Project title:	Pear: The effect of soil moisture on fruit storage quality
Project number:	TF 179
Project leader:	Tim Biddlecombe, Farm Advisory Services Team Ltd. Brogdale Farm, Brogdale Road, Faversham, Kent, ME13 8XZ
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Previous report:	None
Key staff:	Gary Saunders (2007 – 2009) James Carew (2009 - 2010)
Location of project:	The Bounds, Hernhill, Faversham, Kent, ME13 9TX
Industry Representative:	Nigel Bardsley
Date project commenced:	1 May 2008
Date project completed:	31 October 2010

DISCLAIMER:

AUTHENTICATION

We declare that this work was done under our supervision according to the procedures described herein and that the report represents a true and accurate record of the results obtained.

James Carew
Trials Coordinator
Farm Advisory Services Team Ltd.

Signature James Carew Date 25th August 2011

Report authorised by:

Tim Biddlecombe
Managing Director
Farm Advisory Services Team Ltd.

Signature Tim Biddlecombe Date 26th April 2011

Contents

Grower Summary

Headline

The use of irrigation successfully maintained soil moisture content and when combined with the use of compost mulch to improve soil structure, its percolation through the soil profile was improved.

Background and expected deliverables

This project arose from the experience of Dutch growers who find that the benefits of irrigation include reducing tree stress, delaying harvest, improving fruit size, quality and particularly storage life. There is therefore a need to investigate the use of water in relation to these characteristics in the UK as the potential benefits from improved pear production are significant. However, in practice, many orchards do not have irrigation and so for this reason, the testing of mulches as soil water conservation measures and the subsequent effect on crop size and quality was included in this project. The two aims of the project were to investigate the effect of irrigation and the effect of various mulches on cropping and fruit quality in pear.

Summary of the project and main conclusions

Three irrigation treatments and four mulch treatments were applied to 'Conference' pear trees in an orchard near Faversham. The irrigation treatments included a control (no irrigation), 1 inch irrigation per week and irrigation controlled using an EnviroSCAN logger to maintain a constant soil moisture content. The mulch treatments included a control (no mulch), composted bark, straw and black polythene.

The effects of the three mulches on soil structure were important and there were clear differences between the three mulches. During the experimental period, the composted bark became incorporated into the upper soil layers and as a result improved soil structure. This resulted in better percolation of water through the soil profile than either the bare soil or plastic mulch treatments. The main effect of the straw mulch was to reduce available nitrogen to the tree roots resulting in reduced leaf and fruit nitrogen. This was probably due to the straw decomposition process which involves microorganisms locking up available soil nitrogen. The mulches therefore did create very different patterns of water absorption and therefore availability to the trees. Both beneficial and negative effects of the three mulches were seen and gaining an understanding of their effects on tree growth and cropping is therefore important.

The effects of irrigation on soil water content are also quite clear and again not surprising. Irrigation clearly improved water availability to the treated areas. Managed irrigation, using EnviroSCAN data, in particular maintained soil water content. This was particularly the case where mulch was used that seemed to improve the soil structure (composted bark and straw). For the bare soil and plastic mulch treatments, the water tended to remain in the upper layers and not to move through the soil profile as readily. The irrigation and compost mulch treatments appeared to be complementary.

There have been a number of studies on irrigation of apples and pears which demonstrate clear effects on growth and fruit size. However, in the work described here on pear irrigation, there were actually only very minor effects on fruit and tree growth and no effect at all on storability of fruit. Based on previous work carried out around the world, this is perhaps surprising but there are three possible reasons for this. The irrigation treatments were applied during July and August. The rationale for this was that this was the period of fruit growth during which a limit to water supply would have been likely to reduce fruit size. In addition this is the method used by a number of growers in Holland and Belgium to increase fruit size. However, most of the published work describing irrigation effects on apples and pears has tested the effect of continuous irrigation throughout the growing season. That irrigation was only applied for two months may not have been sufficient to achieve significant effects on fruit growth. The experiment was run in a Conference orchard planted in the early 1980s with an intra row spacing of 2m. The trees were therefore mature and the tree volume was large. By implication the root system would have been well developed and would have extended to a diameter of around 2m, similar to the canopy size. Irrigation was applied using a single line of emitters as in commercial orchards and whilst the volume of irrigated soil would spread as the water moved through the soil profile, there would still have been part of the root system unaffected by the irrigation treatments. Perhaps if the experiment had been conducted in a younger orchard the effects would have been more significant. Finally, the tree to tree variation was large and would have obscured effects particularly where parameters are related such as fruit number and fruit size.

It should be noted that whilst in the experiment described here there were very few significant effects of the irrigation treatments on either fruiting or storability of fruit there are a number of reports from around the world where effects have been observed. It is therefore dangerous to conclude from these data alone that irrigation has no effect and the data presented in this report should be viewed in the light of commercial experience where irrigation is believed to significantly affect growth and yield of pears. The reasons for this difference are discussed in more detail in the Science Section of the report.

Financial Benefits

Neither the irrigation nor mulch treatments resulted in consistent, significant effects on fruit growth or storability. Therefore it is not possible to calculate the financial benefits of the results described within this report.

Action Points

- No change to current best practice is recommended based on the results described within this report.

Science Section

Introduction

This project arose from the experience of Dutch growers that the observed benefits of irrigation include reducing tree stress, delaying harvest and improving fruit size, quality and particularly storage life. There is therefore a need to investigate the use of water in relation to these characteristics in the UK as the potential benefits from improved pear production are significant. The problem with this idea is that many orchards do not have irrigation. For this reason, the testing of mulches as soil water conservation measures and the subsequent effect on crop size and quality was included. There were therefore two aims of this work. Firstly to investigate the effect of irrigation and secondly the effect of various mulches on cropping and fruit storage in pear.

Over the last few years, there have been a number of experiments conducted to investigate irrigation effects on pears. In a field experiment investigating the effect of sub- and supra-optimal irrigation on 'Blanquilla' pear trees in Spain, the main effect of deficit irrigation was to increase fruit counts and return bloom whereas excess irrigation actually reduced fruit numbers per tree. This then had a knock-on effect on yield which also increased with irrigation deficit. However, the increased fruit numbers, combined with lower irrigation, reduced fruit size. In actual fact the optimum yield and size was obtained with the unaltered irrigation regimes. Negative effects of over and under irrigation were sufficient to negate any positive effects (Marsal *et al*., 2002). In a similar experiment conducted using container grown trees Marsal *et al*. (2000) demonstrated that the effects on fruit size of deficit irrigation in the period following bloom was due to smaller cell sizes in the fruit rather than effects on fruit cell numbers. Even if higher irrigation levels were applied later on in fruit development, the negative effects on cell size were never overcome. Mitchell *et al*. (1984) tested the effect of four deficit irrigation levels on fruit and tree growth. In contrast to other reports, lowering irrigation actually had no effect on fruit size or yield, although return bloom was increased. This induced varying degrees of biennial bearing in the deficit irrigated trees. In contrast Kang *et al*. (2002) testing the effect of different irrigation regimes in field grown pear trees actually found no effect on either fruit number or yield. Their conclusion was that reduced irrigation could be used to improve water use efficiency in pears. Zhao *et al*. (2007) similarly found little effect of irrigation on yield or fruit size in pears.

There is some disagreement therefore in the literature of what effect irrigation has on pear growth and yield. A number of studies report effects on return bloom, yield and fruit size. Conversely other studies show no effect of differing irrigation levels. Part of the reason for this may be the sensitivity to different irrigation systems on pears. In an experiment where extreme drought levels were tested, Proebsting and Middleton (1980) found pear trees to be less sensitive to irrigation than for example peach trees.

The other reason for these differing effects may be due to timing of applications. Pear trees follow a clearly defined pattern of development throughout the year, passing through a number of phases of development, with the potential that each could respond differently to irrigation. So whilst the data described above shows variability in the effects of irrigation, this may be connected with these differing responses to irrigation during different phases of development.

Reproductive cell division in pears lasts for around 30-40 days after full bloom (Zhang *et al*., 2006) and is accompanied by initial fruit growth. Water stress in this reproductive cell division stage does not generally affect the number of cells produced by the fruits (Marsal *et al*., 2000) but at harvest the cells in the fruits of the stressed trees tend to be smaller. This suggests that water stress during the cell division stage affects the potential size of these cells. Just following this stage, the trees enter the fruit drop phase which is increased by water stress. A greater fruit drop may have a knock on effect on fruit size whereby the lower number of fruit being produced increases the potential fruit size, negating the effect on cell division phase.

Fruit growth of apple (Lakso *et al*., 1995) and pear (Naor *et al*., 2000) both increase exponentially during the reproductive cell division stage then growth becomes linear thereafter. In many studies the post-cell-division stage, which extends up to harvest, seems less sensitive to water stress. Moderate water stress up to 102 days after full bloom has been shown to reduce canopy growth in apple (Behboudian *et al*., 1998), whereas water stress applied after this period had no effect. This is clearly because the main shoot growth period ends during July. On return bloom, similar differences have been seen. A deficit immediately following flowering created moderate water stress and resulted in a lower return bloom, whereas no reduction in return bloom was apparent in late-deficit treatments (Kilili *et al*., 1996; Behboudian *et al*., 1998).

In the project described here the effect of irrigation was tested from July onwards. This equated to 75 days after full bloom in 2009. This is after the period of initial cell division, when the fruit is swelling until harvest.

In a project to determine the long-term effect of the use of compost as a mulch in a Braeburn/Cox orchard in Kent (Carew, 2010), significant beneficial effects on fruit growth and yield have been observed of applying a composted green waste mulch. This continues on from previous WRAP funded work which showed positive effects of the use of composted green waste as mulches in a number of fruit crops. Generally all the fruit crops tested responded well, with yield increases (fruit weight per tree) in mulched blackcurrant (23%), Bramley (30%) and Conference pear (54%) compared to unmulched controls. Such increases are of economic significance to the growers and once again highlight the potential of compost mulch for improving top and soft fruit yields. These effects have been identified as being due to a combination of higher soil water content and increased nutrient availability, although recently evidence has been gathered showing that soil structure may also be improved through the use of green waste compost. The effects of compost on tree growth and yield are therefore significant and complex. Effects on soil nutrient content and microbial activity vary and the effect of compost from year to year varies. However, from work already conducted it does look like the use of green waste compost can increase yield significantly.

In the project described here the effect of composted bark mulch was tested alongside the effects of straw and black polythene mulch. The aim was to determine the benefit of these on soil moisture and whether these could be used to replace the need for irrigation in situations where it is not possible to irrigate.

Moniruzzaman *et al*. (2007) studied the effects of mulching and pruning in pear with two levels of mulching (mulched and non-mulched) combined with four levels of pruning (0, 25, 50, and 75 percent). The combination of mulching combined with 50% pruning gave the highest yield. In Norway black plastic mulch was compared with grass and herbicide strips by Mågea (1982). Young apple trees planted in soil covered by black plastic had the most vigorous growth and the highest crop. Trees in permanent grass had the lowest growth and yield. The effect of black plastic mulch on yield was due to increases in both soil temperature and moisture content. Interestingly, leaf nitrogen was initially higher in the black plastic mulch treatment but decreased later in the experiment. Chang-Zeng *et al*. (2002) likewise found fruit size to increase in straw mulched pear trees but only when the fruit number did not increase by more than 12%. Where fruit number did increase by more than this there was no increase in fruit size. This illustrates very well the problem with running experiments such as this where effects can be confounded by other effects.

The effect of both irrigation and mulches is complex and depends not only on the rate of irrigation for example, but also the timing of its application. That certain published data demonstrate significant effects of irrigation and others show no effect is important. It demonstrates the need to test the effect of irrigation under UK conditions. Mulch clearly is likely to have significant effects on growth and the project outlined aims to determine the effect of three different types of mulch – black plastic, straw and composted bark.

Materials and methods

The experiment was conducted at The Bounds, Boughton, Kent in a ‘Conference’ pear orchard planted in 1982. The soil is sandy clay loam. Whilst the farm does not have irrigation, a specific system was installed with which to run the project described here. The trees are fairly widely spaced at a spacing of 2m within the row and 3.5m between the rows. The width of the herbicide strip is 2.5m.

In March 2007, the composted bark, straw and black plastic mulch was applied to the herbicide strip in a completely randomized block arrangement. There were three levels of irrigation (No irrigation, 1” per week, Irrigation determined by EnviroSCAN data). There were four types of mulch (Composted bark, straw, black plastic and control) (Figure 1).

The composted bark was applied in a strip which covered the herbicide strip and was 2-3cm deep. The straw was applied similarly but was slightly deeper – around 5cm deep but due to the nature of the product, the depth did vary slightly. The black plastic mulch was stretched across the herbicide strip and pinned in place. All treatments were applied by hand.

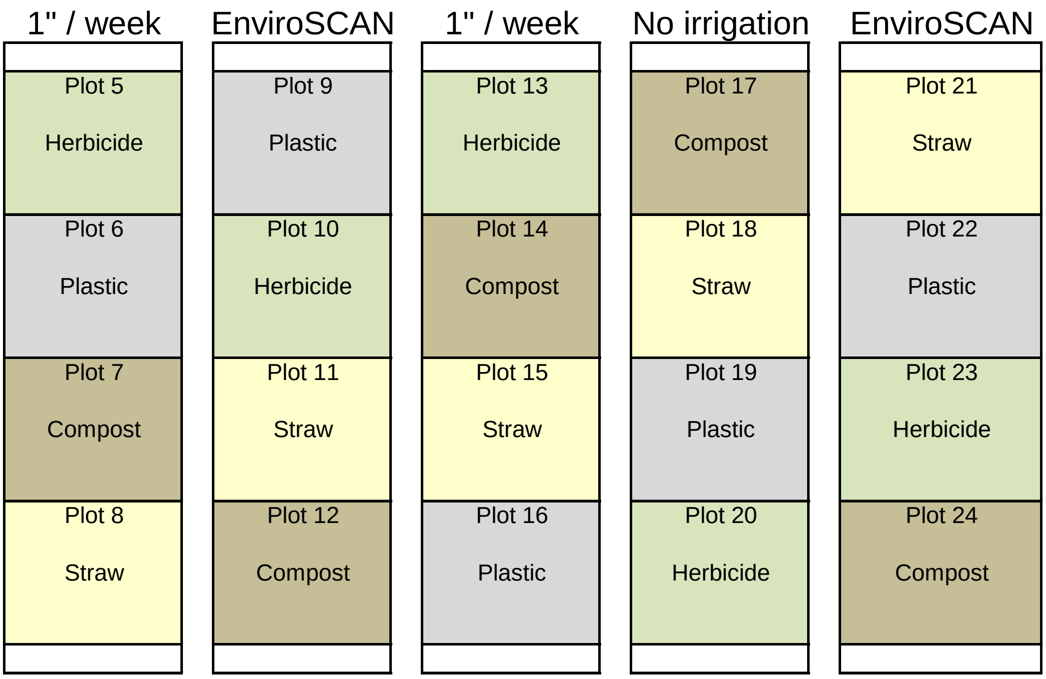

Figure 1. The completely randomized block design of the irrigation and mulch treatment combinations. Two replicate plots were included for each treatment combination.

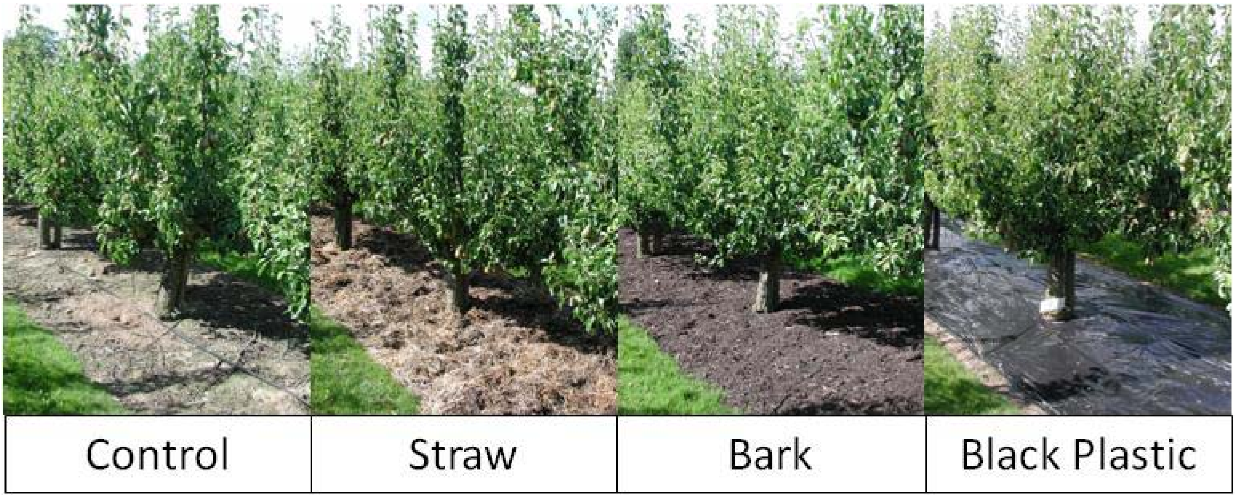

Figure 2. Photograph showing the arrangement of the compost treatments.

In addition a single line of RAM irrigation pipe was run down each length of trees in those sections to be irrigated. Different header pipes were used for each irrigation treatment so that they could be used independently. The pipes were connected to a 5m^3 aluminium water tank which was placed at the top of a hill around 100m from the trial site. This would allow gravity to force water through the irrigation lines. These were operated manually as and when required. The RAM irrigation pipe delivered water at the rate of 0.5mm per hour.

During 2007, 2008 and 2009, assessments of fruit development were made to determine the effect of the irrigation and mulch treatments. Fruit diameter of 50 fruit was measured weekly from June to September for each treatment. Final fruit number was recorded at harvest. Maturity tests were conducted with a view to determining storage potential of fruit. Fruit was then placed in commercial pear stores courtesy of Gaskains Ltd. and Adrian Scripps Ltd. In addition, soil, leaf and fruit samples were analysed to determine the impact of compost on soil fertility.

EnviroSCAN soil moisture loggers were used to determine the effect of compost on soil moisture content. The probes were placed at depths of 10, 20, 30, 40, 50, 60, 70 and 80cm and recorded the soil moisture content (mm) every 5 minutes.

ANOVA was used to determine the statistical significance of treatments and multiple range tests conducted to determine significance of individual treatment combinations.

Results

Results from 2007

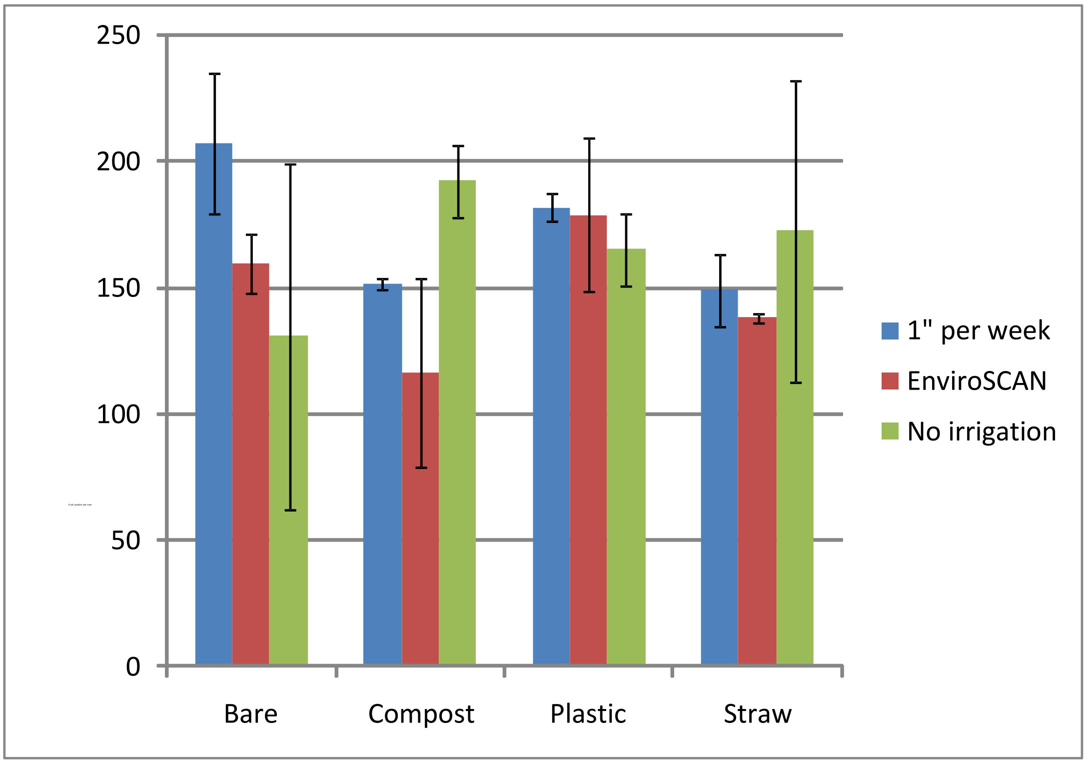

Figure 3. Fruit number per tree at harvest. Data from 2007. Standard error bars are shown.

There was no significant effect of either mulch or irrigation treatment on fruit number per tree. The variation between treatments was large and tended to obscure any effects that may have been present. For example the variation (as demonstrated by the standard error) in fruit number within the bare soil/no irrigation treatment was as much as 68 fruit per tree. For there to be significant differences between treatments, the difference in fruit number would need to be more than 100 fruit per tree, which seems unlikely. For this reason, and because there was no interaction between the two factors (irrigation and mulch treatments), the data for each factor was averaged and is shown in Figures 4 and 5.

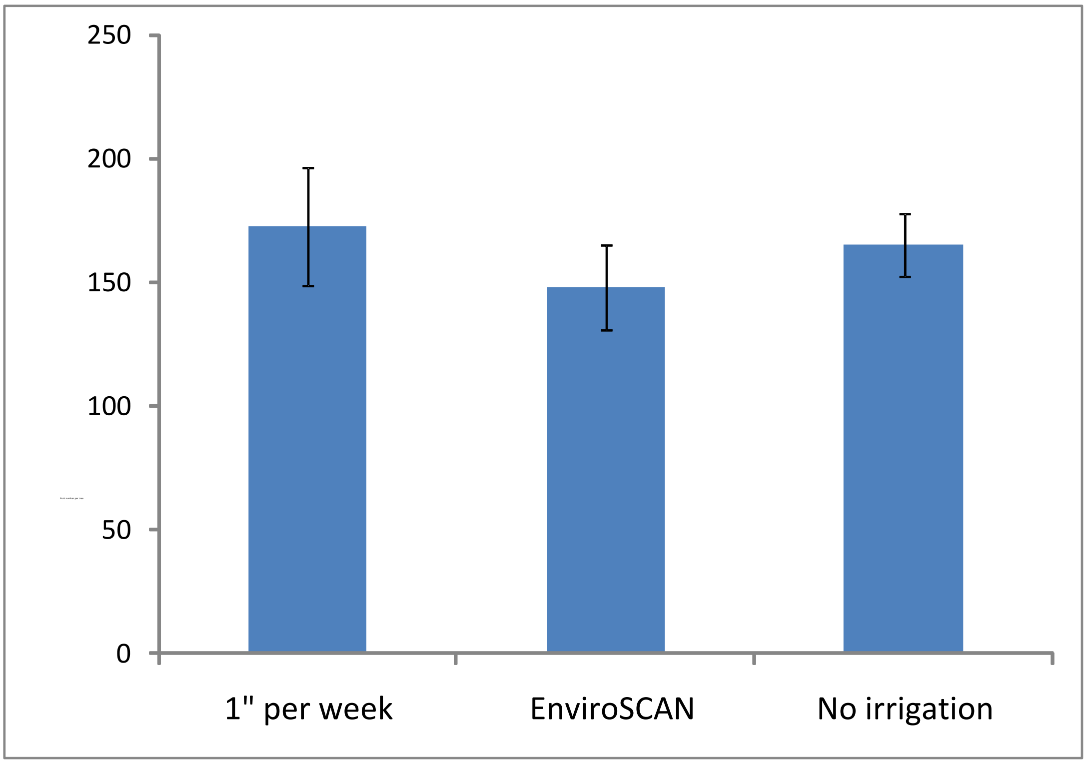

Figure 4. Fruit number per tree at harvest for the irrigation treatments. Data from 2007. There was no interaction between mulch and irrigation treatments and so averages for all irrigation treatments are given here. Standard error bars are shown.

The effect of irrigation treatment on the number of fruit produced per tree in 2007 is shown in Figure 4. There was no significant effect of irrigation treatment. The 1” per week treatment did produce slightly more fruit per tree than the other two irrigation treatments and the EnviroSCAN treatment produced slightly fewer fruit. However these differences were not significant with the differences between treatments being smaller than the variation within treatments.

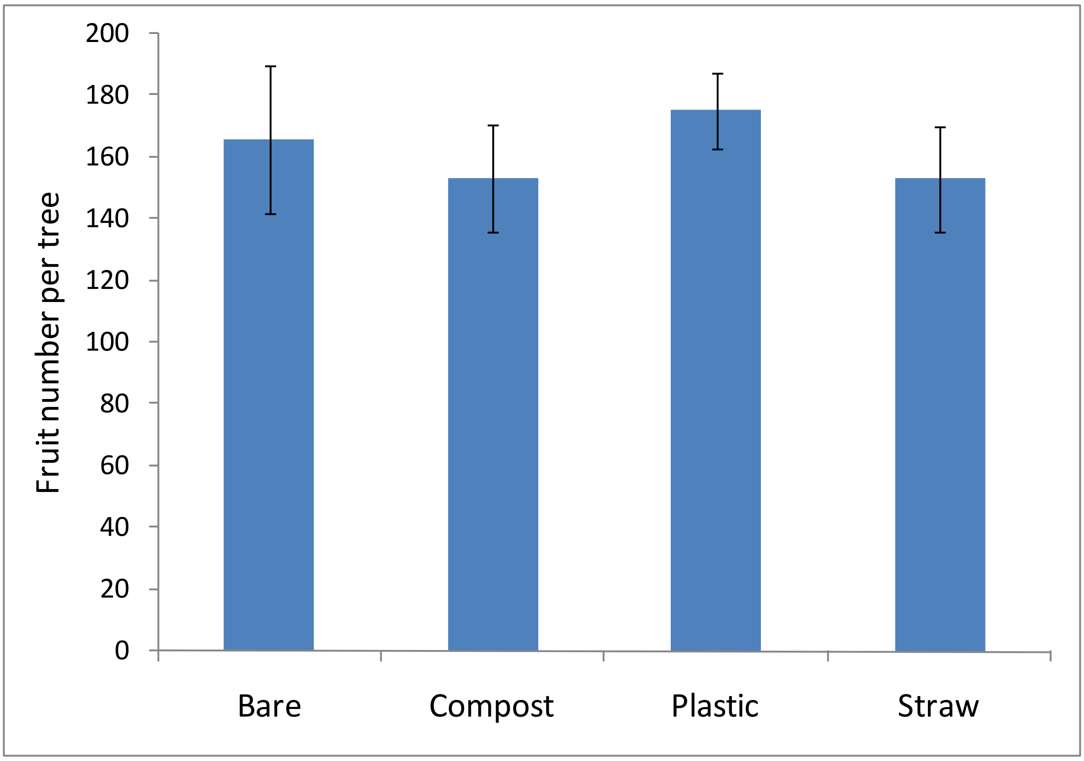

Figure 5. Fruit number per tree at harvest for the mulch treatments. Data from 2007. There was no significant interaction between mulch and irrigation treatments and so averages for all mulch treatments are given here. Standard error bars are shown.

