the number of fruits per tree. Fruits of the treatments T3 and Co-F trees had the highest number of fruits compared to T1 and T2 and yet the former treatments produced fruits of bigger size compared to the latter ones. Powell (1976) in contrast, observed an increase in the number of large apple fruits with increased water supply as a consequence of reduced number of fruits per tree. Drake et al. (1981) found that the application of reduced irrigation amounts in Golden Delicious apple trees led to a decreased yield without any effect on fruit size. T3 (RDI) trees performed better in terms of yield and fruit number per tree compared to the two reduced irrigation treatments and the control and even better than the farm control (Co-F) trees. Mitchell et al. (1989) found similar results in pears. RDI increased the total yield of trees as a result of increased fruit number Mitchell et al. (1989).

2.3.2. Fruit colour, total soluble solids and fruit firmness

Peel colour

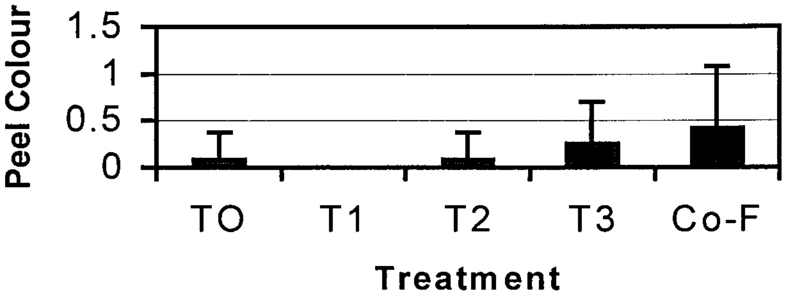

Fig. 2.5. Peel colour of mango fruits as affected by different irrigation treatments at harvest in 2001. Each data point represents mean ±SD of 4 replicates of 32 fruits. Peel colour was visually evaluated and rated according to the following classifications: 0 = 0% colour change, 1 = 25% colour change, 2 = 50% colour change, 3 = 75% colour change and 4 = 100% colour change. For description of irrigation treatments see legend Fig 2.1.

The fruits were harvested at a mature green stage according to commercial practices for mangoes (Medlicott et al., 1986). The peel colour starts changing, when fruits are ripening, from green to yellow or orange often showing a red blush as a result of chlorophyll loss and carotenoid and phenolic synthesis (Medlicott et al., 1986). No significant differences were observed in the peel colour of the different irrigation treatments including the Co-F (Fig. 2.5.). When the fruits were ripe, T0 shipping and shipping control fruits developed significantly poorer peel colour than fruits of the RDI treatment (T3) and the farm control (Co-F) fruits (Fig. 2.6.). An increase in vegetative growth resulting in poor light penetration into the canopy (Behboudian and Mills, 1997) could have been the reason for the poor peel colour of T0, T1 and T2 fruits, since direct sunlight is required for anthocyanin pigment synthesis in some fruit species (Westwood, 1993). These observations are in agreement with those of Kilili et al. (1996a), Drake et al. (1981) and Mills et al. (1994) who found that RDI produced fruits of better skin colour than fully irrigated trees.

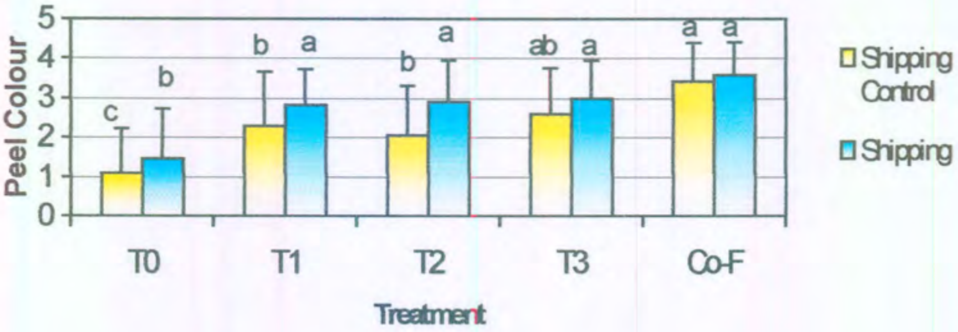

Fig. 2.6. Peel colour of ripe mango fruits as influenced by different irrigation treatments, after ripening at room temperature (shipping control) and after shipping simulation for four weeks at 11° followed by ripening at room temperature (shipping), in the 2000/2001 season. Each data point represents mean ±SD of 4 replicates of 32 fruits. Different letters denote significant differences between treatments at $P = 0.05$. For description of irrigation treatments and peel colour classes see legend Fig. 2.1. and Fig. 2.5., respectively.

treatments and peel colour classes see legend Fig. 2.1. and Fig. 2.5., respectively.

It is, however, unclear if vegetative growth affected peel colour development in this study since it was not measured. Fruits from shipping conditions generally developed better peel colour (during and after shipping) compared to the shipping control fruits and this could have resulted from increased ethylene forming capacity in the peel of fruits during cold storage (Lara and Vendrell, 1998).

Flesh colour

Fruits evaluated immediately at harvest showed no significant differences in flesh colour among treatments (Fig. 2.7.).

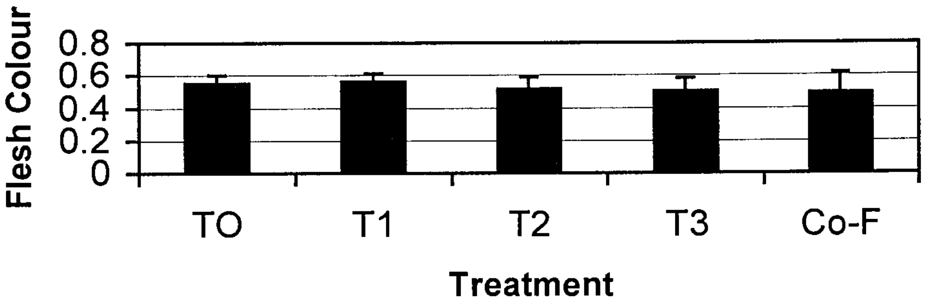

Fig. 2.7. Flesh colour of fruits from mango trees under different irrigation treatments at harvest in 2001. Each data point represents mean ±SD of 4 replicates of 32 fruits. For description of irrigation treatments see legend Fig. 2.1.

Shipping control fruits from Co-F trees had significantly poorer flesh colour compared to the other treatments, while Co-F shipping fruits had significantly poorer colour to only T0 and T3 (Fig. 2.8.). Fruits from the T0 treatment, on the other hand, had better colour than all the other treatments under both conditions, but was only significantly different to the Co-F treatment (Fig. 2.8.). These results suggest

(Jackson and Looney, 1999) and the same principles apply in peel and flesh colour development (Lizada, 1993). In contrast to the peel colour (Fig. 2.6), cold storage negatively affected the flesh colour intensity of shipping fruits compared to those from the shipping control.

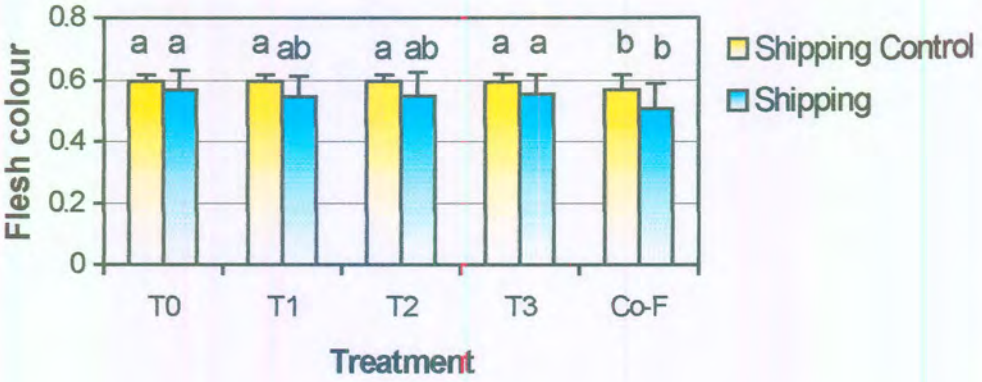

Fig. 2.8. Flesh colour of ripe mango fruits as influenced by different irrigation treatments after ripening at room temperature (shipping control) and after shipping simulation for four weeks at 11° followed by ripening at room temperature (shipping), in the 2000/2001 season. Each data point represents mean ±SD of 4 replicates of 32 fruits. For description of irrigation treatments see legend Fig. 2.1.

Total soluble solids

Trees of the RDI (T3) and T1 treatments produced fruits with significantly higher concentrations of total soluble solids (TSS) at harvest compared to fruits from the farm control (Fig. 2.9.). The farm control (Co-F) fruits had also reduced TSS concentrations compared to T0 and T2. The reason for the low TSS content in the other treatments compared to T1 and T3 could be associated with a dilution effect as suggested by Sanchez Blanco et al. (1989). Increased water content in Verna lemon (*Citrus limonum* L.) fruits tended to dilute the soluble solids present resulting in low suggested by Sanchez Blanco et al. (1989). Increased water content in Verna lemon (*Citrus limonum* L.) fruits tended to dilute the soluble solids present resulting in low TSS and thus poor flavour (Beverly et al., 1993). Similar reductions in TSS were observed in apple (Assaf et al., 1975; Drake et al., 1981; Irving and Drost, 1987), citrus (Sanchez-Blanco, 1989; Castel and Buj, 1990; Peng and Rabe, 1996; Huang et al., 2000) and peach (Crisosto et al., 1994).

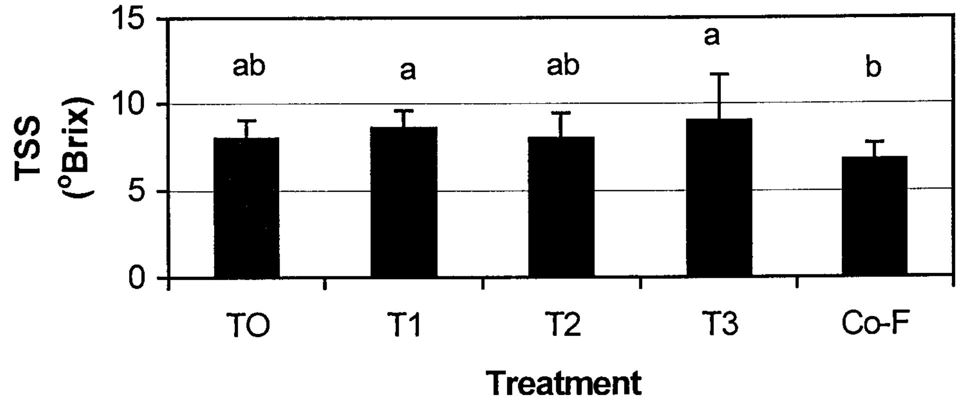

Fig. 2.9. Mean concentrations of total soluble solids (TSS) in mango fruits as influenced by different irrigation treatments at harvest in 2001. Each data point represents mean ±SD of 4 replicates of 32 fruits. Different letters denote significant differences between treatments at P = 0.05. For description of irrigation treatments see legend Fig. 2.1.

