

Full Length Research Paper

Growth and expansion of strawberry fruit (*Fragaria x ananassa* Duch.) under water stress conditions

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This investigation was carried out to find out if a constant number of strawberry fruit in the plants would have differing rates of growth and expansion when subjected to different levels of water stress at specific growth stages. Soil water stress treatments were imposed at flowering (flo) and at fruiting (fru), by withholding water until the available soil water were 0.40 to 0.45% v/v for the normal stress treatment (normal), 0.35 to 0.40% v/v mild stress (ms) and 0.25 to 0.35% v/v for severe stress (ss). The ms fru, ss fru and ss flo treatments showed significantly lower fruit weights than other treatments while fruit firmness was significantly increased by ms fru and ss fru treatments in the primary, secondary fruit and tertiary fruit. The total soluble solids (TSS) were not affected significantly by the water stress treatments. Osmotic adjustment may be attributed to the ability of the water stressed strawberry fruit to grow and expand post anthesis. This research provides an understanding of the effects of water deficits on fruit quality when other factors such as fruit number and fruit positioning on the inflorescence are similar in all experimental units. Strawberry producers may consider reduced crop loading to ameliorate reduced fruit size, when faced with water deficit irrigation regimes.

Key words: Crop load, fruit size, fruit weight, total soluble solids (TSS), water stress.

INTRODUCTION

Plants carrying a heavy crop load have a lower turgor potential when compared to those that have a light load thus are likely to show reduced fruit growth and fruit size (McFadyen et al., 1996). The premise is that reduction in fruit size, diameter and weight can be counteracted by the reduction in crop load of water stressed strawberries. Naor et al. (1997, 1999) and Mpelasoka et al. (2001) suggested that there would be increased levels of assimilate availability through increased photosynthesis (P_n) and subsequently increased fruit turgor potential (Ψ_{fp}) and fruit growth due to reduced crop load. Pomper and Breen (1995, 1997) suggested that osmotic adjustment may enable fruit expansion to take place due to solute accumulation in the apoplast of strawberry fruit.

Dwyer et al. (1987) remarked that since the fruit is a major sink in plants, water stress imposition even if mild could reduce fruit yield significantly. Although a lot of research work has been done on the effect of crop load on water relations in fruit, none have addressed the possibility of reducing crop load to counteract the reduction in fruit size and weight in water stressed fruit of strawberries. There are no reports in the literature of any studies that have been conducted on strawberry fruit expansion under deficit irrigation where fruit load is reduced to single trusses. The objective of this experiment was therefore to determine the rate of fruit expansion under deficit watering in primary, secondary and tertiary fruit, when the crop load had been reduced to

a few fruit in the strawberry plant. It is postulated that water stress effects can be mitigated by reducing crop load in strawberry without negative implications on fruit quality as determined by Naor et al. (2008) and Lopez et al. (2010) in studies on apples and peach trees respectively.

The use of deficit irrigation strategies have been applied previously to conserve water and to control vegetative growth of plants where water shortages are increasingly becoming a problem in peach (Chalmers et al., 1981), pear (Chalmers et al., 1986), grapevines (Matthews et al., 1987) and on apple (Ebel et al., 1995) thus increasing farmers profits (Feres and Soriano, 2007; Geerts and Raes, 2009) and increasing the quality of fruit produced (Trought and Naylor, 1988).

MATERIALS AND METHODS

Plant material and treatments

This study was conducted at the University of Nottingham in the United Kingdom. Bare rooted strawberry seedlings cv. Elsanta were grown in 13 cm pots containing Levington M2 compost. The plants were established in a polytunnel and transferred to the glasshouse three weeks later when roots had fully developed. Plants only received natural sunlight in the glasshouse. Upon flowering (on the 5th week), the primary, secondary and tertiary flowers were tagged using different colour tags for ease of identification. The rest of the flowers were removed and plants were not allowed to develop any more flowers. Only one truss per plant (primary truss) was allowed to grow and develop fruit therefore the primary, secondary and tertiary fruit were all located on the primary truss. The experimental unit did not encompass a full crop load as a control as this would have produced an undesired dimension to this study. The aim was not to compare heavy with light loads but to measure performance under various water regime treatments. To achieve good fruit set and to ensure normal fruit development, flowers were hand pollinated at anthesis every 2 to 3 days between 10H00-12H00 h, with a soft squirrel brush.