The effect of mulch treatment on the number of fruit produced per tree in 2007 is shown in Figure 5. There was again no statistically significant effect of mulch treatment. The plastic mulch and bare soil treatments did produce slightly more fruit than the compost and straw treatments. However these differences were not significant, with the differences between treatments being smaller than the variation within treatments.

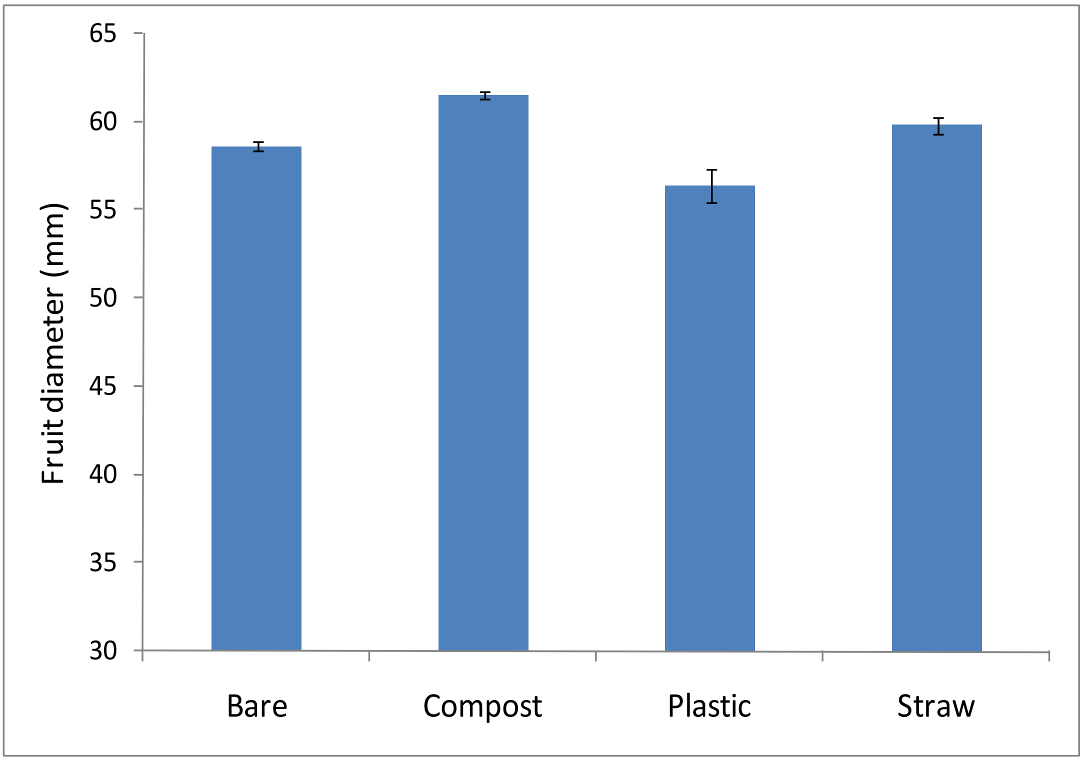

Figure 6. The effect of mulch treatment on fruit size just prior to harvest. Data from 2007. Standard error bars are shown.

There was a consistent effect of mulch treatment on fruit size which appeared to be related to the differences in soil moisture content between the mulch treatments. The compost treatment produced fruit of the largest diameter with an average size of 62mm. The straw treatment produced the fruit with the next largest diameter at 60mm. The plastic mulch treatment produced fruit with the smallest average diameter of 56mm. The bare soil treatment was intermediate between the straw and plastic mulch treatments. This tended to indicate an effect whereby the mulch treatments which maintained a higher soil moisture content produced the largest fruit. The plastic mulch treatment which prevented rainfall from reaching the soil produced the smallest fruit. It should be noted that trees in those treatments which produced the largest fruit also produced the fewest fruit (See Figure 5), which would have had an additional effect on fruit size.

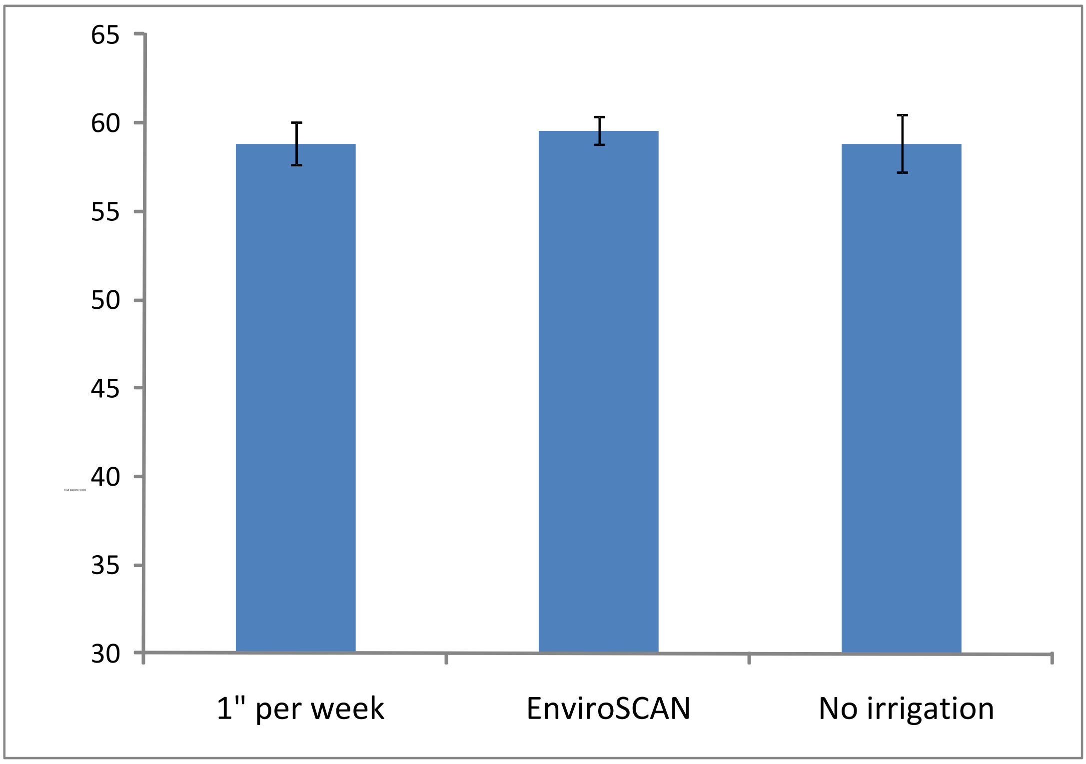

Figure 7. The effect of irrigation treatment on final fruit diameter just prior to harvest. Data from 2007. Standard error bars are shown.

There was no significant effect of mulch treatment on fruit diameter. All treatments produced fruit of similar average sizes, approximately 58mm.

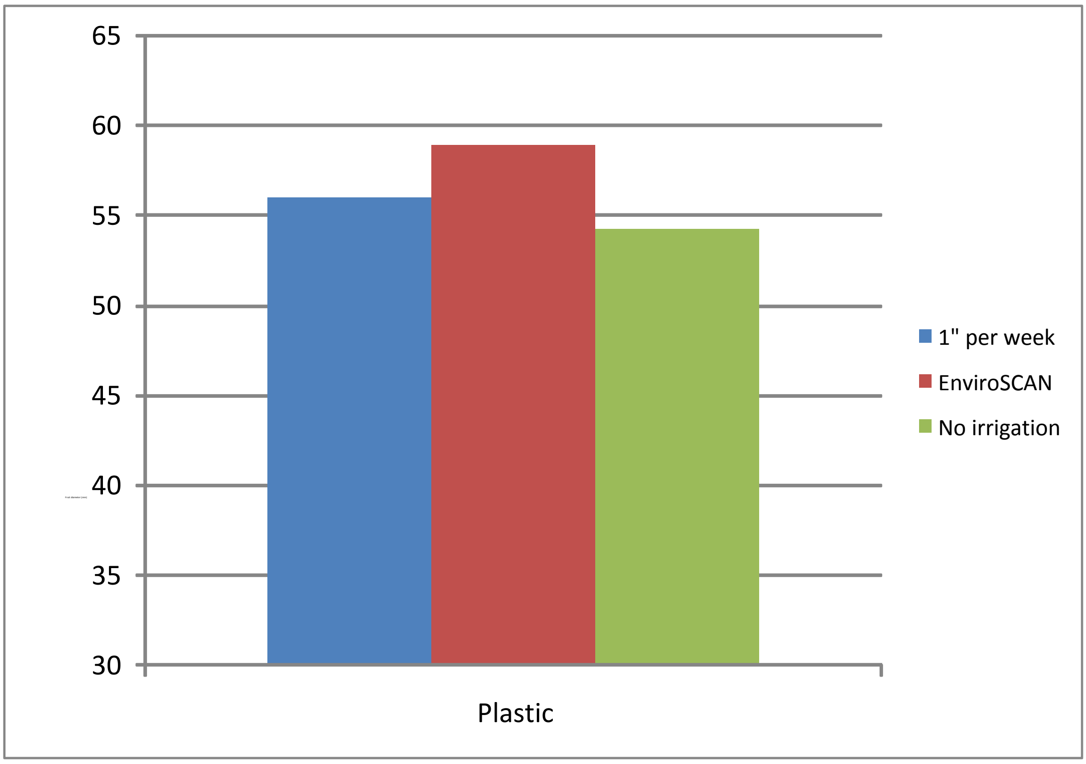

Figure 8. The effect of irrigation treatment on fruit size of trees which had been treated with plastic mulch. Data from 2007.

The effect of mulch on fruit size shown in Figure 6 seemed to indicate that the mulch treatments which increased the soil moisture content caused larger fruit to be produced. Figure 8 illustrates this point and shows the effect of irrigation on fruit size from the plastic mulch treatment. Fruit size was significantly greater in the irrigated treatments than the non-irrigated control. The difference was greatest between the EnviroSCAN and no irrigation treatments with a difference in fruit size of 4.4mm. This difference demonstrates that soil moisture did affect fruit size. Variation in other treatments seems to have obscured the effect of soil moisture on fruit size.

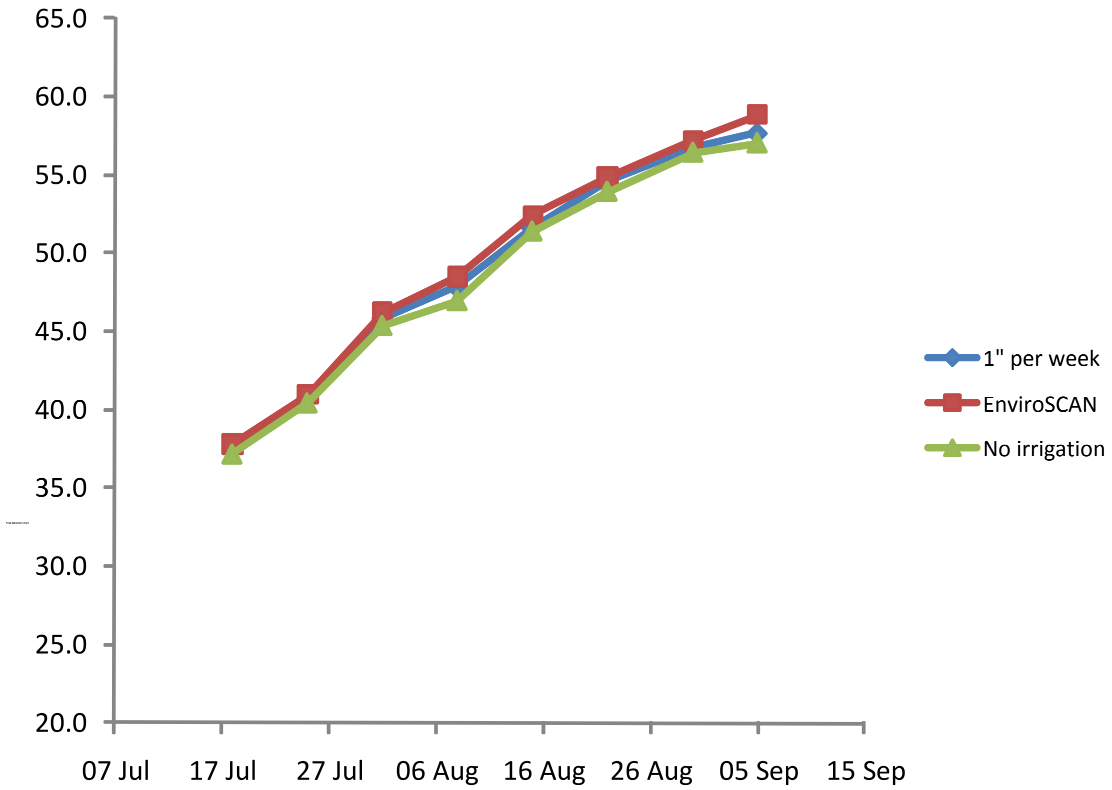

Figure 9. The effect of irrigation treatment on fruit size measured weekly during the growing season. Data from 2007.

The fruit growth curves for the irrigation treatments demonstrate that the rate of growth of the fruit was not significantly affected by irrigation treatments. Fruit diameter increased from 37mm in July at the start of the treatments to 60mm. In 2007 232mm of rain fell in the period 1st June to 31st August. In July 90mm rain fell giving the control a similar quantity of water to the 1" per week irrigation treatment. The rainfall during August was 67mm.

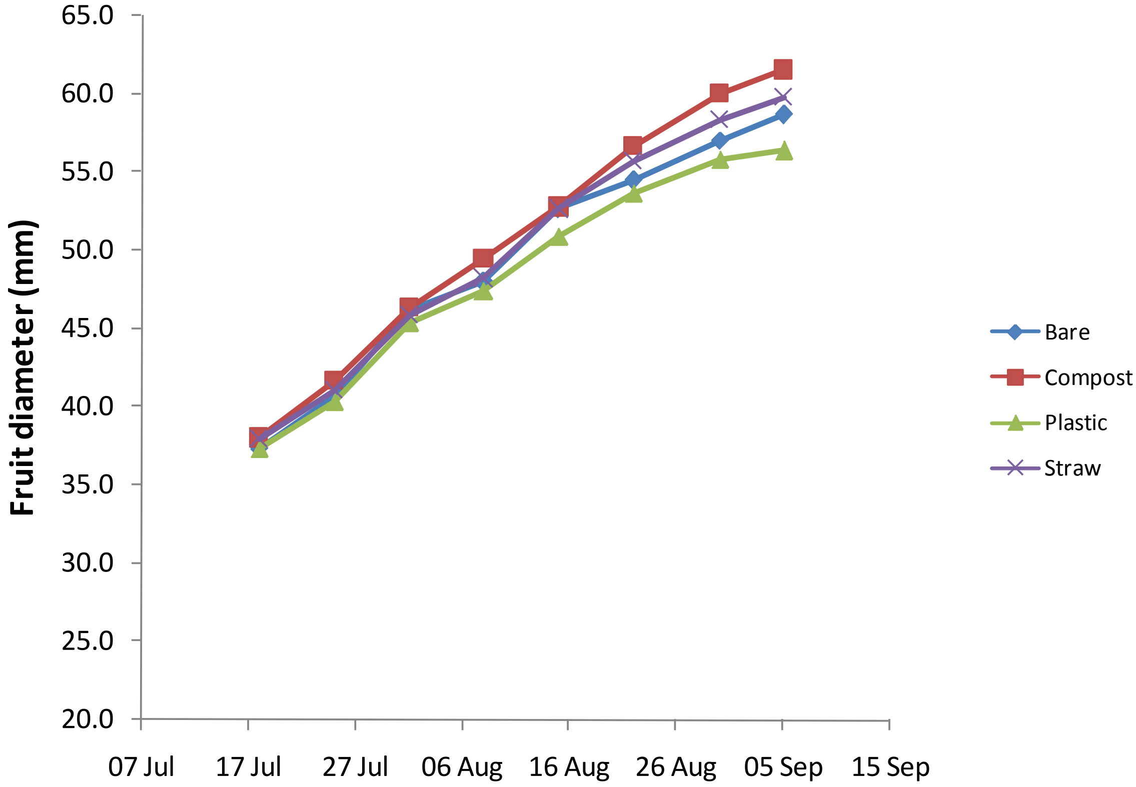

Figure 10. The effect of mulch treatment on fruit size measured weekly during the growing season. Data from 2007.

There was a significant effect of the mulch treatments on the rate of growth of fruit (P=0.026). For the first three weeks, until the end of July the treatments showed similar growth rates. However, from this point onwards the growth of the fruit was significantly affected by mulch treatment. The compost caused fruit to continue growth at a similar rate during the next four weeks. However, following this, growth did slow towards the end of the growing season in September. The straw and bare soil treatments caused the next greatest fruit size with growth slowing in late August. The plastic mulch treatment caused the smallest fruit to be produced with growth slowing at the end of July. This suggests that up to this point soil moisture was not limiting but following this point, the soil moisture levels started to reduce fruit growth.

Table 1. The effect of mulch treatment on dry leaf nutrient analysis results. Leaves were collected during August and analysed using an acid extraction method. Data is given in mg/kg. Data from 2007.

Mulch	N	P	K	Mg	Ca
Bare soil	2.04	0.12	0.82	0.43	2.50
Compost	2.10	0.13	0.93	0.45	2.81
Plastic mulch	2.08	0.13	0.95	0.42	2.36
Straw	2.03	0.13	0.92	0.44	2.61

Clear differences in leaf analysis caused by the mulch treatments are shown in Table 1. Nitrogen was greatest in the compost treatment and least in the straw treatment. The immobilization of nitrogen that occurs when straw decomposes is significant and clearly here this has had an effect on leaf nitrogen. Composted green waste is known to have high potassium content and so it is unsurprising that leaf analysis shows an increase in leaf potassium here in the compost treatment. What is perhaps more surprising is the higher potassium content of leaves from the plastic mulch treatment. This may be related to leaf calcium and magnesium. Lime was applied to the field by the grower and this contained both magnesium and calcium. As a result, we see significantly lower magnesium and calcium content of leaves in the plastic mulch treatment and higher levels in the other three mulch treatments. This would have had a subsequent effect on leaf potassium caused by the antagonistic relationship between potassium and magnesium/calcium uptake.

Table 2. Fruit analysis taken just prior to harvest averaged over the different irrigation treatments. Data is given as mg/100g fresh weight. Data from 2007.

Mulch	N	P	K	Mg	Ca	K:Ca
Bare soil	43.3	10.4	126.7	6.3	9.8	12.9
Compost	45.7	10.7	126.7	6.3	10.6	12.1
Plastic mulch	42.0	10.1	120.0	6.1	9.7	12.5
Straw	47.0	10.4	127.3	6.3	9.6	13.4

Whilst fruit nitrogen was higher in the compost treatment than the plastic mulch or bare soil treatments, the straw treatment caused a higher fruit nitrogen content than any other treatment. This is the opposite of the effect of treatment on leaf nitrogen content where straw caused the lowest nitrogen level. In general the differences in fruit nutrient content were less significant than the effects on leaf nutrient content. This may have been because of differences in fruit size caused by the treatments. The fruit mineral content did not limit the ability of the fruit to store under commercial conditions.

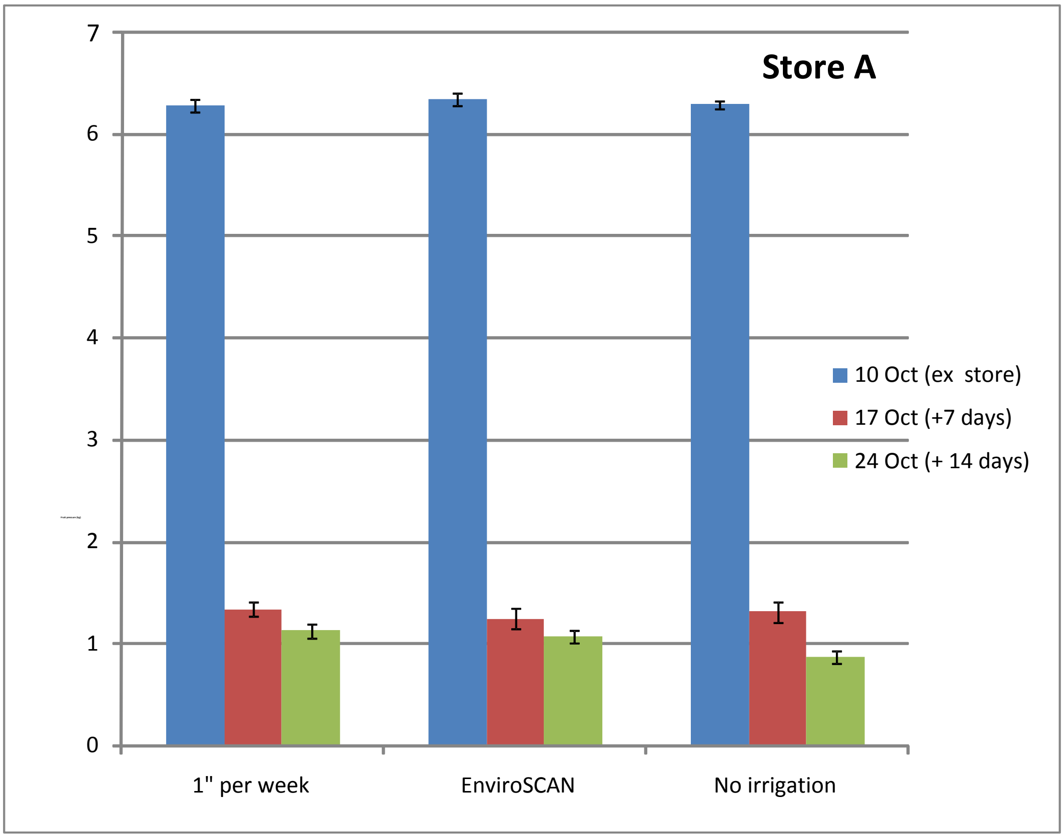

Figure 11. The effect of irrigation on fruit storage life as recorded by fruit firmness (pressure)from store. Data for 2007 from Store A. Standard error bars are shown.

One of the aims of this project was to determine whether the use of irrigation would have detrimental effects on fruit storage life. To determine this, fruit pressures were recorded following removal from store on 10th October. There was no effect of irrigation treatment either when the fruit was removed from store or following either one or two weeks shelf life testing (P=0.93). There was also no effect of mulch treatment on fruit pressures following removal from store (P=0.50) – data not shown.

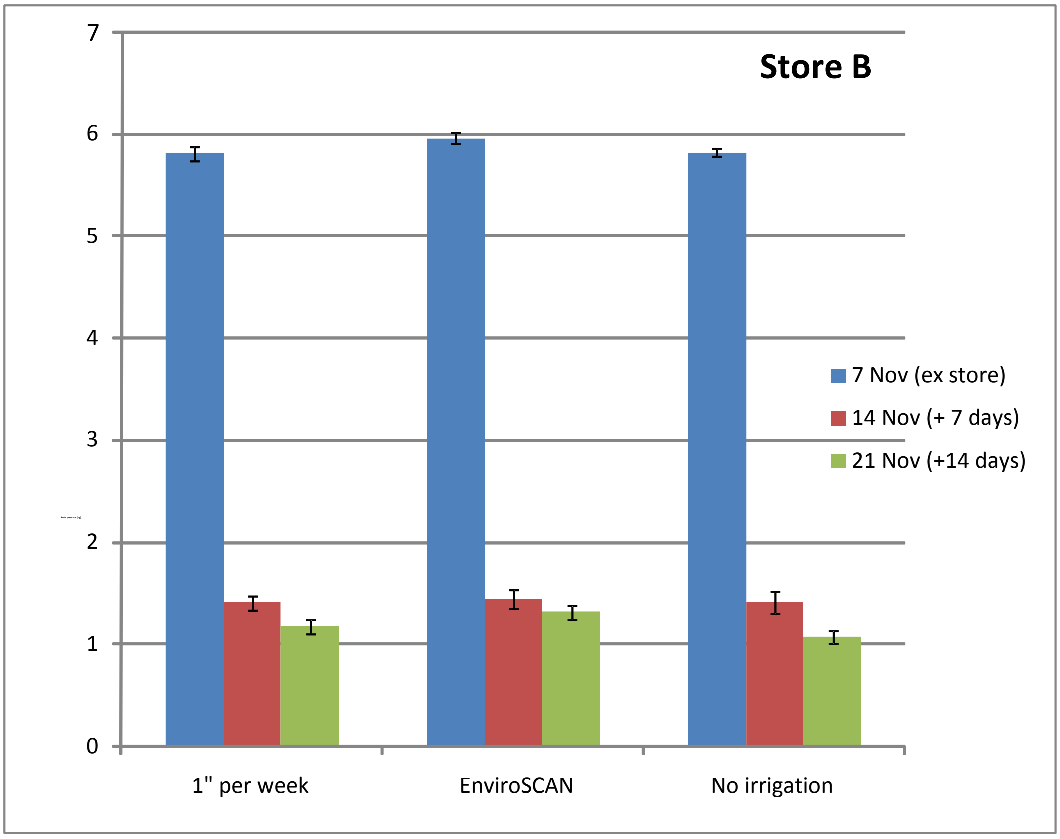

Figure 12. The effect of irrigation on fruit storage life as recorded by fruit firmness (pressure)from store. Data for 2007 from Store B. Standard error bars are shown.

Figure 12 shows the effect of irrigation treatment on the pressure of fruit taken from store B on 7th November 2007 and then again after 1 and 2 weeks shelf life. The fruit pressure decreased from just less than 6kg on removal from store to 1.4kg after 1 week's shelf life and then dropped slightly again after the second week's shelf life. However there was no effect of irrigation treatment on the fruit pressures.