After ripening, shipping fruits from Co-F trees and shipping control fruits from RDI and Co-F trees showed significantly lower concentrations of TSS compared to the other irrigation treatments (Fig. 2.10.). Fruits stored under shipping conditions had insignificantly higher concentrations of TSS than those stored at room temperature. However, fruits after shipping simulation had poorer flavour compared to the shipping control (sensory evaluation, data not shown). The poor flavour of those fruits could have been caused by imbalances in the sugar to acid ratio, since these two components largely determine fruit flavour (Tucker, 1993; Paull, 1999).

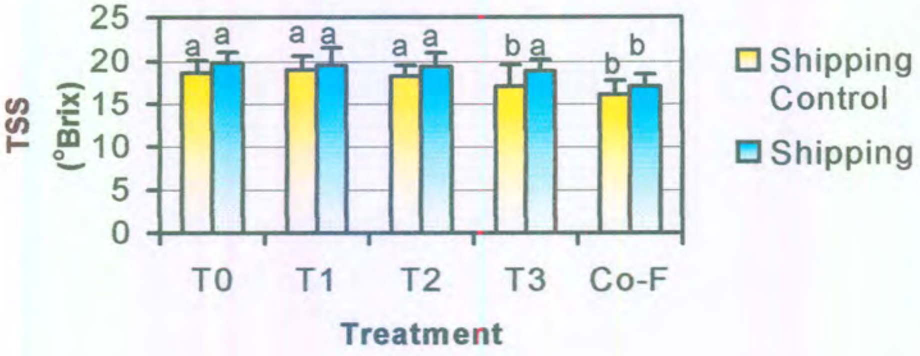

Fig. 2.10. Mean concentrations of total soluble solids (TSS) in mango fruits as influenced by different irrigation treatments, after ripening at room temperature (shipping control) and after shipping simulation for four weeks at 11° followed by ripening at room temperature (shipping), in the 2000/2001 season. Each data point represents mean ±SD of 4 replicates of 32 fruits. Different letters denote significant differences between treatments at $P = 0.05$. For description of irrigation treatments see legend Fig. 2.1.

Levels of acids generally decline during ripening due to their utilisation as respiratory substrates (Ulrich, 1970), while sugar levels on the other hand increase (Whiting, 1970). This could be as a result of either increased sugar importation from the plant or of the mobilisation of starch reserves within the fruit depending on the type of fruit and whether it is ripened off or on the plant (Tucker, 1993). From the high TSS level of the shipping fruits, it can be assumed that sugars were not responsible for their poor flavour. A tremendous decrease in organic acids during cold storage might have therefore contributed to the poor flavour of shipping fruits, since both sugars and organic acids form a major contribution to the overall flavour of fruits. Lara and Vendrell (1998) found that the concentration of acids in apples was strongly reduced by cold storage. Studies showing strong decreases in the acidity and increases in the sugar content of mango fruits during cold storage are also documented by Singh (1960). The difference in flavour appeared to be rather related to storage conditions after harvest, than to the different irrigation regimes.

Firmness

Fruits of the RDI treatment (T3), without any significance, were firmer at harvest than fruits from the other three irrigation treatments and the farm control (Co-F) (Fig. 2.11.). These results are contradictory to those of Marsal et al. (2000) who observed decreased firmness in RDI treated pear fruits at harvest. According to Marsal et al. (2000) decreased firmness or softening at harvest indicated early maturation. Fruits of the RDI treatment (T3) might therefore have matured later than fruits from the other treatments.

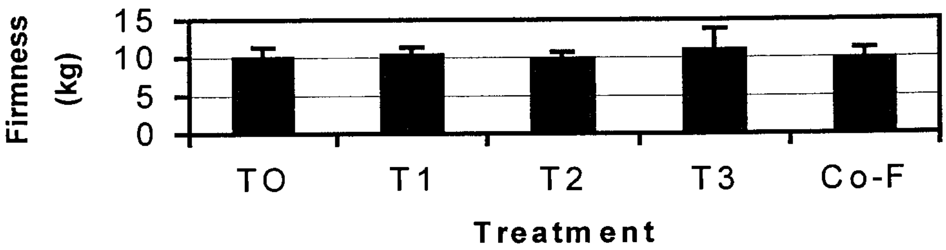

Fig.2.11. Mango fruit firmness as influenced by different irrigation treatments at harvest in 2001. Data points represent mean ±SD of 4 replicates of 32 fruits. For description of irrigation treatments see legend Fig. 2.1.

After "shipping", Co-F fruits were firmer than those from all the irrigation treatments except for T2. Fruits from the shipping control followed a similar trend, however, none of the differences were statistically significant (Fig. 2.12.). Ebel et al. (1993) found firmness to be influenced by size with smaller fruits being firmer than larger fruits due to a higher cellular density. A large fruit is generally composed of a population of larger cells and the number of cells per unit volume will be less compared to those of small fruits (Harker et al., 1997). Thus the amount of cell wall and the number of cell to cell contacts within a fixed volume of tissue will be lower resulting in the reduction of the strength of large fruits relative to small fruits (Harker et al., 1997). In this study, no relation was found between firmness and fruit size, since T3 fruits (RDI treatment) at harvest and Co-F fruits (farm control) after shipping tended to be firmer while these fruits were also insignificantly larger than fruits from other treatments. Other unknown factors, however, could be responsible for these contradictory findings.

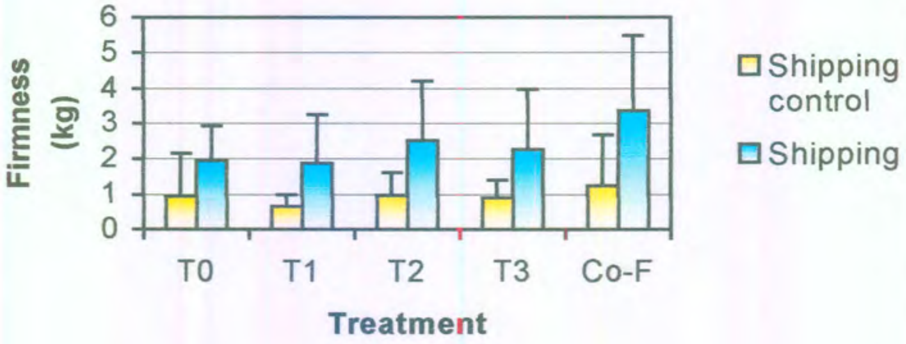

Fig. 2.12. Firmness of ripe mango fruits as influenced by different irrigation treatments, after ripening at room temperature (shipping control) and after shipping simulation for four weeks at 11° followed by ripening at room temperature (shipping), in the 2000/2001 season. Each data point represents mean ±SD of 4 replicates of 32 fruits. For description of irrigation treatments see legend Fig. 2.1.

2.3.3. Storage potential

After harvest, fruits continue to transpire in the absence of a water supply (Wills et al., 1998) and thus lose weight due to water loss. To reduce water loss, fruits are usually placed into cold storage resulting in prolonged storage life (Westwood, 1993). No significant differences between treatments were found in the weight loss of shipping control fruits (Fig. 2.13.).

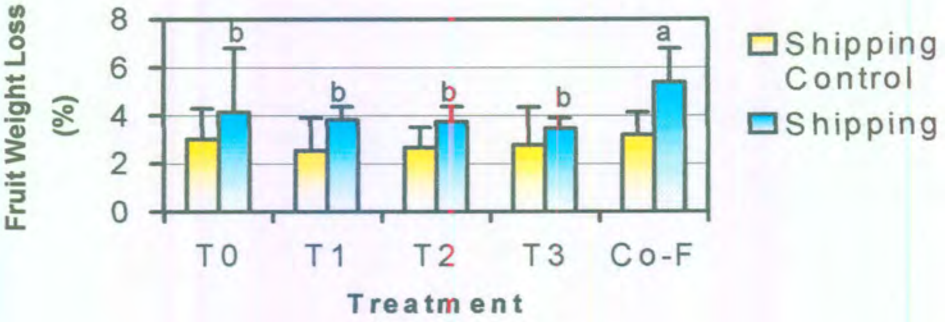

Fig. 2.13. Mean weight loss of mango fruits as influenced by different irrigation treatments, after ripening at room temperature (shipping control) and after shipping simulation for four weeks at 11° followed by ripening at room temperature (shipping), in the 2000/2001 season. Each data point represents mean ±SD of 4 replicates of 32 fruits. Different letters denote significant differences between treatments at $P = 0.05$. For description of irrigation treatments see legend Fig. 2.1.

After "Shipping", Co-F fruits had the highest percentage weight loss compared to fruits from the other treatments. Co-F fruits had apparently a poor storage potential since a higher rate of respiration is equivalent to a shorter storage life (Salunkhe et al., 1991). According to Jackson and Looney (1999) trees grown under non-irrigated conditions often produce fruits of excellent keeping quality. This would explain the low weight loss of the fruits from the reduced irrigation treatments (T1, T2 and T3). Jackson and Looney (1999) reported large fruits to seldom store as well as small fruits. The surface area to volume ratio of a fruit determines the moisture it sustains during a period of storage (Singh, 1960; Wills et al., 1998). A small fruit will therefore lose weight faster than a relatively large one since it has a high surface area to unit volume ratio resulting in greater loss by evaporation (Wills et al., 1998). In contrast, Co-F fruits together with T3 fruits were largest and yet Co-F fruits had the highest weight loss. The TSS data (Fig. 2.9.) suggested that Co-F fruits had more water resulting in a lower TSS concentration. Co-F fruits had therefore more water to lose than the fruits from the other treatments.

