Project Number:	TF 177
Project Title:	Apples: Long term effects of applied composted green waste mulch on the cropping of Braeburn and Cox
Project Leader:	Tim Biddlecombe Farm Advisory Services Team Ltd. Brogdale Farm Brogdale Road Faversham Kent ME13 8XZ
Contractor:	Farm Advisory Services Team Ltd.
Industry Representative:	Peter Checkley
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DISCLAIMER

The results and conclusions in this report are based on an investigation conducted over a one-year period. The conditions under which the experiments were carried out and the results have been reported in detail and with accuracy. However, because of the biological nature of the work it must be borne in mind that different circumstances and conditions could produce different results. Therefore, care must be taken with interpretation of the results, especially if they are used as the basis for commercial product recommendations.

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.

[Name]
[Position]
[Organisation]

Signature .... Date ....

[Name]
[Position]
[Organisation]

Signature .... Date ....

Report authorised by:

[Name]
[Position]
[Organisation]

Signature .... Date ....

[Name]
[Position]
[Organisation]

Signature .... Date ....

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GROWER SUMMARY

Headline

- The use of compost as a mulch increased fruit number per tree, at the same time as increasing fruit size. This resulted in yield increases of around 7kg per tree for Braeburn and 13kg for Cox.

Background and expected deliverables

Previous work has been carried out to determine the effect of the application of composted green waste as a mulch in apple production. Positive effects on fruiting as well as growth have been observed but work tended to be relatively short term and concentrate on testing the effect in the four years following planting. This project continues on from previous work funded by WRAP which tested the effect of green waste compost mulch on the growth and fruiting of two varieties of apple (Cox and Braeburn) with an extended evaluation of the effect on growth and fruiting of the trees over four years. The final report will also include an economic analysis of the use of composted green waste as a mulch for apple production.

Summary of the project and main conclusions

The trial was conducted on two apple varieties: Cox and Braeburn to which mulch was applied to half the field on two occasions. In 2004 when the trees were planted, a 10cm layer of compost was applied giving a rate of 30 tonnes per hectare. This was then repeated in 2007. The mulched area is being compared to one where the herbicide strip had been left bare.

Fruit number and size were recorded at harvest. A series of fruit maturity tests were conducted on both varieties during August, September and October as an additional measurement to test whether the compost mulch altered maturity characteristics and fruit quality. In addition, samples of Cox were placed in store to test whether the compost treatment altered storability. Length of shoot growth was recorded in October. Soil, leaf and fruit nutrient analysis was carried out to determine the effect of mulch on soil nutrient content and uptake by the tree. Enviroscan soil moisture probes were used to determine the effect of green compost on soil moisture content.

Fruit size increased by 6.6mm in Cox and by 5.7mm in Braeburn. Fruit number also increased in both varieties with the use of compost mulch. In Braeburn the increase was only 12 fruit per tree but for Cox the difference in fruit number was 87 fruit per tree. As in previous years, there was a difference in the amount of shoot growth between the two treatments with the compost increasing growth by 27% and 118% in Braeburn and Cox respectively. The combined effect of increased growth over the last 6 years has meant the compost treated trees have now filled their spaces whereas those in the herbicide strip have not. For this reason, the compost treated trees were able to produce so much more fruit without a detrimental effect on fruit size.

The application of composted green waste increased the fruit nitrogen and decreased fruit phosphate levels. This has implications for fruit storability and may mean that fruit treated with compost will not store for as long as fruit from trees grown in bare soil. It will certainly mean that fertilizer and foliar feed applications need to be based on current analyses. The effect on storability was monitored by placing fruit in stores on two harvest dates. The compost treated fruit had a significantly lower percentage starch and the fruit firmness was lower confirming the detrimental effect on storability. The series of maturity tests conducted, demonstrated that the fruit from the compost treated area, matured around 2 weeks earlier than the fruit from the untreated area, having a significantly lower percentage starch and fruit firmness. It also had a yellower background colour although this was more a result of the fruit nitrogen content rather than any effect of maturity.

Clear differences in soil moisture between the two treatments have been observed in each year the project has been running. However, in 2011 the differences between the two treatments were less than in previous years. This is probably due to the extremely dry start to the season combined with the higher water demand from the compost treated trees. The main difference in 2011 was the greater percolation of water through the soil profile. Full details of the differences can be found in the Science Section of the report.

Main conclusions

The use of compost as a mulch increased fruit number per tree, at the same time as increasing fruit size. This resulted in yield increases of around 7kg per tree for Braeburn and 13kg for Cox.

- Fruit and leaf nutrient levels were significantly altered by the use of compost mulch. Fertilizer and foliar feed applications need therefore to be based on recent analysis results.
- Significant differences in fruit maturity timings and storability of fruit have been observed between the two treatments. Compost mulch advanced maturity by around two weeks and reduced fruit quality after storage.

- Similar differences in soil moisture content have been seen in 2011 as in previous years. The main effect seen in 2011 though was the greater percolation of water through the soil profile in the compost treatment.
- Growth is significantly increased through the use of compost and is becoming excessive now the compost treated trees have filled their spaces. This makes careful pruning and growth regulation necessary to maintain fruiting/growth balance.

Financial benefits

Yield of Braeburn increased by 7.3kg per tree with the addition of compost. Yield of Cox increased by 12.5kg per tree with the addition of compost. Using a farm gate price of £80 for a 330kg bin, these represent increases in return of £1.76 per tree for Braeburn and £3.03 per tree for Cox. At the density of 2,300 trees per hectare, these equate to increases in gross return of around £4,048 and £6,969 per hectare respectively. It should be noted that Paul Aylward, Manager of North Court Farm has monitored the extra costs incurred in the compost treated section and the only increased cost was the pruning which took longer in the compost treated trees due to their excessive vigour. This added an extra 30p per tree. The cost of application of compost at a rate of 50 tonnes per ha is £550 per ha. Spread over the 7 years of the orchard, to date, this would equate to an annual cost of £78 per ha. However, in the trial described here, the application rate was much greater at around 450 tonnes per ha. This would equate to an annual cost of £707 per year based on the seven year life of the orchard, but obviously this annual cost would be reduced over the complete life of the orchard.

Action points for growers

- Use mulch to aid establishment and growth of trees.
- Mulch can be used in situations where increased growth is required. This has been shown to result in improved yield as tree volume increases.
- However, where vigour is already adequate or strong, the use of a mulch could lead to problems of excessive vigour.
- Conduct leaf and fruit analysis to determine whether fertilizer and foliar applications are necessary.
- Assess maturity and obtain fruit analysis separately to non-treated blocks of trees as maturity and storability can be affected by compost mulch applications.

SCIENCE SECTION

Introduction

A series of trials on the use of compost as a mulch in fruit orchards in Kent were conducted as part of a WRAP funded project over the four years prior to the start of this project. The current project, funded by the HDC, aims to determine the effect of long-term compost use beyond the WRAP funded part of the project.

All of the sites tested as part of the original WRAP funded work showed similar soil alterations with addition of compost mulch which included increases in soil organic matter, pH, and general increase in the pool of available nutrients (N, P, K, S).

Generally the fruit crops tested all responded well with yield increases (fruit weight per tree) of blackcurrant (23%), Bramley apple (30%) and Conference pear (54%) compared to un-mulched controls. Such increases are of economic significance to growers and highlight the potential of compost mulch for improving top and soft fruit yields.

However the effects in 2008 on the apple cultivar Braeburn were very different. The use of compost mulch actually resulted in a decrease in fruit yield per tree of approximately 15%, which was completely out of line with other previous findings. The conclusion made was that increasing levels of nutrients (nitrogen, potassium and phosphate) appeared to have triggered a shift towards vegetative growth (stem/shoot/leaf) rather than the real target of increased fruit production. In the years prior to 2008, there were generally positive effects of mulch on fruiting with yield increasing by around 50%. It was possible that the different results observed in 2008 were down to the extended duration of compost application (Lock et al., 2008) but the variable effect of mulch use has been observed by a number of authors.

In work on the cultivar Empire, Merwin and Stiles (1994) found the use of straw mulch increased yield over the tilled control in each year tested but only in certain years was the yield greater than with the herbicide treatment. This was related to increased growth as recorded by the trunk cross-sectional area. In contrast, Rumberger et al. (2005) found that preplant compost or fumigation soil treatments had no effect on tree growth when applied in an apple replant situation. Yaoa et al. (2006) also found little effect of compost in a replant site, with the only significant effect being an increase in lateral extension growth. Neilsen et al. (2003) tested the effects of six mulch types ranging from black polythene to bark and straw mulches. In general the mulches all increased yield, partly due to an increased fruit size. However this did vary from year to year and was again related to the relative increase in vegetative growth. Interestingly, there were no consistent effects of the mulches on leaf nutrient content. Autio et al. (1991) also showed benefits on growth of newly planted Gala apple trees but the difference in growth was much greater in later years than those immediately following planting. It is clear therefore that the effect of mulches on growth and yield are generally positive but that their effect does vary between years. This variation is presumably due to the climate during the different years. Different authors have used a range of mulch types from polythene to straw, bark and manure. The differences in results would be compounded by these differences in treatments.

The project described here aimed to determine the effect of compost further, not only its effects on growth and fruiting but also on nutrient availability and uptake and on soil moisture content.

The use of compost in orchards has been tested in a number of studies around the world and has been shown to affect not only growth and fruiting of trees but also management of weeds, fungal diseases and insect pests. For example, Brown and Tworkoski (2004) found populations of leaf miner and wooly aphid to be reduced through the use of compost in apple orchards in the USA. In a Golden Delicious orchard the use of compost was found to increase natural insect predator levels (Matthews et al., 2004), which may explain the reduction in leaf miner and aphid levels as described above.

Mulches have also been shown to alter the tree nutrient status. In previous work composted sewage sludge increased growth of apple seedlings, possibly through an increased level of tissue Ca. Other effects included an increased pH, which alleviated the effect of naturally high manganese levels (Korkak, 1980). Work on the cultivar Macounfound compost to increase tree growth seven years after compost application but yield was increased only in alternate years, suggesting that the use of compost needs to be managed carefully to obtain consistent effects. Interestingly, in this trial there was no effect of applied monoammonium phosphate (Moran and Schupp, 2005). This is important because one of the effects of compost observed in the trial described here was to increase the level of phosphate. However in complete contrast, Wilson et al. (2004) found exactly the opposite. Compost had no effect whilst monoammonium phosphate increased tree growth significantly. Effects of compost addition include altered soil nutrient and physical characteristics. Compost treatments have been shown to result in higher microbial activity over standard fertilizer treatments in apple replant sites and also cause higher levels of nitrogen, phosphorus, potassium, and organic matter (Travis et al., 2006). pH also increases with the addition of compost.

It is clear that the effects of compost on apple tree growth are complex and varied. Effects on soil nutrient content and microbial activity vary and the effect of compost from year to year varies. The aim of the project described here is to determine the long term effect of compost mulch on two cultivars of apple: Braeburn and Cox. The cumulative effect of the compost will be tested over the duration of this project.

Materials and methods

The experiment was conducted at North Court Farm, Old Wives Lees, Kent in a Braeburn/Cox orchard planted in 2004. The farm is on the South Downs and the soil is generally clay over flint. The farm does not have irrigation. This was the first site to become involved in the previous WRAP project (RMD 0002-008) when compost was first applied in June 2004. The compost was applied in a strip one metre wide and 7 to 10 cm deep which was equivalent to approximately 4 tonnes of mulch per 100m of row. Application along the rows of Braeburn and Cox trees was accomplished using a side spreader adapted from straw/manure application systems.