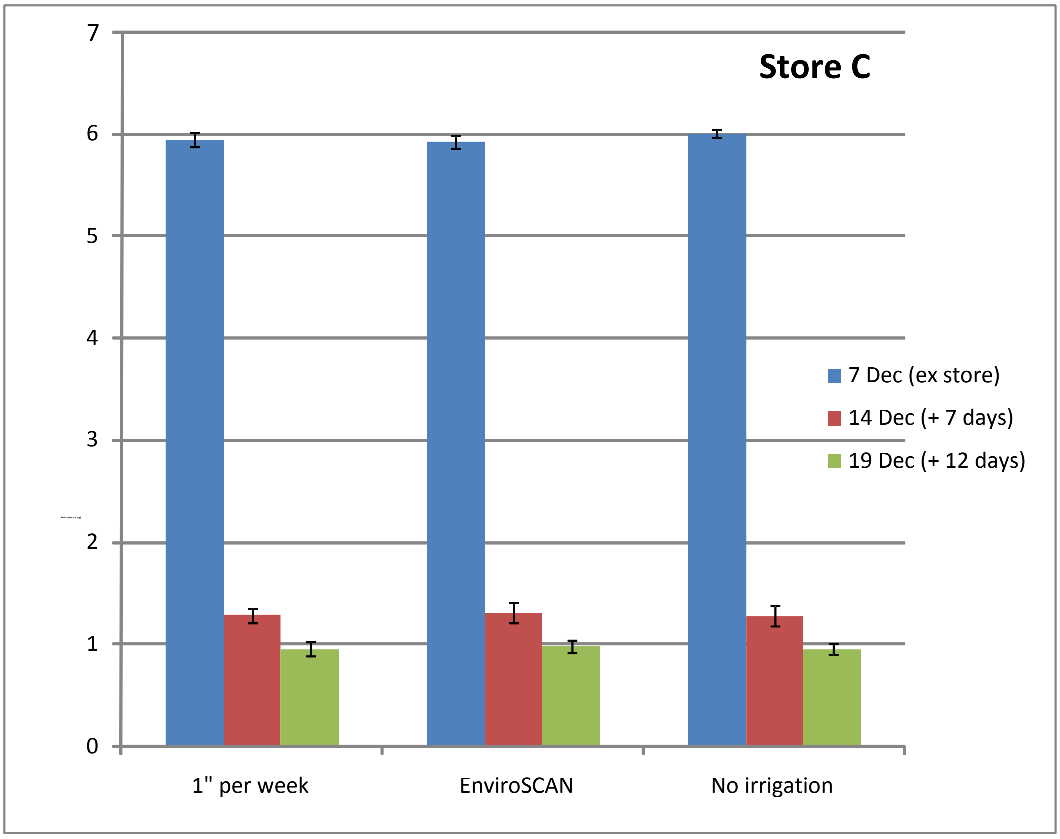

Figure 13. The effect of irrigation on fruit storage life as recorded by fruit firmness (pressure)from store. Data for 2007 for fruit removed from store C on 7th December 2007. Standard error bars are shown.

Figure 13 shows the effect of irrigation treatment on fruit pressure for the third store where the fruit was removed on 7th December. Storage of fruit until December again resulted in no significant effects of irrigation on fruit pressures either immediately following removal from store or after one or two weeks shelf life (Mulch P=0.99; Irrigation P=0.92). Fruit pressures on removal from store were just less than 6kg, falling to 0.9kg after two week's shelf life.

Results from 2008

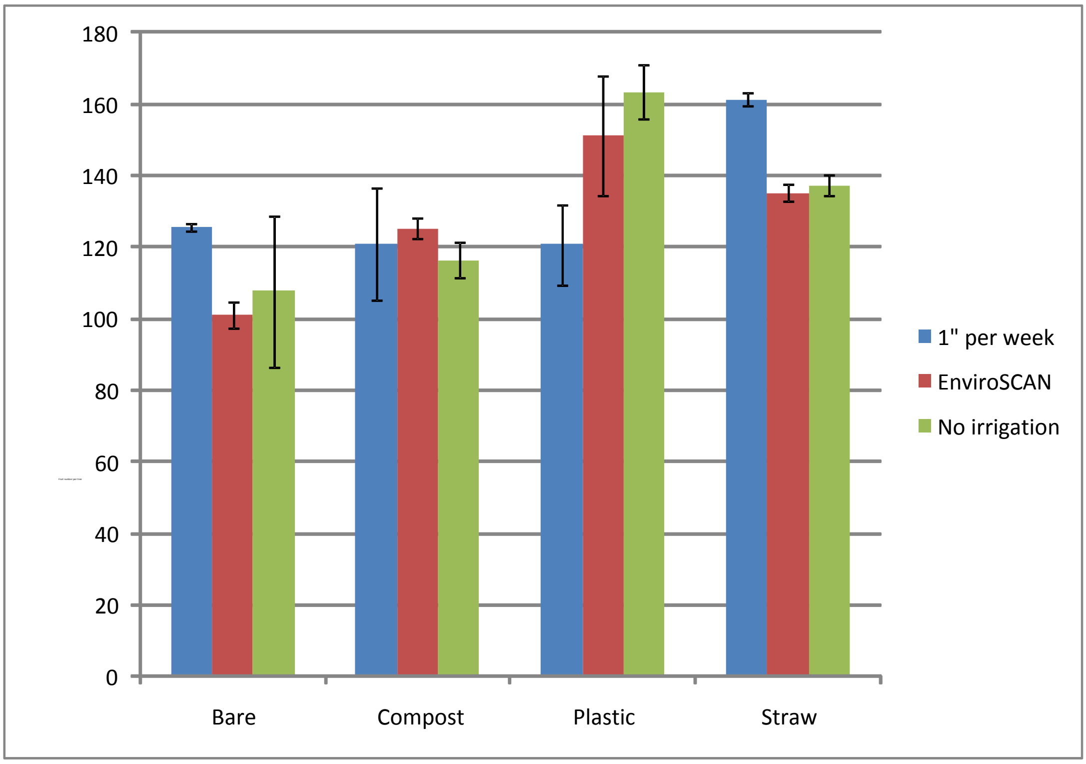

Figure 14. Fruit number per tree at harvest. Data from 2008. Standard error bars are shown.

There was no significant effect of either mulch (P=0.60) or irrigation (P=0.62) treatment on fruit number per tree. The interaction between mulch and irrigation treatments was again not significant. The variation between treatments again was large but generally less than in 2007. Fruit number per tree ranged from 100 and 160. Because there was no interaction between the two factors (Irrigation and Mulch) the data for each factor was averaged and is shown in Figures 15 and 16.

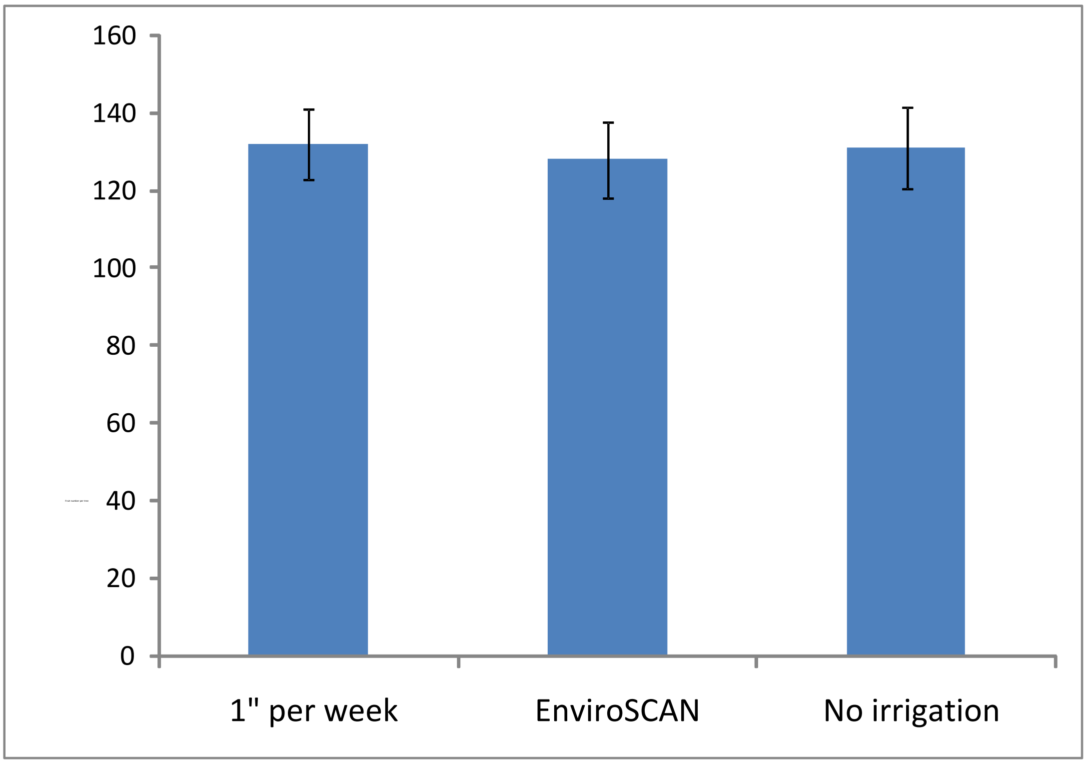

Figure 15. Fruit number per tree at harvest for the irrigation treatments. Data from 2008. There was no interaction between mulch and irrigation treatments and so averages for all irrigation treatments are given here. Standard error bars are shown.

There was no effect of irrigation treatment on fruit number per tree in 2008. All treatments produced approximately 130 fruit per tree.

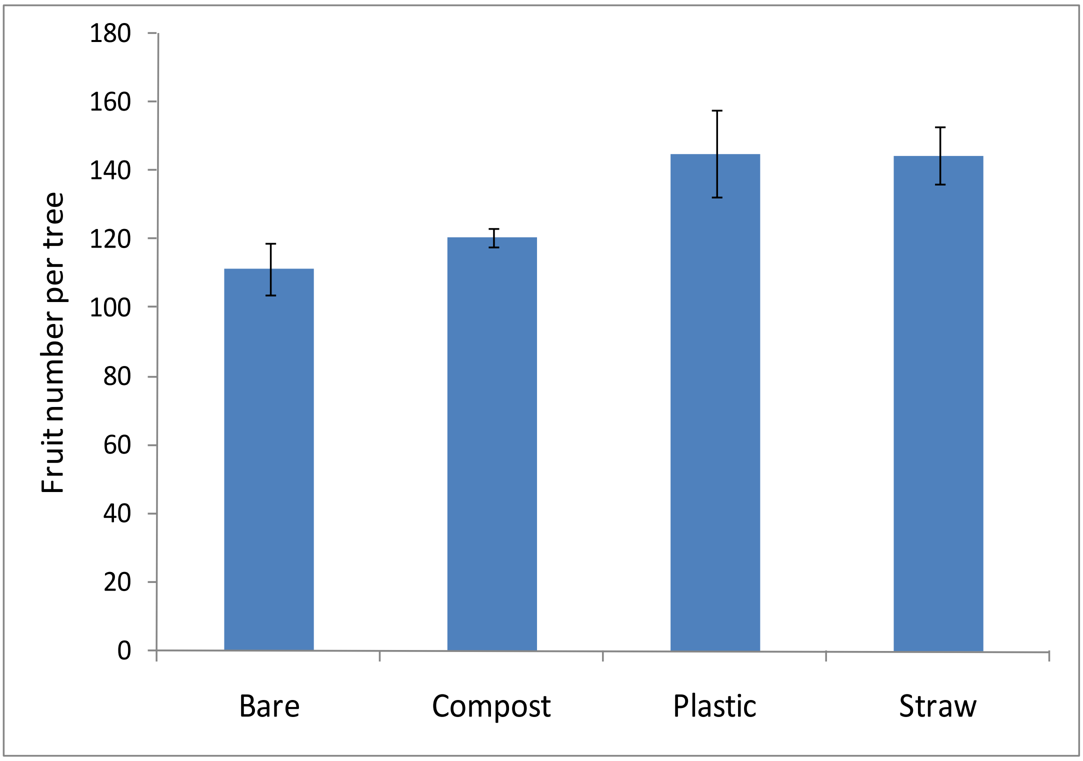

Figure 16. Fruit number per tree at harvest for the mulch treatments. Data from 2007. There was no interaction between mulch and irrigation treatments and so averages for all mulch treatments are given here. Standard error bars are shown.

Whilst the overall effect of mulch was not significant, there were individual differences between mulch treatments in 2008. The plastic mulch and straw treatments did produce slightly more fruit than the bare soil and compost treatments. In the case of the plastic mulch treatment, this was primarily due to a greater number of fruit in the no irrigation treatment whereas in the straw treatment this was primarily due to a high fruit number in the 1" per week treatment.

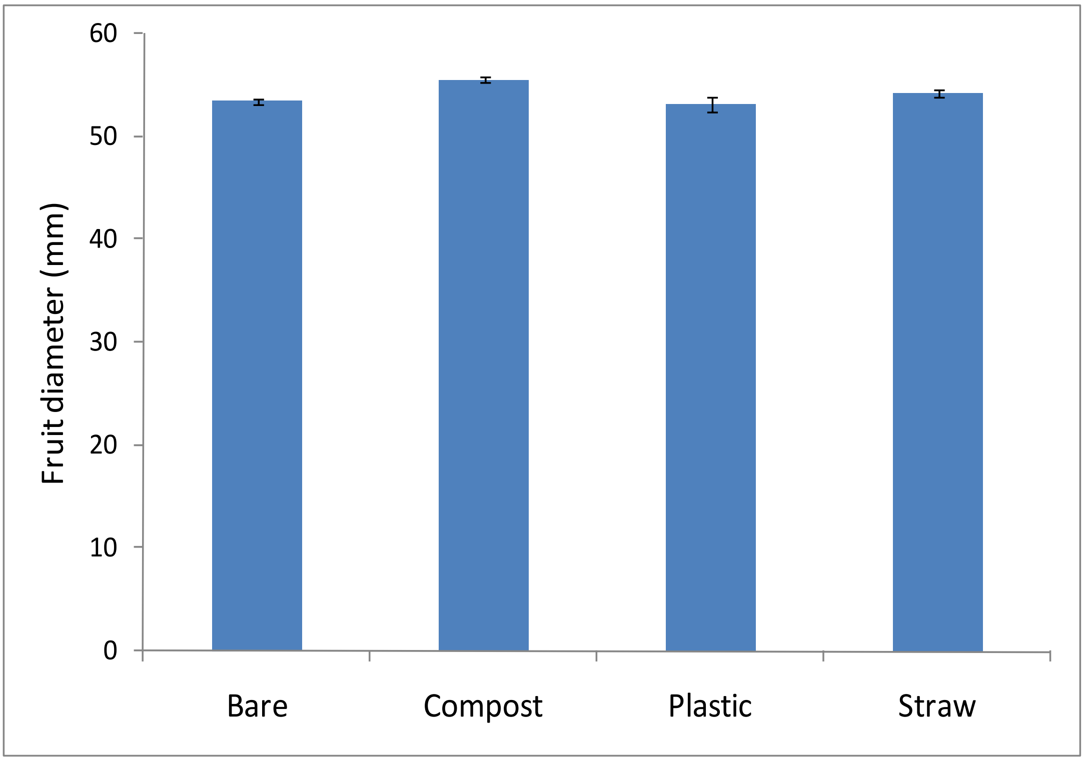

Figure 17. The effect of mulch treatment on fruit size just prior to harvest. Data from 2008. Standard error bars are shown.

In 2007, the effect of mulch treatment on fruit size was significant, with larger fruit size in the compost and straw mulch treatments. In 2008, the same effect is seen with the compost treatment again giving fruit with the largest diameter. The plastic mulch treatment again caused the smallest fruit to be produced. It seems likely that this is because the effect of the compost and straw mulches was to improve soil moisture content whereas the plastic mulch reduced soil moisture content. The differences were smaller though in 2008 than in 2007.

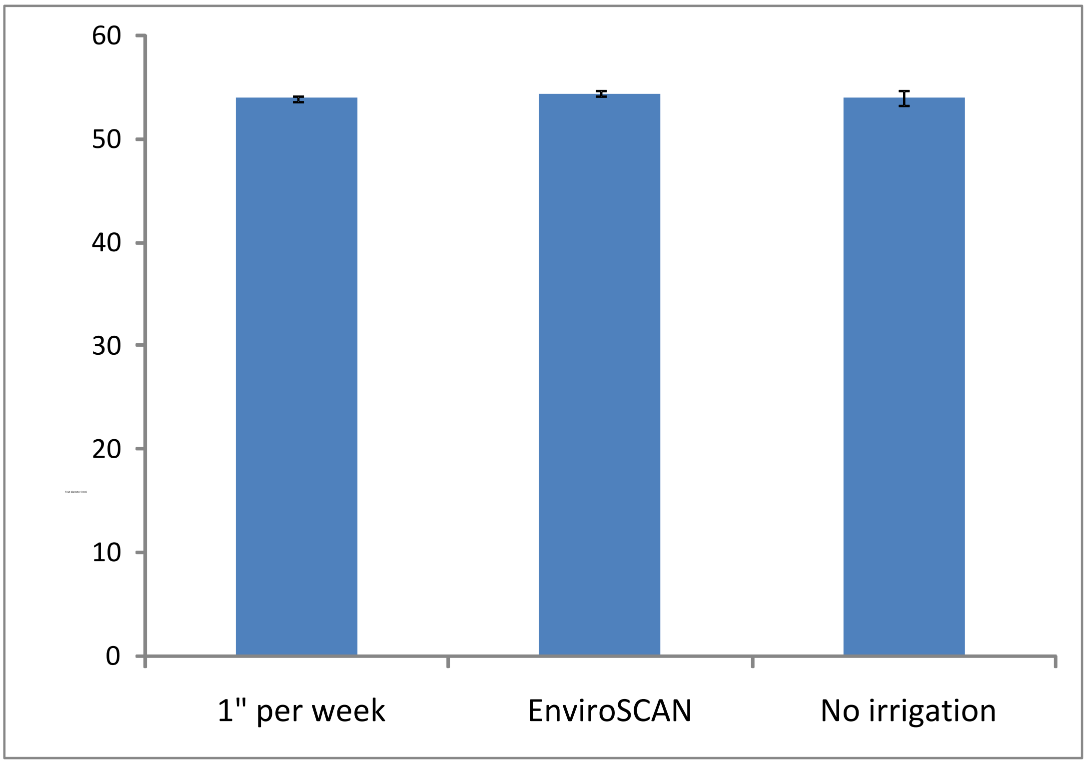

Figure 18. The effect of irrigation treatment on fruit size just prior to harvest. Data from 2008. Standard error bars are shown.

In 2007 there was no effect of irrigation treatment on fruit size and this was again the case in 2008. The average fruit diameter differed by 0.4mm between treatments.

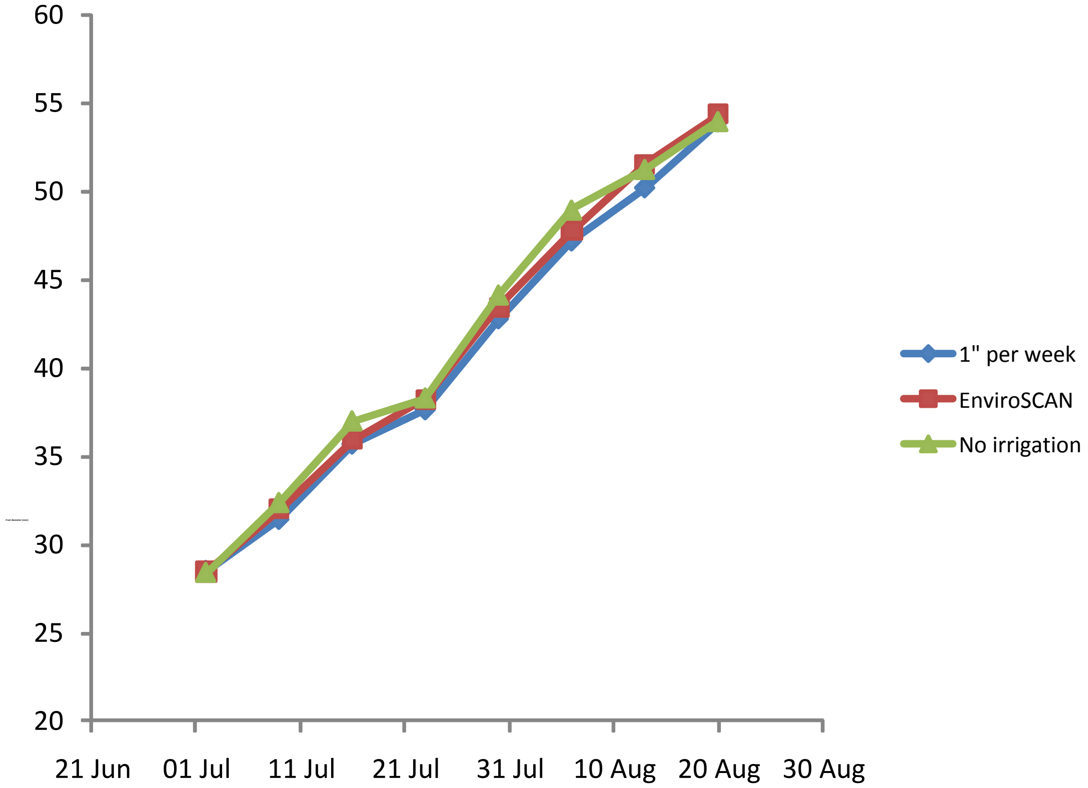

Figure 19. The effect of irrigation treatment on fruit size measured weekly during the growing season. Data from 2008.

Figure 19 shows the effect of irrigation treatment on fruit diameter from the irrigation treatments measured weekly from July to August. There was no significant difference in the rate of fruit growth between treatments.

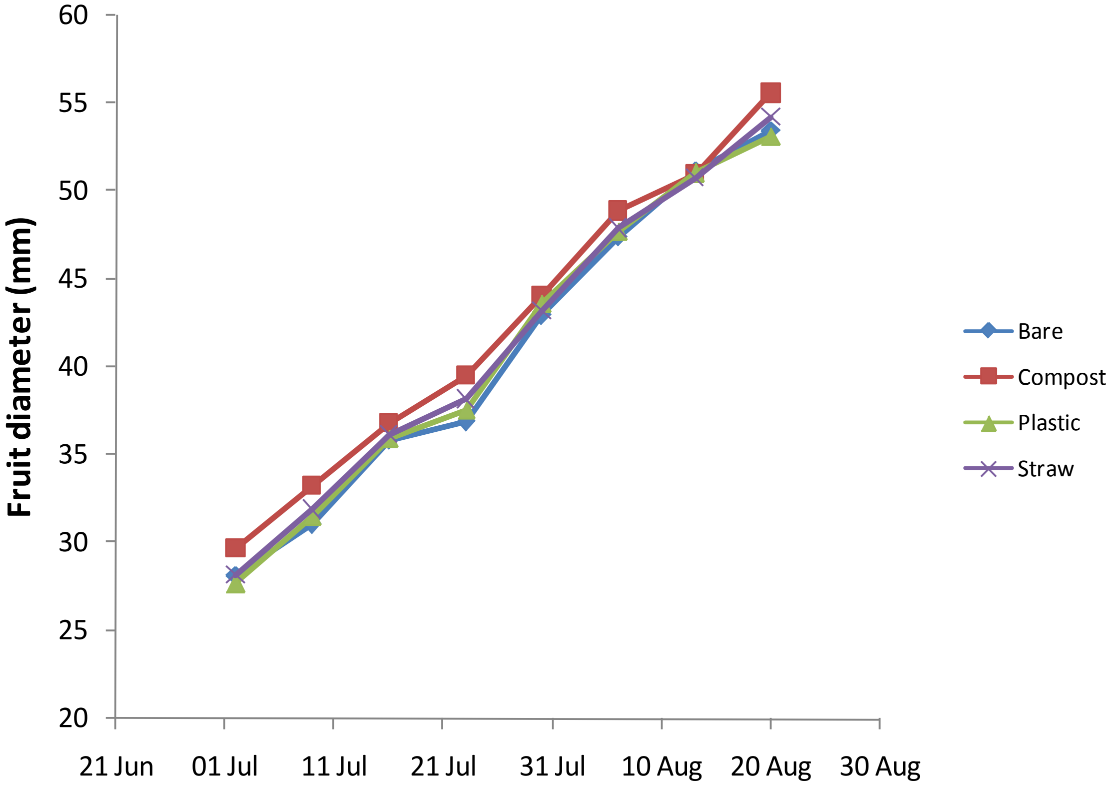

Figure 20. The effect of mulch treatment on fruit size measured weekly during the growing season. Data from 2008.

In 2007 the compost treatment produced fruit with the largest diameter. This was again the case in 2008. However, in 2007, the differences between treatments started to become apparent at the end of July and up to this point the fruit sizes were similar. In 2008, a different pattern is apparent. Fruit size of the compost treatment was greater throughout the duration of the project, possibly indicating a continuation of treatment effects from 2007 or the effect of rainfall which was around 50% less in 2008 than 2007 during the period from June to August.

Table 3. The effect of mulch treatment on dry leaf nutrient analysis results. Leaves were collected during August and analysed using an acid extraction method. Data is given in mg/kg. Data from 2008.

Mulch	N	P	K	Mg	Ca	K:CA
Bare soil	1.97	0.14	1.03	0.41	2.51	79
Compost	1.97	0.13	1.14	0.41	2.71	81
Plastic mulch	1.95	0.12	0.95	0.43	2.51	85
Straw	1.89	0.13	1.12	0.39	2.35	85

In 2007, the mulch treatments caused differences in leaf nutrient content and in particular in leaf nitrogen and potassium. In 2008 similar differences were seen. Leaf nitrogen was reduced by the straw treatment. As straw decomposed, nitrogen was immobilized and caused a reduction in soil nitrogen. This had a knock-on effect on leaf nitrogen which was lowest in the straw treatment. Potassium was again greatest in the compost and straw treatments. Both compost and straw contain significant concentrations of potassium and so given this, it is perhaps unsurprising that these treatments affected the potassium content.

Table 4. Fruit analysis taken just prior to harvest averaged over the different irrigation treatments. Data is given in mg/100g fresh weight. Data from 2008.

Mulch	N	P	K	Mg	Ca	K:CA
Bare soil	54.3	11.2	136.3	6.7	9.9	13.9
Compost	56.0	11.6	143.7	6.9	10.0	14.5
Plastic mulch	58.3	11.4	139.7	7.0	10.8	13.0
Straw	52.7	10.8	136.3	6.6	10.0	13.7

The straw treatment also caused the lowest fruit nitrogen content with the compost treatment causing the greatest fruit nitrogen. Potassium again was highest in the compost treatment as it had been for the leaf potassium. This was different to 2007 where differences in leaf potassium and nitrogen were not mirrored by differences in fruit nitrogen and potassium. It is possible that the effect of treatments over two years caused this effect.