2.3.4. Physiological disorders

The occurrence of split pit in fruits of the shipping control conditions was statistically insignificant among treatments (Fig. 2.14.). Shipping fruits of the RDI treatment (T3) had insignificantly more split pit than fruits from the other treatments, while Co-F fruits under the same conditions had significantly lower percentages of split pit compared to the four irrigation treatments.

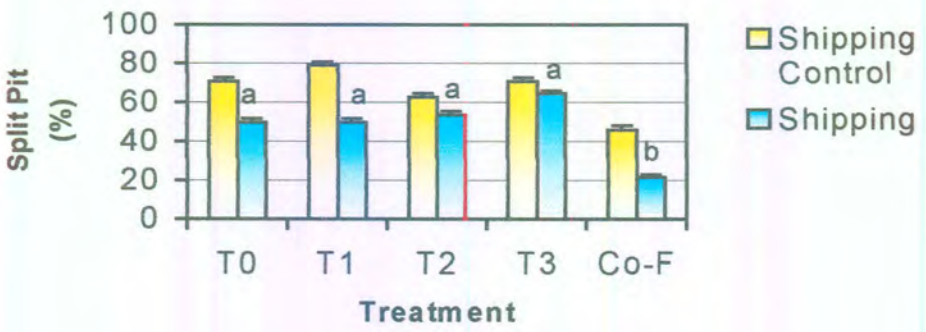

Fig. 2.14. Occurrence of split pit as influenced by different irrigation treatments after ripening at room temperature (shipping control) and after shipping simulation for four weeks at 11° followed by ripening at room temperature (shipping) in the 2000/2001 season. Each data point represents mean ±SD of 4 replicates of 32 fruits. Different letters denote significant differences between treatments at P = 0.05. For description of irrigation treatments see legend Fig. 2.1.

Soil moisture may affect the concentration of mineral elements resulting in physiological disorders of fruits (Brun et al., 1985a, 1985b). Brun et al. (1985a) found that a reduced irrigation regime during the postbloom period would curtail shoot growth and might improve the Ca status of developing fruit, thereby diminishing calcium-related fruit disorders. Decreases, however, in mineral contents such as N (Goode and Ingram, 1971; Brun et al., 1985b), Ca (Goode and Ingram, 1971) and Cu (Brun et al., 1985b) as a result of reduced irrigation have been reported. Water deficits have also been reported to increase the occurrence of disorders such as cracking (Irving and Drost, 1987) and drought spot of apple (Jackson and Looney, 1999). Split pit could be related to a more severe disorder, "fruit splitting". This disorder is characterised by a longitudinal splitting of the fruit usually starting from the distal end ending up at the pedicel (Tong Kwee and Khay Chong, 1985). The splitting occurs as a result of immense hydrostatic pressure developing within the fruit due to a rapid and excessive intake of water occurring when heavy rain falls after a dry spell (Tong Kwee and Khay Chong, 1985). The occurrence of split pit may, however, not be influenced by irrigation. It might be as a result of other unknown factors or the susceptibility of the cultivar to this disorder.

2.3.5. Fruit damages caused by Sunburn

No significant differences were found in the occurrence of sunburned fruits among treatments (Fig 2.15.). T2 trees (receiving 50% water of T0), however, followed by T3 fruits had the tendency to produce more sunburned fruits than the other treatments. Lotter et al. (1985) also observed an increased number of sunburned fruits from deficit irrigation treatments. Sunburn occurs as a consequence of high skin temperatures, since fruit temperatures increase when plants are under water stress (Woolf and Ferguson, 2000). No sound explanation can be offered for the high percentage of sunburned fruits in T0 since these fruits were not under water stress (De Villiers, 2001).

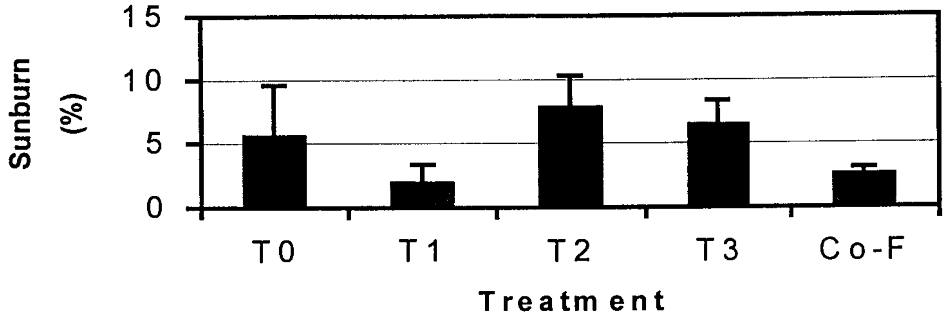

Fig.2.15. Occurrence of sunburn as influenced by different irrigation treatments at harvest in 2001. Each data point represents mean ±SD of 4 replicates of 6 trees. For description of irrigation treatments see legend Fig. 2.1.

2.4. Conclusions

From the insignificant differences of the yield data (including fruit number and mean fruit weight), it can be concluded that reducing irrigation water did not affect the yield of mango trees during the season of 2000/2001. The reason for this could be the ability of mango trees to survive short periods of water deficits as a result of their drought tolerance. Total soluble solid concentrations (TSS), firmness and the peel colour of fruits were not negatively affected by deficit irrigation. However, slight improvements in deficit irrigated fruits were observed especially in terms of peel colour compared to fully irrigated trees. This could be as a result of reduced vegetative growth in deficit irrigated trees. Reduced vegetative growth allows better penetration of light into the canopy. Flesh colour on the other hand was negatively affected by progressively reduced irrigation and improved by RDI. It might be possible to save water through reduced irrigation strategies without loss of tree productivity and fruit quality. Regulated deficit irrigated (RDI) trees performed better than the progressively reduced irrigated trees and the normal farm practices. For this reason, RDI is therefore recommended as an irrigation strategy to save water and even improve yields without any adverse effects on fruit quality. Although fruits from cold storage (shipping) had a better peel colour and higher TSS levels across all treatments compared to the shipping control, they were of poor eating quality as a result of poor flavour. Fruit flavour in this study seemed to be more affected by cold storage than the irrigation treatments. The insignificant differences in this study could also suggest that the reduced irrigation strategies did not cause adverse deficits in the soil. However, this study was conducted over one growing season and further studies therefore need to be conducted on a longer-term basis to evaluate any carry-over effects into subsequent years.

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3. Effects of shade on fruit yield and quality in mango

3.1. Introduction

Wind and intensive sunlight are some of the factors severely influencing the production of mangoes especially around Hoedspruit, Northern Province, South Africa (longitude 34°, latitude, 25°) (Fivaz and Lonsdale, 2001). Light is an important environmental factor required for the productivity of plants (Kappel, 1989; Rom, 1990; Marini et al., 1991; Kappel and Neilsen, 1994; George et al., 1996; Lakso and Robinson, 1997; Garriz et al., 1998). Excessive light, however, can negatively affect the appearance of the final product (Kays, 1999) making it less desirable and unattractive for sales.

Wind affects mango trees in several ways. High velocities of wind not only reduce the moisture which is necessary for optimum plant growth (Singh, 1960) but also causes abrasions to the skin of fruits thereby reducing their quality and market value (Whiley and Schaffer, 1997). The protection of mango trees from wind is therefore very important to prevent reductions in tree growth, yield and the occurrence of bacterial black spot (*Xanthomonas campestris pv. mangiferaeindicae*) infections (Whiley and Schaffer, 1997). The provision of windbreaks in orchards is, however, expensive with decisions to be made on the use of either living or artificial shelters (Whiley and Schaffer, 1997). Freeman (1976) found that the use of polyethylene nets as windbreaks resulted in increased yields and quality through the reduction of windscar in citrus. The use of artificial shelter compared to natural windbreaks has the advantage of the utilisation of small amounts of space and the absence of competition for water, light and nutrients (Freeman, 1976).

Mango growers in South Africa have been using *Casuarina cunninghamiana* trees as windbreaks and spraying white protective wetable powders such as Reflecto®, Shadow® or "Kaolin" on trees or using aerothene caps as methods of sun protection (Fivaz and Lonsdale, 2001). The use of shade nets is, therefore, not common to South African mango growers. There are also very little studies conducted on the use of shade nets in this crop compared to other crops such as apples. Fivaz and Lonsdale

(2001) found that the overhead erection of shade cloth on eight-year old mango trees (cv. Kent) for two seasons resulted in the absence of sunburn, reduced wind damage and occurrence of bacterial black spot. The quality of fruits from the shade cloth was found to be superior to fruit from the control orchard over the two seasons of shading.

Although the use of shade nets may seem essential as a management tool, contradictory findings exist about the effects these structures have on yield and fruit quality. In a study with Cox's Orange Pippin apple trees on M.26 rootstocks, Jackson and Palmer (1977) observed progressively low yields when trees were shaded at three levels (37, 25 and 11% of full sunlight-FS) for one year. The yield reductions were positively correlated with the shade levels. The yield of the most severe shading treatment (11% FS) was the most reduced compared to the control trees (Jackson and Palmer, 1977). The yield reductions in this study were caused by decreases in average fruit size and fruit numbers. In the following year, lower yields were produced by trees shaded the previous year compared to the control trees due to effects on fruit bud formation in the year of shading and to residual effects of shading on fruit set. Fruit size was, however, increased (because of reduced fruit numbers) as a residual consequence of shading. The residual influence of shade on fruit bud formation, fruit set and fruit retention could be more important than its direct effects on fruit shedding and growth (Jackson and Palmer, 1977). May and Antcliff (1963) also observed decreased fruitfulness resulting in low yields of sultana trees as a result of heavy shading for about two months in the previous season.

The developmental stage at which shade is applied is very important in determining the productivity of trees. May and Antcliff (1963) applied shade during the period of active shoot extension and observed decreased internode length with little effect on fruitfulness and yield when shade was removed well before flowering. Shading prior to flowering could be detrimental to fruit set while fruit size could be more affected by shading after flowering (May and Antcliff, 1963). Snelgar et al. (1992), however, found that post-flowering shading of kiwifruit had a greater effect on return bloom than on fruit size. Shading at all stages of fruit development reduced fruit size but heavy shading at pre-stone hardening of 'low-chill' peach fruits had the greatest effect, reducing final fruit diameter by 12% compared to reductions by 8 and 5% from shading during stage II and stage III, respectively (George et al., 1996). Garriz et al.