Three levels of soil water stress were imposed (normal, mild and severe) by withholding water for different periods until the available soil water was 0.40 to 0.45% v/v for the normal stress treatment, 0.35 to 0.40% v/v mild stress (ms) and 0.25 to 0.35% v/v for severe stress (ss) as measured using a Theta probe – Soil Moisture Sensor (Type ML2X, Delta-T Devices Ltd, Cambridge). The plants were re-watered to achieve field capacity after each stress period. The stresses were applied at flowering (flo), that is, when at least 80% of the flowers had opened, and at fruiting (fru), at the green fruit stage that is, 10 days after anthesis.

The plants were arranged in three randomised blocks. Each block consisted of five plots with each plot being representative of a stress treatment. Each plot had 6 replicate plants with guard plants at the end of the back row and guard rows at the sides of each plot. A row was thus randomly allocated a water stress treatment and this was replicated over the other two additional blocks. Therefore there were 30 plants per block giving a total of 90 experimental plants for all 3 blocks.

Fruit measurements

After ripening, the primary, secondary and tertiary fruit were weighed, analysed for texture and measured for firmness, total soluble solids (TSS), fruit length and diameter.

Fruit weight

Fruit were weighed when ripe using an electronic balance (PJ Precisa Junior 500 C, Precisa Balances Ltd, Bucks, UK).

Texture

The freshly picked strawberries were analysed for firmness using a Stevens – LFRA Texture Analyser (Stevens, Coventry, UK) with a penetration probe of 13.6 mm diameter applied to the longitudinal axis of the fruit. The maximum force required for the probe to penetrate the fruit by 6 mm at a speed of 1.0 mm s⁻¹ was recorded. Fruit from each plant was individually weighed and used for firmness determination. The same fruit was also used for measurement of total soluble solids.

Total soluble solids (TSS)

TSS measurements were also taken from the same fruit used for texture analysis. A Delta refractometer (Bellingham and Stanley Ltd, Kent, UK) was used for measuring the TSS. Juice was squeezed from the fruit by hand at the distal end to release about 0.01 ml juice onto the lens of the refractometer.

Fruit length

Measurements were taken every other day in the morning longitudinally on primary and secondary fruit using an electronic vernier calipers (Mitutoyo (UK) Ltd).

Diameter

Measurements were taken every other day in the morning on the equatorial axis on primary and secondary fruit also using the electronic vernier calipers.

Plant measurements

Canopy height

Measurements of canopy height were taken at both the fruiting and the ripening stage using a ruler. The canopy heights measured from the soil surface were recorded.

Number of leaves

Leaves were counted manually during the fruiting stage and at the ripening stage of the fruit.

Plant fresh and dry weights

At the end of the experiment, plant biomass (whole canopies) were cut at the soil surface and weighed before placing in pre-weighed paper bags for drying in the oven. Dry weights were determined after 48 h of drying in a 70°C oven. All plant, fruit growth and quality measurements were taken on 6 plants per treatment/block, each plant had 3 fruit (primary, secondary and tertiary) giving a total of 18 fruit per treatment per block.

Data analysis

Data collected were subjected to analysis of variance (ANOVA)

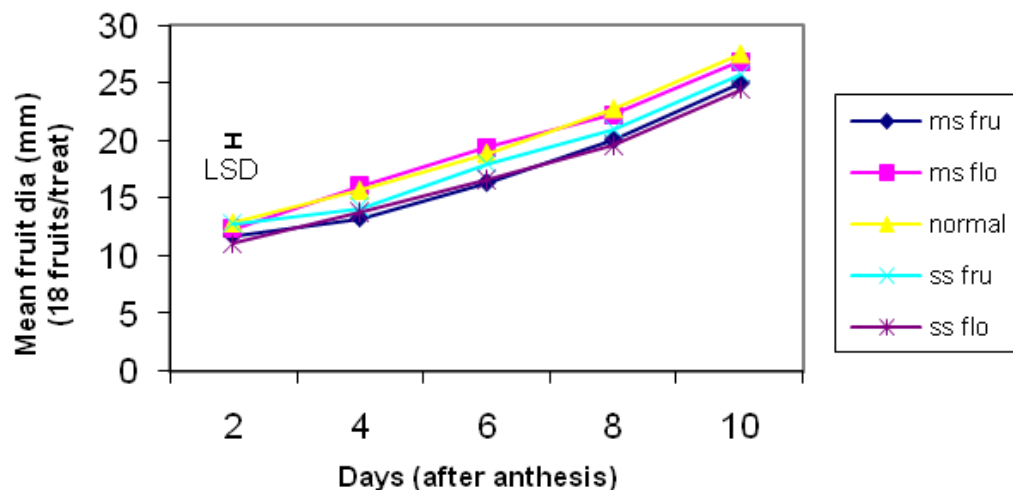


Figure 1. Effect of treatments on primary fruit length per 2 day interval diameter increase per 2 day interval.