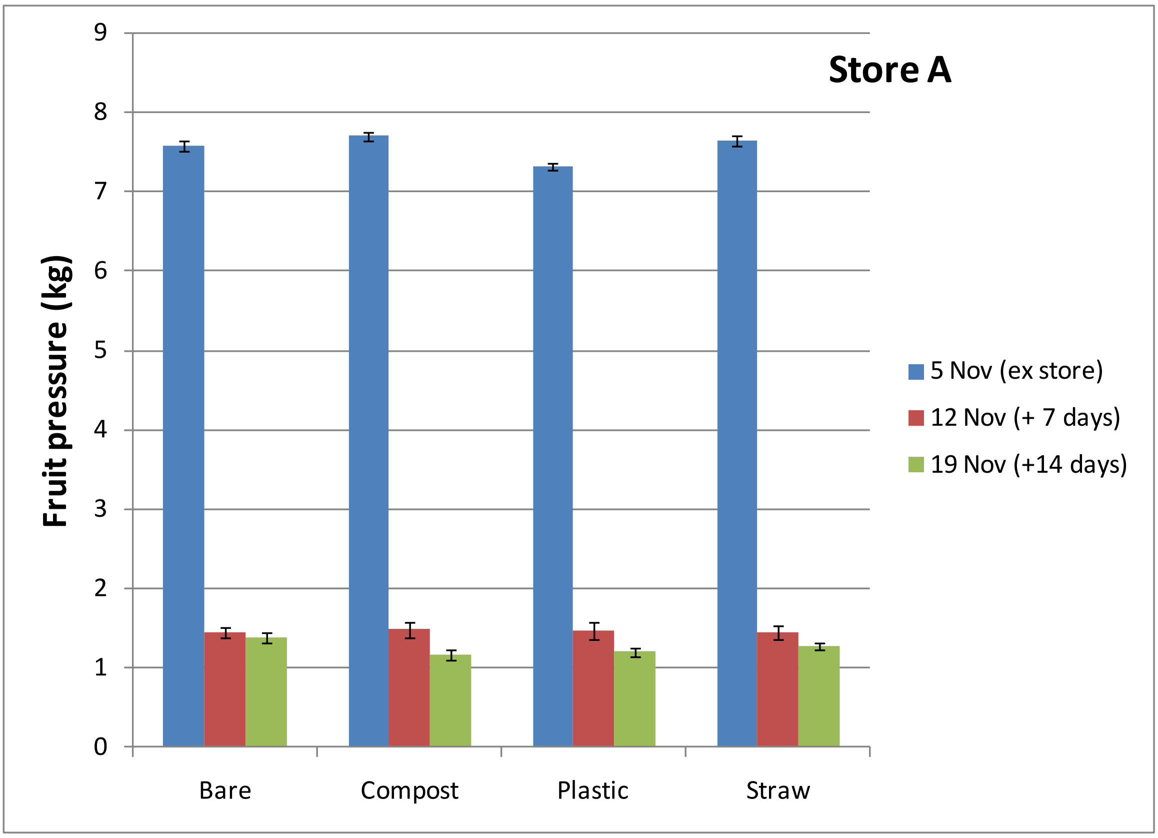

Figure 21. The effect of mulch treatment on fruit storage life as recorded by fruit firmness (pressure) from store. Data for 2008 for fruit removed from Store A on 5th November. Standard error bars are shown.

There was no significant effect of irrigation treatment on fruit pressures from the first store removal date at the start of November although the 1" per week did cause a slightly lower pressure immediately following removal from store. However, this difference was not significant.

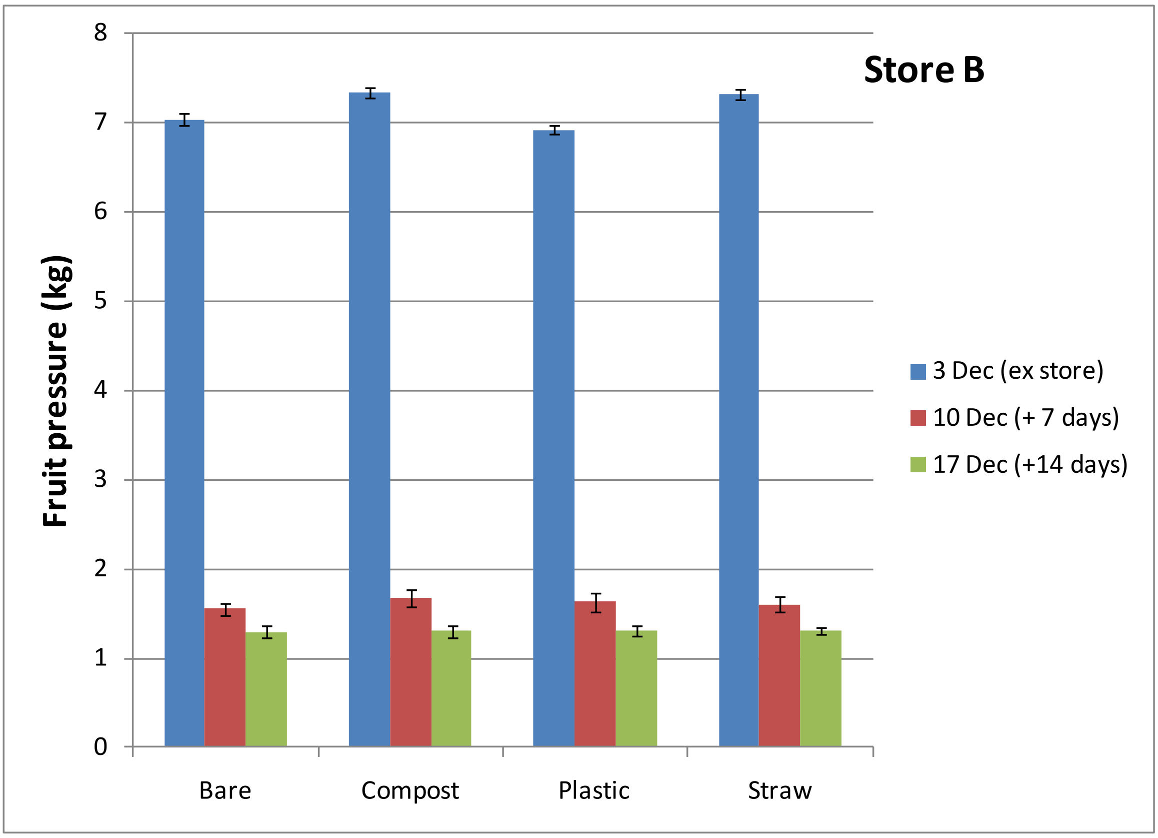

Figure 22. The effect of mulch treatment on fruit storage life as recorded by fruit firmness (pressure) from store. Data for 2008 for fruit removed from Store B on 3rd December. Standard error bars are shown.

After a further month in store the fruit pressures had reduced from 7.2 down to just less than 7kg. Again there was no consistent, significant effect of irrigation treatment on fruit pressures, either immediately following removal from store or during the two weeks shelf life following this.

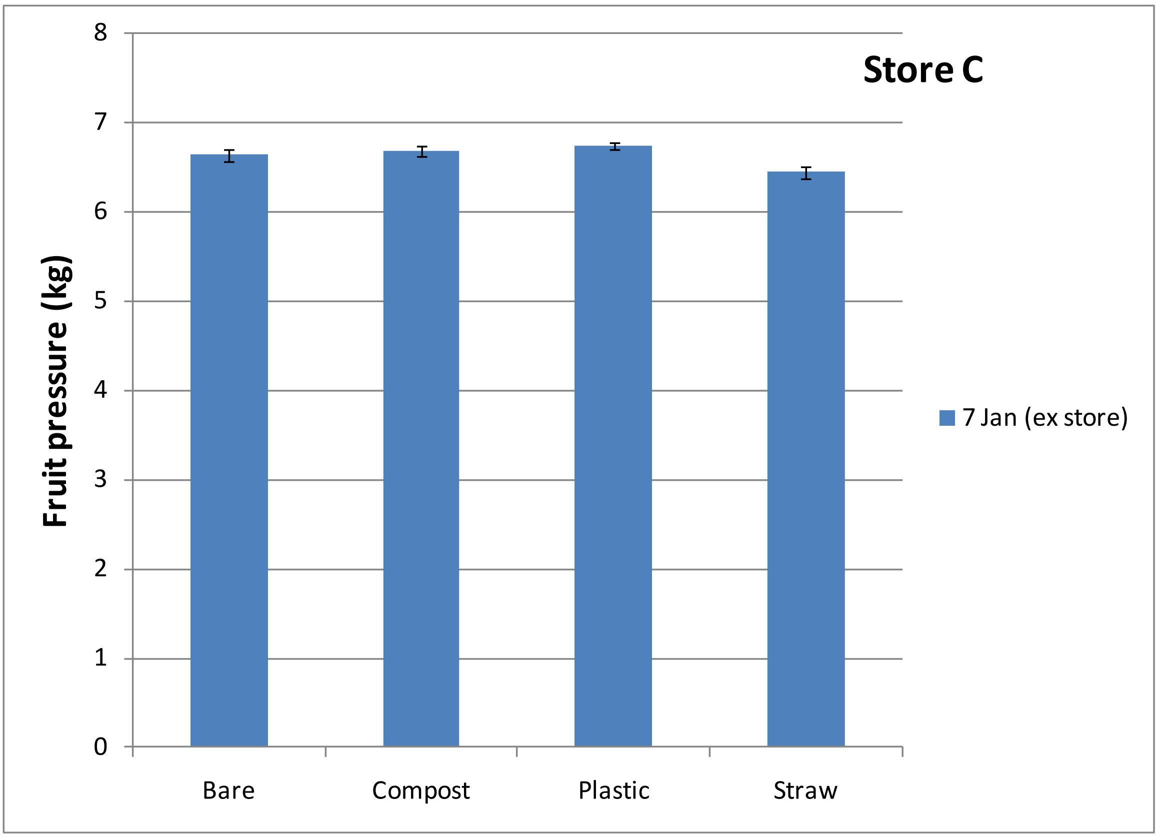

Figure 23. The effect of mulch treatment on fruit storage life as recorded by fruit firmness (pressure) from store. Data for 2008 for fruit removed from Store C on 7th January. Standard error bars are shown.

The final date at which fruit was removed from store was in January and again showed no effect of irrigation treatment. Whilst the fruit from the EnviroSCAN treatment did have slightly higher fruit pressures, this was not significant. Overall therefore, on no date were significant differences between treatments seen.

Results from 2009

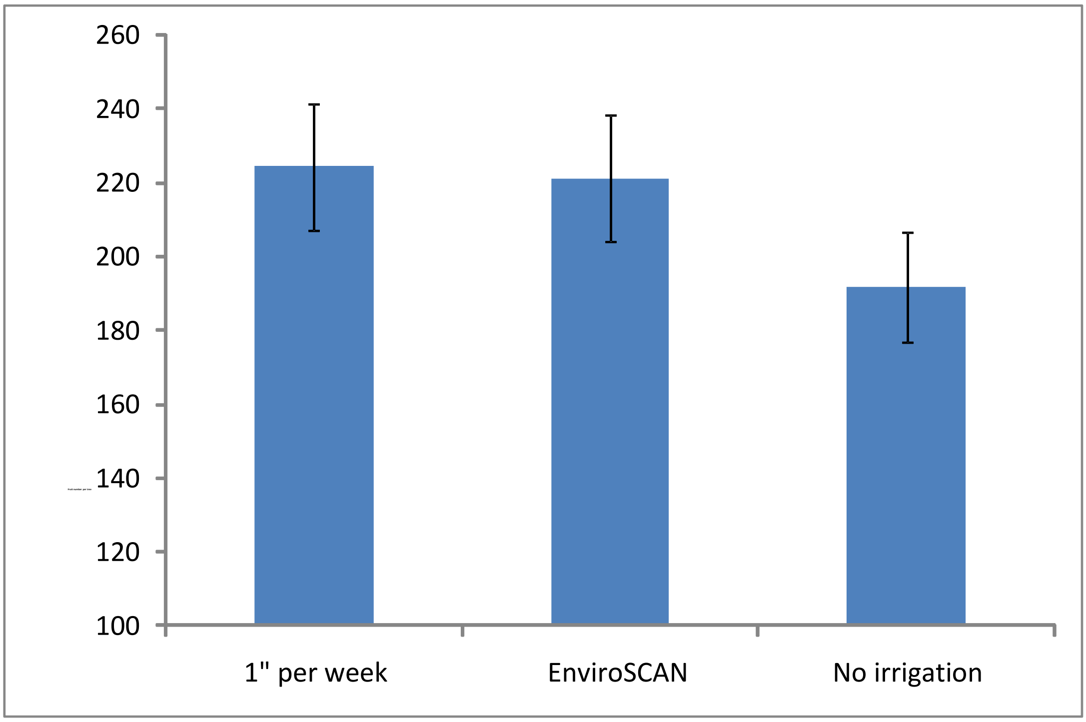

Figure 24. Fruit number per tree at harvest for the irrigation treatments. Data from 2009. There was no interaction between mulch and irrigation treatments and so averages for all mulch treatments are given here. Standard error bars are shown.

The effect of irrigation treatment on fruit number was significant in 2009. Fruit number was generally much greater in 2009 than in 2008 and 2007 which may explain the greater effect of irrigation. Those trees receiving no irrigation produced around 35 fewer fruit per tree than those which did receive irrigation. Whilst the greatest number of fruit were produced by trees in the 1" per week irrigation treatment, the difference between the two irrigation treatments were not significant. This may have been an additive effect of treatment over the duration of the experiment.

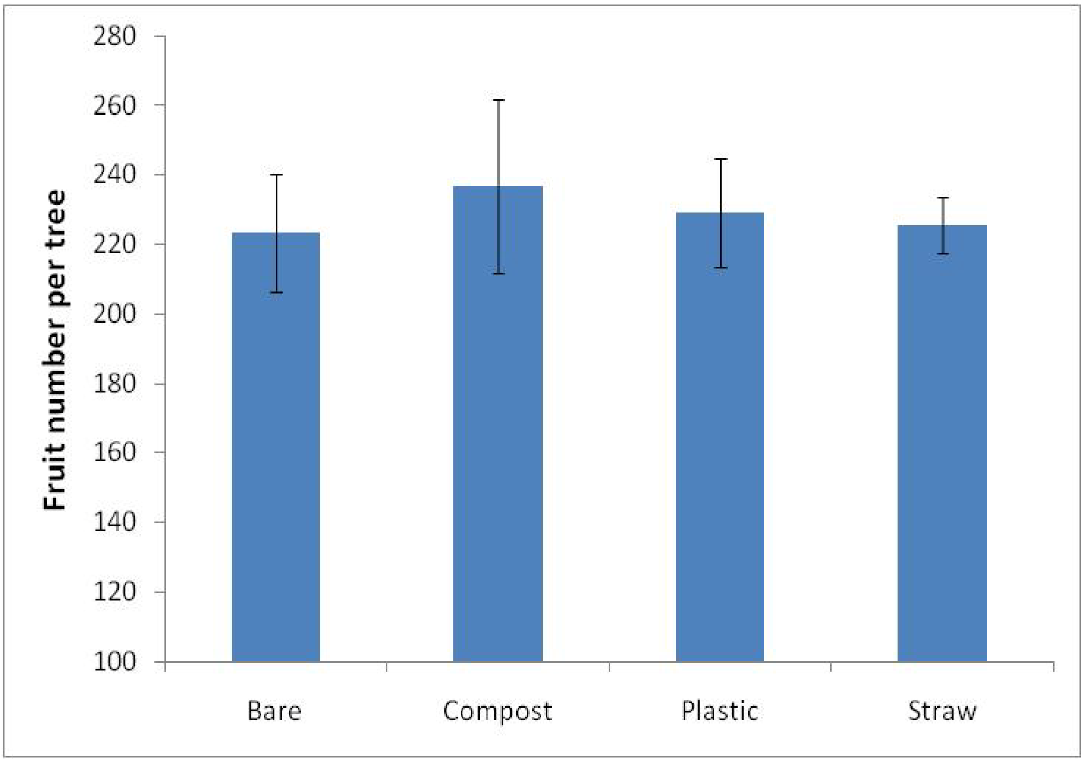

Figure 25. Fruit number per tree at harvest for the mulch treatments. Data from 2009. There was no interaction between mulch and irrigation treatments and so averages for all irrigation treatments are given here. Standard error bars are shown.

Fruit number per tree varied between 220 and 240 fruit per tree in the compost treatments. The greatest number of fruit was produced by the compost treated trees and the fewest fruit produced by the bare soil treatment. However these differences were not significant due to the tree to tree variation.

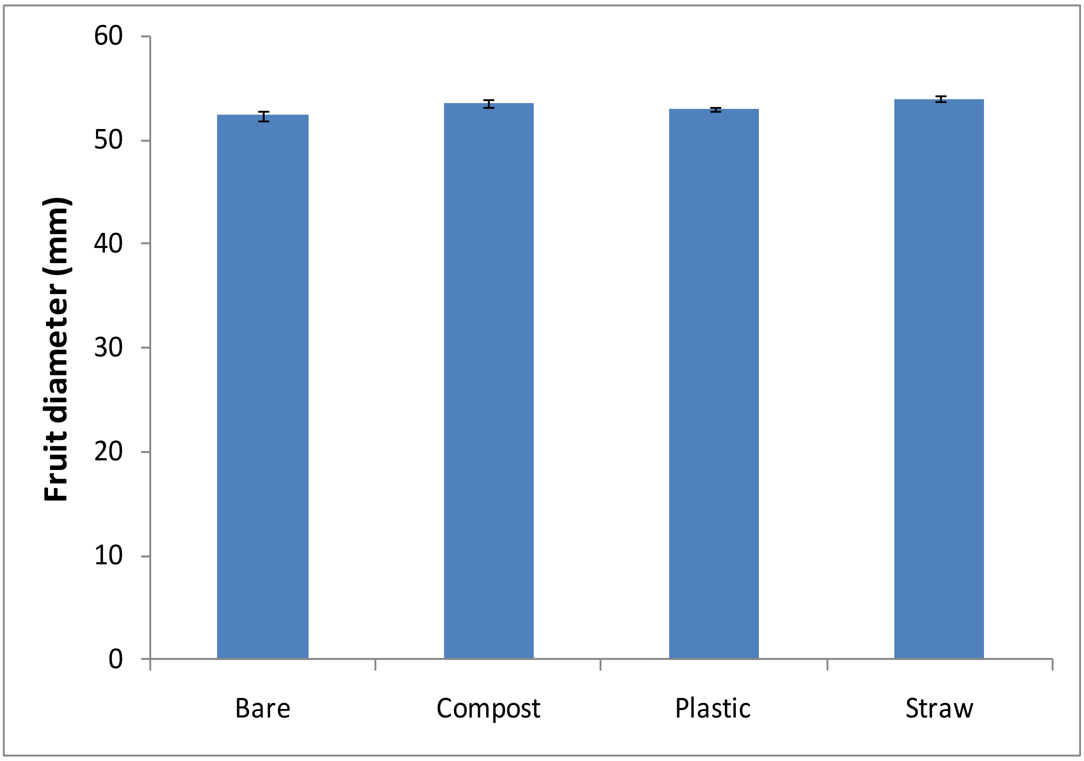

Figure 26. The effect of mulch treatment on fruit size just prior to harvest. Data from 2009. Standard error bars are shown.

In 2009 the compost and straw treatments caused the greatest fruit size compared to the plastic mulch and bare soil treatments. This effect was likely a result of the higher soil moisture contents under these mulches. This was similar to 2007 and 2008 and indicates a small but consistent effect of mulch treatment on fruit size.

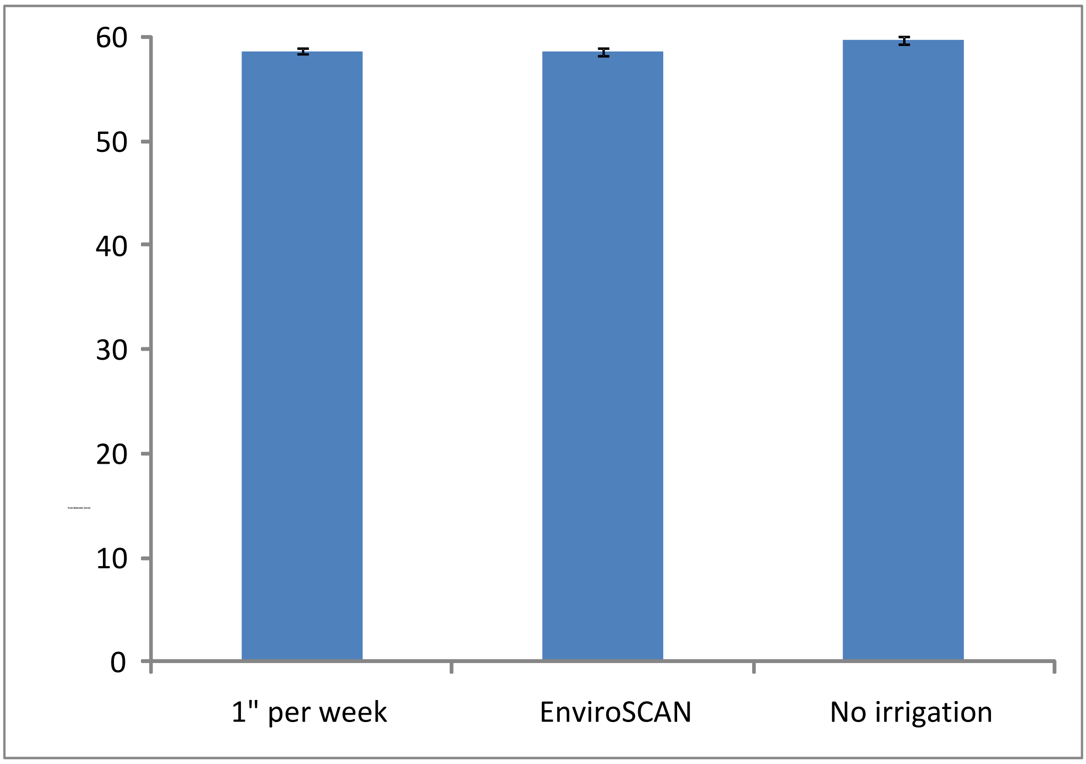

Figure 27. The effect of irrigation treatment on fruit size just prior to harvest. Data from 2009. Standard error bars are shown.

There was no significant effect of irrigation treatment on fruit size in 2009. This is consistent with results from 2007 and 2008 where there were also no effects seen. Fruit size differed between 58.6mm and 59.2mm in the three treatments.

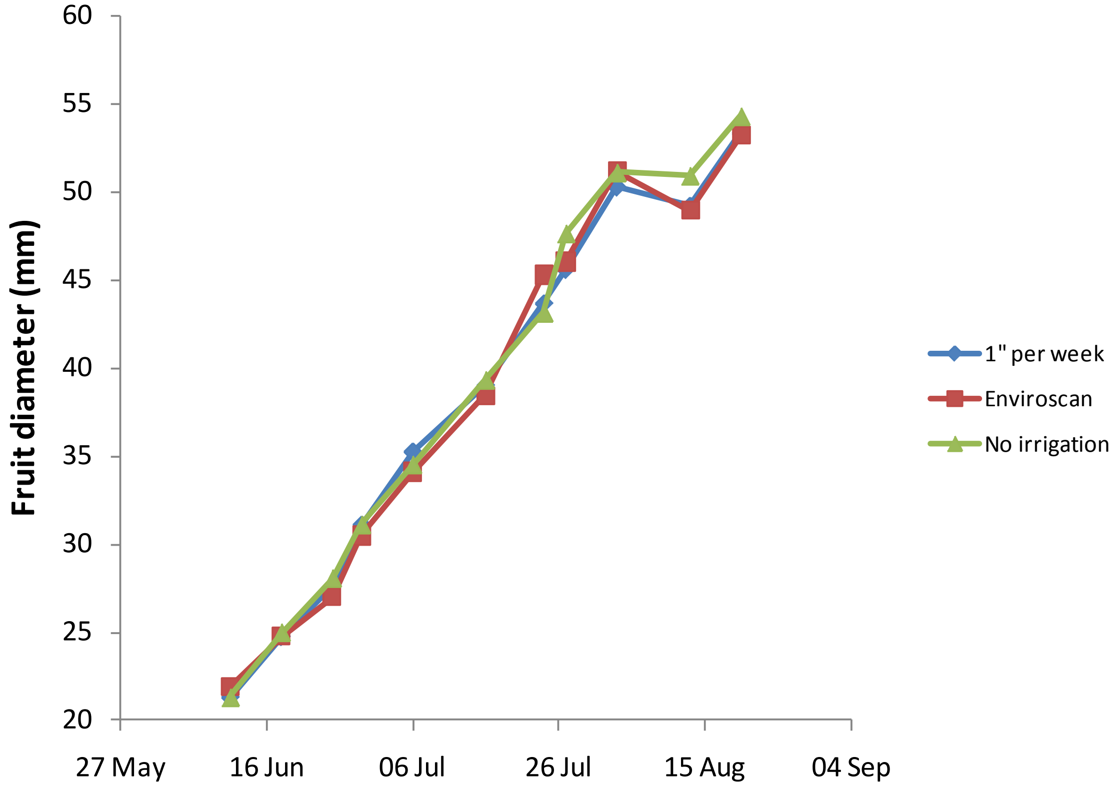

Figure 28. The effect of irrigation treatment on fruit size measured weekly during the growing season. Data from 2009.

Figure 28 shows the effect of irrigation treatment on average fruit diameter throughout the course of the experiment during 2009. Towards the end of the season larger fruit were harvested by the grower resulting in an initial decline in fruit size just prior to the end of the season. However, it can still be seen that there was no effect of irrigation effect on the rate of growth of fruit during the season.