In 2007, the compost was re-applied to the same trees which had received compost in 2004. The compost was applied to 13 rows of trees at a width of 1m and depth of 0.1m at a rate of 11.5 tonnes per row. Delivery and application took place in late spring to allow the soil to absorb as much moisture as possible during the winter and for the soil to warm in the spring before applying the compost. The rest of the orchard was not treated.

During 2011, assessments of crop growth and development were conducted to determine the effect of the compost mulch seven years after its initial application. Fruit size and number was recorded at harvest as was shoot growth, both new shoot growth in 2011 and tree radius. The length of new shoot growth in 2011 was recorded for shoots arising from the terminal bud of second year shoots. Tree radius was measured from the trunk to the furthermost point on the tree circumference. In addition, soil, leaf and fruit samples were analysed to determine the impact of the compost on the tree's nutrient status.

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.

A series of fruit maturity tests were conducted on both varieties to determine whether the compost mulch was affecting the fruit maturation process. The method used was as recommended by the UK Quality fruit group. Samples of 10 fruit from both varieties were taken from four sections of both the treated and untreated areas giving a total of 40 fruit tested per cultivar per treatment. Fruit firmness was tested using a bench penetrometer. Total soluble solids were tested using a refractometer and starch was recorded by halving the fruit transversely and dipping the cut side in a potassium iodide solution. The purple/black colouration pattern was then compared with the standard CTIFL colour chart to estimate the percentage starch present. Finally, the percentage of the fruit surface coloured block red was estimated, as was the red and green colour, using standard variety specific colour charts.

For Cox, samples of fruit were harvested when the starch reached between 70 and 80% and placed both in a commercial store at North Court Farm under controlled atmosphere (CA) conditions and in an air store at 1^{o}C at Brogdale Farm to determine the effect of compost treatment on storability. Fruit was removed after three months and a further maturity test conducted on each sample to determine the effect on storage of the fruit.

Because in previous years a reduction in fruit calcium content had been observed in the compost treatments, three gypsum treatments were applied to determine whether the lower calcium content could be corrected in this way. Gypsum was applied at two levels (1t/ha and 2t/ha) to four randomized sections of eight trees in each treatment. In addition a further four sections of eight trees were left untreated. Three guard trees prevented the gypsum from one treatment affecting the next.

The compost had been applied to one half of the field, the other half remaining without compost as the control treatment (Figure 1), rather than applying the compost in a completely randomized block design. Therefore, whilst statistical analysis was carried out to determine the effect of compost, it was not possible to dissociate this from position effects. As the only way around this problem, samples were taken for each measurement from four sections across each half of the field to minimize variation caused by location. ANOVA was used to determine the statistical significance of treatments.

Figure 1. Photograph showing the arrangement of the compost treatments.

Results

Effect of treatment on fruit number

For both varieties, the compost treated trees produced a greater number of fruit per tree than the no compost control trees (Figures 4 and 5). For Braeburn this increase in fruit number per tree was only 12 fruit per tree but for Cox, the difference was much greater at 87 fruit per tree. For Braeburn these differences were not significant (P=0.31) but for Cox the effect of compost treatment on fruit number was significant (P=0.0011). This has been a trend which has been shown in previous years but yield differences still arise, even in Braeburn, due to the combined effects of the slight difference in fruit number and the greater difference in fruit size.

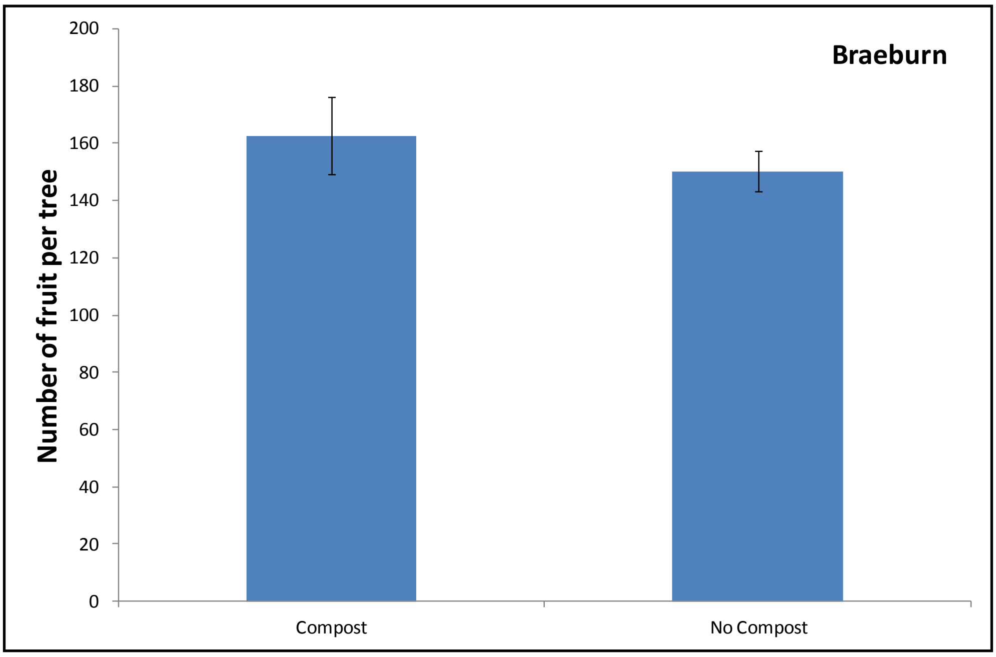

Figure 2. Effect of compost treatment on number of fruit per tree for Braeburn in 2011. Standard error bars are shown.

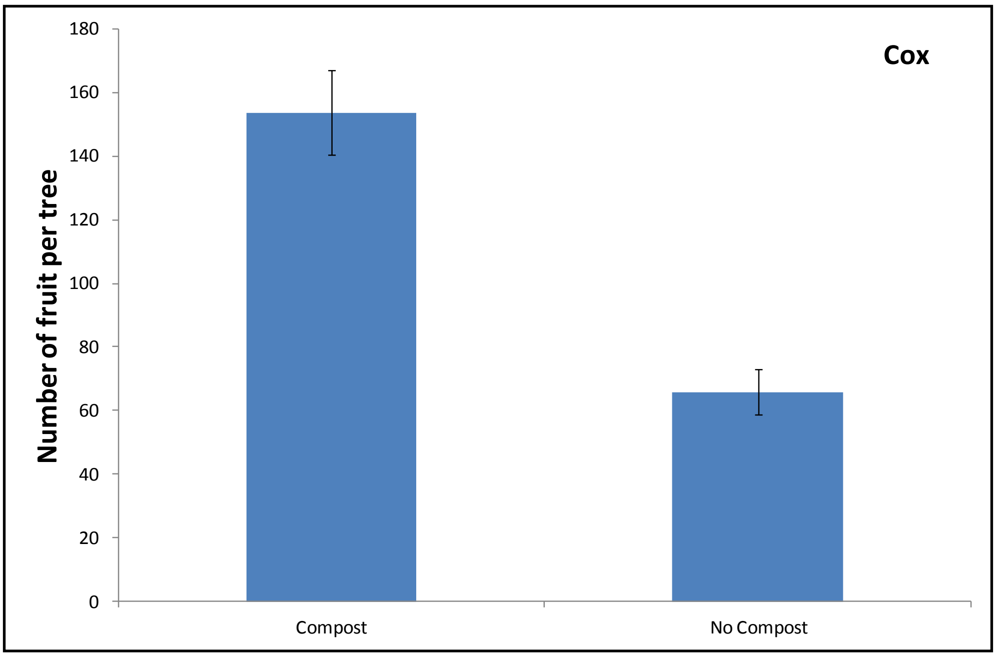

Figure 3. Effect of compost treatment on fruit number per tree of Cox in 2011. Standard error bars are shown.

Effect of treatment on fruit diameter at harvest

160 fruit were sampled just prior to harvest from each variety and treatment to determine final fruit diameter. Compost increased final fruit diameter in both varieties. For Braeburn the difference was greater in 2011 at 5.7mm (P=0.006) than in 2010 when the difference in fruit diameter was 1.5mm (Figure 6). For Cox, the difference in fruit size was slightly greater than for Braeburn at 6.6mm (P<0.001) (Figure 7). That the differences were greater in 2011 than in 2010 was due to the difference in weather conditions between the two years.

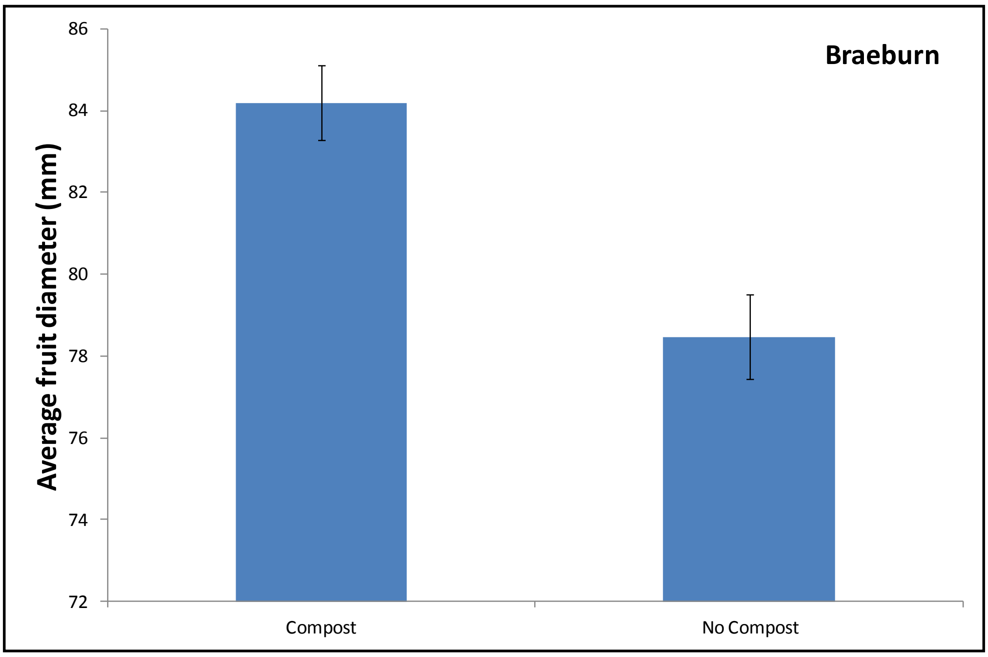

Figure 4. The effect of compost treatment on the fruit diameter for Braeburn in 2011. Standard error bars are shown.

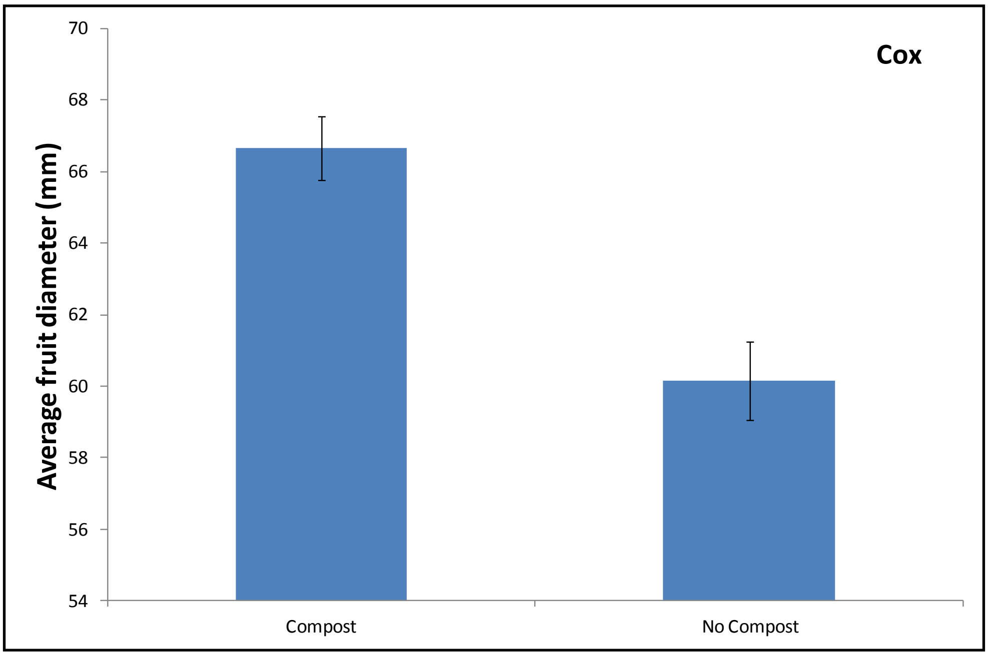

Figure 5. The effect of compost treatment on the fruit diameter for Cox in 2011. Standard error bars are shown.