(1998) found that pear fruit size was more reduced by shading during stage II than stage I, whereas yield reduction occurred as a result of fruit drop when shade was applied during stage I (George et al., 1993; Yamanishi and Hasegawa, 1995). Pre-harvest fruit drop in citrus was associated with fungal necrotic lesions, since shade indirectly created conditions that were favourable for fungal growth in the soil (Yamanishi and Hasegawa, 1995). Fruit growth of heavily shaded (20% FS) citrus trees was also suppressed with the consequence of reduced fruit weight at harvest. The reduced fruit growth was attributed to reduced shoot growth associated with the decreased production of assimilates by the leaves (Yamanishi and Hasegawa, 1995). High fruit flesh temperatures both in terms of diurnal fluctuations and long-term exposure can alter internal quality properties such as sugar content, firmness and oil levels as well as mineral content (Woolf and Ferguson, 2000).

Generally, most fruits when exposed to sunlight develop better colour while heavily shaded fruits tend to remain green and have minimum development of other colours (Jackson and Looney, 1999). Fruit colour has also been found to differ with its position in the tree with fruits from the outer (exposed) zones having better colour than that from the inner (shaded) zones (Jackson et al., 1971; Krishnaprakash et al., 1983; Morgan et al., 1984; Barrit et al., 1987; Rom 1990). Cherries, strawberries and grapes will develop colour almost as well when shaded and are an exception to the general rule of light requirements (Jackson and Looney, 1999). Light above photosynthetic saturation levels, especially intense exposure has been reported to increase fruit temperature resulting in loss of firmness (Sams, 1999). Heinicke (1966) and Rom and Ferree (1986) found that fruit firmness decreased with increased light exposure. In contrast, Doud and Ferree (1980) found that shading of 'Delicious' apple fruits reduced firmness. Antognozzi et al. (1995), however, found no significant differences in the flesh firmness of exposed and shaded fruits. Shade has also been found to reduce solar injury in fruits (Morgan et al., 1984; Renquist et al., 1987) as a result of reductions in the fruit surface temperature (Renquist et al., 1987). Occurrences of physiological disorders such as skin cracking and russeting have also been reduced by shade in apple (Jackson et al., 1971; Jackson et al., 1977).

The objective of this study was to assess the effects of long-term shading on the yield and quality (especially sunburn and black spot) of mangoes with the intention of using shade structures to improve the appearance and overall quality of fruits without adversely affecting yield.

3.2. Materials and Methods

This study was conducted in the same geographical area as described previously (chapter 2.2.).

Five-year-old mango (*Mangifera indica* L. cv. Kent) trees, grown on 'Sabre' roostock and planted at a density of 6 x 1.5 m, were covered on a long-term basis with tents of white polyethylene shade cloth. Each tent consisted of four rows with seven trees each (28 trees). One of the two middle rows was used as data trees except for the border trees on each end of the row (5 data trees/tent). The following mesh densities were used: 50 (T2), 75 (T3), 100 (T4) and 125 g m^{-2} (T5) offering approximately 20, 30, 40 and 50% shade, respectively. Unshaded trees randomly distributed over four orchards served as the control (T0). Each treatment (tent with specific shade density) was replicated four times and then assigned to four orchards so that each treatment occurred once in each orchard (randomised block design). Cultural practices such as irrigation, pest control and fertilisation were not altered.

At harvest, fruits (8 fruits x 4 replicates per treatment) were treated in the same way as described in chapter 2.2. Yield and fruit quality parameters, such as flesh and peel colour, firmness, total soluble solids and weight loss were determined as illustrated in chapter 2.2. Additionally, fruit damages caused by black spot, sunburn and wind damage were evaluated. Analysis of data was conducted as described previously (chapter 2.2.).

3.3. Results and Discussion

3.3.1. Yield, fruit number and weight

Trees exposed to light shading (mesh density: 50 g m^{-2}, T2) had insignificantly higher yields compared to the other treatments while having significantly higher yields compared to T5 (Fig. 3.1.).

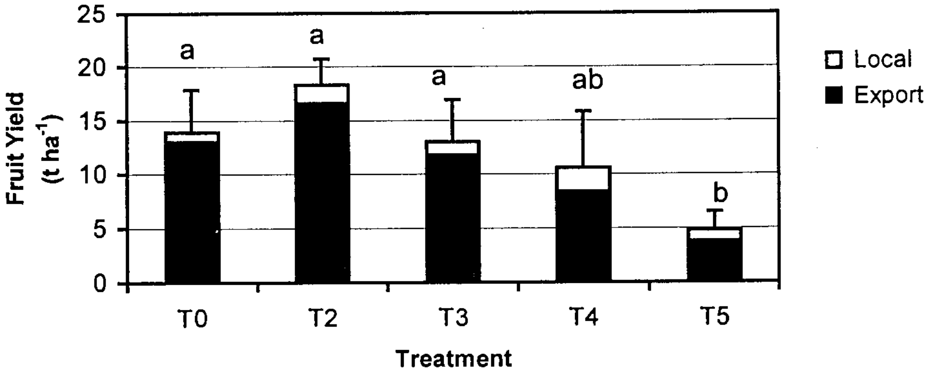

Fig. 3.1. Mean yield of mango fruits as influenced by different shade treatments at harvest in 2001. Local ( ): fruits < 330 and >776g and export ( ): Fruits >330 and <776g. Shade treatments consisted of different shade net densities: 50 (T2), 75 (T3), 100 (T4) and 125 g m^{-2} (T5), and unshaded trees served as the control (T0). Each data point represents mean ±SD of 4 replicates of 5 trees. Different letters denote significant differences between treatments at P = 0.05.

The yield reductions seemed to be positively correlated with the level of shade except that the control trees (T0) produced lower yields compared to the T2 shade treated trees. The higher yield in T2 compared to the control might indicate that light shade netting could have decreased the evaporative demand. Trees of the treatment T5 (mesh density: 125 g m^{-2}) had significantly lower yields as well as fruit numbers (Fig. 3.2.) compared to all the other treatments except for T4. Fruits from the treatments T2, T4 and T5 were larger than those from T0 and T3 trees (Fig. 3.3.). The differences in mean fruit weight were, however, not statistically significant. Snelgar et al. (1991) also observed a significant reduction in the number of kiwifruits per vine and total yield when vines were grown under heavy shading (45% FS).

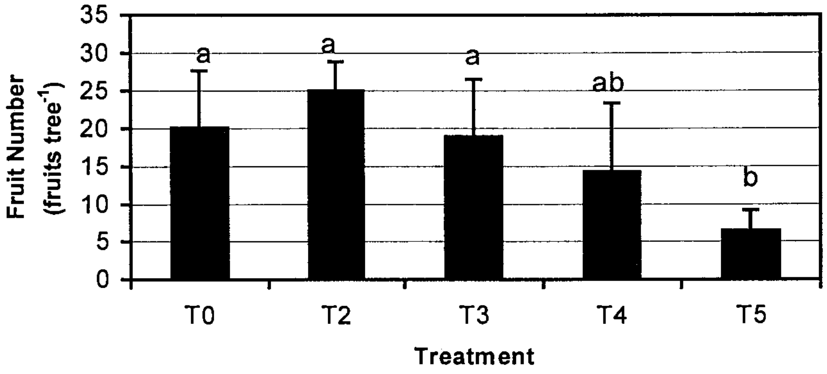

Fig. 3.2. Mean fruit number of mango fruits as influenced by different shade treatments at harvest in 2001. Each data point represents mean ±SD of 4 replicates of 5 trees. Different letters denote significant differences between treatments at $P = 0.05$. For details of the shade treatments see legend of Fig. 3.1.

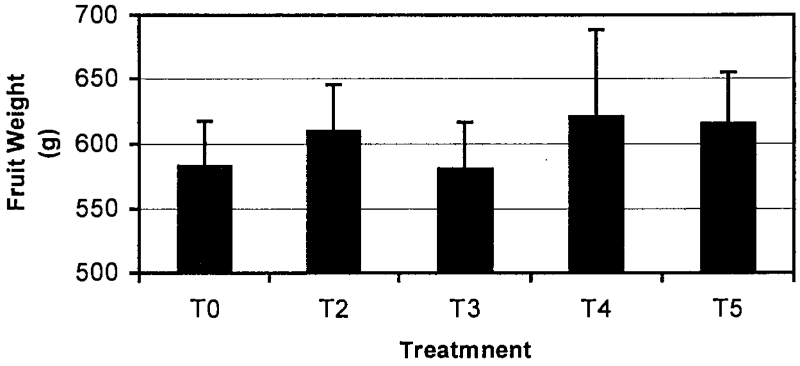

Fig. 3.3. Mean fruit weight of mango fruits as influenced by different shade treatments at harvest in 2001. Each data point represents mean ±SD of 4 replicates of 5 trees. For details of the shade treatments see legend of Fig. 3.1.

The large reduction in the number of fruits in those vines resulted in the mean fruit weight being similar to that of non-shaded vines (Snelgar et al., 1991). Israeli et al. (1995) also observed that growing bananas under shade reduced bunch weight as a result of reduced finger weight with the consequence of decreased yields. Without any significant differences, T0, T2, T3, T4 and T5 trees produced 93.61, 90.56, 90.51, 79.55 and 79.18%, respectively, fruits of export size (Fig. 3.1.). Shade apparently reduced the amount of fruits suitable for export with the level of shade being negatively correlated to the export fruits. This reduction can also be observed in the fruit counts (Fig. 3.4.) which were almost similar in all treatments with the four shade treatments having mostly fruits between counts 6 and 8 (export market counts, SAMGA guidelines). Similar observations have been made by Snelgar and Hopkrik (1988) who observed that the heavy shading of kiwi vines reduced the number of fruits available for export. In contrast to Snelgar and Hopkirk (1988), no inverse correlation was found in the mean fruit weight and number of fruits in this study. For instance, T2 trees had the highest number of fruits than all the other treatments and yet produced fruits of similar size as T4 and T5 trees and of larger size than T0 and T3 trees (Figs. 3.2; 3.3).