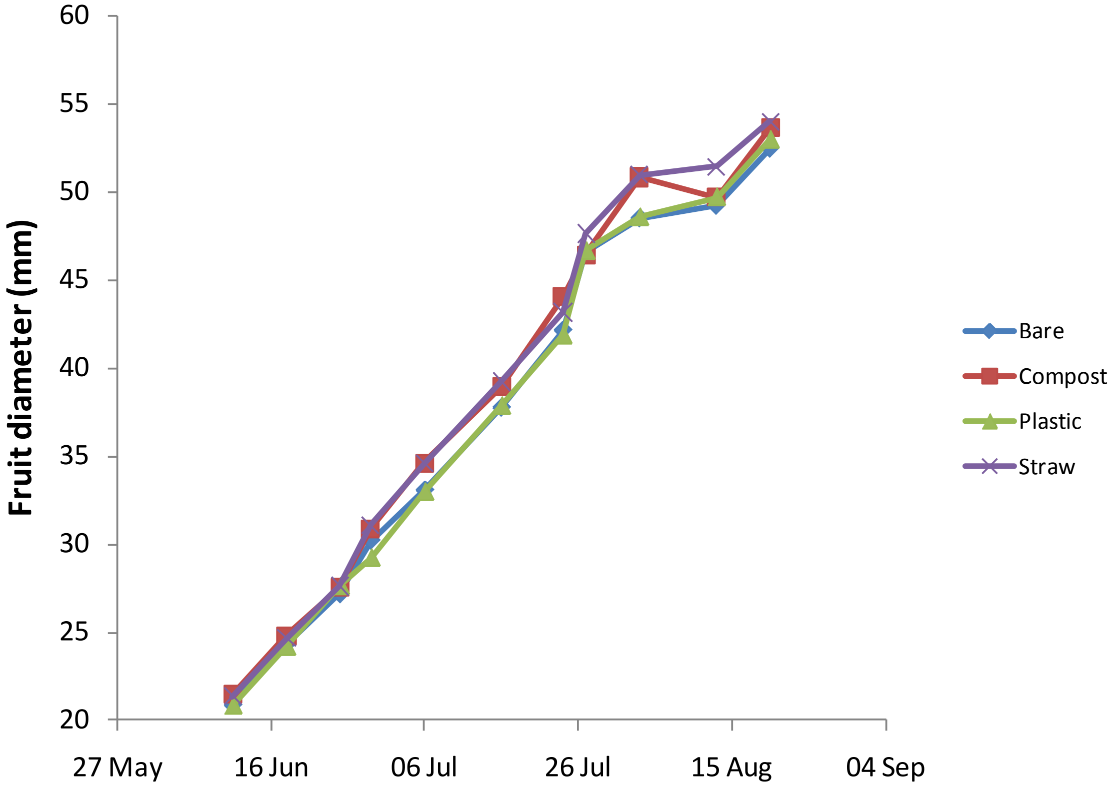

Figure 29. The effect of mulch treatment on fruit size measured weekly during the growing season. Data from 2009.

Throughout the duration of the season the compost and straw treatments caused a slightly greater average fruit size than the bare soil and plastic mulch treatments. Whilst towards the end of the season those larger fruit were harvested by the grower the effect of treatment prior to this was consistent with previous years.

Table 5. The effect of mulch treatment on dry leaf nutrient analysis results. Leaves were collected during August and analysed using an acid extraction method. Data is given in mg/kg. Data from 2009.

Mulch	N	P	K	Mg	Ca
Bare soil	2.03	0.13	0.95	0.43	2.52
Compost	2.15	0.14	1.08	0.44	2.74
Plastic mulch	2.10	0.14	0.96	0.47	2.51
Straw	2.01	0.13	1.04	0.42	2.51

In 2009, the mulch treatments caused differences in leaf nutrient content and in particular in the leaf nitrogen and potassium. In both 2007 and 2008 similar differences were seen. Leaf nitrogen was reduced by the straw treatment particularly compared to the compost treatment due to the straw decomposition causing nitrogen to be immobilized, resulting in a reduction in soil nitrogen. This has had a knock-on effect on leaf nitrogen, which is lowest in the straw treatment. Potassium is again greatest in the compost and straw treatments. Green waste compost in particular contains high concentrations of potassium, which is clearly causing a higher leaf potassium level. Interestingly the leaf calcium is highest in the compost.

Table 6. Fruit analysis taken just prior to harvest averaged over the different irrigation treatments. Data is given mg/100g fresh weight. Data from 2009.

Mulch	N	P	K	Mg	Ca
Bare soil	45.2	9.8	125.2	5.8	8.2
Compost	48.1	10.4	146.8	6.2	8.0
Plastic mulch	43.2	9.4	125.6	5.7	8.5
Straw	48.8	10.1	134.7	6.2	8.0

The compost and straw treatments caused the highest fruit nitrogen content once again. Phosphate content and potassium was highest in the compost treatment but also relatively high in the straw treatment.

Table 7. The effect of mulch treatment on soil nutrient analysis results. Samples were taken in April 2009 from a depth of 0 to 15cm. Compost and straw were removed prior to the sample being taken.

	Bare soil	Compost	Plastic mulch	Straw
pH	5.2	6.2	4.9	5.6
EC	0.1	0.13	0.09	0.1
Nitrate	27	26	29	24
Phosphate P	154	220	118	129
Potassium	180	616	158	272
Calcium	1,450	2,140	1,260	1,740
Magnesium	85	151	71	97
OC	2.95	3.26	2.31	2.84

The soil analysis data for 2009 demonstrates the effect of the treatments on soil nutrient content over the duration of the experiment. The main effect of the compost treatment was to increase the soil pH. The plastic mulch treatment caused a significant decrease in pH, presumably because the lime applied was prevented from being washed into the soil profile. Perhaps the greatest effect of the mulch treatments was on soil potassium, which increased from 180 in the control to 616 in the compost treatment. There was a slight decrease in soil nitrogen in the straw treatment which mirrored the effects on leaf and fruit nitrogen. However, where leaf and fruit nitrogen were greater in the compost treatment, this was not the case in the soil analysis. The compost treatment caused a significant increase in organic matter content but the straw treatment did not. The plastic mulch treatment caused a decline in organic matter content.

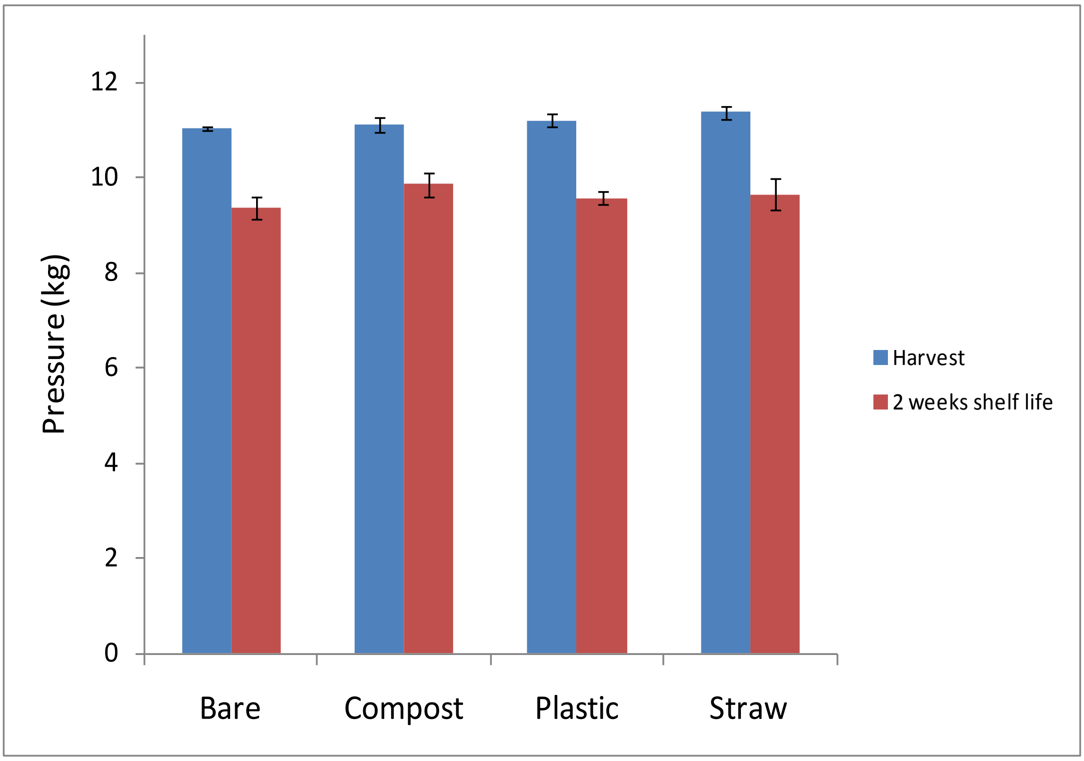

Figure 30. The effect of mulch treatment on fruit pressure at harvest (7th September) and following two weeks shelf life. Data for 2009. Standard error bars are shown.

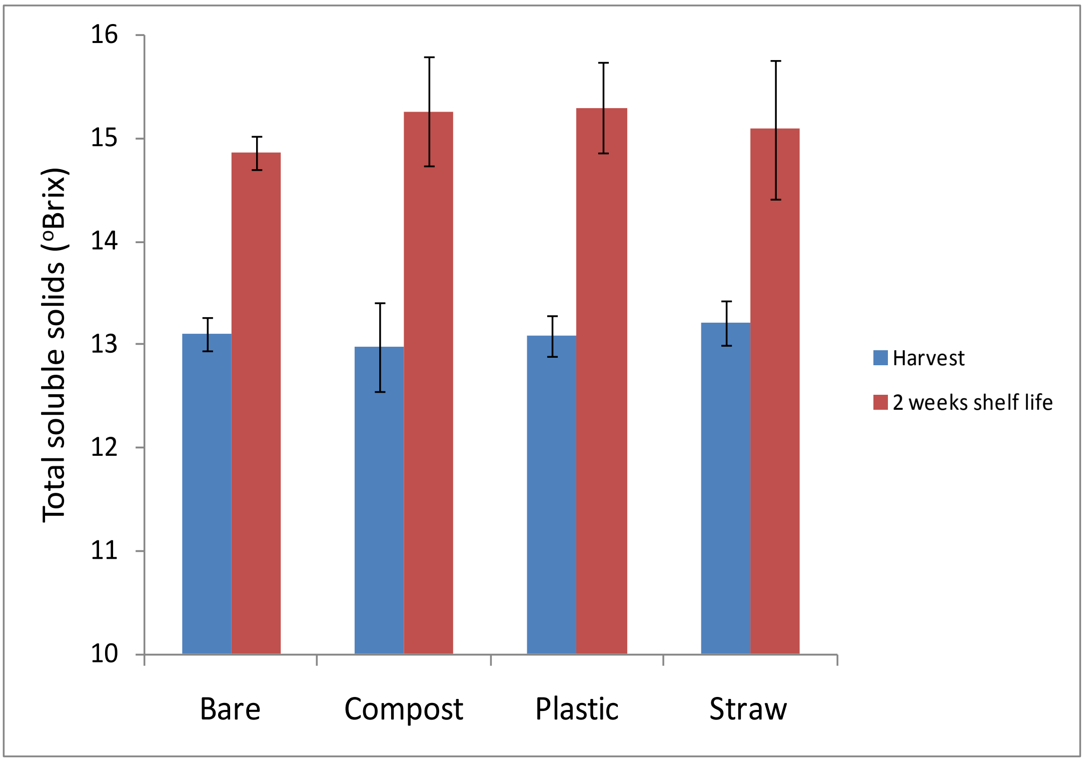

Figure 31. The effect of mulch treatment on fruit total soluble solids content at harvest (7th September) and following two weeks shelf life. Data for 2009. Standard error bars are shown.

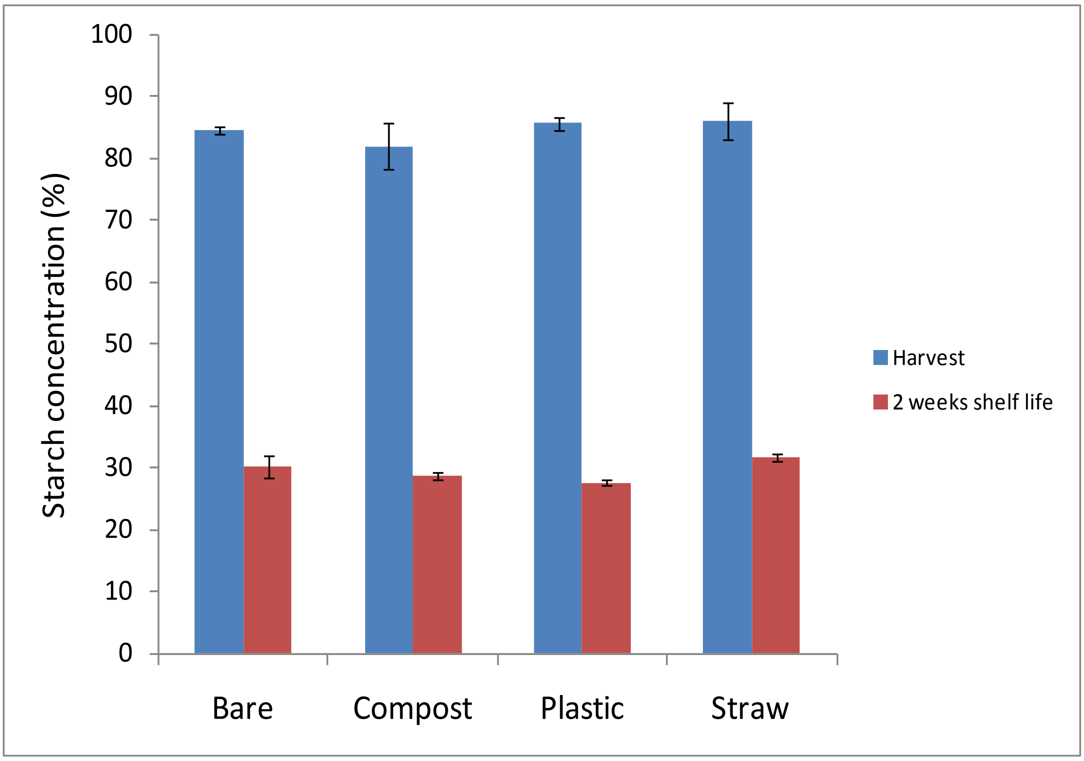

Figure 32. The effect of mulch treatment on fruit starch concentration at harvest (7th September) and following two weeks shelf life. Data for 2009. Standard error bars are shown.

The effect of mulch treatment on fruit quality at harvest and after two weeks shelf life is shown in Figures 30 to 32). There was no significant effect on fruit firmness of the mulch treatments (Figure 30). Following two weeks shelf life the fruit pressure had reduced by around 2kg across all treatments. The total soluble solids content was also not significantly affected by mulch treatment, varying by less than 1^{o}Brix between treatments (Figure 31). Following two weeks shelf life it increased by around 2^{o}Brix in all treatments. Conversely the percentage starch declined by around 50% following shelf life but again this was not affected by mulch treatment (Figure 32).

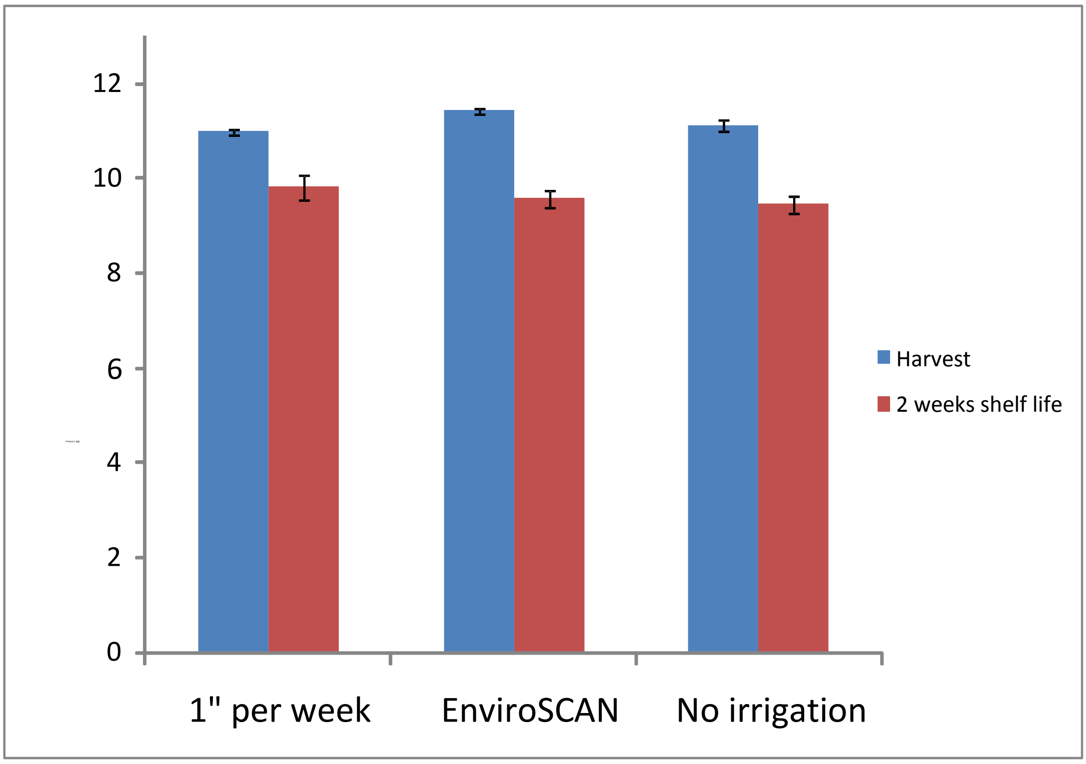

Figure 33. The effect of irrigation treatment on fruit firmness (pressure) at harvest (7th September) and following two weeks shelf life. Data for 2009. Standard error bars are shown.

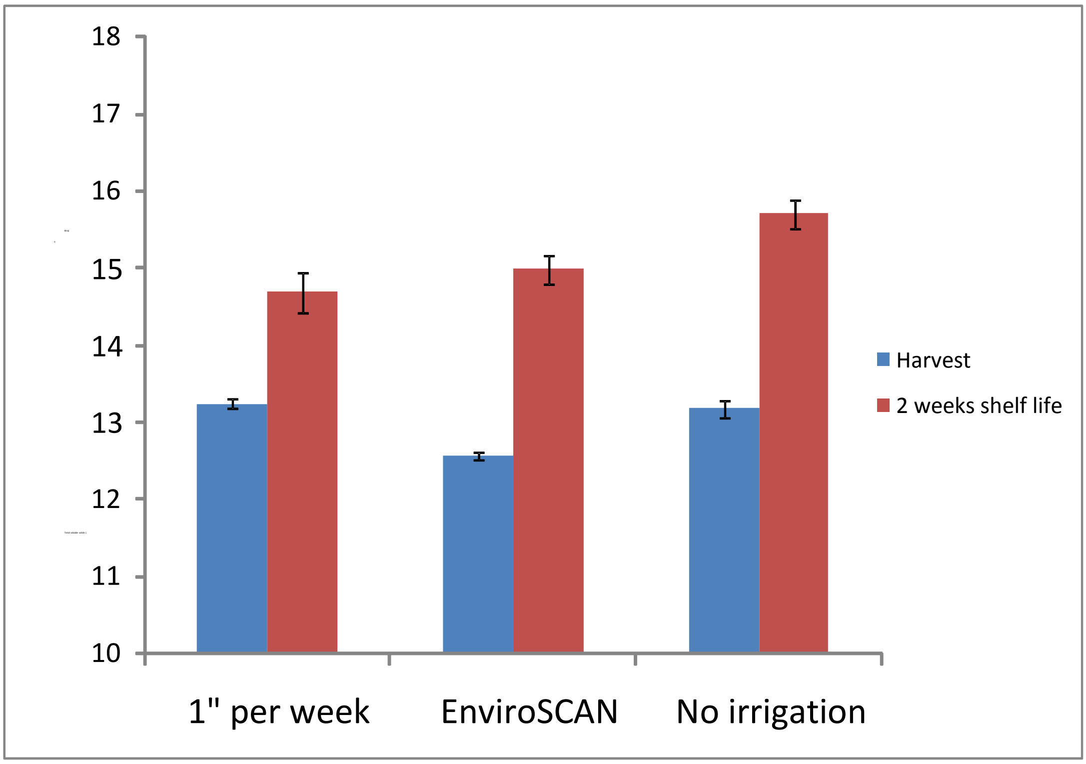

Figure 34. The effect of irrigation treatment on total soluble solids content at harvest (7th September) and following two weeks shelf life. Data for 2009.

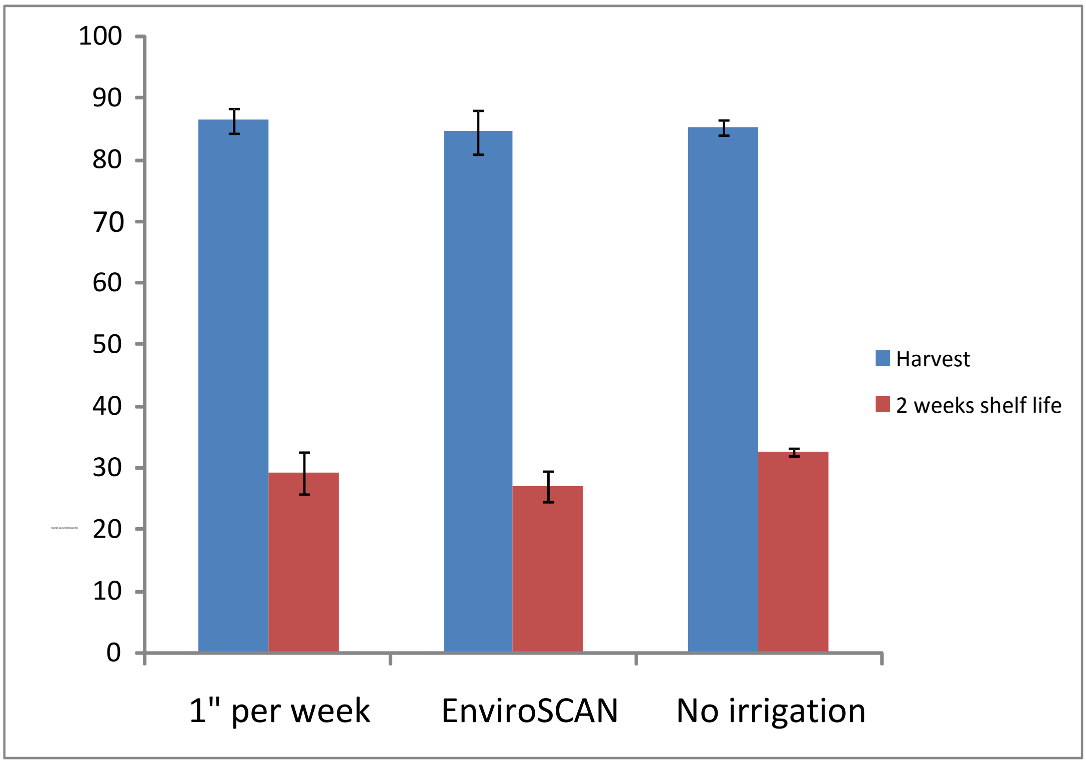

Figure 35. The effect of irrigation treatment on fruit starch concentration at harvest (7th September) and following two weeks shelf life. Data for 2009. Standard error bars are shown.

The effects of irrigation treatment on fruit quality parameters at harvest and following two week's shelf life are shown in figures 33 to 35. The only significant effect was on total soluble solids at harvest where the no irrigation treatment caused a slight but significantly higher ^{o}Brix. There was no effect of irrigation treatment following shelf life.

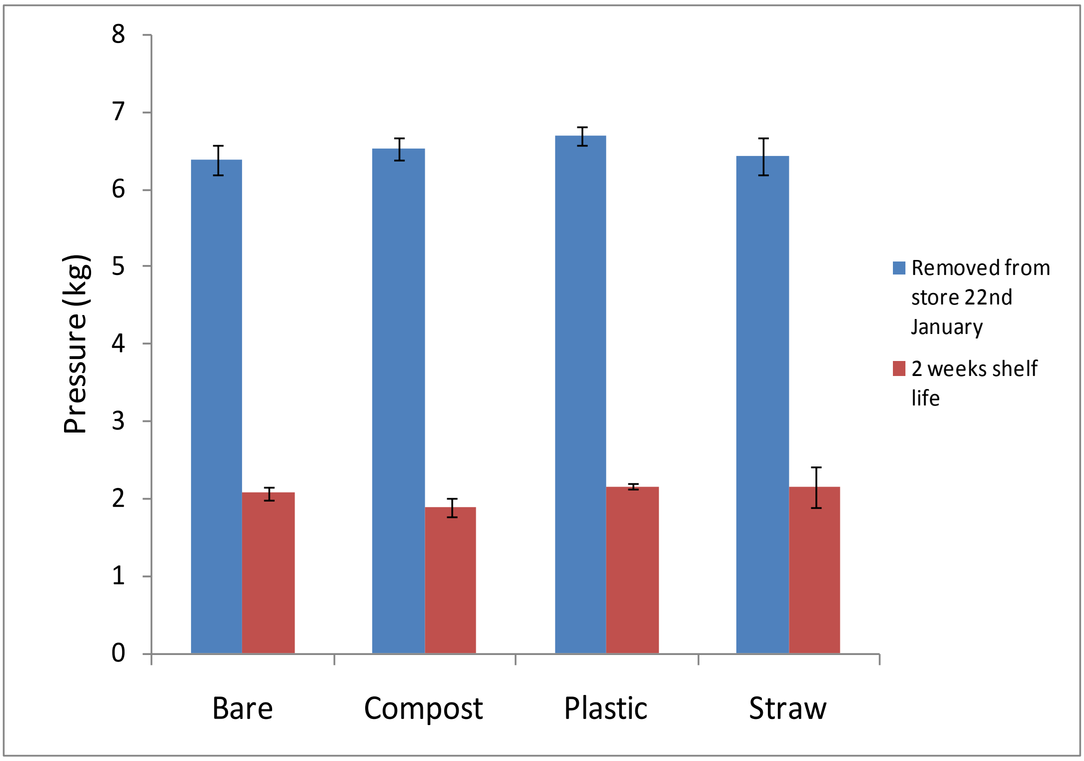

Figure 36. The effect of mulch treatment on fruit firmness (pressures) for fruit removed from store on 22nd January and following two weeks shelf life. Data for 2009. Standard error bars are shown.