Effect of treatment on fruit size at harvest

The effect of treatment on fruit size (Figures 8 and 9) was also recorded through measuring individual fruit weight from the same 160 fruit per treatment sampled at harvest which were used to calculate fruit diameter. Individual fruit weight was greater in the compost treatment for both varieties. For Braeburn the difference was 39g per fruit (P=0.0004), and for Cox the increase in fruit weight was slightly smaller at 34g per fruit (P<0.0001). The effect of compost on fruit size has been consistent throughout the duration of the trial, with the exception of Braeburn in 2009. This is important as not only does this impact the total yield but also the percentage of Class 1 fruit harvested from each variety.

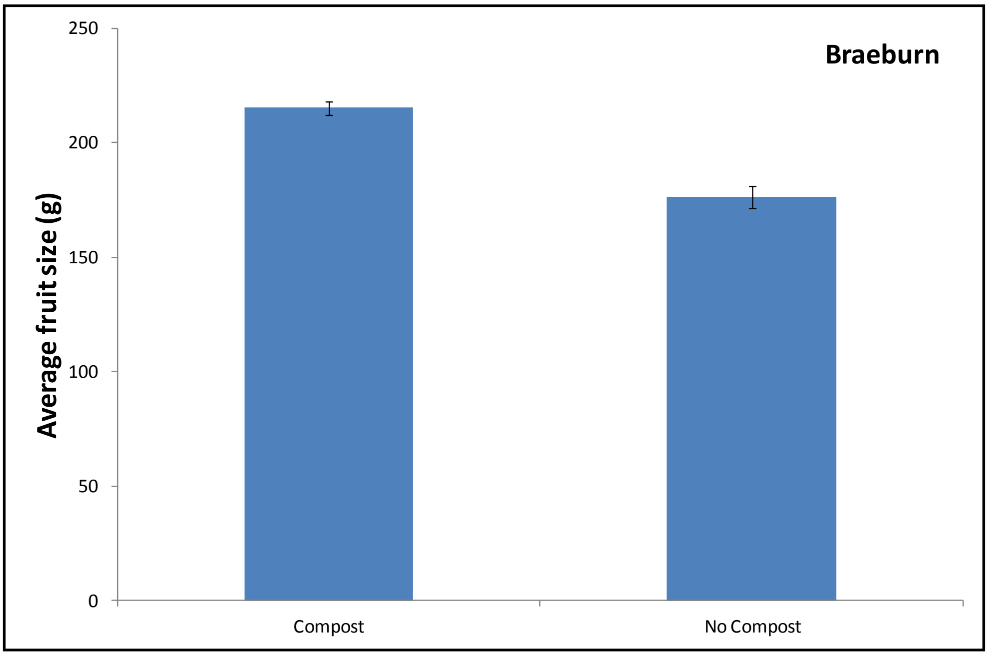

Figure 6. The effect of compost treatment on the fruit size for Braeburn in 2011. Standard error bars are shown.

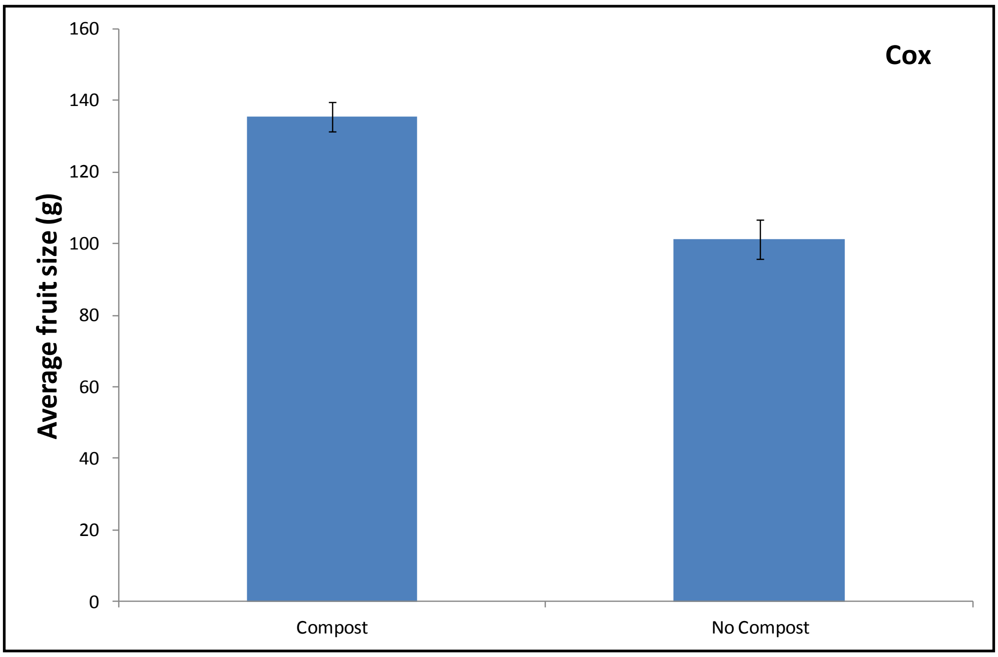

Figure 7. The effect of compost treatment on the fruit size for Cox in 2011. Standard error bars are shown.

Effect of treatment on yield

The effect of compost treatment on the calculated yield per tree is shown in Table 1. This was calculated from the recorded fruit numbers and sizes. In both varieties, the effect of compost mulch was to increase the yield per tree. For Braeburn and Cox, yield increased by 7.3kg and 12.5kg per tree respectively. The yield increase for Braeburn was similar to the increases in yield seen in 2009 and 2010 but the yield increase for Cox was much greater in 2011 than in previous years. Clearly this is an economically important yield increase and the equivalent yields per hectare are given in Table 2. That yields in the compost treatment have been greater since the first cropping year is important and the trend is one of an increasing difference over the duration of the crop.

Table 1. Effect of compost tree on yield per tree (kg per tree) for 2011. Standard errors are shown in parentheses.

	NO COMPOST	COMPOST
BRAEBURN	33.7 (1.7)	26.4 (1.2)
COX	19.1 (1.6)	6.6 (0.5)

Table 2. Effect of compost tree on yield per hectare (tonnes per hectare) for 2011.

	NO COMPOST	COMPOST
BRAEBURN	57.3	45.0
COX	32.5	11.2

Effect of treatment on shoot growth

Shoot growth was assessed in two ways in 2011. Firstly, new shoot growth for 2011 was recorded from 40 branches per treatment. For Braeburn, the shoot growth was 27% greater in the compost treatment (P=0.018) (Figure 10) and for Cox the difference was even greater, with the compost treatment more than doubling new shoot growth in 2011 (P=0.0014). For Cox average new shoot growth increased from 0.2m in the no compost control to 0.44m in the compost treatment (Figure 11). For Braeburn, average shoot growth in 2011 was 0.30m in the no compost control treatment and 0.38m in the compost treated trees.

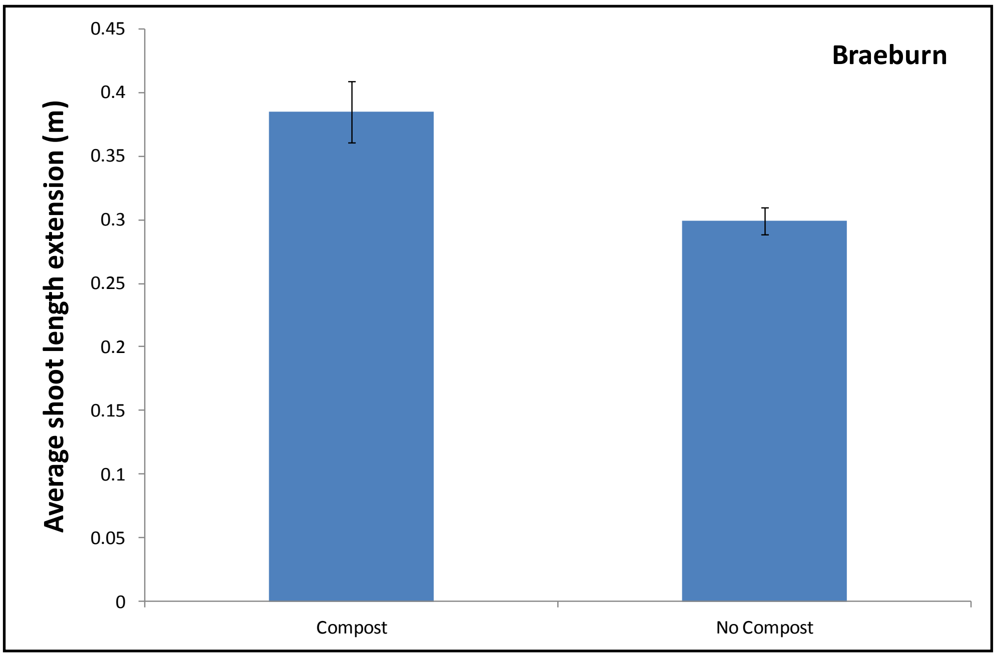

Figure 8. The effect of compost on new shoot growth of Braeburn in 2011. Standard error bars are shown.

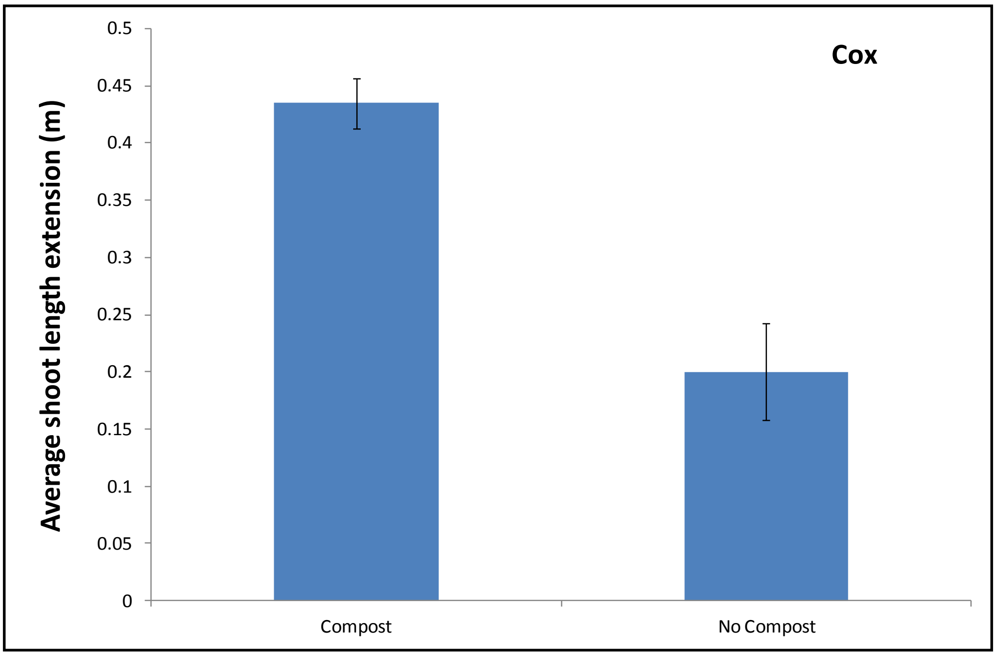

Figure 9. The effect of compost on new shoot growth of Cox in 2011. Standard error bars are shown.