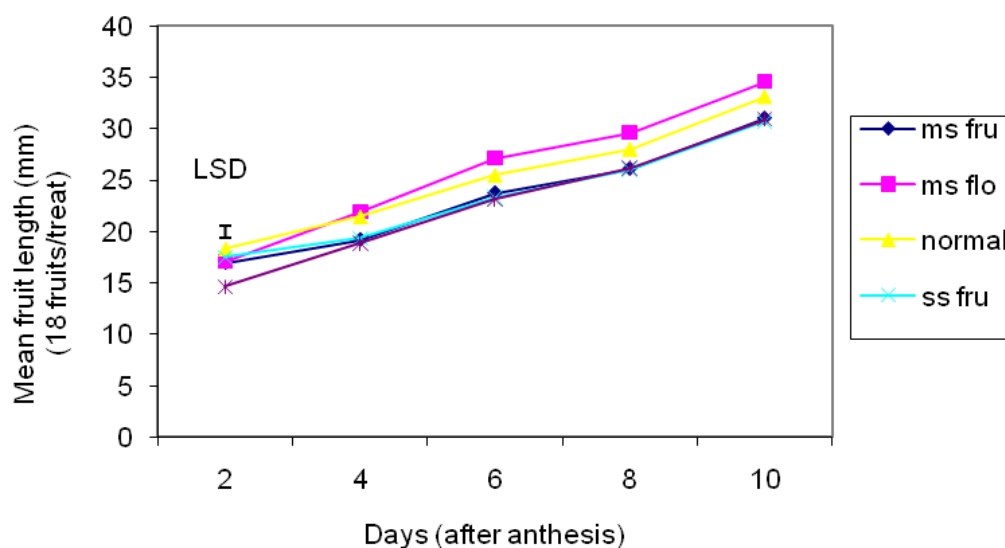


Figure 2. Effect of treatments on primary fruit length per 2 day interval diameter increase per 2 day interval.

using Genstat (Rothamstead) and the results were considered to be significant $P < 0.01$ level of probability. Means were separated using the Least Significant Difference (LSD).

RESULTS

Primary fruit

There were differences in the diameter and in the length of primary fruit among the treatments (Figures 1 and 2). Fruit from ms fru, ss flo and ss fru treatments were significantly smaller than those from normal and ms flo treatments. On average, every 2 days there was an

increase of between 3.3 and 3.65 mm in the diameter of primary fruit up to the 10th day when fruit became ripe. The largest mean diameter increases were between 2nd and 6th day and between 8th and 10th day after anthesis. The mean length of primary fruit increased by between 3.29 and 4.36 mm per day until ripening on the 10th day after anthesis (Figure 2). The difference between mean length due to ss fru and normal treatments when computed over overall mean diameter increase for all treatments every 2 days (3.84 mm) was 14%. The largest mean length increasing trend was between 2 and 4 days and 8 to the 10th day after anthesis ($R^2 = 0.95$) and were shown by ms flo, ss flo and normal treatments (Figure 2).