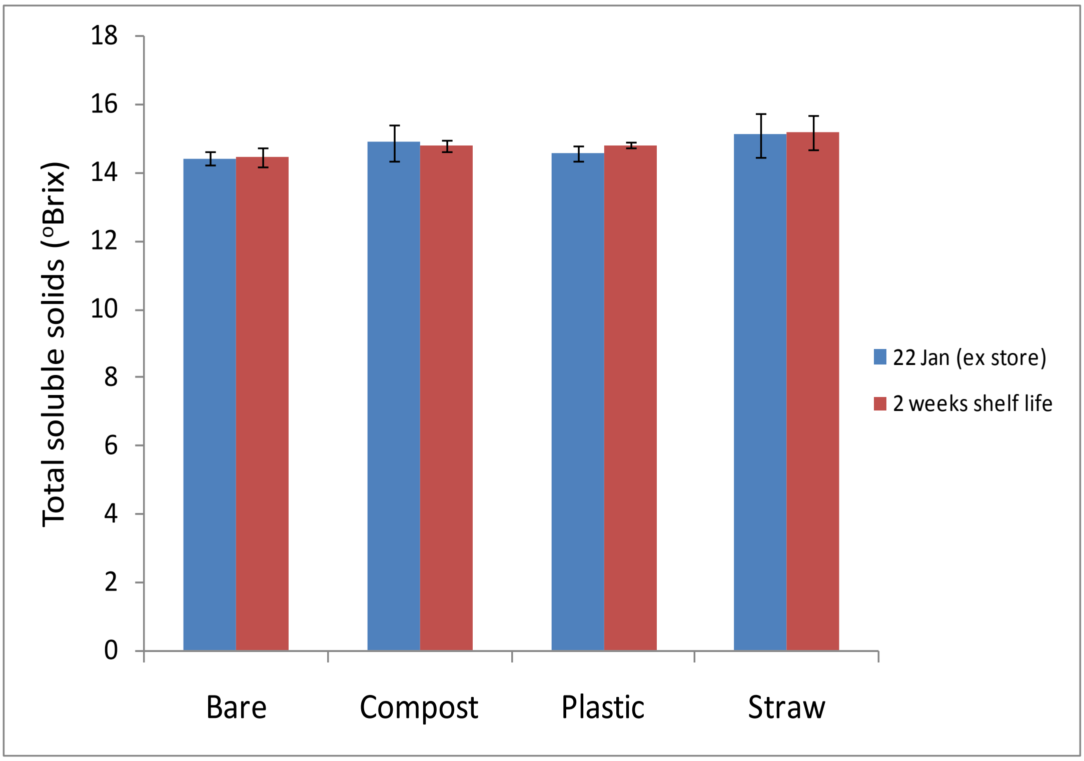

Figure 37. The effect of mulch treatment on fruit total soluble solids for fruit removed from store on 22nd January and following two weeks shelf life. Data for 2009. Standard error bars are shown.

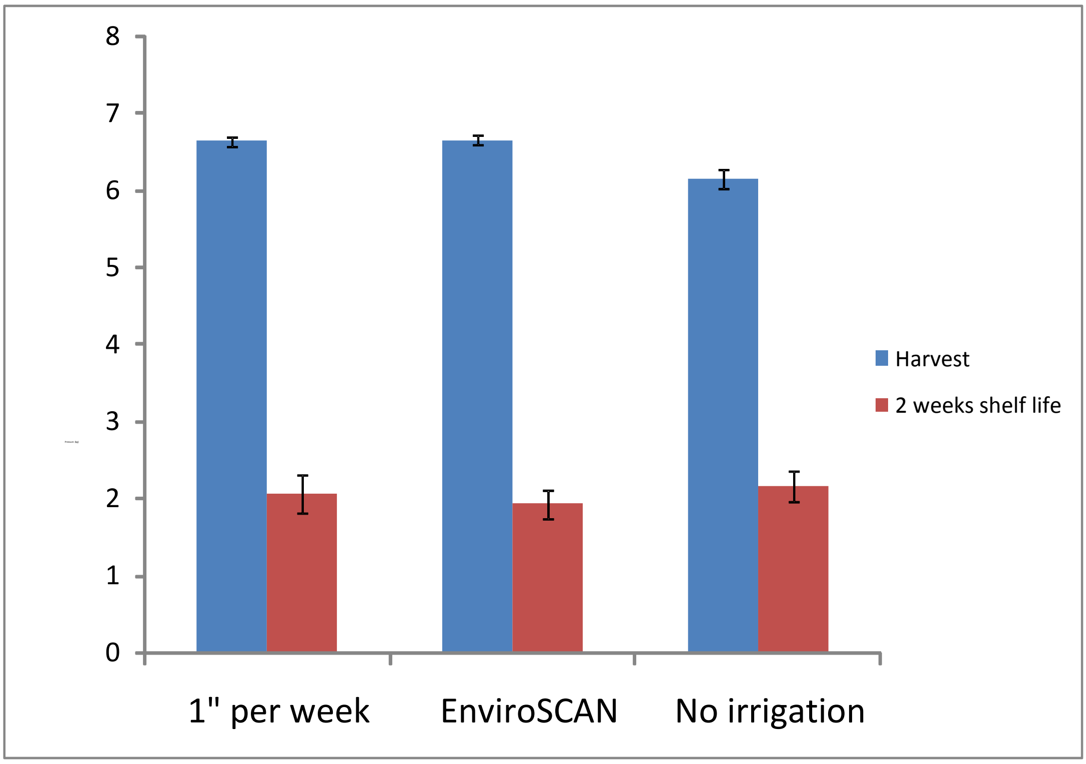

Figure 38. The effect of irrigation treatment on fruit firmness (pressures) for fruit removed from store on 22nd January and following two weeks shelf life. Data for 2009. Standard error bars are shown.

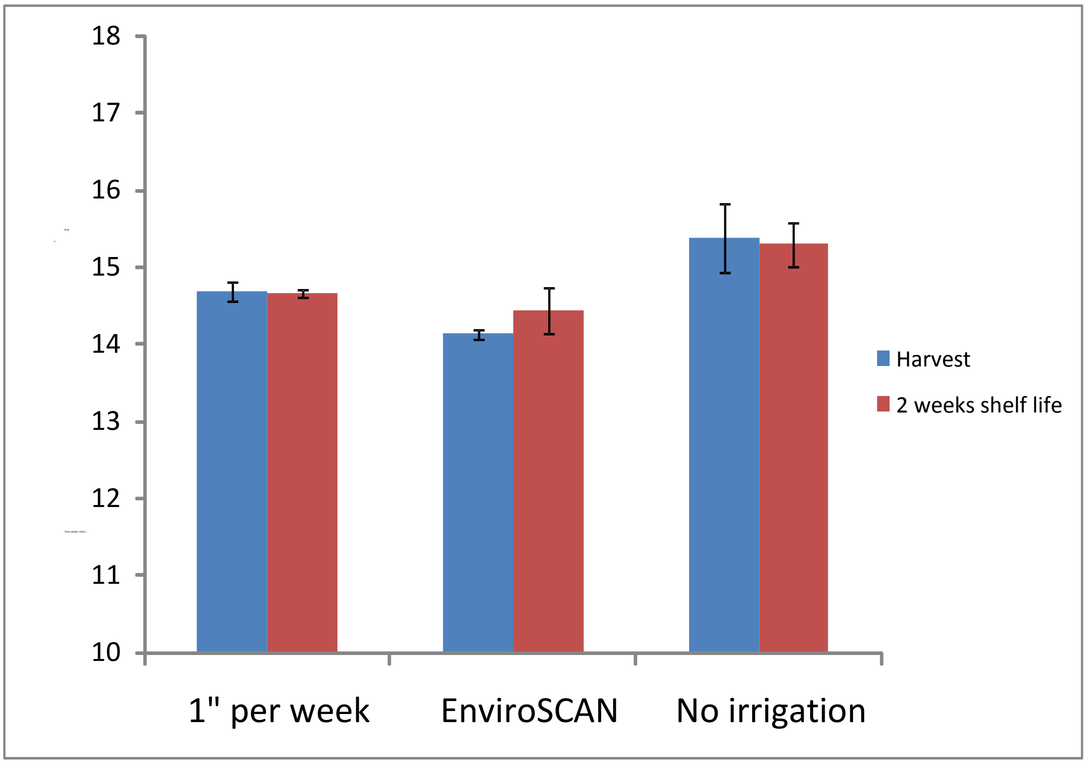

Figure 39. The effect of irrigation treatment on fruit total soluble solids for fruit removed from store on 22nd January and following two weeks shelf life. Data for 2009. Standard error bars are shown.

The effects of mulch and irrigation treatments on fruit quality during 2009 are shown in Figures 36 to 39. No significant effects of mulch treatment on fruit firmness or total soluble solids were seen (Figures 36 and 37). There was a slight reduction in fruit firmness between the irrigation treatments and the no irrigation control which may have been a result of moisture content of fruit but again this difference was not statistically significant (Figures 38 and 39).

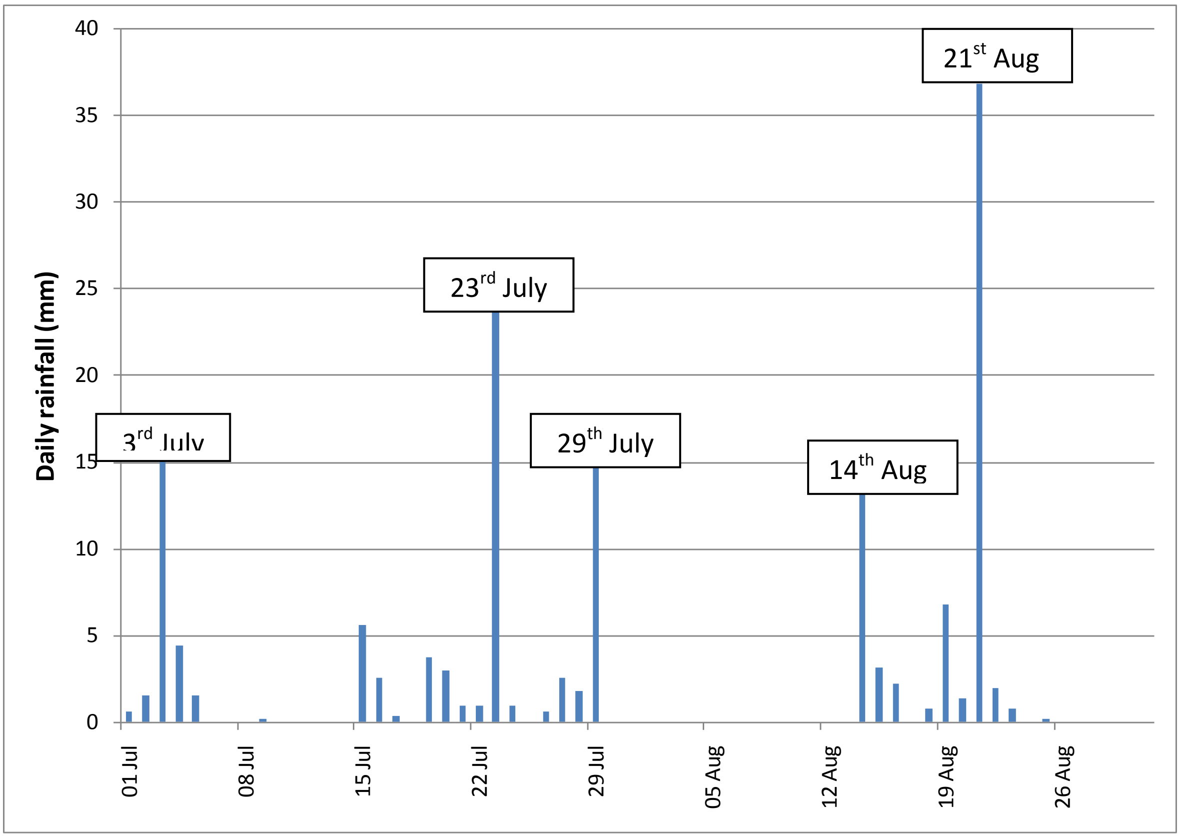

Figure 40. Rainfall during June, July and August 2007

Figure 40 shows the daily rainfall pattern during July and August. There were four main rain events which appear to have altered the soil moisture content in the treatments and have been highlighted here. In total there were 29 rain events during this period giving a total of 154 mm rain.

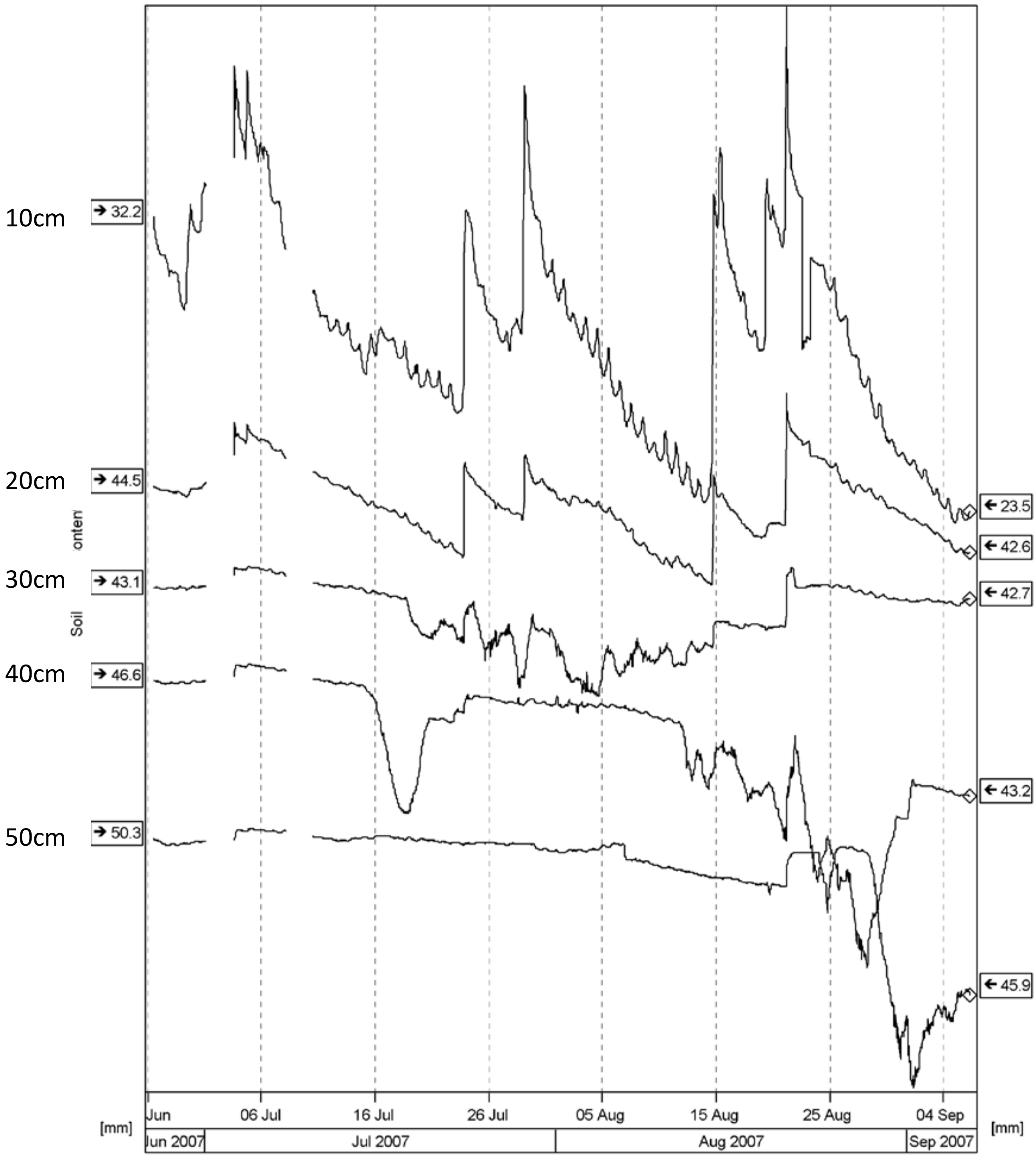

Figure 41. Data from EnviroSCAN soil moisture probe with sensors at 10cm, 20cm, 30cm, 40cm and 50cm. Treatment is bare soil, no irrigation – 2007.

The EnviroSCAN logger measured soil moisture content increasing from 29mm to 34mm at the 10cm probe on 3rd July 2007. Following this, there was a period of nearly three weeks during which the soil moisture content at this level (10cm) merely declined, coinciding with a period between 5th July and 15th July during which there was no rainfall other than 0.2mm on 9th July. On 23rd July and 29th July the soil moisture content increased dramatically again coinciding with two rainfall events on these dates. Again following this soil moisture merely declined until 14th August where a further rainfall of 13.4mm had the effect of once again increasing soil moisture. On 21st August there was a further increase in soil moisture content caused by rainfall of 34mm.

During July and August the soil moisture content at 10cm decreased from 32mm to 23mm. Clearly demonstrating that the trees were potentially under water stress during this period. Confirming this is the fact that the trees were drawing water from the lowest depths of the EnviroSCAN probes – 40cm and 50cm, particularly during late August.

Water was draining generally only to 20cm. For example, on 3rd July following 15mm rainfall, the soil moisture content at 20cm increased from 44 to 45mm whereas at 30cm, 40cm and 50cm there was no such increase. Towards the end of the period, on 21st August, there was an increase in soil moisture down to 50cm but this not only followed a period during which soil moisture at this level had decreased significantly but also the rainfall was 34mm in one day.

The EnviroSCAN logger was sensing the rainfall at 10cm but only in extreme conditions did the soil moisture content at 40 and 50cm increase. There is evidence from the data that the trees were operating under water stress and being forced to draw water from the lower levels down to 50cm.

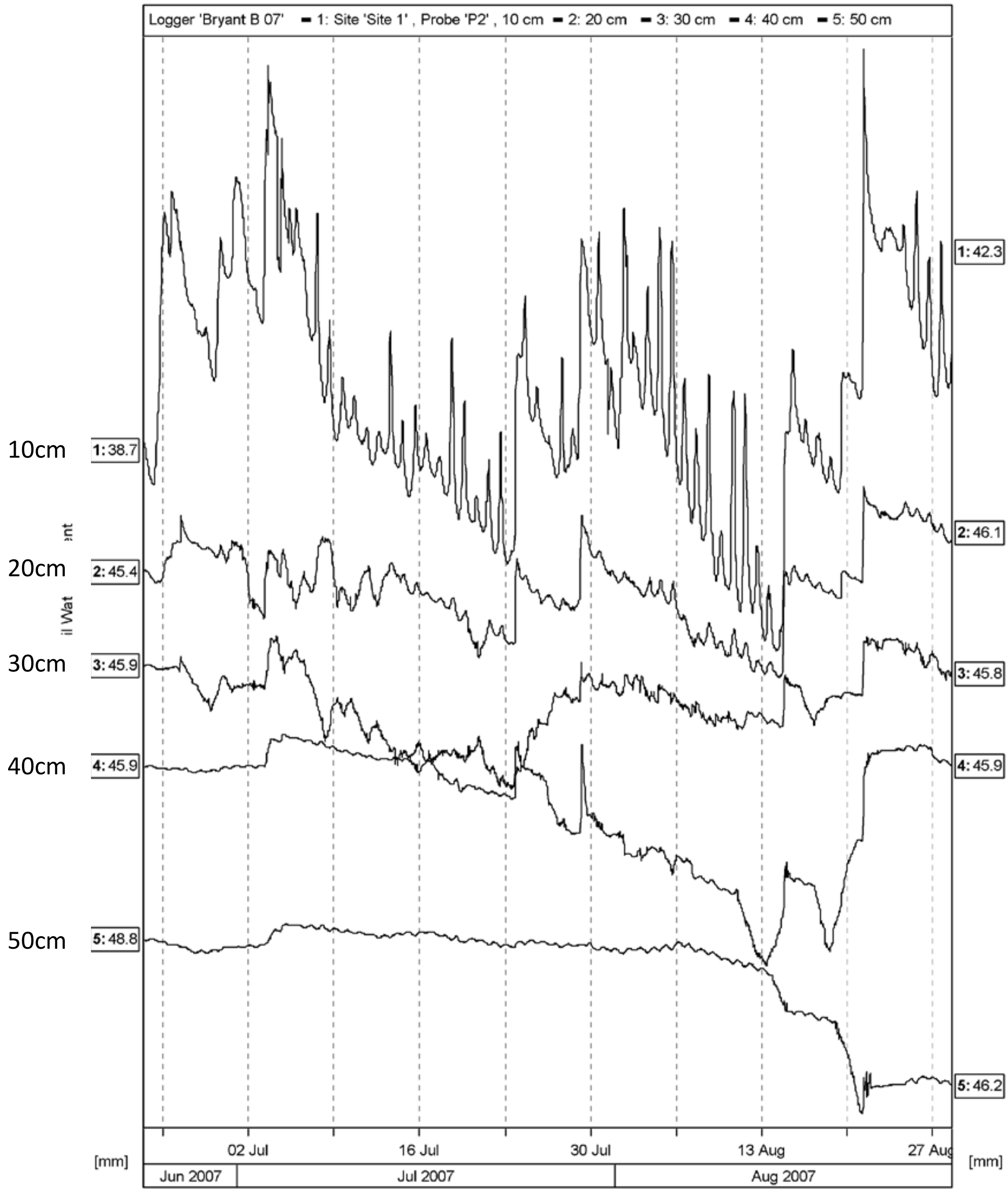

Figure 42. Data from EnviroSCAN soil moisture probe with sensors at 10cm, 20cm, 30cm, 40cm and 50cm. Treatment is bare soil, EnviroSCAN controlled irrigation – 2007.

Figure 42 shows the data from the bare soil, EnviroSCAN controlled irrigation treatment and the chart is included to demonstrate the effect of irrigation being applied, particularly on the uppermost probe at 10cm. Clearly the effect of the irrigation was to improve soil moisture content over the unirrigated plots, with the difference being seen perhaps most clearly at the lower depths where the soil moisture was maintained, except during the period at the start of August.

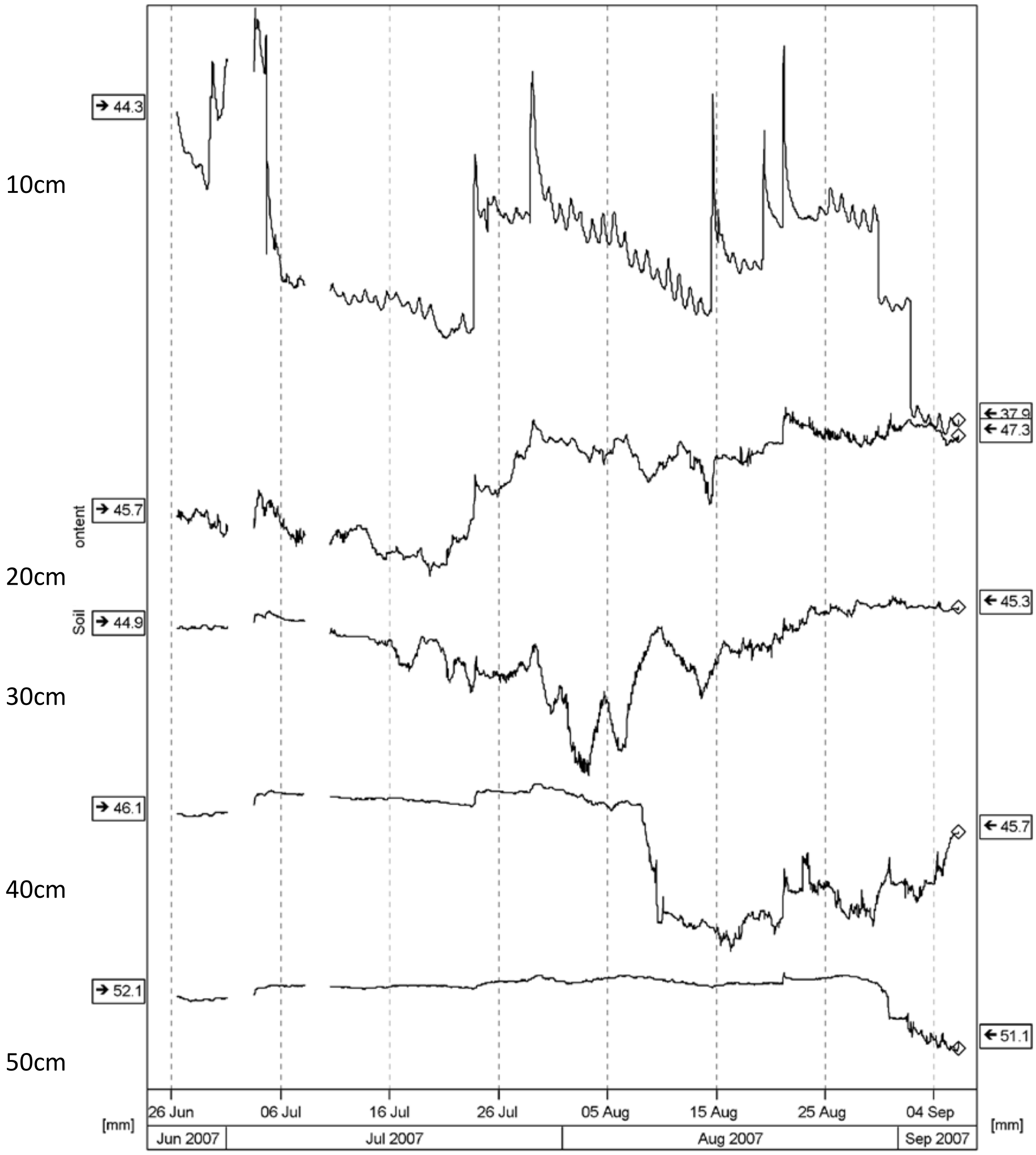

Figure 43. Data from EnviroSCAN soil moisture probe with sensors at 10cm, 20cm, 30cm, 40cm and 50cm. Treatment is compost mulch, no irrigation – 2007.

Figure 43 shows the data from the EnviroSCAN datalogger probes placed in the compost treatment, no irrigation treatment. Here similar effects of the main rainfall events can be seen to the bare soil treatment. For example the 36mm rainfall on 21st August caused a significant increase in soil moisture as it had done so in the bare soil, no irrigation treatment. However, there are differences between the compost and bare soil treatments which become apparent on closer inspection.

Firstly, whilst the soil moisture content at 10cm did still fall during July and August, the decrease was less than in the bare soil treatment. At 20cm the soil moisture content actually increased from 45mm to 47mm and at the other depths the decrease in soil moisture content was also less.

Secondly, in the bare soil treatment, rainfall results in an immediate increase in soil moisture at both 10cm and 20cm. In the compost, no irrigation treatment, there is an increase in soil moisture content but this occurs over a much extended period, perhaps because the compost has modified the soil structure allowing for better water percolation through the soil profile. This is certainly something that is seen in later years.

Finally, the trees in the compost, no irrigation treatment did take water from 40cm and 50cm. However, the soil moisture content at these levels did not fall by as great an amount as in the bare soil treatment, suggesting that the soil moisture content became less deficient in the compost treatment.