Tree radius

As a measure of overall tree size, the average tree radius was recorded for each treatment by measuring from the tree centre to the furthermost point on the tree circumference. This is generally used on the Continent as a measure to predict tree productivity. For Braeburn

(Figure 12) there was a significant increase in tree radius with the use of compost (P=0.004), with the tree radius increasing from 1.06m in the no compost control trees to 1.35m in the compost treated trees. However for Cox (Figure 13) the difference was slightly less, increasing from 1.11m in the no compost treatment to 1.31m in the compost treatment (P=0.013). This is similar to the effects seen in previous years with the trees in the compost treatment being significantly larger than the no compost control trees. In most cases the compost treated trees have now filled their spaces, whereas there are still gaps between the no compost control trees.

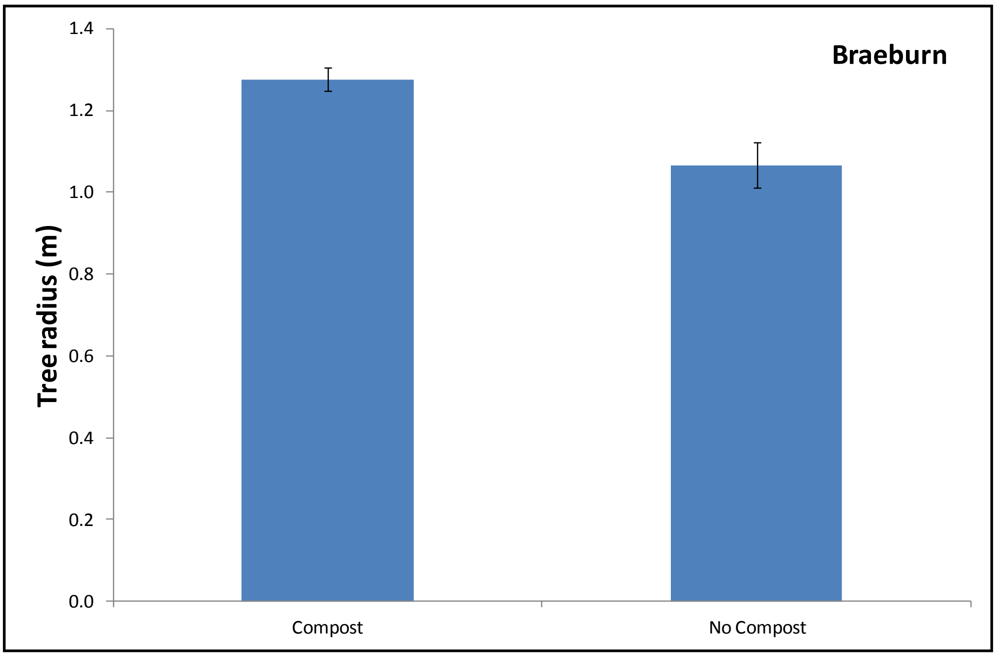

Figure 10. The effect of compost on tree radius of Braeburn in 2011. Standard error bars are shown.

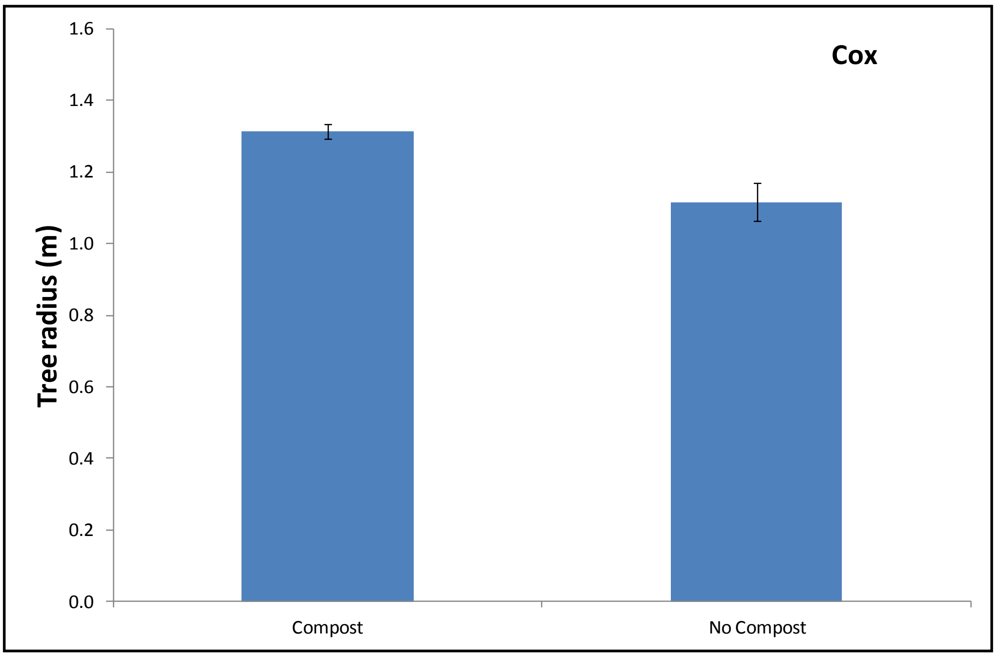

Figure 11. The effect of compost on tree radius of Cox in 2011. Standard error bars are shown.

Over the last six years there has been a continuous effect of compost treatment on vegetative growth in both varieties, which has resulted in very different tree sizes. The photographs shown in Figures 14 and 15 demonstrate very clearly how compost has increased growth, resulting in larger trees which have filled their spaces. Any further increases in growth could now be viewed as undesirable.

Figure 12. Braeburn trees which had been treated with compost mulch (L) and control trees which had been not been treated with compost mulch (R).

Figure 13. Cox trees which had been treated with compost mulch (L) and control trees which had been not been treated with compost mulch (R).

Fruit maturity

In 2010, fruit maturity was tested at harvest for Cox and Braeburn to determine whether the compost caused a significant difference in maturity of fruit. In 2011, a series of maturity tests was conducted to determine the effect of compost treatment on the six maturity parameters commonly measured in standard maturity tests: percentage starch, % block red, red and green intensity, total soluble solids (^{o}Brix) and fruit pressures. By conducting a number of tests over time the pattern of fruit development can be seen, with very clear differences in maturity between the two treatments, particularly for Cox. Significant differences were observed in starch degradation, fruit colouration and fruit firmness but not in the levels of total soluble solids.

Figure 14 shows the percentage starch for fruit from the two treatments for Cox and how it declines as the fruit starts to mature. On the first maturity test conducted on 12 August 2011, fruit from both treatments had a starch level of nearly 100%, showing that the maturity process had not yet begun. Over the following five weeks the percentage starch fell in both treatments. There was a significant difference in starch percentage though between the treatments, with the compost treatment causing a much more rapid decline than the no compost control treatment. The fruit from the compost treatment were maturing at a faster rate. Assuming that Cox for long-term storage should be harvested when starch is between 70% and 80%, the difference in optimum harvest date was around two weeks between the two treatments.

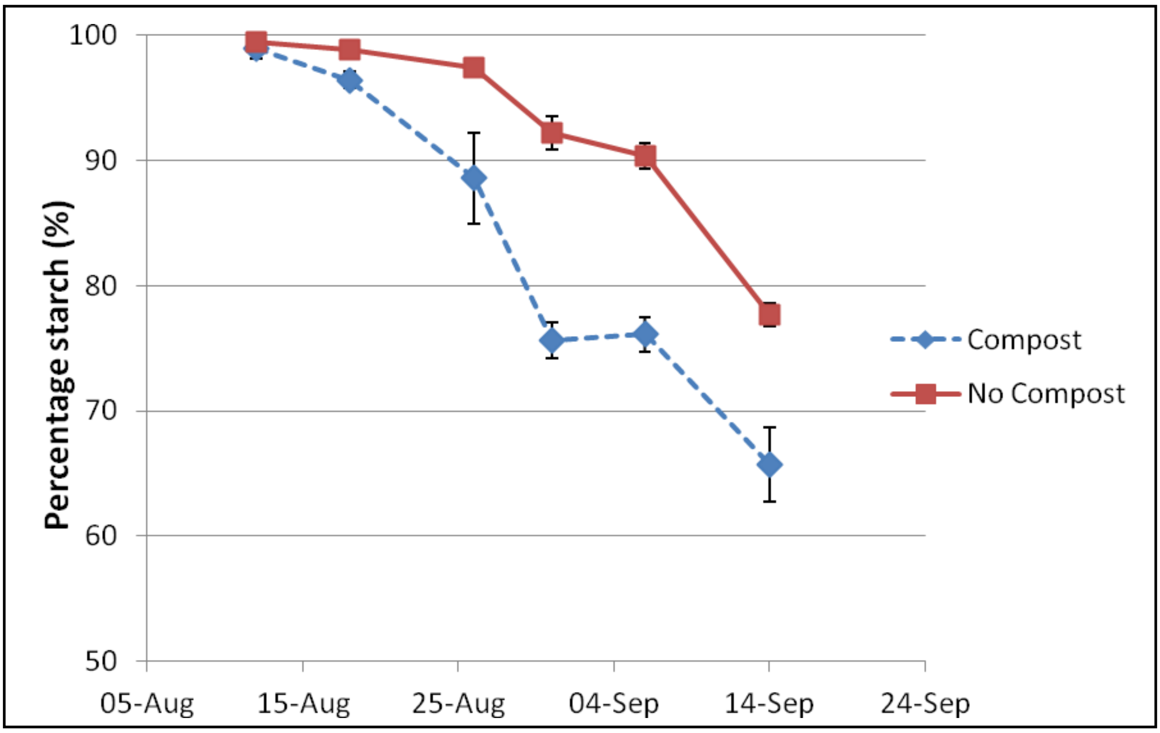

Figure 14. Effect of compost treatment on starch degradation for Cox in 2011. Standard errors are given in brackets.

The decline in starch and the colouring of fruit are important indicators of harvest date. This was recorded in three ways. The fruit background colour (Figure 15), the percentage of the fruit surface coloured block red (Figure 15) and the intensity of the red colour of the fruit (Figure 16) were estimated using apple colour charts.