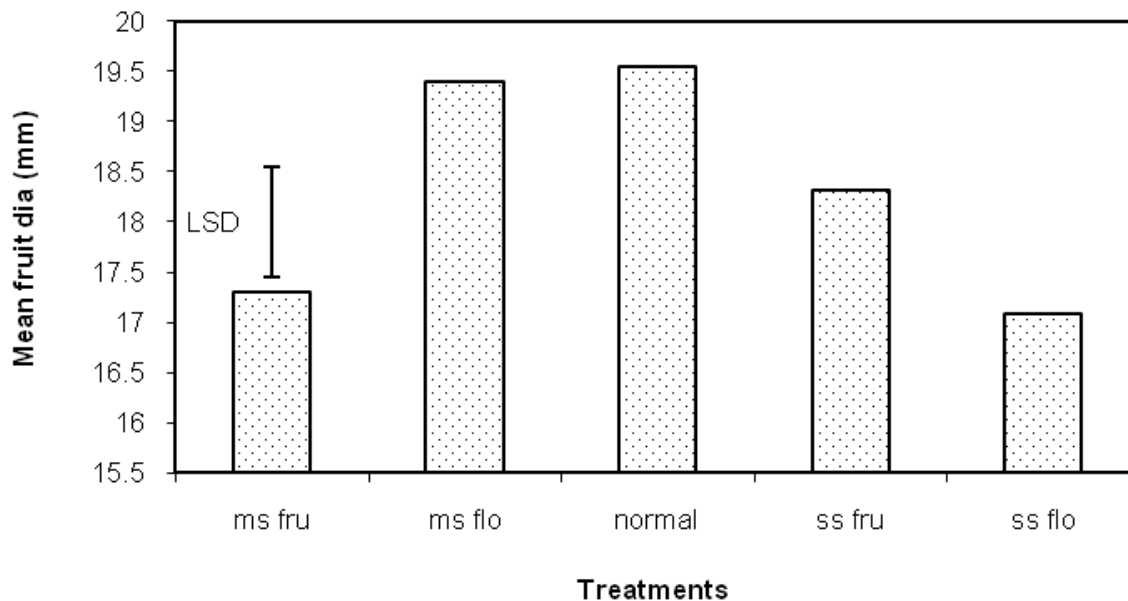


Figure 3. Effect of treatments on final diameter of primary fruit at ripening stage (that is, 10 days after anthesis).

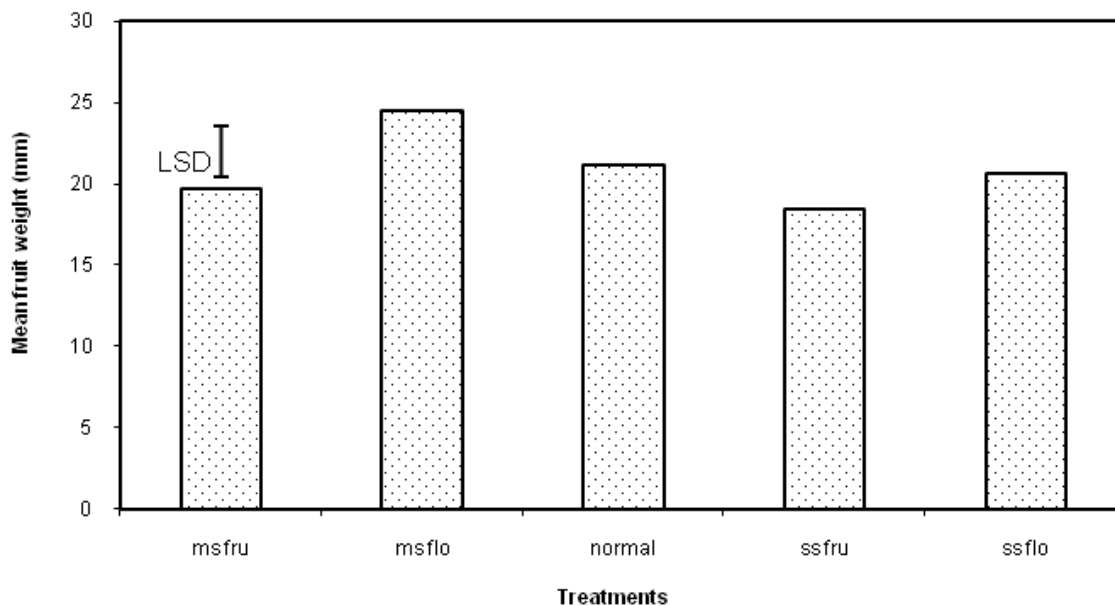


Figure 4. Effect of treatments on weight of primary fruit at harvest at ripening stage (that is, 10 days after anthesis).

At the end of the experiment the ms fru, ss fru and ss flo treatments resulted in significantly smaller fruit in terms of diameter (Figure 3) compared to normal treatment and lower weight for ms fru and ss fru (Figure 4). The ms flo and normal treatments were not significantly different from each other. TSS was plotted against mean fruit weight (of all primary fruit) using CurveExpert 1.3 (Zen University). There was a linear decrease in TSS of

primary fruit with increased fruit weight, the correlation coefficient was 0.78 (Figure 5).

Secondary fruit

The secondary fruit showed a different trend to the primary fruit. The diameter was not significantly affected