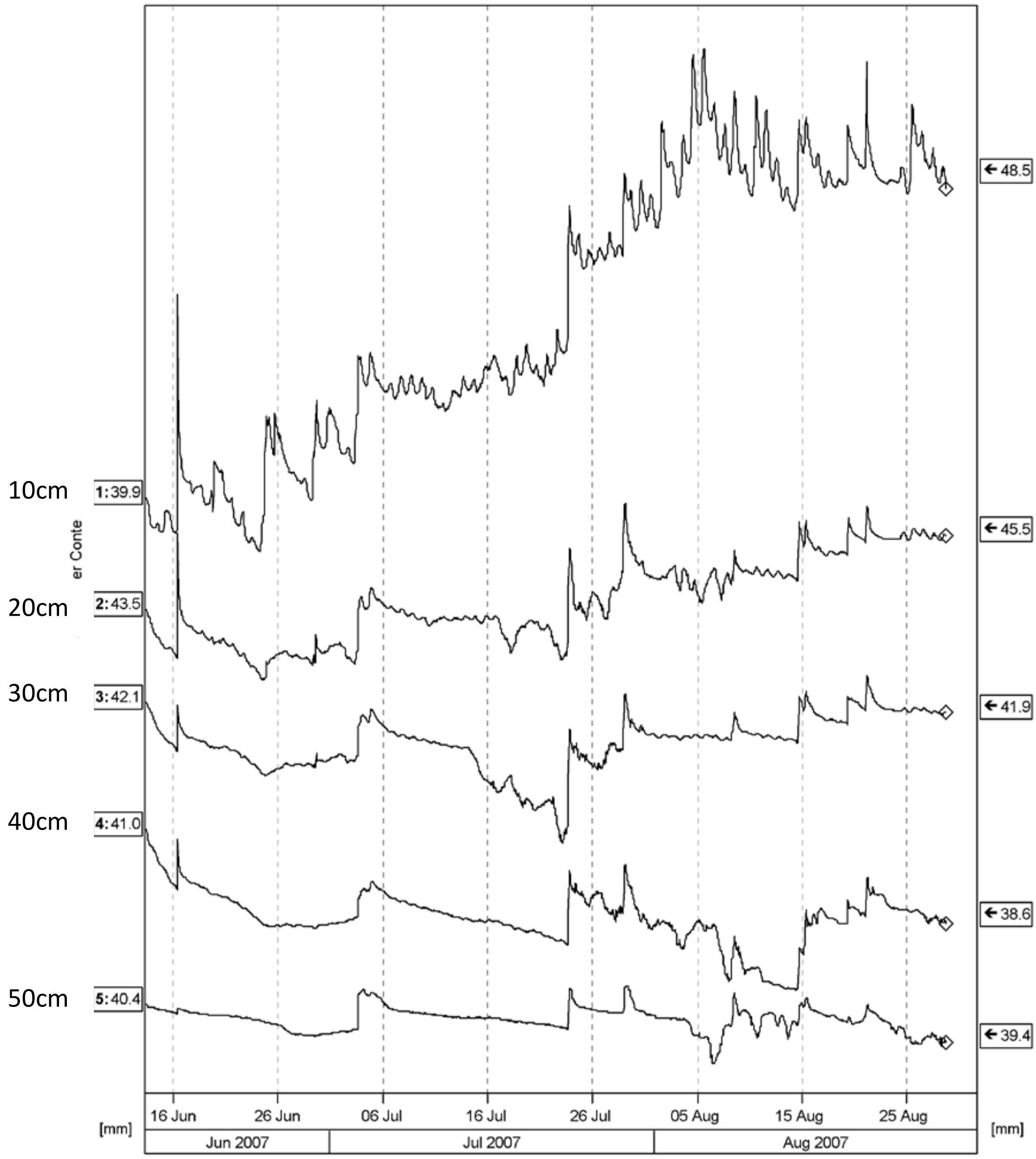

Figure 44. Data from EnviroSCAN soil moisture probe with sensors at 10cm, 20cm, 30cm, 40cm and 50cm. Treatment is compost mulch, EnviroSCAN controlled irrigation – 2007.

Figure 44 shows the data from the EnviroSCAN logger probes placed in the compost treatment with irrigation controlled by EnviroSCAN. Here, similar effects of the main rainfall events can be seen to the bare soil treatment but are obscured by the effect of the irrigation treatments being applied. For example, on 21st August there was a peak caused by the 36mm rainfall event but the soil moisture content was already at a relatively high level and so the increase in soil moisture following the rainfall is less evident.

The greatest difference caused by the irrigation can be seen in the overall increase in soil moisture at all depths. Where no irrigation had been applied (Figures 40 and 41), soil moisture declined at all depths. Here in the compost, EnviroSCAN treatment the soil moisture content actually increased at all depths.

Because the overall soil moisture content was greater, it can be seen that water was percolating to the 50cm depth after both rainfall and irrigation events. This is perhaps seen most clearly on 3rd July where the soil moisture content down to 50cm increases following the rainfall on that day. For example soil moisture content at 50cm increased by 1mm.

The success of the irrigation applications is perhaps best demonstrated by the fact that when the 10cm soil moisture content decreased, it was immediately followed with irrigation except where rainfall was able to correct the low soil moisture content.

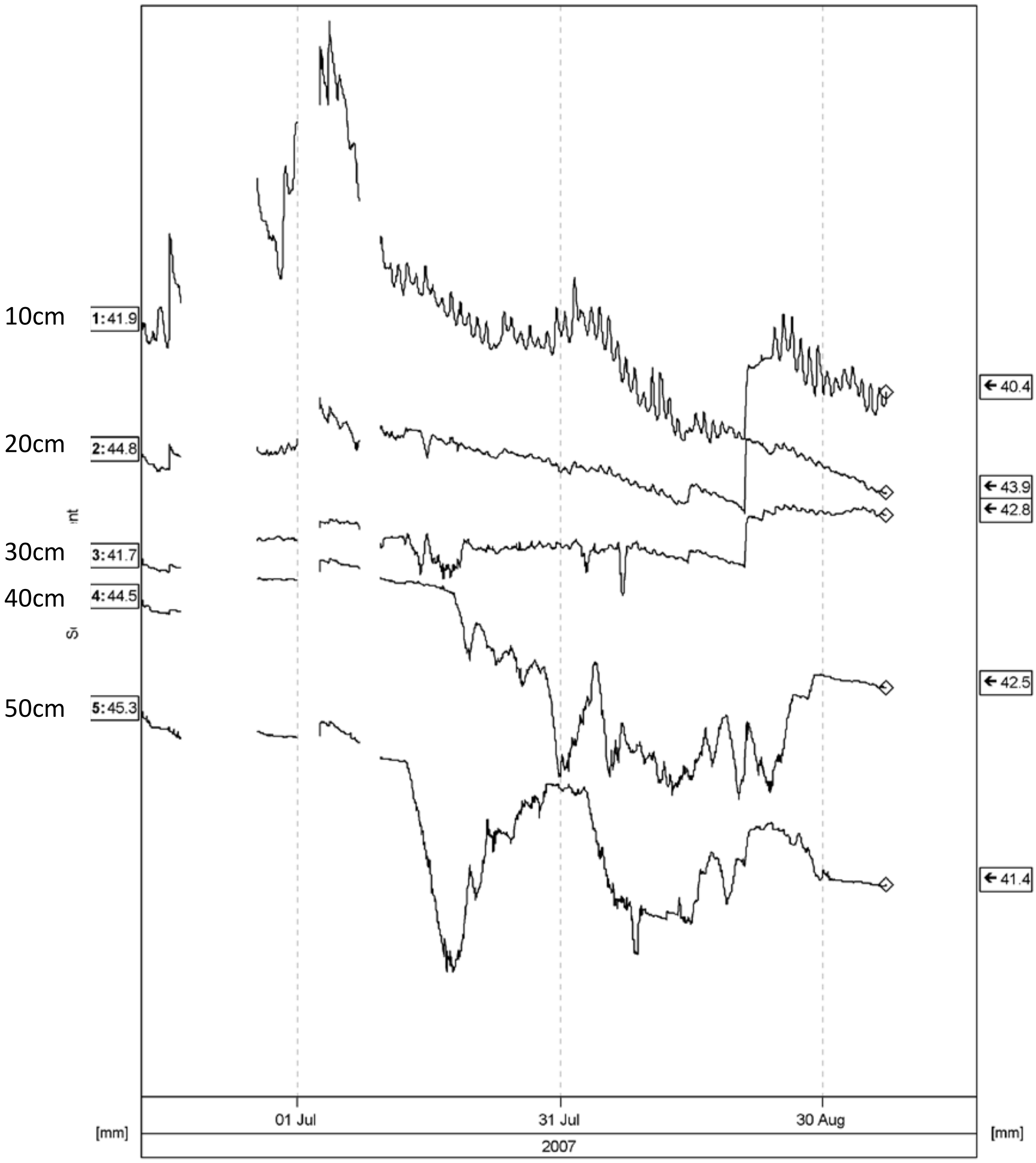

Figure 45. Data from EnviroSCAN soil moisture probe with sensors at 10cm, 20cm, 30cm, 40cm and 50cm. Treatment is plastic mulch, no irrigation – 2007.

Figure 45 shows the data from the EnviroSCAN datalogger probes placed in the plastic mulch, no irrigation treatment. The main difference between this treatment and the compost/bare soil treatments was the virtual absence of any rainfall events affecting the soil moisture. The rainfall on 3rd July did cause an increase in soil moisture but following this the soil moisture content merely declined at 10cm. This was clearly the effect of the plastic mulch preventing the rainfall from entering the soil profile.

Interestingly, at lower depths, particularly at depths of 40 and 50 cm, there were periods where soil moisture increased. This was presumably caused by water draining into the soil profile from the grass alleyways.

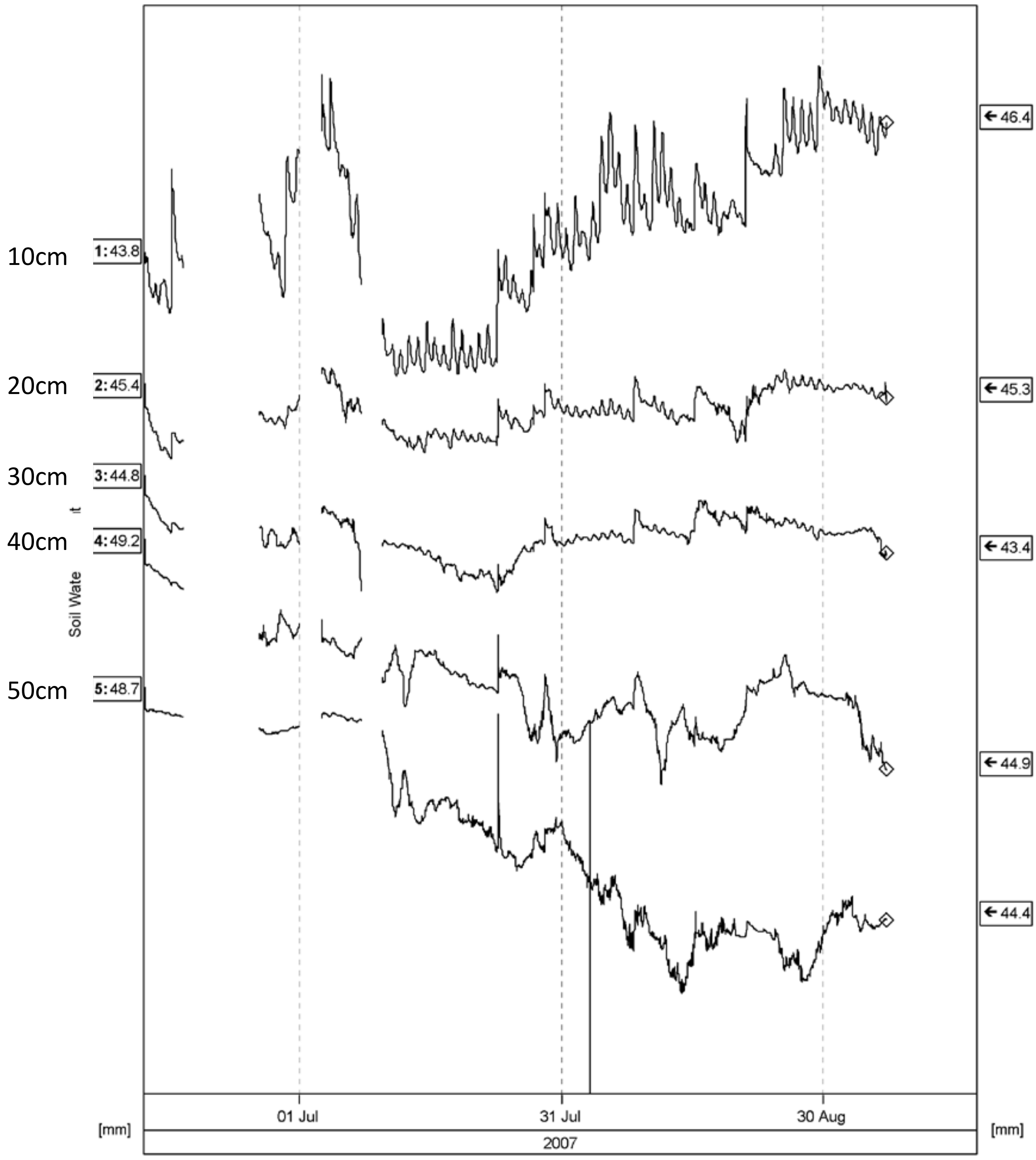

Figure 46. Data from EnviroSCAN soil moisture probe with sensors at 10cm, 20cm, 30cm, 40cm and 50cm. Treatment is plastic mulch, 1" per week irrigation – 2007.

Figure 46 shows the data from the EnviroSCAN datalogger probes placed in the plastic mulch, 1" per week irrigation treatment. The effect of the irrigation was to increase soil moisture content at 10cm, where the soil moisture content would have merely declined during this period had no irrigation been applied.

However, the soil moisture content at 40 and 50cm declined throughout this period, suggesting that the amount of irrigation applied had not been sufficient to maintain moisture content to this depth or alternatively that the irrigation water was trapped in the upper part of the soil profile.

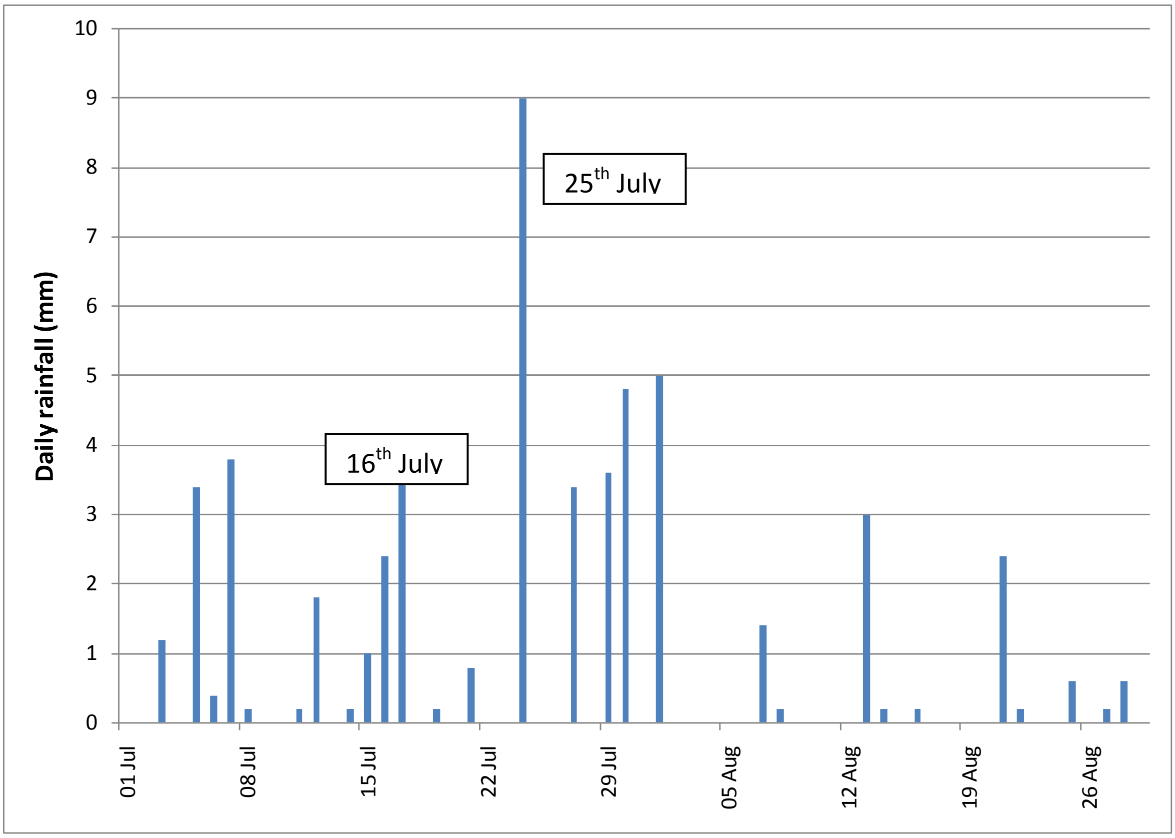

Figure 47. Rainfall during June, July and August 2009.

Compared with 2007, there was much less rainfall in 2009. During July and August a total of 54mm rain fell in 2009 and 154mm in 2007. However the number of rainfall events was similar in both years – 29 in 2007 and 28 in 2009. In 2007 the rain was of greater intensity.

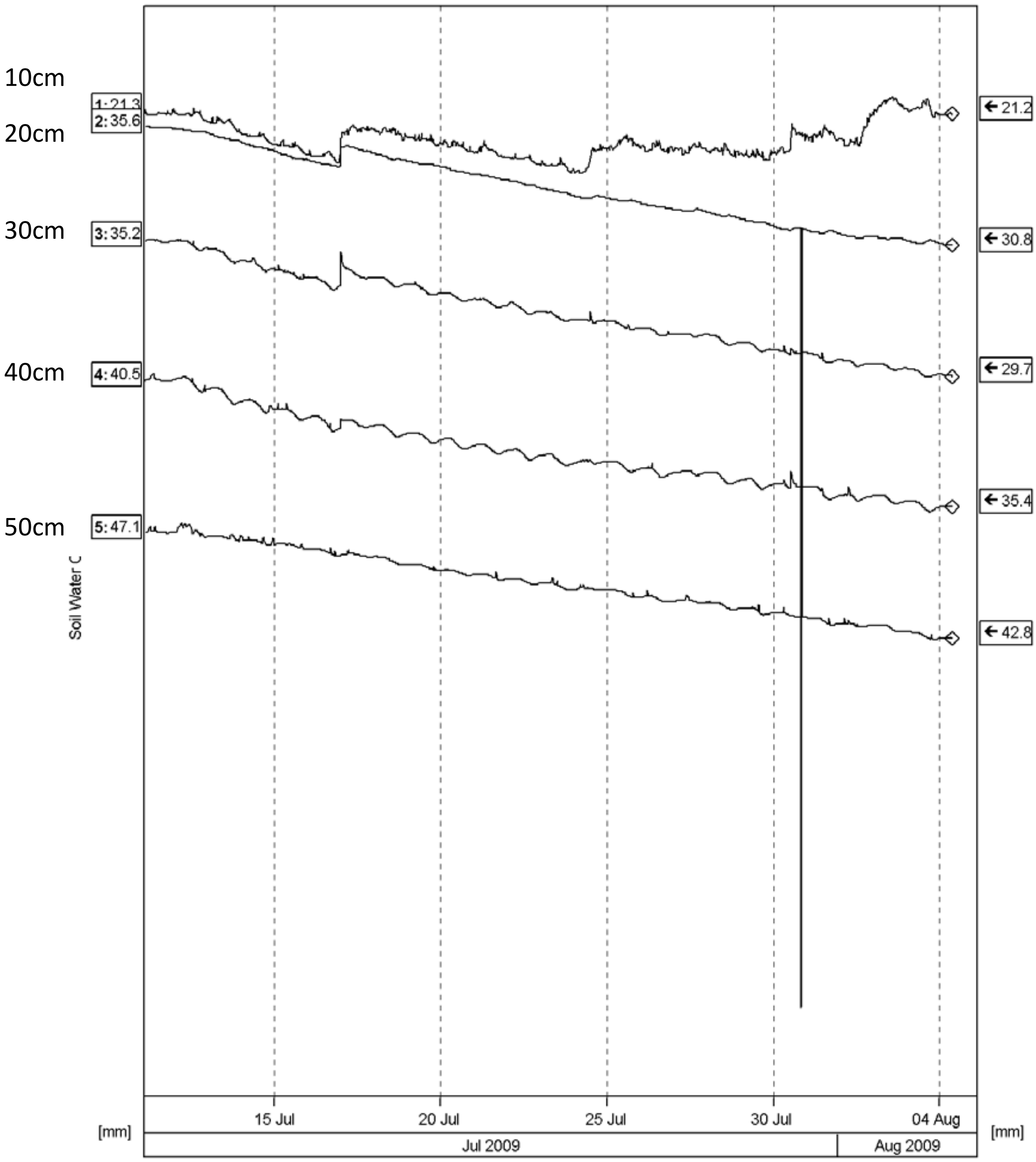

Figure 48. Data from EnviroSCAN soil moisture probe with sensors at 10cm, 20cm, 30cm, 40cm and 50cm. Treatment is bare soil, no irrigation – 2009.

Figure 48 shows the data from the EnviroSCAN datalogger probes placed in the bare soil, no irrigation treatment. Soil moisture content simply declined at all soil levels other than the uppermost 10cm. Rainfall events did not alter soil moisture content other than at the 10cm level. The exception to this was the rainfall on 16th July which caused an increase in soil moisture down to 30cm. Therefore throughout this period the moisture content in the uppermost 10cm was being replenished by rainfall but not below this level. The lack of percolation or drainage through to the lower soil levels demonstrates that soil structure may be an issue, with soil compaction preventing the downward movement of water. This is compounded by the uppermost 10cm layer being extremely dry with an average soil moisture content of only 21mm water.

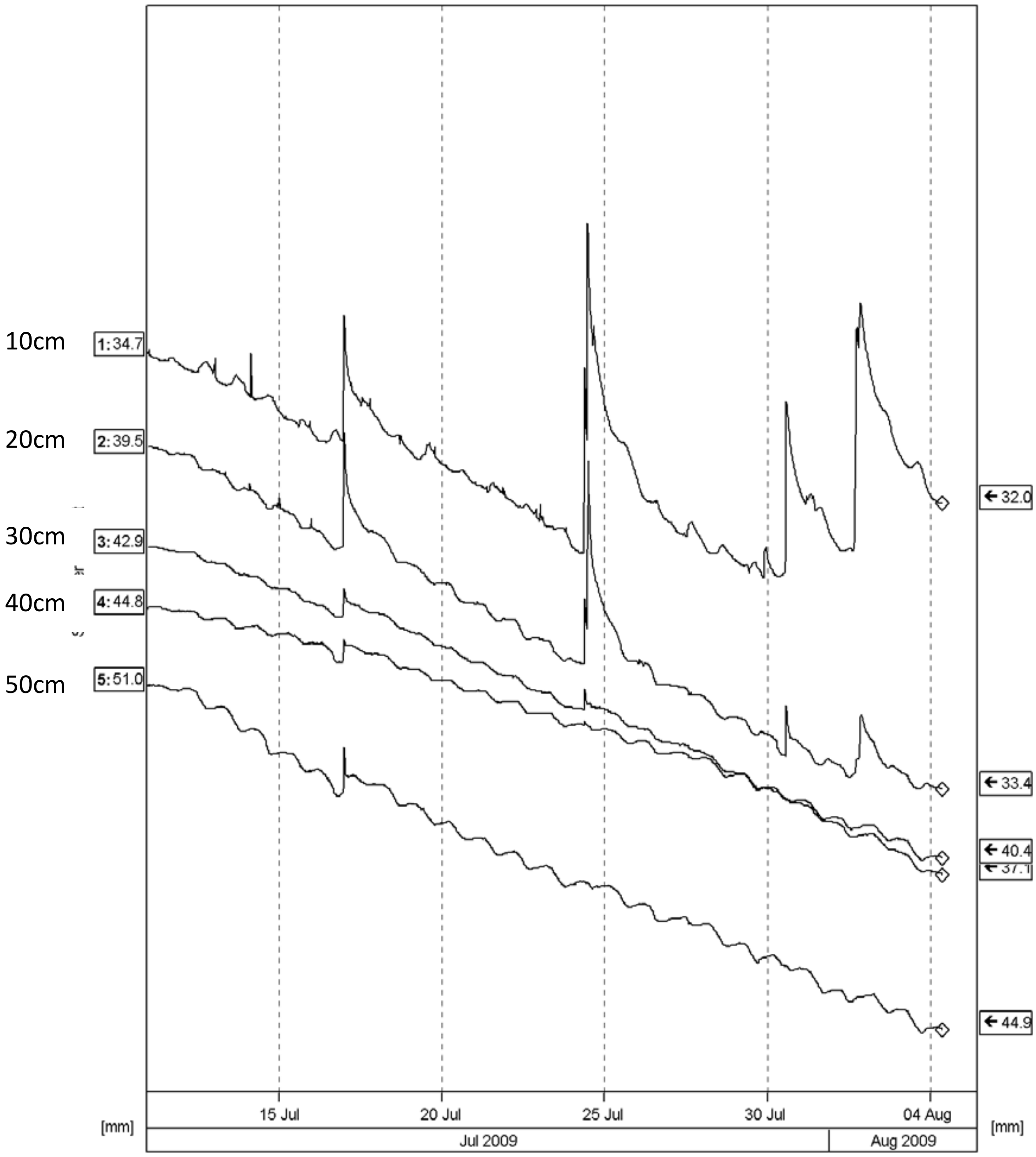

Figure 49. Data from EnviroSCAN soil moisture probe with sensors at 10cm, 20cm, 30cm, 40cm and 50cm. Treatment is compost mulch, no irrigation – 2009.

Figure 49 shows the data from the EnviroSCAN datalogger probes placed in the compost mulch, no irrigation treatment. Here the effect of rainfall is significantly more apparent than in the bare soil treatment. There were six distinct peaks in the uppermost 10cm following rainfall and in contrast to the bare soil treatment these affected the soil moisture lower down the soil profile. For example the rainfall on 16^{th} July caused an increase in soil moisture down to 50cm. This presumably is the result of improved soil structure allowing water to percolate through the soil profile to lower levels. Having said that though, the overall soil moisture still declined at all levels, particularly from 20cm and below. Clearly the trees were using more water than can be supplied by the rainfall.