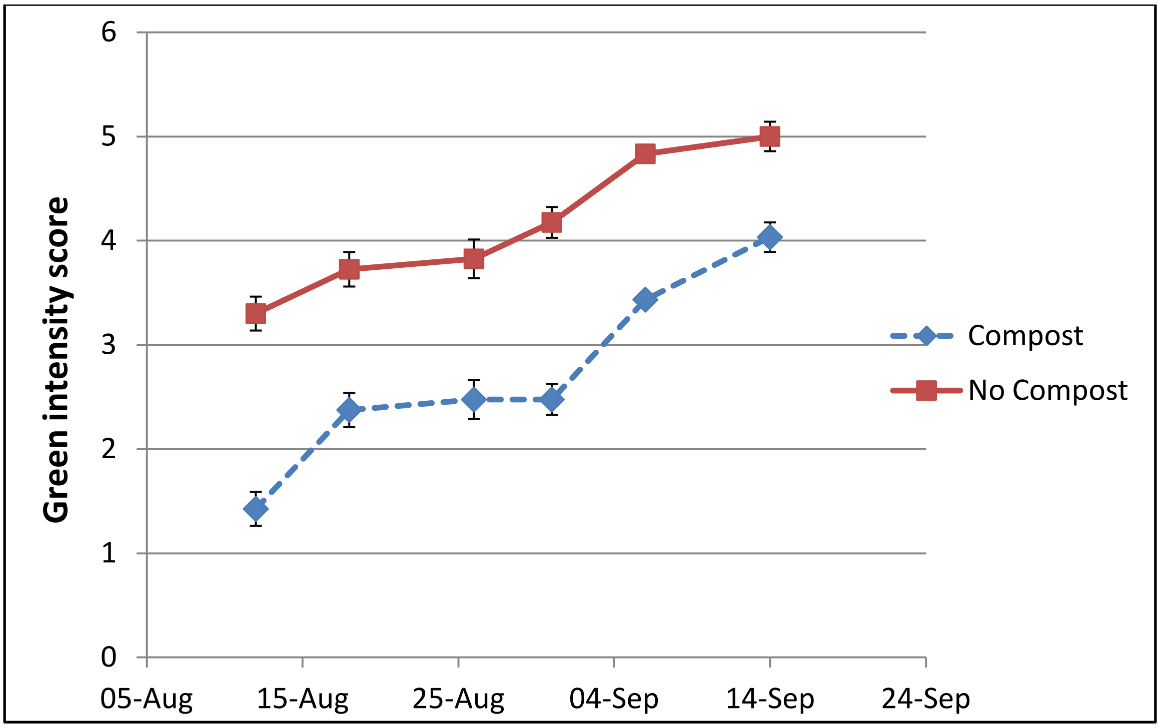

Figure 15. Effect of compost treatment on green intensity score based on the Cox colour chart for Cox in 2011. Standard error bars are shown.

The effect of compost treatment on the background green colouration of fruit is shown in Figure 15. As the background colour changes from green to yellow, this is seen as an increase in the green colour score. A score of 1 represents a darker green background colour than a score of 5, where the fruit is more yellow. This difference is likely to be due to the effect of fruit nitrogen content, which was much greater in the compost treatment than the no compost control treatment. However, many factors will influence this and so it is difficult to assess the exact causes.

The red colouration of fruit develops partly due to the effect of light and so shading caused by excessive vigour or by the position of the fruit within the canopy can limit the red colouration of fruit. Temperatures also influence the red colouration of fruit. Cox and Braeburn require at least 60% of the fruit surface to be red for the fruit to be graded as Class 1. As can be seen in Figure 16, the % block red increased at a similar rate in both treatments. However, there was a difference of around 20% between the treatments during August and September, with the compost reducing percentage red fruit colour by around 20% compared to the no compost control trees. Clearly the effect of compost treatment was significant, presumably due to the increased shading caused by the greater growth rates of the compost treated trees.

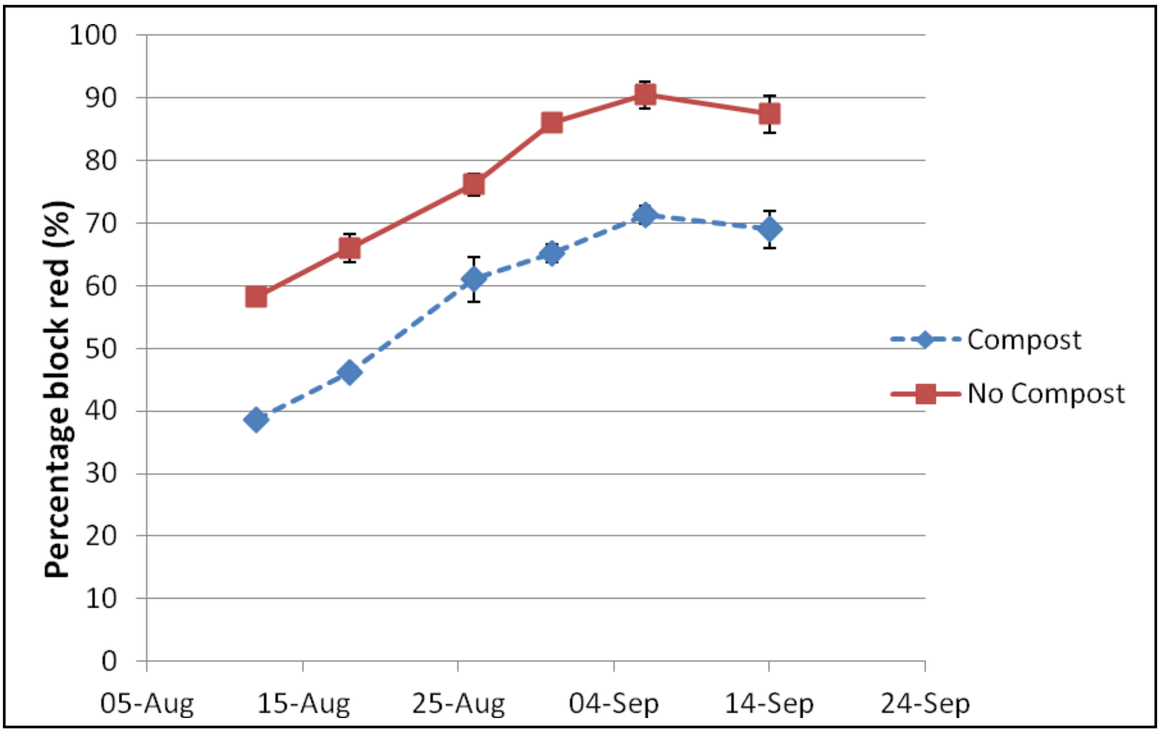

Figure 16. Effect of compost treatment on the percentage of the fruit surface which was block red (%) for Cox in 2011. Standard errors are given in brackets.

Figure 17 shows the effect of compost treatment on the intensity of the fruit red colour. The effect of treatment was similar to the effect on the percentage block red as shown above. The differences between the two treatments were significant, with the red score being greater in the no compost control treatment. Clearly the effect of light on fruit development was significant, with the shading caused by the increased growth in the compost treatment causing less fruit colour development than in the no compost control treatment. Fruit from the no compost control treatment had a greater proportion of the surface block red but also the intensity of the red colour was greater.

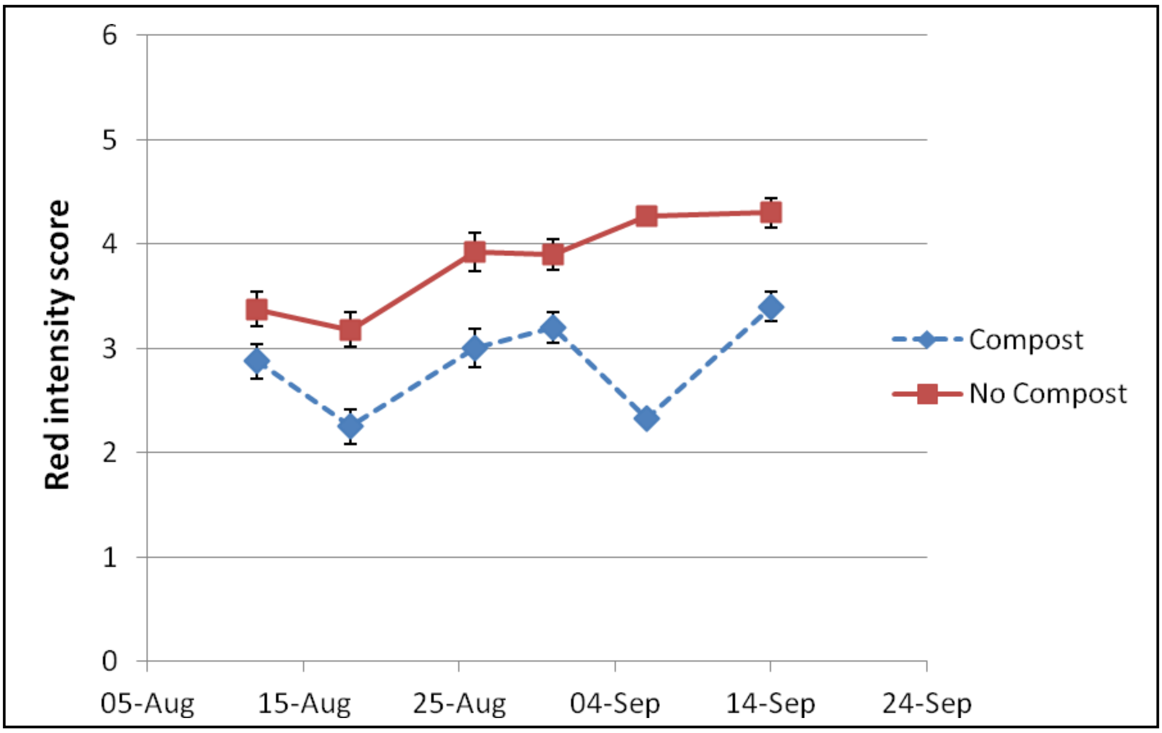

Figure 17. Effect of compost treatment on red intensity score based on the apple colour chart for Cox in 2011. Standard error bars are shown.

The effects of compost treatment on total soluble solids and fruit firmness, as recorded using a penetrometer, are shown in Figures 18 and 19. There was very little difference in the fruit total soluble solids, with both treatments following a similar pattern, increasing from 10 to 12^{o} Brix over the course of the maturity tests.

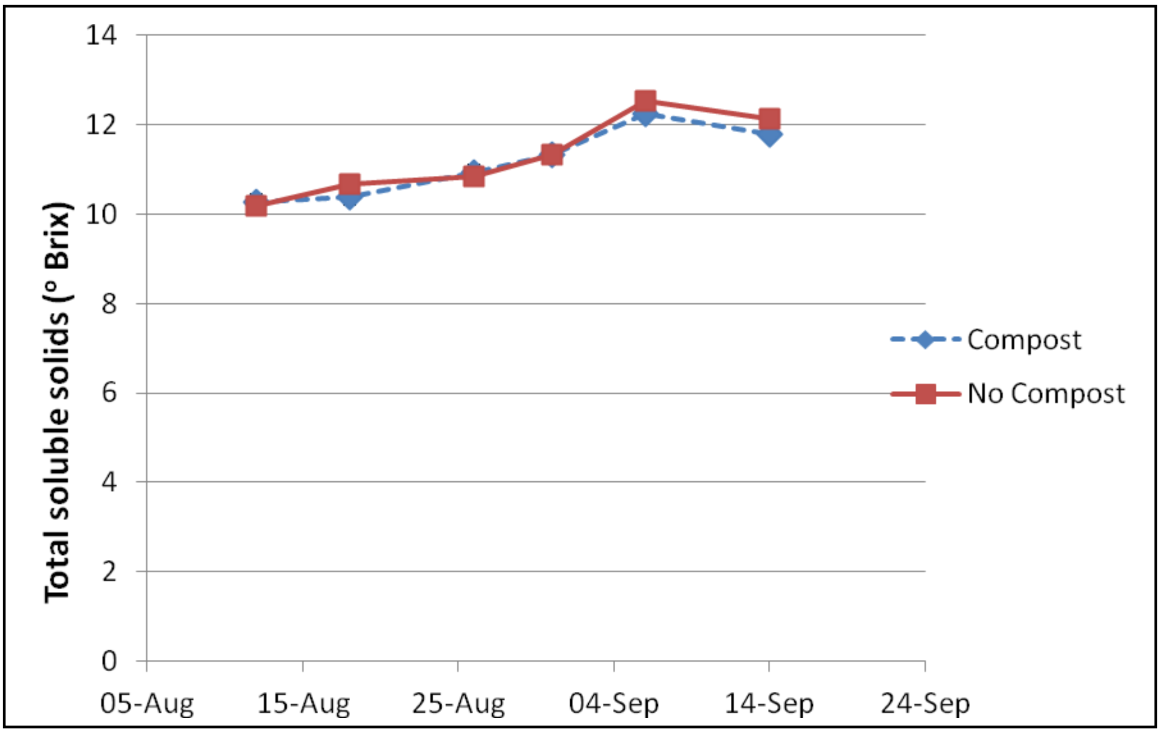

Figure 18. Effect of compost treatment on total soluble solids content (°Brix) for Cox in 2011. Standard errors are shown.