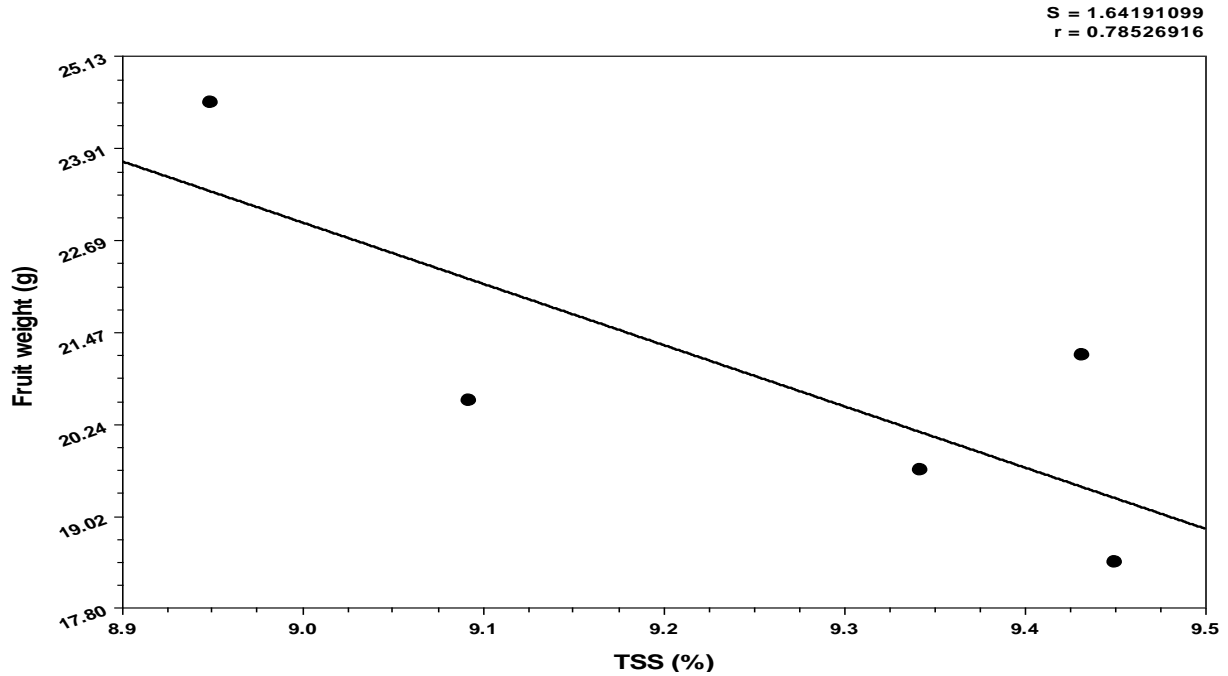


Figure 5. Relationship of TSS with fruit weight of primary fruit (mean of 6 fruit).

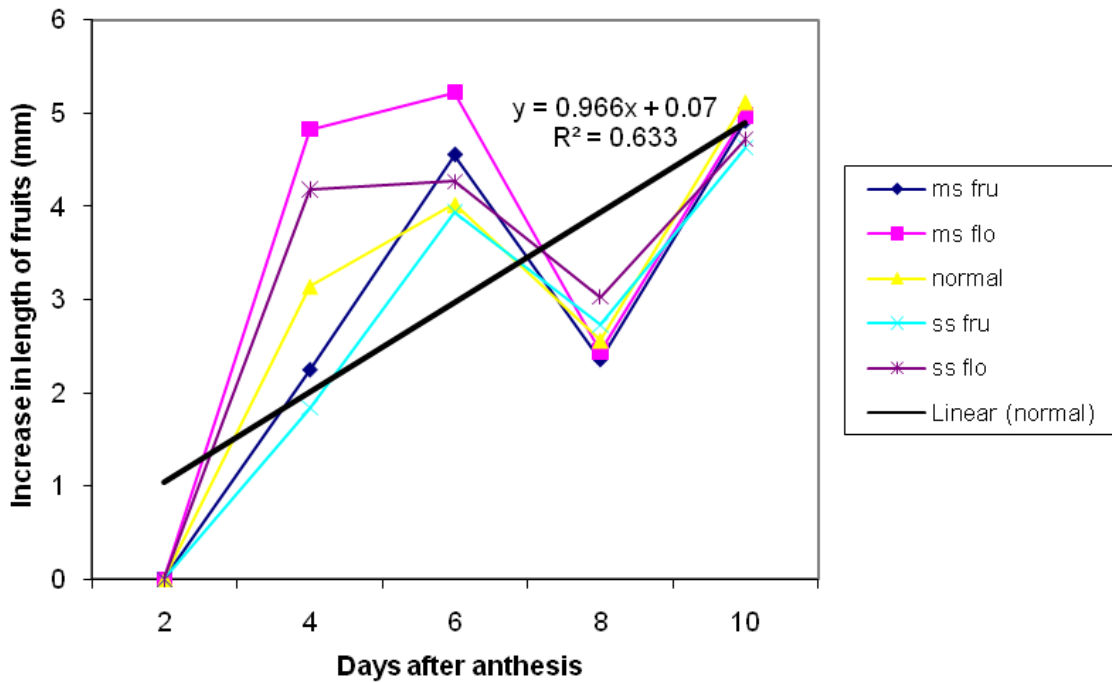


Figure 6. Mean increase in secondary fruit diameter during growth and development until ripening, due to treatments.

by the treatments but there was a significant difference in the mean diameter of the fruit (Figure 6). The ss fru and ms fru treatments caused significantly smaller fruit compared to other treatments. There were no interactions

between treatments and days but there was a date effect. The largest mean increase of the diameter thus was between the 2nd and 4th day and also between the 8th and 10th (Figure 6).