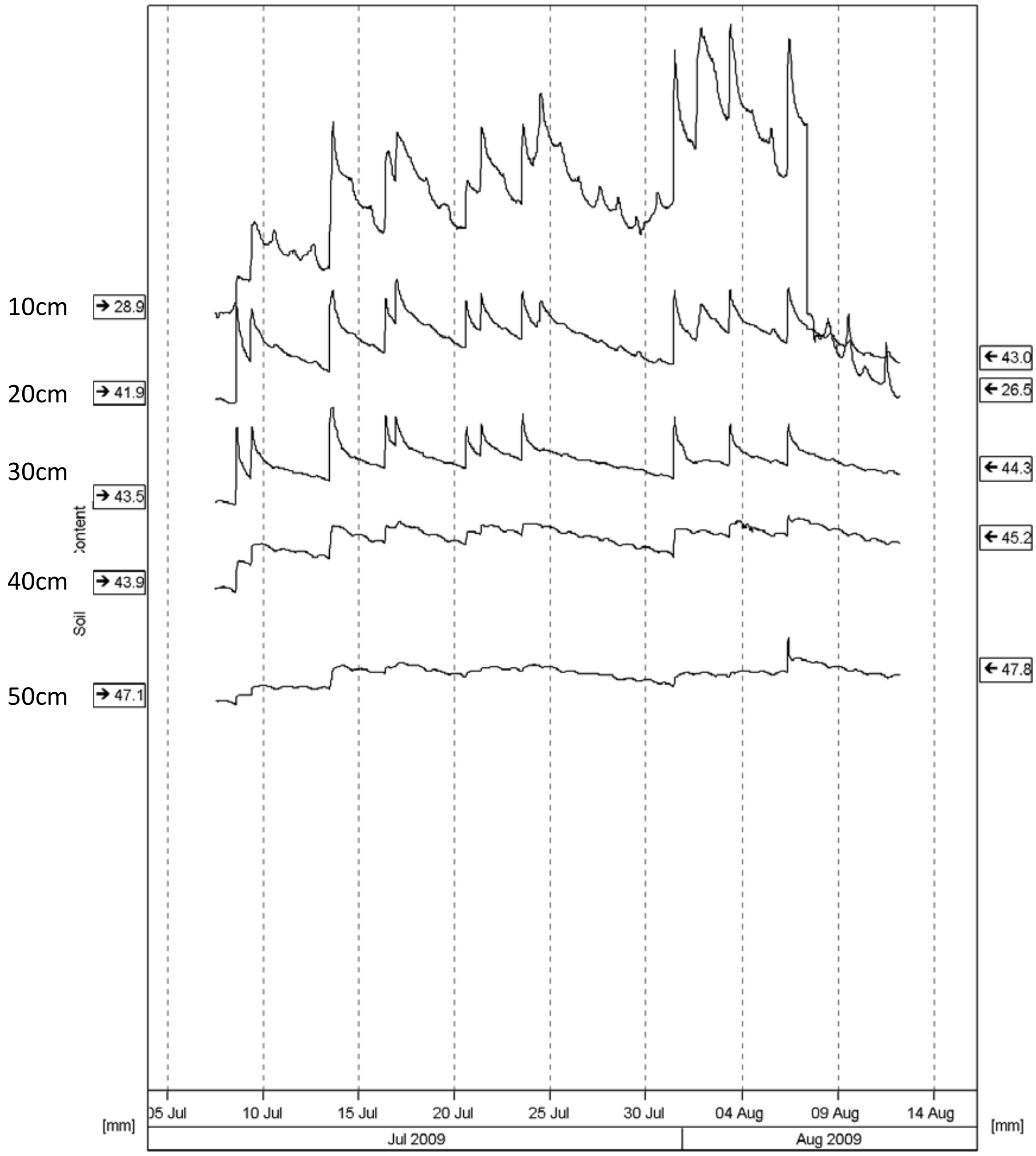

Figure 50. Data from EnviroSCAN soil moisture probe with sensors at 10cm, 20cm, 30cm, 40cm and 50cm. Treatment is compost mulch, EnviroSCAN controlled irrigation – 2009.

Figure 50 shows the data from the EnviroSCAN datalogger probes placed in the compost mulch, EnviroSCAN controlled irrigation treatment. The effect of the irrigation treatment is clear. Firstly the soil moisture content actually increased at all soil levels with clear drainage from the upper part of the profile right down to 50cm. Clearly the combined effect of improved soil structure and increased water availability resulted in better percolation through the soil profile. The fact that soil moisture was maintained suggests that the trees had received adequate water during this period.

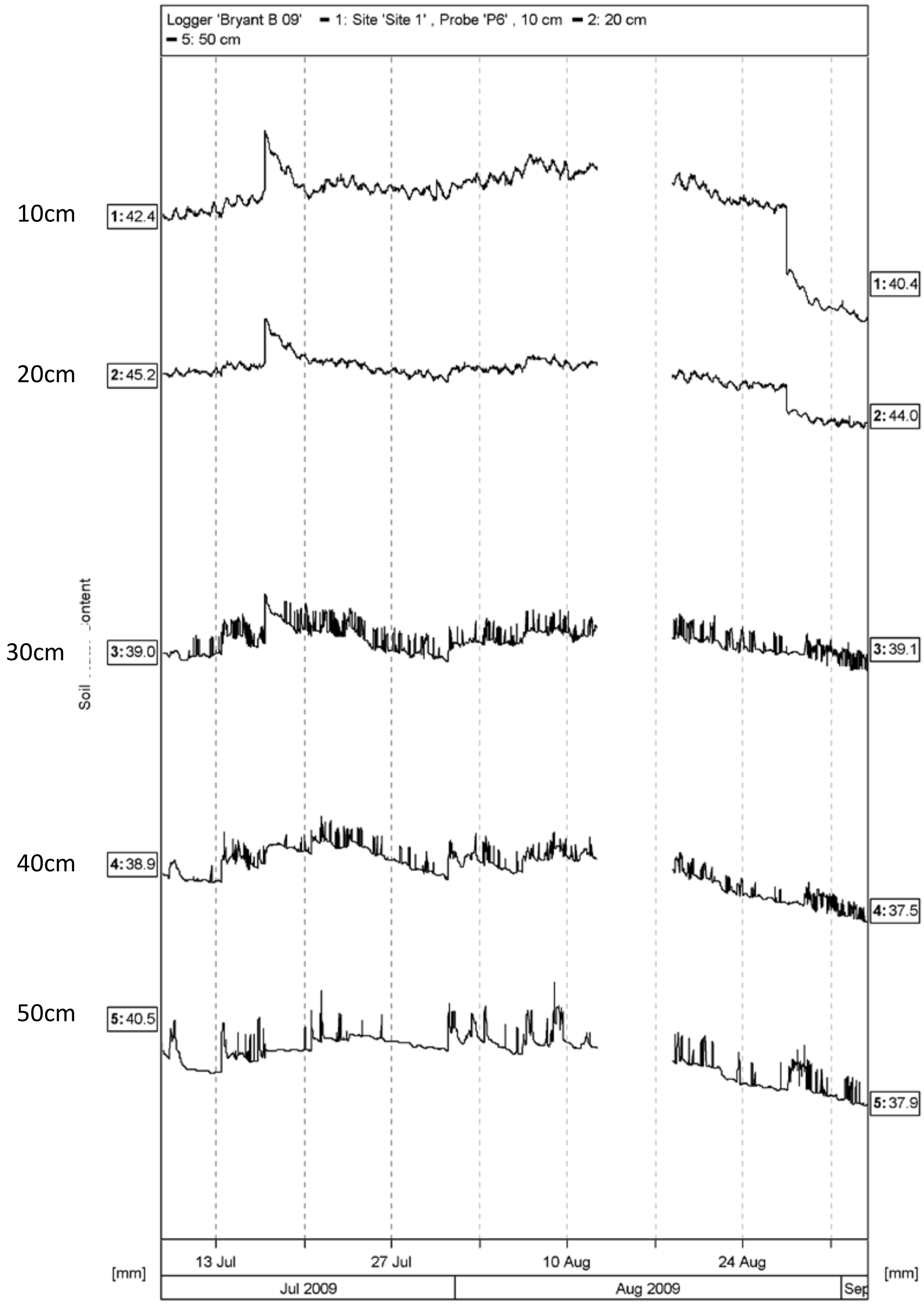

Figure 51. Data from EnviroSCAN soil moisture probe with sensors at 10cm, 20cm, 30cm, 40cm and 50cm. Treatment is plastic mulch, no irrigation – 2009.

Figure 51 shows the data from the EnviroSCAN datalogger probes placed in the plastic mulch, no irrigation treatment. The effect of the plastic mulch is extremely clear. It clearly prevented rainfall from moving into the soil profile in the centre of the row. One rain event on 16th July did cause an increase in soil moisture content but other than this there was no significant increase. That the soil moisture content did not decrease during this period suggests that water did move from the grass alleyway into the tree row but not at a sufficiently high rate.

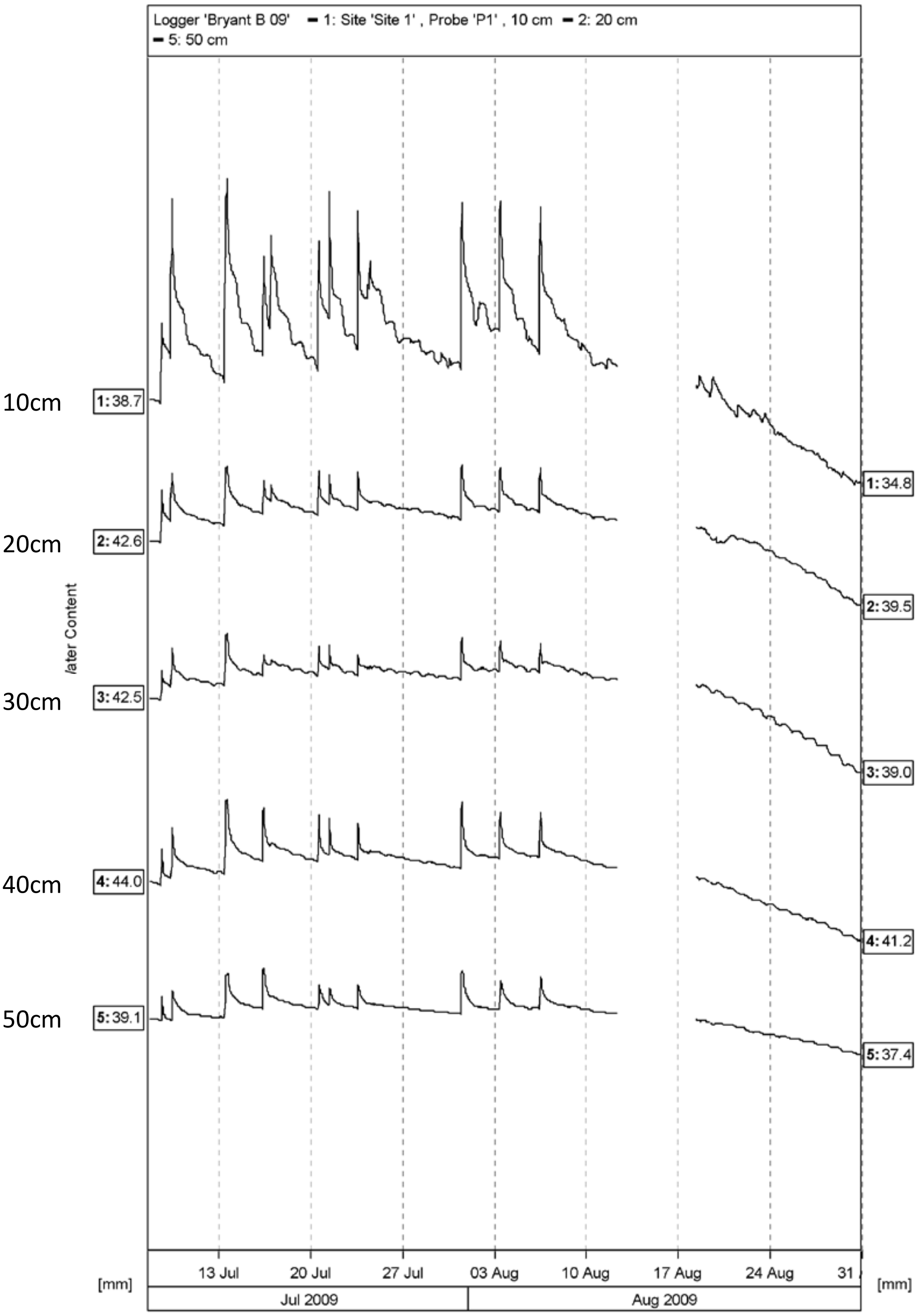

Figure 52. Data from EnviroSCAN soil moisture probe with sensors at 10cm, 20cm, 30cm, 40cm and 50cm. Treatment is plastic mulch, EnviroSCAN controlled irrigation – 2009.

Figure 53 shows the data from the EnviroSCAN datalogger probes placed in the plastic mulch, EnviroSCAN controlled irrigation treatment. The effect of the irrigation cycles was to cause increases in soil moisture content down to 50cm as water drained through the profile.

Discussion

The effects of the three mulches on soil structure were important and there were clear differences between the three mulches. Compost is known to improve soil structure and the effects seen were not surprising, with the compost mulch causing better percolation of water through the soil profile than the bare soil. In the HDC project TF177 looking at compost effects on apples, it was also shown that the compost improved water penetration through the soil profile (Carew, 2010). Other reports from around the world have also identified this effect of compost mulch. For example Pinamonti (1998) tested a sewage sludge/bark compost mix and found increased organic matter content, porosity and water retention capacity as well as reducing evaporation of water from the soil. Edwards *et al*. (2000) found that mulching increased soil water content by 6–7% and soil penetration resistance below the root zone was reduced almost 20%. This work was carried out in an area of agricultural production in the US but does demonstrate the impact of mulching on soil characteristics. Faucette *et al*. (2004) measured the run off of rain from 10 different composts ranging from poultry litter to municipal solid waste to composted bark and compared results with soil. Run off was lower in every compost sample than soil with the exception of poultry litter. The conclusion was made that the level of runoff was related to pore space and the ability of the compost mulch to absorb water. Clearly in a comparison with a plastic mulch and bare soil, as in the experiment described, here the differences in water percolation through the profile and runoff from the soil surface are likely to be significant - which they were, and this effect is consistent with other published data in a number of other crops. The other main effect of the straw mulch was to reduce leaf and fruit nitrogen, which is believed to be a result of the decomposition of straw requiring nitrogen, resulting in less nitrogen being available to the trees. Lower leaf nitrogen levels have been recorded in a number of crops treated with straw mulch. For example, in strawberry the use of straw mulch reduced leaf nitrogen by around 30% (Neuweiler, 1997). Combining the straw with a nitrogen rich material such as manure can overcome this effect.

The mulches created very different patterns of water absorption and therefore availability to the trees. Both beneficial and negative effects of the three mulches were seen and gaining an understanding of their effects on tree growth and cropping is therefore important.

The effects of irrigation on soil water content are also quite clear and again not surprising. Irrigation clearly improved water availability to the treated areas. The managed irrigation treatment using EnviroSCAN data enabled soil moisture to be maintained throughout the soil profile. This was particularly the case where a mulch was used that seemed to improve the soil structure. For the bare soil and plastic mulch treatments, the water tended to remain in the upper layers and not move through the soil profile as readily.

The rainfall during the three years of the experiment would have also had a significant impact on soil moisture. During 2007 there were 29 rain events which gave a total of 154mm rain during July and August. During 2008, there were 30 rain events which gave a total of 88mm rain during July and August. During 2009, there were 28 rain events which gave a total of 54mm rain during July and August. The number of rain events in each year was therefore similar but the total volume of rain falling differed considerably. 2007 was the wettest year followed by 2008 and then 2009. Current normal grower practice is to apply 1 inch water per week which equates to 200mm during July and August and so in no year was rainfall sufficient to satisfy the generally accepted requirement of trees. The fruit number was most affected by irrigation in 2009, which was the driest year, and may indicate an interaction between rainfall and irrigation effect. Having said this though, the rainfall appeared to be insufficient in 2008 and 2007 and yet the effect of irrigation was not significant on fruiting.

Over the last 20 years there have been a number of studies of irrigation of apples and pears which demonstrate clear effects on growth and fruit size. However, there are also reports where no effects were observed. Atkinson *et al*. (1998) found increased fruit size with irrigation and put this down to an increase in cortex cell size rather than cell number. In this work, fruit size was also increased with the use of a polytunnel where the temperatures reduced fruit set with irrigation enhancing this effect. Haynes (2006) compared N fertilization with irrigation and concluded that whilst there was a small effect of irrigation on fruit size and growth, this increased with added N fertilizer. Comparing the effect of managing irrigation to replenish water at the 0-60 and 0-120 cm layers Assaf *et al*. (1975) found the 0-60cm layer to be most important and final fruit yield was linearly related to the percentage available water in this layer. Interestingly they also determined that fruit firmness and soluble solids content were reduced by frequent irrigation, both directly and indirectly through the increased fruit size. Neilsen *et al*. (1997) compared daily and weekly irrigation to 100% and 50% field capacity and found that the more frequent irrigation treatment caused a 50% increase in yield over three years as well as a 10% increase in tree height. This was related to root growth, which was significantly greater in the daily irrigation regime. The effects of variable irrigation rates were compared in a ‘Bartlett’ pear orchard and did not influence fruit yield or size in the first year of the study but in further years there was an effect on fruit size (Ramos *et al*., 1994).

In the work described here on pear irrigation, there were actually only very minor effects on fruit and tree growth and no effect at all on storability of fruit. Based on the work described above, this is perhaps surprising but there are three possible reasons for this.

1. The pear irrigation treatments were applied during July and August. The rationale for this was that this was the period of fruit growth during which a limit to water supply would have been likely to reduce fruit size. In addition this is the method used by a number of growers in Holland and Belgium to increase fruit size. However, most of the published work describing irrigation effects on apples and pears tested the effect of continuous irrigation throughout the growing season. That irrigation was only applied for two months may not have been sufficient to achieve significant effects on fruit and growth. The other complicating factor is that, as discussed previously, pears do respond differently to irrigation depending on the timing of its application in relation to the fruit development stage. Whilst early development is characterised by a period of cell division, deficit irrigation during this phase can still impact on fruit size at harvest (Marsal *et al*., 2000). The rainfall during the period from April through to June may have therefore affected the results, particularly in 2009 when the rainfall during this period was particularly low.

2. The experiment was run in a 'Conference' pear orchard planted in the early 1980s with an intra row spacing of 2m. The trees were therefore mature and the tree volume was large. By implication the root system would have been well developed and would have extended to a diameter of around 2m, similar to the canopy size. Irrigation was applied using a single line of emitters as in commercial orchards and whilst the volume of irrigated soil would spread as the water moved through the soil profile, there would still have been part of the root system unaffected by the irrigation treatments. The roots would also have been able to "mine" water from a significant volume of soil meaning that water supply may not have been limiting. Perhaps if the experiment had been in a younger more intensive orchard the effects would have been more significant.

3. There was significant variation between trees in fruit number, with trees in the same plot varying by as much as 70 fruit per tree. This would in turn have affected fruit size. It does seem possible therefore that the effects of irrigation were masked by this variation as the scale of the likely irrigation effects may have been smaller than the tree to tree variation. This could obviously be overcome by using a greater replicate number.

The fruit storability was tested in each year primarily by examining the decline in fruit firmness during storage, although percentage starch and total soluble solids were also determined for each treatment. However, in none of the three years was a significant effect of treatment observed. A number of authors have shown the potential positive impact of improved soil moisture levels on fruit storability of pears and apples. Cabral *et al*. (1995) determined firmness of fruit during storage to be significantly improved with irrigation. Comparing trickle irrigation with no irrigation, the fruit firmness was improved by around 5% in the irrigated trees. However, in an experiment on 'Bartlett' pear, where 3 levels of irrigation was tested, the fruit firmness was found not to be influenced by tree water status (Ramos *et al*., 1993). Whilst storage effects were not assessed these data may suggest at least that storability was not likely to have been affected. In apples, Bonany and Camps (1998) tested the effect of five irrigation regimes on apple quality and determined a significant negative linear relationship between increasing irrigation and fruit firmness, although the plot variation was large. It is clear therefore that irrigation has been shown to affect fruit growth in a number of experiments. The effect on storage however, varies. In the work discussed above clear effects on fruit size for example have been observed. That these effects were not seen in this trial on pears suggests that any storage effects are not likely to be observed. Whether this is due to the age of the trees, the level or duration of irrigation is not clear.

Conclusions

The differences in the effects of the three mulches on soil structure were important. Compost in particular is known to improve soil structure and the same effects were seen here with the compost mulch causing better percolation of water through the soil profile than for example the bare soil.

Irrigation clearly improved the availability of water to the trees, which is not surprising and demonstrates that, where possible, irrigation can be used to improve soil moisture availability and to actively manage soil moisture content. Water availability throughout the soil profile was most improved by the combination of both irrigation and composted bark mulch, as the improved soil structure allowed better availability of irrigation water throughout the profile. Whilst these effects were expected to result in improvements to yield and fruit size, the differences were not significant.

The fact that there were very few significant effects of the treatments seems to be due to one or more of the three possible reasons which are discussed above. For example the size of tree may have affected the results, the tree – tree variability would have affected the results and so whilst the data does show that in certain situations irrigation effects are minimal, general conclusions about the use of irrigation cannot be made, particularly as growers' experience is at odds with the data collected here.

Knowledge and Technology Transfer

1. FAST Top Fruit Conference 2008
2. HDC Tree Fruit Review 2010

References

Assaf R., Levin I., Bravdo B. (1975). Effect of irrigation regimes on trunk and fruit growth rates, quality and yield of apple trees. Journal of Horticultural Science 50: 481-493.

Atkinson C.J., Taylor L., Taylor J.M. and Lucas A.S. (1998). Temperature and irrigation effects on the cropping, development and quality of ‘Cox's Orange Pippin' and ‘Queen Cox' apples. Scientia Horticulturae 75: 59-81.

Behboudian M.H., Dixon, J. and Pothamshetty, K. (1998). Plant and fruit responses of lysimeter-grown 'Braeburn' apple to deficit irrigation. Journal of Horticultural Science and Biotechnology 73: 781-785.

Bonany J. and Camps F. (1998). Effects of different irrigation levels on apple fruit quality. Acta Horticulturae 466: 47 – 52.

Cabral M.L., Barreiro M.G. and Franco J. (1995). Effect of irrigation on storage capability of ‘Rocha’ pear. Acta Horticulturae 379: 167-174.

Carew J.G. (2010). Apples: Long term effects of compost. Horticultural Development Company report for project TF 177.

Chang-Zeng Z., Lu L., Bai-Hong C. and Cun-Zhi P. (2002). Effect of straw mulching on leaf physiological properties, size and growth curves of pear fruit in an arid desert area. Acta Horticulturae 587: 605-610.

Edwards L., Burney J.R., Richterc G. and MacRae A.H. (2000). Evaluation of compost and straw mulching on soil-loss characteristics in erosion plots of potatoes in Prince Edward Island, Canada. Agriculture, Ecosystems & Environment 81: 217-222.

Haynes R.J. (2006). Some observations on the effect of grassing-down, nitrogen fertilisation and irrigation on the growth, leaf nutrient content and fruit quality of young golden delicious apple trees. Journal of the Science of Food and Agriculture 32: 1005–1013.

Kang S.Z., Hu X.T., Goodwin I., Jirie P., Zhang J. (2002). Soil water distribution, water use and yield response to partial root zone drying under flood-irrigation condition in a pear orchard. Scientia Horticulturae 92: 277–291.

Kilili A.W., Behboudian M.H. and Mills T.M. (1996). Postharvest performance of 'Braeburn' apples in relation to withholding of irrigation at different stages of the growing season. Journal of Horticultural Science 71: 693-701.

Lakso A.N., Corelli L., Barnard J. and Goffinet M.C. (1995). An expolinear model of the growth pattern of the apple fruit. Journal of Horticultural Science 70: 389-394.

Mågea F. (1982). Black plastic mulching, compared to other orchard soil management methods. Scientia Horticulturae 16: 131-136.

Marsal J., Mercè M., Arbonés A., Rufat J. and Girona J. (2002). Regulated deficit irrigation and rectification of irrigation scheduling in young pear trees: an evaluation based on vegetative and productive response. European Journal of Agronomy 17: 111-122.

Marsal J., Rapoport H.F., Manrique T. and Girona J. (2000). Pear fruit growth under regulated deficit irrigation in container-grown trees. Scientia Horticulturae 85: 243-259.

Mitchell P.D., Jerie P.H., Chalmers D.H. (1984). Effects of regulated water deficits on pear tree growth, flowering, fruit growth, and yield. Journal of the American Society of Horticultural Sciences 109: 604-606.

Moniruzzaman M., Mozumder S.N., Islam M.R. (2007). Effect of mulching and pruning on yield and quality of pear. Bangladesh Journal of Agricultural Research 32: 225-233. Abstract only.

Naor A. (2001). Irrigation and crop load influence fruit size and water relations in field-grown ‘Spadona’ pear. Journal of the American Society for Horticultural Science 126: 252 – 255.

Naor A. (2006). Irrigation Scheduling and evaluation of tree water status in deciduous orchards. In: Horticultural Reviews 32, Ed. J. Janick, John Wiley and Son, 111 – 165.

Neilsen G. H., Parchomchuk P., Berard R. and Neilsen D. (1997). Irrigation frequency and quantity affect root and top growth of fertigated ‘McIntosh’ apple on M.9, M.26 and M.7 rootstock. Canadian Journal of Plant Science 77: 133–139.

Neuweiler R. (1997). Nitrogen fertilization in integrated outdoor strawberry production. Acta Horticulturae 439: 747 – 751.

Pinamonti F. (1998). Compost mulch effects on soil fertility, nutritional status and performance of grapevine. Nutrient Cycling in Agroecosystems 51: 239-248.

Proebsting E.L. and Middleton J.E. (1980). The behaviour of peach and pear trees under extreme drought stress. American Society for Horticultural Science 105: 380-385.

Ramos D.E., Weinbaum S.A., Shackel K.A., Schwankl L.J., Mitcham E.J., Mitchell F.G., Snyder R.G., Mayer G. and McGourty G. (1994). Influence of tree water status and canopy position on fruit size and quality of Bartlett pears. Acta Horticulturae 367: 192-200.

Ramos D.E., Weinbaum S.A., Shackel K.A., Schwankl L.J., Mitcham E.J., Mitchell F.G., Snyder R.G., Mayer G. and McGourty G. (1994). Influence of tree water status and canopy position on fruit size and quality of Bartlett pears. Acta Horticulture 367: 192-200.

Shaozhong K., Hua X., Goodwin I. and Jerieb P. (2002). Soil water distribution, water use, and yield response to partial root zone drying under a shallow groundwater table condition in a pear orchard. Scientia Horticulturae 92: 277-291.

Zhang C., Tanabe K., Wang S., Tamura F., Yoshida A. and Matsumoto K. (2006). The impact of cell division and cell enlargement on the evolution of fruit size in *Pyrus pyrifolia.* Annals of Botany 98: 537–543.

Zhao C., Lu L. and Peng C. (2002). Effect of straw mulching on leaf physiological properties, size and growth curves of pear fruit in an arid desert area. Acta Horticulturae 587: 605 – 610.

Zhao Z., Cheng F.H., Gao Y., Tian C., Song H. and Liang W. (2007). Effects of different irrigation methods and quantity on yield and water use efficiency in pear. Journal of Fruit Science, 01. Abstract only.