For fruit firmness there were significant differences between the two treatments, whereby the compost treatment caused a reduced fruit firmness compared to the no compost control treatment (Figure 19). This is another indicator that the fruit maturity was advanced by the compost treatment. It also indicates why the difference in fruit weight was greater than the difference in fruit diameter. It seems that the compost treated fruit were less dense than the fruit from the no compost control treatment. It would be worth testing the dry matter content of the fruit to confirm whether this is the case, although size:weight ratios can also be used as an indicator of fruit density.

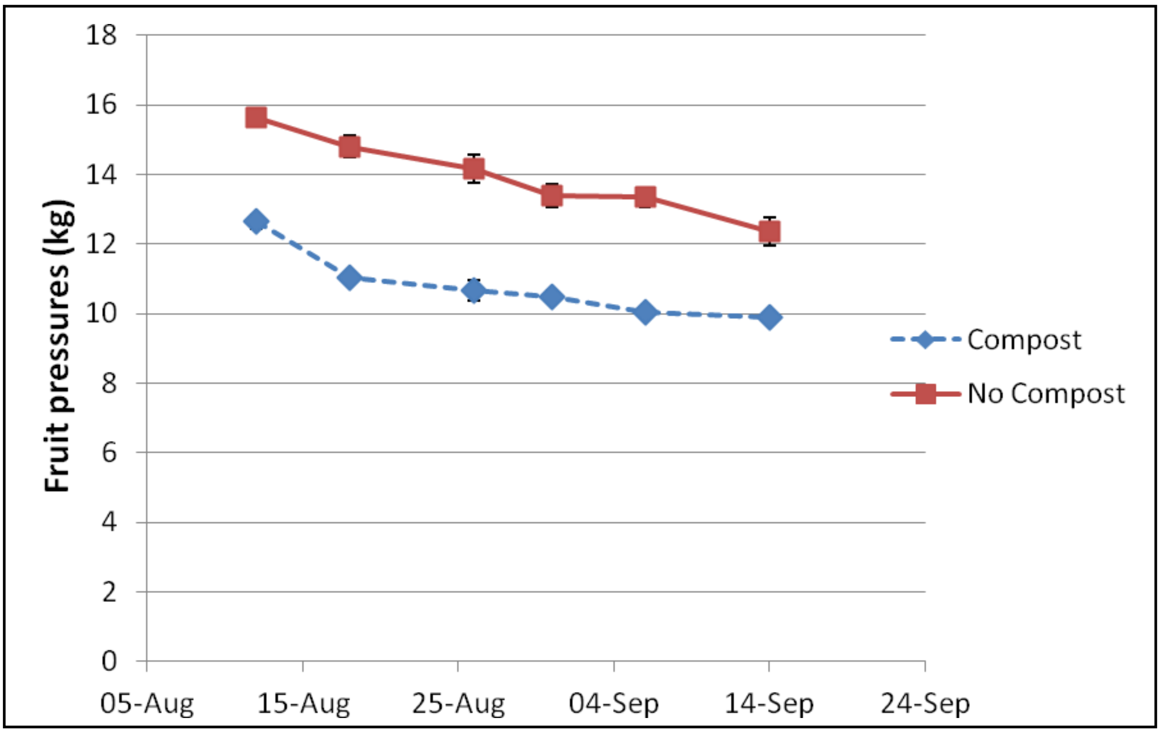

Figure 19. Effect of compost treatment on fruit pressures for Cox in 2011. Standard errors are shown.

For Braeburn, data from two maturity tests, conducted on 27 September and 5 October, are shown in Tables 3 and 4. The effect of compost treatment on fruit colour was similar to Cox. The percentage block red was 20-30% greater in the no compost control treatment than the compost treatment. Both the green and red scores as recorded using a CTIFL colour chart were greater in the no compost control treatment. These results are similar to the data for Cox and show the same effect of differences in shading of fruit causing differences in fruit colouration - the greater the growth caused by the compost treatment reduced fruit red colouration. Interestingly, whilst starch was greater on both dates in the no compost control treatment, the difference was much less than for Cox. For Braeburn the differences recorded were 2-3%, whereas for Cox the differences were 12.1% . The differences in fruit firmness and in total soluble solids were not significant. So whilst similar trends can be seen for both varieties, the differences in the maturity test results for the two treatments were much greater for Cox than for Braeburn.

Table 3. Effect of compost treatment on fruit maturity for Braeburn Cox in 2011 (Data from 27 September 2011). Standard errors are given in brackets.

	TSS (^{o}Brix)	Green score	Red score	Block red (%)	Pressure (KG)	Starch (%)
Compost	10.28	3.50	3.13	47.53	10.42	85.00
(SE)	(0.11)	(0.10)	(0.37)	(5.06)	(0.16)	(0.50)
No compost	10.50	3.62	3.33	70.50	10.47	87.25
(SE)	(0.10)	(0.08)	(0.27)	(8.20)	(0.14)	(0.48)

Table 4. Effect of compost treatment on fruit maturity for Braeburn Cox in 2011 (Data from 5 October 2011). Standard errors are given in brackets

Compost treatment	TSS (^{o}Brix)	Green score	Red score	Block red (%)	Pressure (KG)	Starch (%)
Compost	10.18	3.15	2.80	64.6	10.06	78
(SE)	(0.12)	(0.10)	(0.12)	(3.02)	(0.12)	(1.55)
No compost	10.22	3.30	3.58	79.2	10.24	81
(SE)	(0.26)	(0.13)	(0.17)	(2.91)	(0.12)	(1.24)

Fruit mineral analysis

Fruit were sampled from each variety in August for mineral analysis. For Cox (Table 5), fruit phosphate was higher in fruit from the no compost control trees than in fruit from the compost treated trees. Potassium level was also higher in fruit from the no compost control trees, which is interesting as for 2009 and 2010 the potassium level had been greater in the compost treated trees, which had caused concerns over the storability of the fruit. In addition, the calcium level was greater in the no compost control treatment. This has been the case since the start of the trial and led to the addition of gypsum at two rates (1t/ha and 2t/ha) to investigate whether this effect of the compost could be reversed. Fruit nitrogen levels have consistently been higher in the compost treated trees than the no compost control trees, possibly one reason why the growth of the compost treated trees have been so much greater over the course of the project. The high nitrogen and lower calcium of the compost treatment reduced the predicted potential storage duration.

Table 5. Effect of compost on fruit nutrient analysis of Cox fruit in 2011. Significance of difference is shown in Table 8.

Compost treatment	N	P	K	Ca	KCA	Mg
Compost - Ca control (SE)	66.6 (2.83)	12.5 (0.58)	149.0 (4.39)	7.43 (0.38)	20.3 (1.07)	6.61 (0.35)
No Compost - Ca control (SE)	48.3 (1.58)	19.2 (0.57)	171.5 (4.28)	10.55 (0.65)	16.4 (1.05)	7.45 (0.15)

Gypsum was applied to both the compost treated trees and to trees in the no compost control treatment at two rates – 1t/ha and 2t/ha as well as leaving an untreated control (0T/Ha). The gypsum was applied in four randomized blocks with three guard trees in between treatments. The applications were made in April. Fruit from each block were then analysed and the average fruit nutrient content is shown in Tables 5 (Compost treatment) and Table 6 (Control, no compost treatment). In both cases the effect of gypsum application was not significant, even on the fruit calcium level. This is perhaps unsurprising due to the short time between application and sampling – the gypsum being applied in April and fruit sampled in August. The dry period of weather in April and May would have exacerbated this because most calcium has been taken up by the fruit by mid-June. It will be important to conduct the tests again in 2012 to test whether any effect can be seen by then.

Table 6. Effect of gypsum application on fruit nutrient analysis of Cox in 2011 for fruit from the compost treated trees. Significance of difference is shown in Table 8.

Compost treatment	N	P	K	Ca	KCA	Mg
Ca control (SE)	66.6 (2.83)	12.5 (0.58)	149.0 (4.39)	7.43 (0.38)	20.3 (1.07)	6.61 (0.35)
Ca 1T SE	66.7 (2.64)	12.7 (0.15)	158.4 (3.45)	6.17 (0.41)	25.9 (1.62)	6.56 (0.18)
Ca 2 T (SE)	67.8 (4.99)	13.1 (0.96)	158.6 (2.51)	6.82 (0.20)	23.5 (1.04)	6.78 (0.41)

Table 7. Effect of gypsum application on fruit nutrient analysis of Cox in 2011 for fruit from the control, no compost treated trees. Significance of difference is shown in Table 8.

No compost treatment	N	P	K	Ca	KCA	Mg
Ca control	48.3	19.2	171.5	10.55	16.4	7.45
(SE)	(1.58)	(0.57)	(4.28)	(0.65)	(1.05)	(0.15)
Ca 1T	47.7	18.6	166.1	9.96	16.7	7.23
SE	(2.00)	(0.61)	(5.41)	(0.44)	(0.45)	(0.29)
Ca 2 T	46.7	18.8	167.0	10.02	16.7	7.60
(SE)	(2.34)	(0.53)	(2.11)	(0.27)	(0.34)	(0.36)

Table 8. Significance of compost treatment and gypsum application on fruit nutrient analysis of Cox in 2011. P-values are shown for each parameter. * represents significant effects, NS shows the effect of treatment was not significant.

P-values for two factors examined	N	P	K	Ca	KCA	Mg
Compost treatment	0.0000 ***	0.0000 ***	0.0011 **	0.0000 ***	0.0000 ***	0.0032 **
Gypsum	0.9994 NS	0.8938 NS	0.8096 NS	0.1454 NS	0.0698 NS	0.5950 NS

Leaf mineral analysis

The leaf analysis results are shown in Tables 9, 10 and 11. Table 9 shows the effect of compost on leaf nutrient analysis.

Table 9. Effect of compost on leaf nutrient analysis of Cox in 2011. Significances of the effects of compost on leaf nutrient content are shown in Table 12.

Compost treatment	N	P	K	Ca	Mg
Compost - Ca control	2.12	0.2	1.69	1.29	0.20
(SE)	(0.06)	(0.01)	(0.03)	(0.05)	(0.001)
No compost - Ca control	1.72	0.37	2.18	1.02	0.13
(SE)	(0.04)	(0.04)	(0.08)	(0.16)	(0.001)

As for the fruit analyses results, nitrogen, phosphate and potassium levels were greater in the compost treated trees than the no compost control treatment. However, where the fruit calcium had been lower in the compost treatment, here the opposite is true with the no compost control treatment having a slightly lower level of calcium than the compost treatment. This difference was not statistically significant though.

The effect of the three gypsum treatments on leaf nutrient analyses was not significant for any parameter measured. This was similar to the effect on fruit analyses and so further samples need to be taken in 2012 to monitor the effect of gypsum applications in 2011.

Table 10. Effect of gypsum application on leaf nutrient analysis of Cox in 2011 for trees from the compost treated trees. Significance of difference is shown in Table 12.