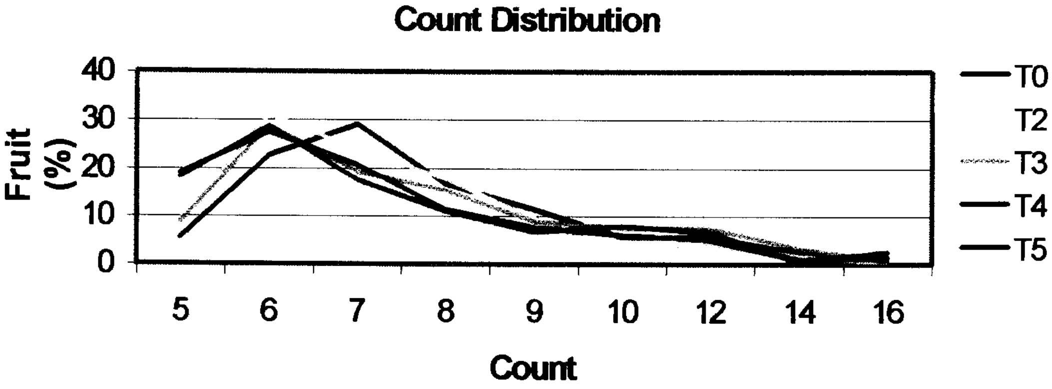

Fig. 3.4. Count distribution of mango fruits as influenced by different shade treatments in 2001. Counts 6 to 12 are for export market whereas counts 13 to 16 are for local market. Each data point represents mean ±SD of 4 replicates of 5 trees. For details of the shade treatments see legend of Fig. 3.1.

3.3.2. Fruit colour, total soluble solids and fruit firmness

Peel colour

When assessing fruit quality, fruit colour followed by taste, depending on the consumer, probably contributes more than any other single factor. Kays (1999) defines colour as a function of the light striking the product, the differential reflection of certain wavelengths and the visual perception of these wavelengths. For example, a red colour in a red apple, is due to the absorption by the pigments of all the other wavelengths in the visible spectrum except the red region which is reflected from the product (Kays, 1999). Light is therefore an important factor for colour development (Jackson and Looney, 1999). No significant differences in peel colour, however, were found between fruits from the different shade treatments at harvest (Fig. 3.5.) and under shipping and shipping control conditions (Fig. 3.6.), indicating that the different shade cloth densities apparently did not affect fruit colour development negatively.

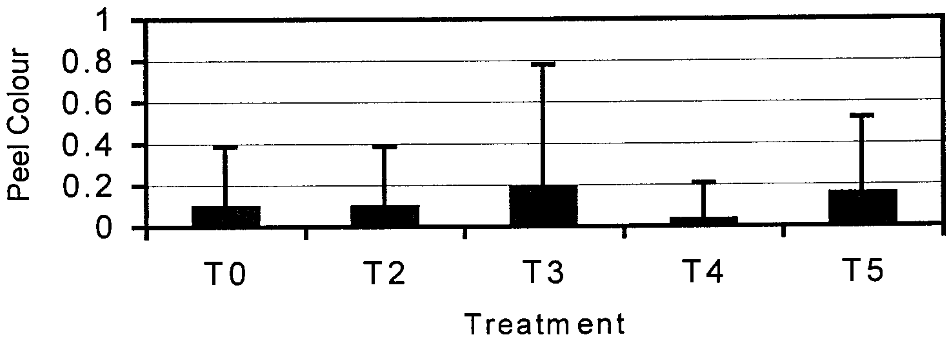

Fig. 3.5. Peel colour of mango fruits at harvest as influenced by the different shade treatments in 2001. Each data point represents mean ±SD of 4 replicates of 32 fruits. Peel colour was visually evaluated and rated according to the following classifications: 0 = 0% colour change, 1 = 25%, colour change, 2 = 50% colour change, 3 = 75% colour change and 4 = 100% colour change. For details of the shade treatments see legend of Fig. 3.1.

These insignificant differences are quite confounding. It was expected of T0 trees to produce fruits of better colour compared to the shaded ones, since the former were exposed to higher intensities of sunlight. Light flux density has been reported to influence the characteristics of fruits (Snelgar and Hopkirk, 1988) with low light intensity being unfavourable to peel colour development (Corelli-Grappadelli and Coston, 1991). Increased exposure to sunlight has also been reported to bring about better colour development as a result of increased synthesis of anthocyanins (Krishnaprakash et al., 1983; Morgan et al., 1984; Erez and Flore, 1986) which are some of the pigments responsible for colour development (Tucker, 1993).

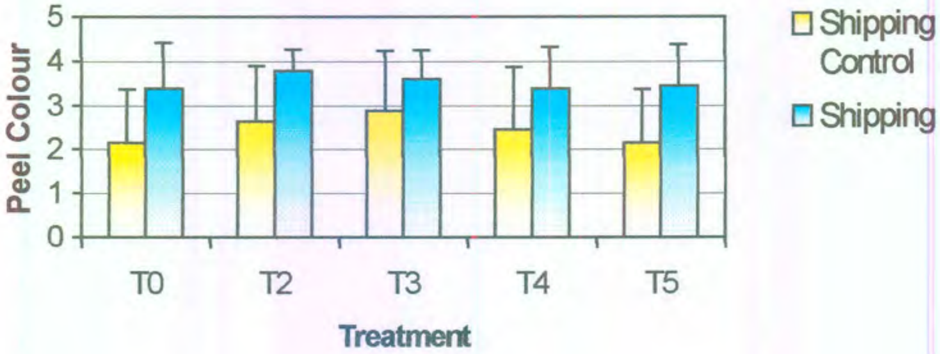

Fig. 3.6. Peel colour of ripe mango fruits as influenced by different shade treatments, after ripening at room temperature (shipping control) and after shipping simulation for four weeks at 11° followed by ripening at room temperature (shipping), in the 2000/2001 season. Each data point represents mean ±SD of 4 replicates of 32 fruits. For details of the shade treatments and peel colour classes see legend of Fig. 3.1. and Fig. 3.5., respectively.

Apple fruits from less shaded regions of trees undergo either a higher rate of chlorophyll cycling or a greater amount of photo-degradation resulting in paler background colour (Tustin et al., 1988). Trees exposed to 70% of full sunlight (FS) were found to produce apple fruits of better colour compared to those exposed to 50% FS (Heinicke, 1966). Similar results were found with the same fruit (Jackson et al., 1977; Lawson et al., 1994) with peach (Erez and Flore, 1986; George et al., 1996) and cherry (Patten and Proebsting, 1986). Mango trees are vigorous in nature (Whiley and Schaffer, 1997), and trees under the shade nets appeared to be more vigorous than the control trees. The position of the fruits on the tree (Tustin et al., 1988) rather than the shade nets apparently might have led to the poor colour development in T0 fruits resulting in similar peel colour as the shaded fruits. George et al. (1996), however, reported a reduction in tree heights and canopy volume as a consequence of the growth reduction of vigorous upright shoots due to shade. The stronger peel colour development of fruits that were shipped compared to the control might have been associated with increased ethylene forming capacity in the peel of fruits during cold storage (Lara and Vendrell, 1998).

Flesh colour

The same principles involved in the development of the peel colour of mangoes seem to apply in the pulp or flesh colour of these fruits (Lizada, 1993). This suggests that the pigments responsible for flesh colour development would also be synthesised as a result of fruit ripening (Lizada, 1993) and increased light exposure (Krishnaprakash et al., 1983; Morgan et al., 1984; Erez and Flore, 1986). At harvest, fruits from T3, T4 and T5 treated trees had poor flesh colour compared to fruits from T0 and T2 trees (Fig. 3.7.). When ripe, under both shipping and shipping control conditions, the flesh colour of T2 and T0 fruits was better than that of T3, T4 and T5 (Fig. 3.8.).

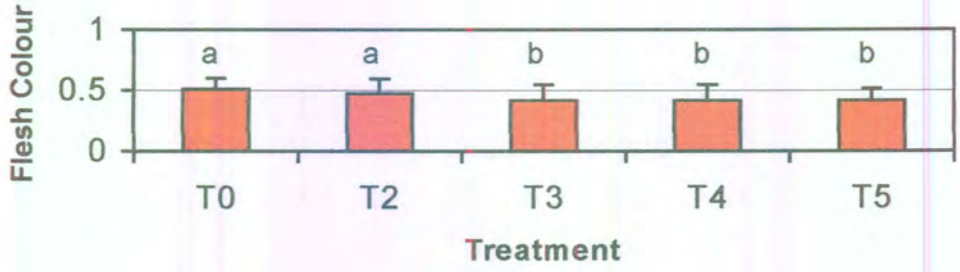

Fig. 3.7. Flesh colour of mango fruits as influenced by different shade treatments at harvest in 2001. Each data point represents mean ±SD of 4 replicates of 32 fruits. Different letters denote significant differences between treatments at P = 0.05. For details of the shade treatments see legend of Fig. 3.1.

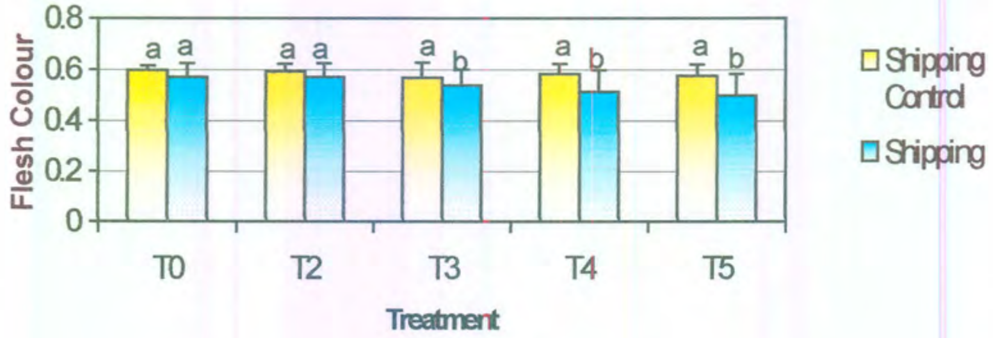

Fig. 3.8. Flesh colour of ripe mango fruits as influenced by different shade treatments after ripening at room temperature (shipping control) and after shipping simulation for four weeks at 11° followed by ripening at room temperature (shipping), in the 2000/2001 season. Each data point represents mean ±SD of 4 replicates of 32 fruits. Different letters denote significant differences between treatments at P = 0.05. For details of the shade treatments see legend of Fig. 3.1.