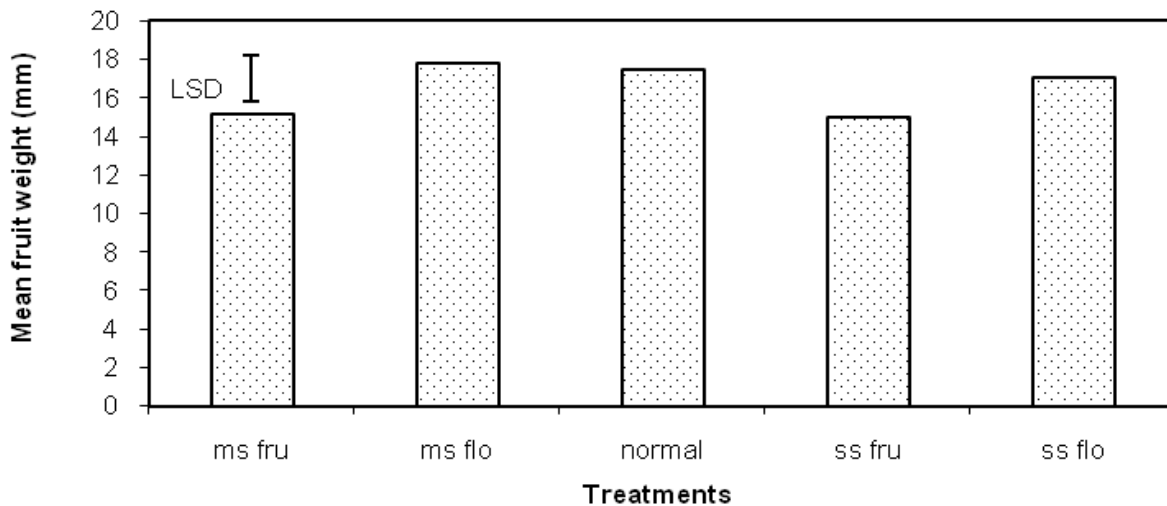


Figure 7. Effect of treatments on secondary fruit weight at harvest.

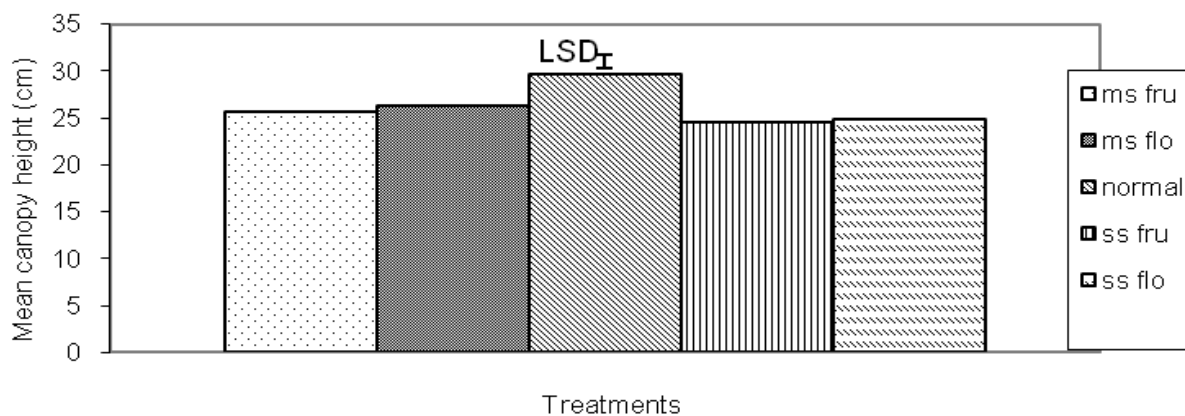


Figure 8. Effect of water stress on canopy height during the fruiting stage.

The mean length of secondary fruit increased by between 3.19 and 3.81 mm per 2 day interval until the fruit were ripening by the 10th day. There was a 7% difference between the mean length of ss fru (3.23 mm) and normal (3.49 mm) treatments when calculated over overall mean increase of all treatments (3.49 mm). There was a date effect and largest mean increases in length of fruit were between 2nd and 4th day followed by a decline and also between the 8th and 10th day (Figure 7). TSS and texture were not affected significantly by the treatments (results not shown). Similarly to primary fruit, there was a decreasing a trend in TSS to increasing fruit weight when these parameters were plotted against each other.