Compost treatment	N	P	K	Ca	Mg
Ca control	2.12	0.2	1.69	1.29	0.20
(SE)	0.06	0.01	0.03	0.05	0.001
Ca 1T	2.14	0.2	1.78	1.17	0.19
SE	0.07	0.01	0.07	0.05	0.01
Ca 2 T	2.14	0.2	1.70	1.29	0.19
(SE)	0.01	0.01	0.03	0.09	0.01

Table 11. Effect of gypsum application on leaf nutrient analysis of Cox in 2011 for trees from the control, no compost treated trees. Significance of difference is shown in Table 12.

No compost treatment	N	P	K	Ca	Mg
Ca control	1.72	0.37	2.18	1.02	0.13
(SE)	0.04	0.04	0.08	0.16	0.001
Ca 1T	1.89	0.45	2.18	1.24	0.14
SE	0.05	0.02	0.09	0.08	0.01
Ca 2 T	1.78	0.40	2.17	1.07	0.14
(SE)	0.04	0.03	0.08	0.16	0.001

Table 12. Significance of compost treatment and gypsum application on leaf nutrient analysis of Cox in 2011. P-values are shown for each parameter. * represents significant effects, NS shows the effect of treatment was not significant.

P-values for two factors examined	N	P	K	Ca	Mg
Compost treatment	0.0000	0.0000	0.0000	0.1451	0.0000
Significance	***	***	***	NS	***
Gypsum	0.1729	0.1901	0.7350	0.9302	0.9531
Significance	NS	NS	NS	NS	NS

The effects of compost treatment and gypsum application on soil nutrient analysis are shown in Tables 13 and 14. The soil samples from the compost treated area were taken by first removing the layer of compost and then sampling the uppermost 15cm of the soil layer. The significant difference in nitrogen between the two compost treatments confirms that this is likely to be the cause of the greener fruit in the compost treated area. Perhaps the largest difference was seen in soil potassium, which was more than double in the compost treatment compared to the no compost treatment. It is interesting that although the soil calcium was greater in the compost treated area, the fruit mineral analysis showed the opposite result, with the compost treated fruit having a lower level of calcium. This is likely to be an effect of growth, whereby a greater proportion of the available calcium was partitioned to the excessive extension growth of the compost treated trees.

The effect of gypsum application in the no compost area was to increase soil calcium, which is to be expected. However, in the compost treated area the gypsum did not alter the soil calcium level. It is thought that this may be a result of the calcium being locked up by the compost. This is confirmed by the increased sulphur content with gypsum application – the added sulphur is not locked up by the compost.

Table 13. Effect of compost treatment and gypsum application on soil nutrient analysis – macro nutrients. Samples were taken in February 2012 from each of the four replicate blocks and combined to form one sample per treatment.

Treatment	pH	EC	N	P	K	Ca	Mg
Compost 0T Ca/Ha	7.8	0.183	7.5	453	789	2580	252
Compost 1T Ca/Ha	7.6	0.140	5	497	886	2510	317
Compost 2T Ca/Ha	7.6	0.142	5.6	446	795	2550	312
No compost 0T Ca/Ha	6.9	0.041	3	333	301	2270	225
No compost 1T Ca/Ha	6.9	0.041	1.5	228	266	2380	221
No compost 2T Ca/Ha	6.6	0.110	1.1	251	252	2430	214

Table 14. Effect of compost treatment and gypsum application on soil nutrient analysis – micro nutrients. Samples were taken in February 2012 from each of the four replicate blocks and combined to form one sample per treatment.

Treatment	Na	S	Zn	Cu	Mn	Fe	B
Compost 0T Ca/Ha	32	55	0.18	0.1	0.05	0.33	1.30
Compost 1T Ca/Ha	31	68	8.15	0.21	0.06	3.2	2.90
Compost 2T Ca/Ha	29	87	8.91	0.18	0.07	3.4	2.80
No compost 0T Ca/Ha	37	38	12.7	0.83	0.07	6.7	1.30
No compost 1T Ca/Ha	36	51	12.2	0.61	0.07	5.1	1.30
No compost 2T Ca/Ha	32	110	13.2	0.79	0.11	5.8	1.30

Effect of compost on storage results

Fruit from both the compost treatment and the control, no compost treatment were harvested for storage on two dates, 31 August and 15 September for the variety Cox. The fruit analysis results suggested that these two treatments may cause a difference in the storability of the fruit. The aim was to harvest fruit when the starch level averaged between 70 and 80%. For the compost treatment, the starch fell below 80% on 31 August and for the control, no compost treatment, the starch fell below 80% on 15 September. Table 13 shows the effect of the compost treatments on the results of storage tests conducted, which included the green colour score, the fruit firmness (pressures), the total soluble solids and the percentage starch.

The data clearly show the difference in the ability of the fruit to store well, with the compost treatment causing reduced quality when removed from store compared to the no compost control treatment (Table 13). The fruit from the compost treatment were yellower (higher green colour score), had lower fruit firmness and lower percentage starch. These parameters all indicate, therefore, that although the fruit were harvested at the same stage of maturity, the storability of fruit was impaired by the use of compost. This corroborates the fruit analysis data, which suggested that the predicted storage dates were around three weeks less for the compost treated fruit than the no compost control fruit.

Table 13. The effect of compost treatment on storage results for Cox. Harvest dates were based on the starch percentage with fruit from the two treatments being harvested when starch reached 75%. Assessments were made on 12 December 2012.

Compost treatment		Harvested 31 August		
	Green colour score	Pressure (kg)	TSS (^{o}Brix)	Percentage starch
Average	5.95	9.16	13.71	2.25
SE	0.17	0.10	0.18	0.48

No Compost treatment		Harvested 15 September		
	Green colour score	Pressure (kg)	TSS (^{o}Brix)	Percentage starch
Average	6.88	9.81	15.93	10.75
SE	0.13	0.10	0.13	0.48

Effect of compost on soil moisture content

In both 2009 and 2010 there were clear differences in soil moisture content between the two treatments, with the differences in 2009 being more distinct than in 2010. This was due to 2010 being a drier year than 2009, which would have mollified some of the effects of the compost on soil moisture. In 2011 the overall rainfall was lower than in 2010, with a total of 417mm from January to October 2011 compared to 490mm from January to October 2010. However, this difference was caused mainly by the lack of rainfall during April and May 2011. Following this were two months during which the rainfall was greater in 2011 than in 2010, although there were only three significant rain events. The remainder of the rainfall during this period fell in small amounts which were not sufficient to significantly alter soil moisture content. The overall pattern of rainfall in 2011 had a significant effect on soil moisture in the two treatments and caused significant differences between the two treatments.

Table 14. Total rainfall from January to October 2010 and 2011. Data is taken from a weather station three miles from the trial site.

	2011	2010
Jan	89.4	37.4
Feb	47.2	85.4
Mar	15.6	56.6
Apr	3.6	19.4
May	9.6	41.6
Jun	85	35.4
July	38	22
Aug	49	81.8
Sep	33.8	48.8
Oct	46	62
Total	417.2	490.4

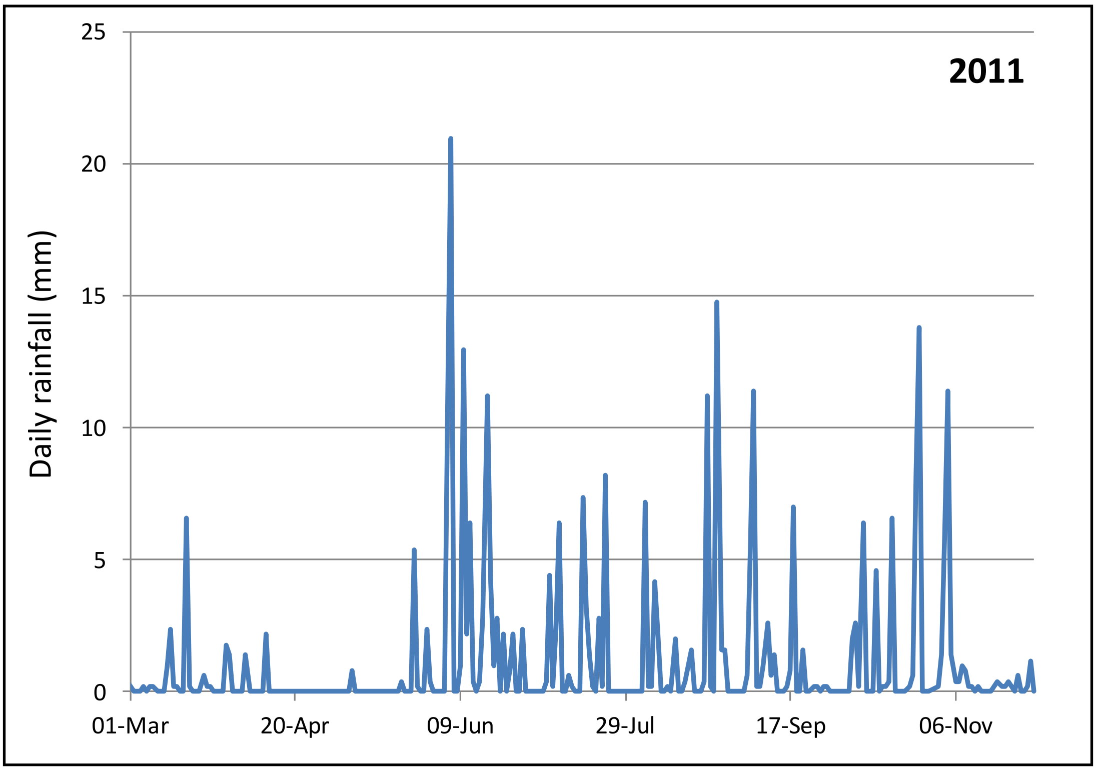

Figure 20. Daily rainfall from March 2011. Data is taken from a weather station three miles from the trial site.

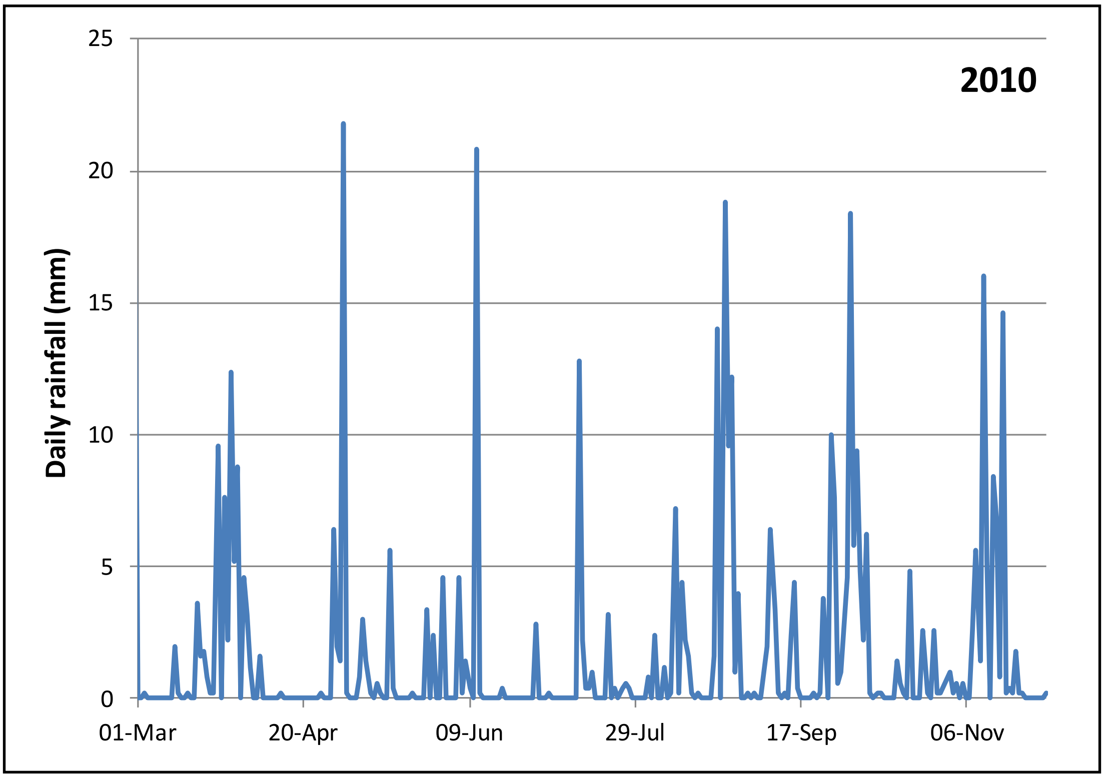

Figure 21. Daily rainfall from March 2010. Data is taken from a weather station three miles from the trial site.