No significant differences were found in the flesh colour of fruits from T0 and T2 trees (Figs. 3.7; 3.8) suggesting that the T2 (50 g m^{-2}) net apparently had no adverse effects on the internal colour of fruits. In contrast to the peel colour, shipping control fruits had generally a better flesh colour compared to fruits from cold storage in all the treatments suggesting that cold storage seemed to inhibit flesh colour development.

Total soluble solids

Shade did not significantly affect TSS of fruits at harvest (Fig. 3.9.). When the fruits were ripe, however, T5 fruits under shipping control conditions had significantly lower TSS compared to fruits from the other treatments (Fig. 3.10.). These results are similar to those found in apple by Heinicke (1966) and Robinson et al. (1983) who reported decreases in TSS with decreasing light exposure.

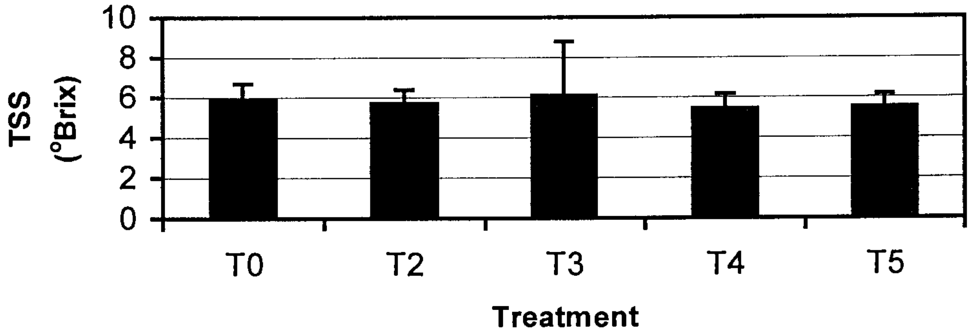

Fig. 3.9. Concentration of total soluble solids (TSS) of mango fruits as influenced by different shade treatments at harvest in 2001. Each data point represents mean ±SD of 4 replicates of 32 fruits. For details of the shade treatments see legend of Fig. 3.1.

These results suggested that 50, 75 and 100 g m^{-2} (T2, T3 and T4) shade net densities providing up to 40% light reduction would not significantly affect the TSS of fruits.

In contrast, Patten and Proebsting (1986) found that shading below 10-15% FS dramatically reduced the soluble solids of 'Bing' sweet cherry fruits. George et al. (1996) also observed reductions of 23% in the TSS of "low chill" peach fruits when heavy shade (70%) was applied at stage III of fruit development. Similar reductions in TSS levels due to shade were also found with pear (Kappel, 1989), apple (Heinicke, 1966; Doud and Ferree, 1980; Morgan et al., 1984; Rom and Ferree, 1986; Tustin et al., 1988; Rom, 1990), kiwifruit (Snelgar and Hopkirk, 1988) and citrus (Yamanishi and Hasegawa, 1995).

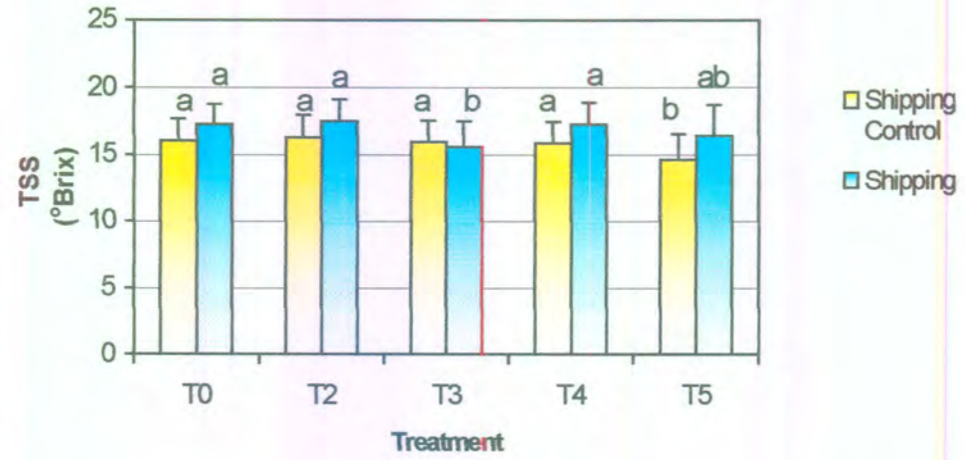

Fig. 3.10. Concentration of total soluble solids (TSS) of ripe mango fruits as influenced by different shade treatments, after ripening at room temperature (shipping control) and after shipping simulation for four weeks at 11° followed by ripening at room temperature (shipping), in the 2000/2001 season. Each data point represents mean ±SD of 4 replicates of 32 fruits. Different letters denote significant differences between treatments at P = 0.05. For details of the shade treatments see legend of Fig. 3.1.

Fruits with low TSS indicate poor or less maturity (Robinson et al., 1983). Heavily shaded shipping control fruits from the 125 g m^{-2} (T5) shade net seemed to be less matured compared to fruits from the other treatments under the same conditions. Under shipping conditions, T3 fruits had significantly lower TSS concentrations compared to fruits from the other treatments except for T5 fruits. Shipping seemed to have little effect on the concentration of TSS. No significant differences were observed between the TSS of T2, T4 and T0 shipping fruits. T2 shipping and the shipping control fruits had slightly higher TSS than fruits from T0 and the other shade treatments. This indicated that T2 (50 g m^{-2} net) could be superior to the other treatments. No sound explanation can be offered for the confounding TSS data obtained in T3 fruits under shipping conditions.

Firmness

Shade levels did not seem to significantly affect the flesh firmness of the fruits at harvest (Fig. 3.11.).

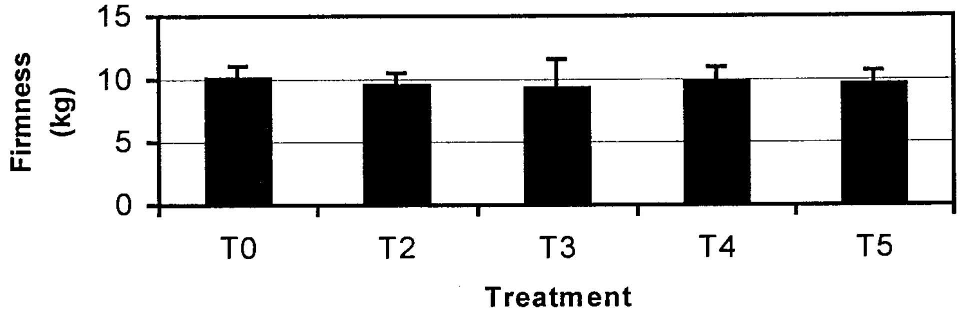

Fig. 3.11. Firmness of mango fruits as influenced by different shade treatments at harvest in 2001. Each data point represents mean ±SD of 4 replicates of 32 fruits. For details of the shade treatments see legend of Fig. 3.1.

Ripe fruits from T0 treated trees had insignificantly lower firmness under shipping control conditions with T3 fruits from shipping conditions on the other hand having significantly lower firmness in contrast to T5 (Fig. 3.12.). Heinicke (1966) and Rom and Ferree (1986) found that shaded apple trees produced fruits much firmer than fruits from exposed trees. In both studies the increased firmness of shaded fruits was attributed to the effects of shade on fruit size and maturity. Firmness has been reported to be influenced by size with smaller fruits being firmer than larger ones as a result of higher cellular density (Ebel 1993; Harker et al., 1997). Shade has also been reported to reduce fruit size (George et al., 1996). The insignificant differences in the flesh firmness of shipping control fruits in this study are therefore not surprising since there were also no significant differences between the mean fruit weights of shaded and exposed trees (Fig. 3.3.). However, several authors found that shading of apple fruits reduced firmness (Doud and Ferree, 1980; Barrit et al., 1987). These findings are in agreement with those found in kiwifruit (Snelgar and Hopkirk 1988; Snelgar et al., 1991) and cherry (Patten and Proebsting, 1986).

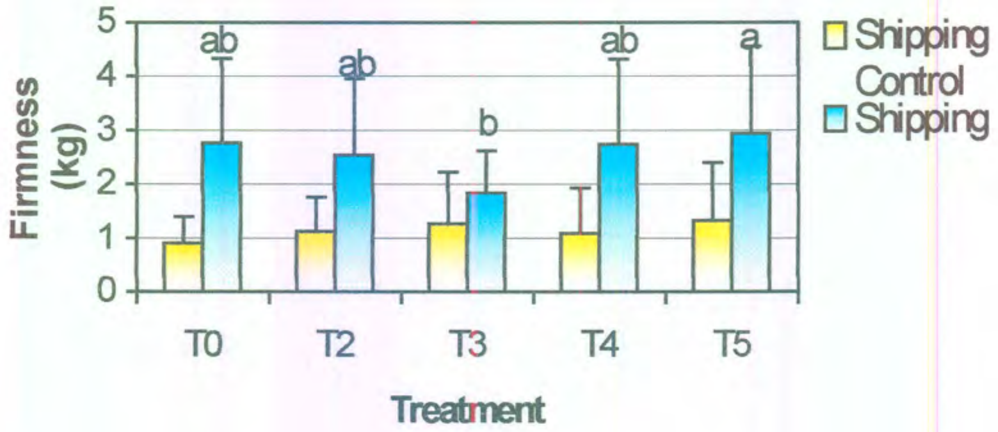

Fig. 3.12. Firmness of ripe mango fruits as influenced by different shade treatments after ripening at room temperature (shipping control) and after shipping simulation for four weeks at 11° followed by ripening at room temperature (shipping), in the 2000/2001 season. Each data point represents mean ±SD of 4 replicates of 32 fruits. For details of the shade treatments see legend of Fig. 3.1.

3.3.3. Storage potential

T5 fruits had a significantly higher weight loss than fruits from the other treatments under both shipping and shipping control conditions (Fig. 3.13.). At the removal of the fruits from cold storage, a small percentage of T5 fruits was starting to shrivel indicating cellular water loss. As a result of respiration and transpiration, cellular water loss has been observed in many fruit species (Salunkhe et al., 1991). Jackson et al. (1977) also observed shrivelling during storage in apple fruits from shaded parts of the tree as a result of water loss. Increased shrivelling in shaded fruits according to Jackson et al. (1977) could be due to lower carbohydrate content of the fruit which would lower the osmotic potential and hence the water retaining capacity of the tissues. This suggested that shading delayed maturity (Kappel, 1989) and fruits harvested too early and then stored for a length of time could shrivel (Salunkhe et al., 1991).