Tertiary fruit

As in the primary and secondary fruit, the ms fru, ss fru and ss flo treatments showed significantly lower fruit

weights than other treatments. TSS was not affected significantly by the water stress treatments. A relationship between TSS and fruit weight could not be established in tertiary fruit.

Measurement of plant parameters

Canopy height

The canopy height of the normal treatment was significantly higher than all other treatments during the fruiting stage of growth (Figure 8) but ss fru, ms fru and ss flo had significantly lower canopies than the other treatments during ripening stage of the fruit.

Plant fresh and dry weights

The plant fresh weights were significantly lower in ss fru

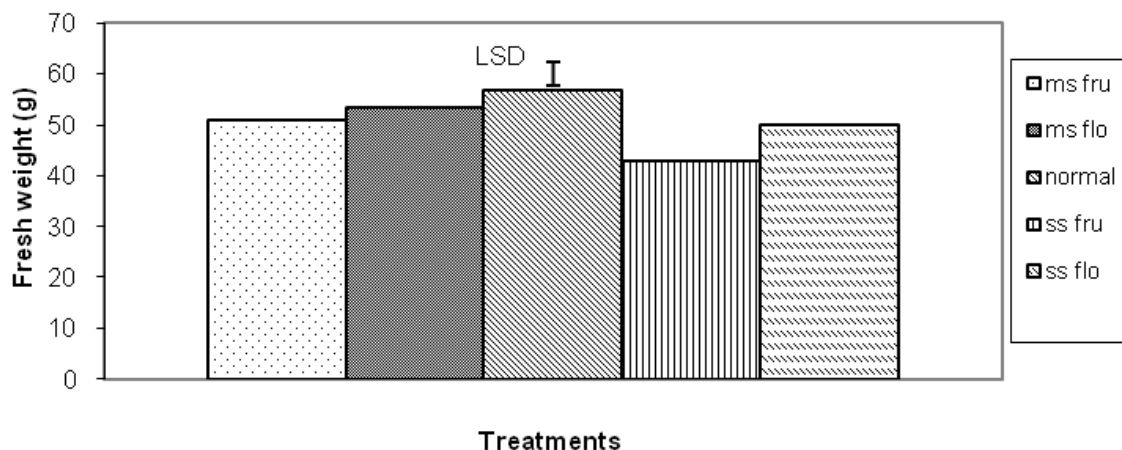


Figure 9. Effect of water stress on fresh weight of the plants.

and ss flo when compared to the rest of the treatments (Figure 9) and so were the dry weights.

Leaf area

Leaf area followed a similar trend to the fresh and dry weights. It was significantly lower in ss fru, ms fru and ss flo also had lower leaf areas though not statistically significant.

DISCUSSION

Primary fruit

The ss fru and ms fru treatments generally resulted in smaller primary fruit in terms of diameter, length and weight, the difference in mean increase between the ss fru and normal treatment was 6% for diameter and 14% for length. The ss fru treatment was selected over other treatments for comparison with the normal treatment because it showed the smallest increases in diameter and length in the measurements in every 2 days. These differences, though statistically significant are not very substantial considering that Mpelasoka et al. (2001) found about 4% reduction in the fruit growth rate of 'Braeburn' apples due to deficit irrigation when the crop load was light and 13% on full crop load. Caspari et al. (1994) proposed that water deficit might inhibit growth by 17% when it was practiced on 'Hosui' Asian pears.

The largest mean increases in the diameter and length of the primary fruit were between 2 and 4 days and 8 to 10 days after anthesis respectively and the treatments that caused this increase were ms flo and ss flo. This finding supports the theory of Caspari et al. (1994) that a short term water deficit that is, applied at anthesis (in this study ms flo and ss flo) when shoots are growing

vigorously, does not affect fruit growth, thus the similar trend between ms flo and ss flo. Water deficits applied at the fruit growth stages (ms fru and ss fru) will inhibit fruit growth (Caspari et al., 1993). These investigators were not able to explain the mechanism of the effects of short-term water deficits. It can be presumed though that there are changes in the hydraulic lift in the soil-plant continuum leading to partitioning of hydraulic conductance into the soil, root and stem components. This is one of the plant adaptations that act to buffer plants against damaging effects of water deficits (Richards and Caldwell, 1987). The results indicate that the 2nd to 4th day after anthesis were periods of rapid fruit growth followed by a lag phase of the 4th to the 6th day and then finally the rapid fruit growth phase leading to fruit ripening. Johnson and Handley (2000) acknowledged that there are rapid periods of growth after bloom followed by a lag phase that precedes the rapid fruit growth prior to harvesting. This type of growth is often referred to as double sigmoidal growth because it is characterized by two periods of rapid growth with an intervening slow phase of growth (Perkins-Veazie, 1995). Schwab and Raab (2004) observed that the growth of fruit fits a single sigmoidal curve or is biphasic depending on the cultivar.

There were no significant increases in the diameter and length of the primary fruit at 10 days after anthesis as the fruit had reached the pink-red colour stages and were beginning to ripen. The maturation period was relatively short (about 13 days after green fruit stage). Perkins-Veazie (1995) reported comprehensively on the disagreements among researchers on the pattern of berry growth. Knee et al. (1977) and Cheng and Breen (1992) have reported a stoppage of cell division between 7 and 15 days after anthesis. They further noted that rapid cell expansion follows cell division resulting in a sharp rise in fruit cell volume 10 days after anthesis. The large diversity in fruit growth patterns is influenced by the

number of receptacle cells per achene, which in turn is a factor of environmental conditions, genetic variation and cultivar type (Cheng and Breen, 1992). The temperatures were high during the experimental period since it was summertime, and this may have aided the rapid growth and development process of the strawberries. This notion was ably explained by Warrington et al. (1999) when affirming that growth and maturity of apple fruit is affected by early season temperatures. Total Soluble Solids of primary and secondary fruit were not affected by water stress treatments (Reynolds et al., 2005). This is contrary to conclusions by Irving and Drost (1987) that water stress increased the levels of TSS in apples, and findings by Mpelasoka and Behboudian (2002) that TSS is increased by deficit irrigation.

Secondary fruit

Unlike the primary fruit, the mean diameter of secondary fruit was not significantly affected by water stress treatments. The mean length and mean fruit weight however, followed a similar trend to the primary fruit; they were significantly lower in the ms fru and ss fru treatments. The differences between the mean length of the ss fru and normal treatments were once more not substantial at 7% although ss fru and ms fru treatments resulted in smaller fruit in length and weight. Primary fruit were slightly larger than secondary fruit in mean diameter and mean length. The differences in the sizes of the fruit was caused by the fact that primary fruit flowers were the first to bloom and were therefore on a superior position on the inflorescence. Fruit size generally declines with fruit placed on inferior positions such as secondary, tertiary and quaternary (Moore et al., 1970). This concept could not be fully established in this research because the blooming of the primary and secondary flowers was almost simultaneous in most cases. TSS and texture of primary fruit was not affected significantly by the various water stress treatments.

Tertiary fruit

The weight of tertiary fruit was significantly low in ms fru, ssfru and surprisingly also in ss flo. The fruit subjected to ms fru and ss fru were smaller than those of other treatments. It can be deduced that water stress reduces fruit size in agreement with Mpelasoka and Behboudian (2002) and Lopez et al. (2010). Total Soluble Solids were not affected significantly by water stress in the tertiary fruit as were the primary and secondary fruit. The terminal (primary) fruit on the peduncle are stronger sinks of substrates unloaded by phloem, followed by secondary fruit and tertiary fruit in order of position on the inflorescence. The fruit weight therefore declines with inferior blossom position (Janick and Eggert, 1968). In this study, the inflorescence developed at the same time

and the hierachial order of flower development was not obvious, thus resulting in differences that were not statistically significant between the weight of primary, secondary and tertiary fruit. Nonetheless, Kassai et al. (2002) found no correlation between berry growth and position within a truss.

Plant measurements

At the fruiting stage that is, at the beginning of anthesis, plant canopy height was significantly lower in all treatments compared to normal treatment. At the fruit ripening stage though, ss fru showed significantly lower canopy height than all treatments followed by ms fru and ss flo. At fruiting, the shoot growth is more rapid therefore water stress would not significantly reduce canopy height, but during the ripening stages particularly the lag phase, shoot growth declines and vegetative growth may be reduced. Predictably, the ss fru treatment also demonstrated lower levels of fresh weight, dry weight and leaf area.

Conclusion

Although water stress can cause reductions in fruit diameter and length, the reduction is on average less than 10% for combined means of primary and secondary fruit when compared to plants that were not water stressed. This study suggests that imposing water stress (mild and/or severe at fruiting results in lower fruit size and weight. Primary trusses generally have larger fruit as the fruit are the first to flower as they are at a superior position. The loss in fruit size was expected to give a compensatory gain by the enhancement of fruit quality e.g. significantly increased sugars in fruit but that was not the case in the present experiment. Even though the strawberry plants were subjected to various water stress treatment levels, evidence presented here shows that fruit were still growing and expanding at a rate of between 3 and 4 mm every 2 days up to 10 days post anthesis. Thus, in countering water stress, reduced crop load may be applied but caution should be exercised not to lose quality of fruit in terms of size.

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