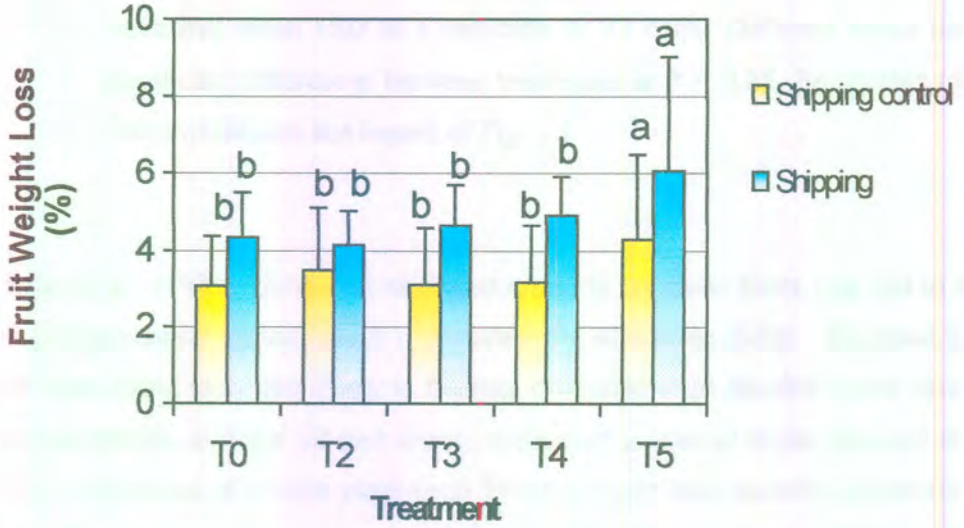

Fig. 3.13. Percentage weight loss of mango fruits as influenced by different shade treatments after ripening at room temperature (shipping control) and after shipping simulation for four weeks at 11° followed by ripening at room temperature (shipping), in the 2000/2001 season. Each data point represents mean ±SD of 4 replicates of 32 fruits. Different letters denote significant differences between treatments at P = 0.05. For details of the shade treatments see legend of Fig. 3.1.

Marini et al. (1991) also reported that peach fruits harvested from different canopy positions (and thus receiving different amounts of light) could have different lengths of storage life. An increased tolerance to low shipping temperatures in exposed fruits compared to shaded fruits was observed in this study. Shipping fruits displayed decreased tolerance, as indicated by the percentage of weight loss, with an increased shade percentage. According to Ferguson et al. (1999) exposure to high temperatures on the tree, particularly close to or at harvest, may induce tolerance to low temperatures resulting in increased post-harvest storage life. Exposed avocado fruits had almost no damage after 28 days storage at 0.5°C, while on the other hand damage of shade fruits was evident after 9 days and increased with longer duration of storage at 0.5°C (Woolf et al., 1999). Exposed fruits were also found to have a longer shelf life than shade fruits (Woolf et al., 1999). Shaded mango fruits (also depending on the level of shade) may need to be harvested later than non-shaded fruits since the former may mature at a later stage compared with the latter (Fig. 3.13). Kappel (1989) also suggested when working with "Bartlett" pear that shaded fruits should remain on the tree until they attain the same firmness as fully exposed trees with the hope of improving the quality of shaded fruits or even attaining the same quality as the fully exposed fruits.

3.3.4. Physiological disorders

Shipping and shipping control fruits from T0 trees had more split pit compared to the other treatments (Fig. 3.14.). T0 shipping fruits had significantly high percentages of split pit compared to T4 and T5 treatments. There were no significant differences in the occurrence of split pit in fruits from the different shade treatments. In this study, the level of shade did not appear to influence the occurrence of this disorder. Studies with apple have shown that the occurrence of physiological disorders in shaded fruits was lower compared to exposed fruits (Jackson et al., 1971; Jackson et al., 1977).

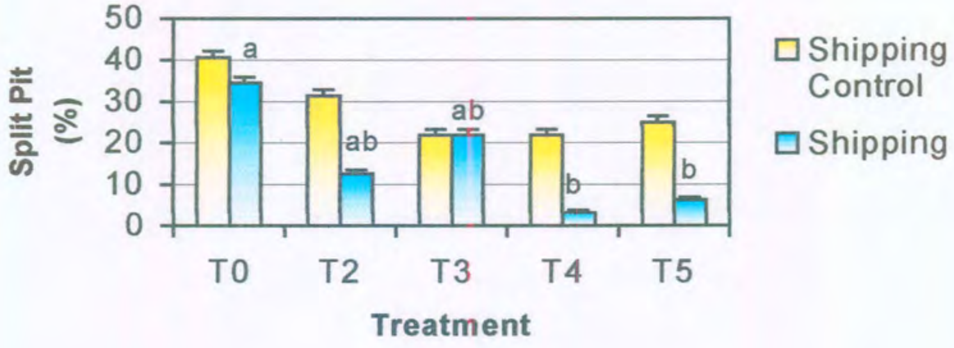

Fig. 3.14. Occurrence of split pit in ripe mango fruits as influenced by different shade treatments after ripening at room temperature (shipping control) and after shipping simulation for four weeks at 11° followed by ripening at room temperature (shipping), in the 2000/2001 season. Each data point represents mean ±SD of 4 replicates of 32 fruits. Different letters denote significant differences between treatments at P = 0.05. For details of the shade treatments see legend of Fig. 3.1.

Jackson et al. (1971) found that minimum cracking on shade fruits was due to their high calcium concentration, which is important for skin extensibility. Exposed apple fruits were found to be less likely to become shrivelled or to develop water core but more susceptible to bitter pit and rotting compared to shaded fruits (Jackson et al., 1971). A shortage of mineral contents in T0 trees might have been the reason for the increased occurrence of split pit, since fruit mineral content has been reported to be an important factor governing fruit storage quality and incidence of internal disorders (Failla et al., 1990). Barrit et al. (1987) found that fruits receiving less sunlight had higher levels of N, P, K, Zn, Ca, Fe, B and Mg compared to well exposed fruits. Fruits with low internal Ca have increased incidences of fruit disorders such as skin cracking (Schaffer et al., 1994). Jackson et al. (1971) and Rom (1990) also observed lower concentrations of nitrogen and calcium per unit fresh weight on exposed fruits and the ratio of Ca to K was lower in such fruits than those receiving less sunlight.

3.3.5. Evaluation of damages caused by sunburn, wind and bacterial black spot

Sunburn

T0 trees had insignificantly the highest percentage of fruits with sunburn (Fig. 3.15.). Sunburn in fruits results from very high air temperatures and exposure of fruits to excessive sunlight (Bagshaw and Brown, 1989; Sams, 1999; Woolf and Ferguson, 2000). It is therefore not surprising that the occurrence of sunburn in this study decreased with increasing shade percentages (Fig. 3.15.), since shade netting slightly reduces air temperatures as well as light flux densities (Oosthuizen, 2001; personal communication).

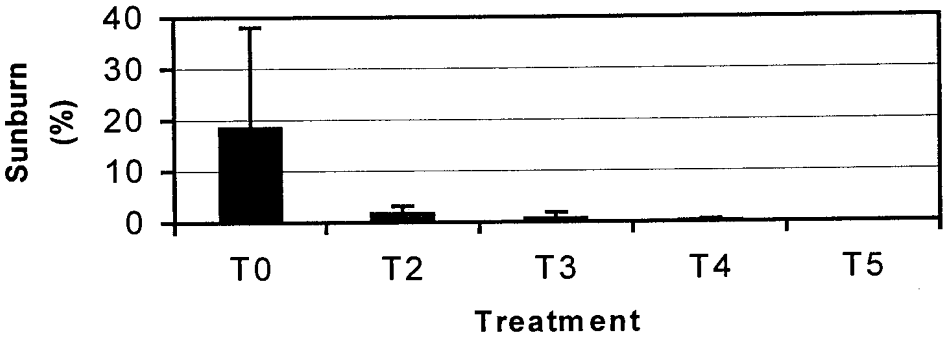

Fig. 3.15. Occurrence of sunburn in mango fruits as influenced by different shade treatments at harvest in 2001. Each data point represents mean ±SD of 4 replicates of 5 trees. For details of the shade treatments see legend of Fig. 3.1.

Reinquist et al. (1987) found that large reductions in solar injury in raspberries could be achieved with 25-30% shade as a result of decreased fruit surface temperatures. Fivaz and Lonsdale (2001) observed similar sunburn reductions in mango fruits as a result of shade. The use of shade structures appears to be, therefore, important in the reduction of sunlight with the benefit of reduced sunburn in fruits leading to increased quality and share in the export market.

Wind damage

The use of shade nets seemed to reduce the occurrence of wind damage in fruits. The uncovered trees (T0) although not statistically significant, had the highest percentage of wind damaged fruits (Fig.3.16.). The occurrence of wind damage seemed to be negatively correlated with the density of the shade nets with T5 fruits having 0% wind damage. Fivaz and Lonsdale (2001) observed large reductions in wind damaged mango fruits grown under a shade cloth. Freeman (1976) using nets as windbreaks for citrus trees also observed reductions in the occurrence of windscar in fruits.

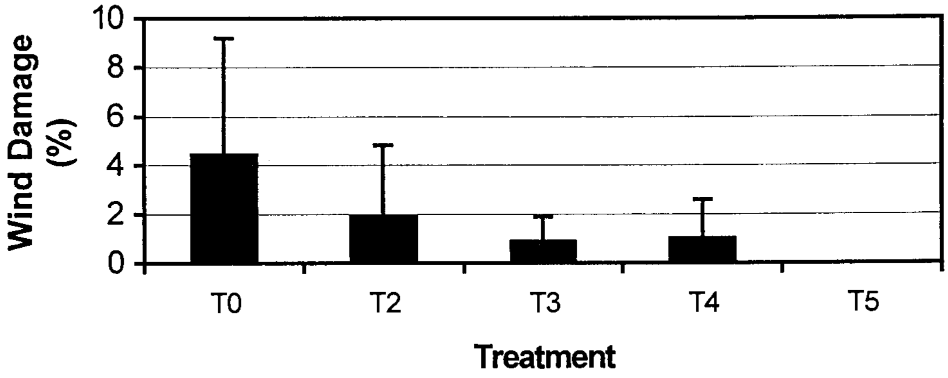

Fig. 3.16. Occurrence of wind damage in mango fruits as influenced by different shade treatments at harvest in 2001. Each data point represents mean ±SD of 4 replicates of 5 trees. For details of the shade treatments see legend of Fig. 3.1.

Bacterial black spot

No bacterial black spot was found in any of the shade treatments or the control trees. Fivaz and Lonsdale (2001) observed a reduction in bacterial black spot (*Xanthomonas campestris pv. Mangiferaeindicae*), when mango trees were grown under shade nets resulting in fruits of superior quality compared to those from non shaded trees. The reduction of wind by nets (Freeman, 1976) appears to be the reason for the reduction of this disease, since wind is one of the factors contributing toward the disease (Doidge, 1915).

3.4. Conclusions

Growing trees under the light shade net (50 g m^{-2}, T2) providing approximately 20% shade did not appear to have adverse effects on the fruit yield and quality of mango trees. Insignificant effects of shade on mean fruit weight resulted in amounts of fruits available for export not being significantly different among treatments. Mango fruit quality was generally not negatively affected by shade. While peel colour was not influenced by shade, flesh colour on the other hand was significantly reduced by shade treatments of more than 20% (75, 100 and 125 g m^{-2}). TSS data from shipping control fruits suggested that shade of at most 40% (50, 75 and 100 g m^{-2}) did not negatively affect TSS of fruits except for the very heavy shading (125 g m^{-2}). The 50 g m^{-2} shade net, however, proved to be superior to the others producing fruits with slightly higher TSS than the others. Flesh firmness was not affected by shade. Shade reduced the shelf life of fruits as a result of high percentages of weight loss during storage with fruits from the heaviest shade treatment (125 g m^{-2}) losing the most weight. During cold storage, fruits from trees grown under the lightest shade net (50 g m^{-2}) had slightly lower percentages of weight loss compared to fruits from the control trees. The occurrence of split pit was significantly reduced only in the heaviest shade nets (100 and 125 g m^{-2}). On the other hand, shade nets insignificantly reduced wind damage and sunburn. Wind damage and sunburn percentages seemed to decrease with increasing levels of shade. It can therefore be concluded that the use of light shade nets such as the 50 g m^{-2} net can be useful in improving the yield and quality of mango fruits. Shade nets providing less than 80% full sun (75, 100 and 125 g m^{-2} nets) cannot be recommended since these appear to have adverse effects on the yield and quality of fruits.

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4. Summary

Irrigation is very important in the production of most fruit tree crops. With water becoming a scarce commodity, however, growers may not be able to attain maximum productivity unless efficient reduced irrigation strategies are adapted. The success of these strategies depend mostly on the time of application, duration and intensity. In this study, yield and quality of mango fruits were not negatively affected by the reduced irrigation regimes. The regulated deficit irrigation (RDI) proved to be superior in terms of yield and quality to the progressively reduced irrigation treatments, the control and also to the current commercial farm practices. Light is also very important for tree productivity. However, severe light intensities can lead to reduced yield and fruit quality as a result of stress. Shade nets can be used to reduce light stress. The mesh densities of the shade nets play a very important role in determining their success. In this study the lightest shade net density (50 g m^{-2}) appeared to be the best compared to the other shade treatments and the unshaded trees. The heaviest shade net (125 g m^{-2}) had negative effects on the yield and fruit quality. The adaptation of deficit irrigation strategies and the use of shade nets may lead to increased productivity and maximised returns for the grower.

5. Appendix

Table 1. Analysis of variance (one factor, completely randomized) of yield and fruit quality as influenced by different irrigation treatments in 2001. Replications per treatment n = 4; treatment 0, 1, 2, 3, 4 = 100% field capacity, 75%, 50%, farm control.

Variable	Source	SS	df	MS	F
Yield	Treatments	85.65	4	12.24	0.83 ns
	Error	176.47	132	14.70	
	Total	262.11	136		
Fruit number	Treatments	297.93	4	42.56	0.95 ns
	Error	537.40	132	44.78	
	Total	835.33	136		
Fruit weight	Treatments	47641.31	4	6805.90	0.47 ns
	Error	173563.18	132	14463.60	
	Total	221204.49	136		
Peel colour at harvest	Treatments	1.47	4	0.24	1.46 ns
	Error	8.87	132	0.17	
	Total	10.33	136		
Peel colour of shipping control fruits	Treatments	74.92	4	10.70	7.61 **
	Error	157.45	132	1.40	
	Total	232.37	136		
Peel colour of shipping fruits	Treatments	68.58	4	9.79	9.39 **
	Error	137.67	132	1.04	
	Total	206.25	136		
Flesh colour at harvest	Treatments	0.06	4	0.01	1.64 ns
	Error	0.34	132	0.01	
	Total	0.41	136		
Flesh colour of shipping control fruits	Treatments	0.02	4	0.003	3.70 *
	Error	0.09	132	0.0008	
	Total	0.12	136		

Variable	Source	SS	df	MS	F
Flesh colour of shipping fruits	Treatments	0.62	4	0.009	1.76 *
	Error	0.67	132	0.005	
	Total	0.73	136		
TSS at harvest	Treatments	42.20	4	7.03	2.88 *
	Error	129.53	132	2.44	
	Total	171.73	136		
TSS of shipping control fruits	Treatments	157.00	4	22.43	7.34 **
	Error	342.20	132	3.01	
	Total	499.20	136		
TSS of shipping fruits	Treatments	142.75	4	20.39	8.71 **
	Error	309.04	132	2.34	
	Total	451.79	136		
Flesh firmness at harvest	Treatments	13.90	4	2.32	0.80 ns
	Error	153.92	132	2.90	
	Total	167.82	136		
Flesh firmness of shipping control fruits	Treatments	4.95	4	0.71	0.80 ns
	Error	99.59	132	0.09	
	Total	104.54	136		
Flesh firmness of shipping fruits	Treatments	41.41	4	5.92	2.20 *
	Error	354.92	132	2.69	
	Total	396.33	136		
Weight loss of shipping control fruits	Treatments	450.68	4	64.38	1.30 ns
	Error	5540.12	132	49.47	
	Total	5990.79	136		
Weight loss of shipping fruits	Treatments	1399.00	4	199.86	3.29 *
	Error	8030.79	132	60.84	
	Total	9429.79	136		

Variable	Source	SS	df	MS	F
Split pit of shipping control fruits	Treatments	2.16	4	0.31	1.39 ns
	Error	24.83	132	0.22	
	Total	26.99	136		
Split pit of shipping fruits	Treatments	3.31	4	0.47	1.97 ns
	Error	31.63	132	0.24	
	Total	34.94	136		
Sunburn damage at harvest	Treatments	60.00	4	8.57	1.27 ns
	Error	80.80	132	6.73	
	Total	140.80	136		

Table 2. Analysis of variance (one factor, completely randomized) of yield and fruit quality as influenced by different shade treatments in 2001. Replications per treatment n = 4; treatment 0, 1, 2, 3, 4 = unshaded, 50, 75,100 and 125 g m^{-2} shade net densities.

Variable	Source	SS	df	MS	F
Yield	Treatments	1752.77	4	159.34	3.28 *
	Error	4268.60	152	48.51	
	Total	6021.37	156		
Fruit number	Treatments	5476.52	4	497.87	3.61 *
	Error	12120.84	152	137.73	
	Total	17597.36	156		
Fruit weight	Treatments	347898.69	4	31627.15	1.10 ns
	Error	2527570.81	152	28722.40	
	Total	2875469.50	156		
Peel colour at harvest	Treatments	2.90	4	0.41	3.30 ns
	Error	19.08	152	0.13	
	Total	21.98	156		
Peel colour of shipping control fruits	Treatments	47.14	4	6.73	4.56 ns
	Error	224.46	152	1.47	
	Total	271.60	156		
Peel colour of shipping fruits	Treatments	16.44	4	2.35	3.66 ns
	Error	97.54	152	0.64	
	Total	113.98	156		
Flesh colour at harvest	Treatments	0.51	4	0.07	6.06 **
	Error	1.82	152	0.01	
	Total	2.33	156		
Flesh colour of shipping control fruits	Treatments	0.04	4	0.006	3.41 *
	Error	0.25	152	0.002	
	Total	0.29	156		

Variable	Source	SS	df	MS	F
Flesh colour of shipping fruits	Treatments	0.13	4	0.02	4.15 *
	Error	0.71	152	0.01	
	Total	0.84	156		
TSS at harvest	Treatments	16.15	4	2.31	1.26 ns
	Error	278.83	152	1.83	
	Total	294.96	156		
TSS of shipping control fruits	Treatments	129.01	4	18.43	7.45 **
	Error	376.19	152	2.48	
	Total	505.20	156		
TSS of shipping fruits	Treatments	122.84	4	17.55	5.66 **
	Error	471.35	152	3.10	
	Total	594.20	156		
Flesh firmness at harvest	Treatments	18.53	4	2.65	1.38 ns
	Error	291.79	152	1.92	
	Total	310.31	156		
Flesh firmness of shipping control fruits	Treatments	9.07	4	1.30	1.95 ns
	Error	101.18	152	1.67	
	Total	110.25	156		
Flesh firmness of shipping fruits	Treatments	36.66	4	5.24	2.65 *
	Error	299.94	152	1.97	
	Total	336.60	156		
Weight loss of shipping control fruits	Treatments	2793.95	4	399.14	6.57 **
	Error	9233.30	152	60.75	
	Total	12027.24	156		
Weight loss of shipping fruits	Treatments	3672.27	4	524.61	6.60 *
	Error	12083.48	152	79.50	
	Total	15755.74	156		

Variable	Source	SS	df	MS	F
Split pit of shipping control fruits	Treatments	2.08	4	0.30	1.49 ns
	Error	30.26	152	0.20	
	Total	32.34	156		
Split pit of shipping fruits	Treatments	2.23	4	.32	2.57 *
	Error	18.86	152	0.12	
	Total	21.09	156		
Sunburn damage at harvest	Treatments	60.00	4	8.57	1.27 ns
	Error	80.80	152	6.73	
	Total	140.80	156		
Wind damage at harvest	Treatments	326.79	4	189.54	2.66 ns
	Error	855.07	152	71.26	
	Total	2181.87	156		