The effect of compost on soil moisture for the growing season between May and September 2011 is shown in Figures 18 and 19. These data were collected using multi-depth probes with sensors set at 10cm intervals from 10cm to 80cm. There were two main effects of the compost on the soil moisture. During the period from the end of May to the end of August the water content of the soil increased at every layer in the upper 60cm of the compost treated area. However, in the no compost control treatment the soil moisture decreased during this period. This shows that the compost treated area was better able to absorb water from the rainfall.

There was also better percolation of water through the soil profile in the compost treated area shown by increases in water content down to 60cm during the first two weeks in June. In the no compost control area this did not happen and the water remained in the uppermost 40cm. This is a trend that has been observed in previous years and relates to the improvement in soil structure caused by the application of compost, which is eventually worked into the lower levels of soil. It may also be an effect of the compost allowing better penetration into the soil surface of the rainfall. In the no compost control treatment the soil surface may have provided a barrier to rain penetration.

Date	Rainfall (mm)
9 July	6.4
16 July	7.4
23 July	8.2
4 August	7.2
7 August	4.2

It was not until late August that the rainfall began to affect soil moisture in both treatments, but from this point onwards soil moisture was seen to increase at all levels in the no compost control treatment and in all but the lowest two layers (70 and 80cm) in the compost treatment. However, these increases in soil moisture corresponded to daily rainfall values in excess of 10mm per day. Less than this and the soil moisture was not affected.

NO COMPOST CONTROL TREATMENT

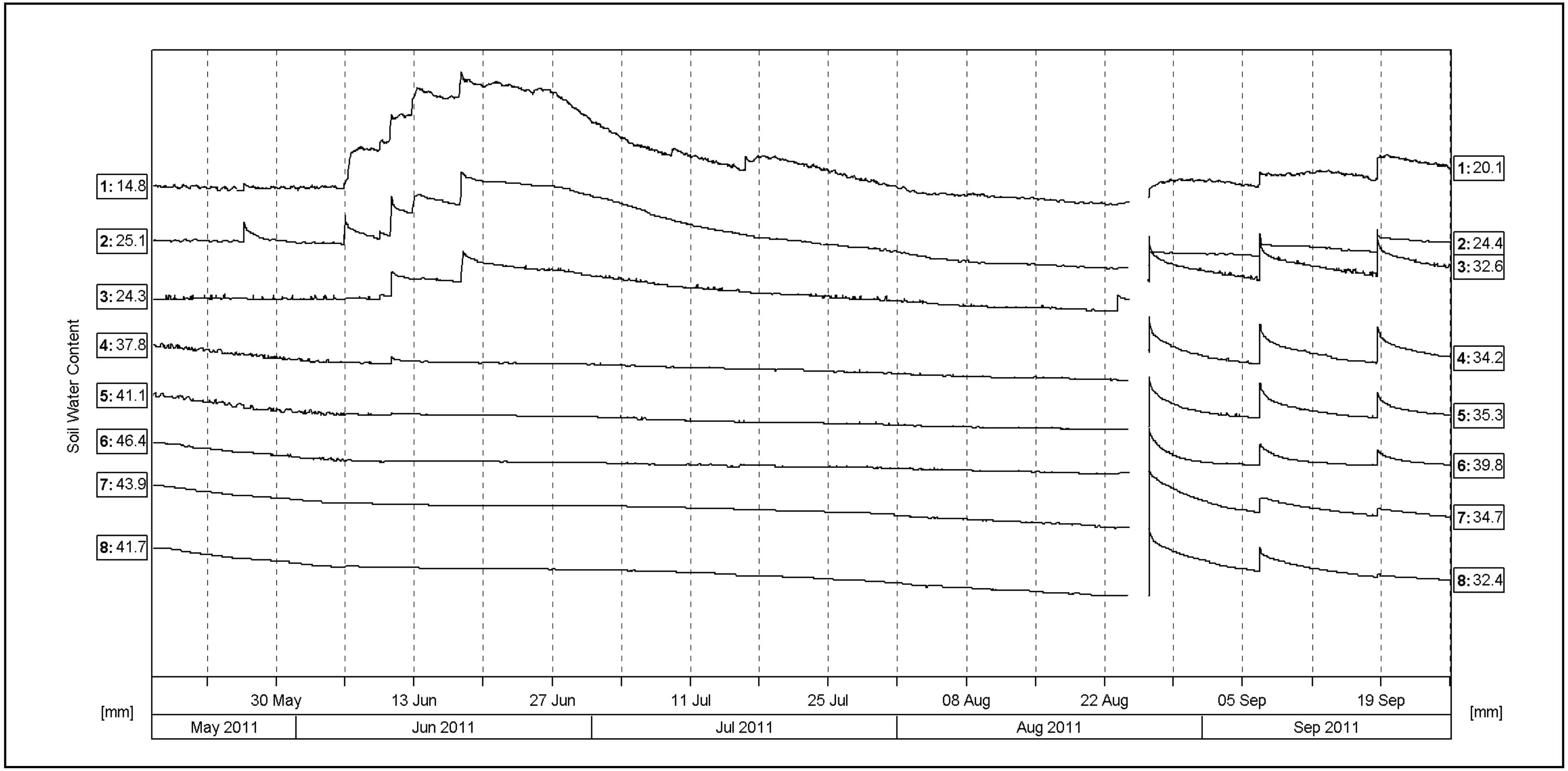

Figure 22. The soil moisture content recorded by the Enviroscan logger in the no compost control treatment. Depths of probes are as follows: 1 = 10cm, 2 = 20cm, 3 = 30cm, 4 = 40cm, 5 = 50cm, 6 = 60cm, 7 = 70cm and 8 = 80cm. Data presented shows soil moisture content in mm.

COMPOST TREATMENT

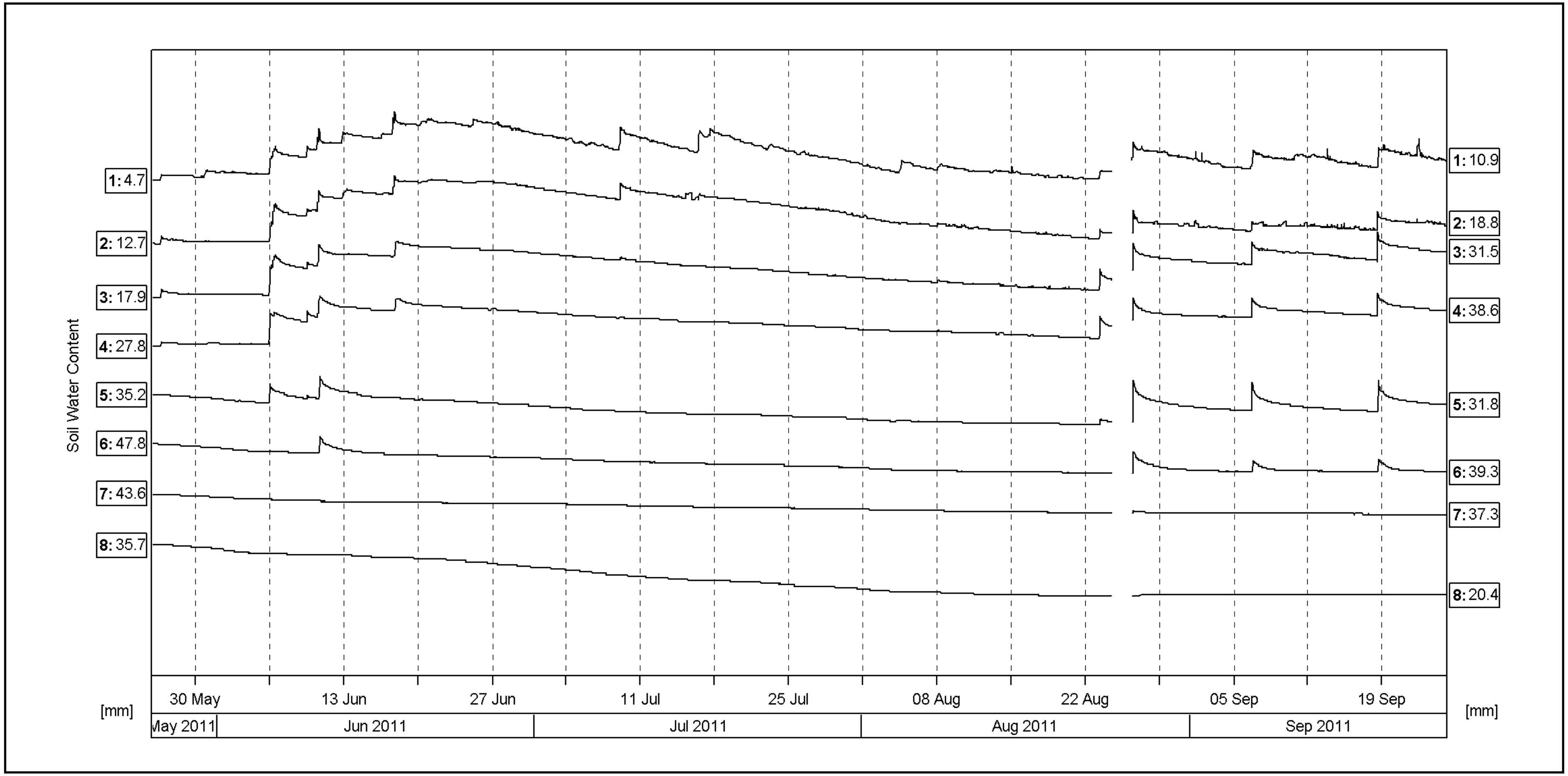

Figure 23. The soil moisture content recorded by the Enviroscan logger in the compost treated treatment. Depths of probes are as follows: 1 = 10cm, 2 = 20cm, 3 = 30cm, 4 = 40cm, 5 = 50cm, 6 = 60cm, 7 = 70cm and 8 = 80cm. Data presented shows soil moisture content in mm.

Discussion

In both varieties there were significant differences in both leaf and fruit mineral status of the two treatments. For example, fruit and leaf nitrogen were increased by the compost treatment whereas phosphate content decreased, a trend which has been observed in previous years. This is likely to significantly alter both the potential storability of fruit and the growth of the trees. The compost treated trees did show significantly increased growth over those in the no compost control treatment. This then had a knock-on effect on fruit calcium, with the compost treatment causing a lower fruit calcium content than the no compost control treatment. These two parameters are likely to have affected the predicted storage date for fruit from the two treatments, with the difference being predicted at just less than one month. This was then confirmed in the storage test conducted on Cox, which showed greater degradation of fruit in the compost treatment than the no compost control treatment.

Along with differences in the fruit analysis data, there were also differences in the maturity characteristics of the fruit, particularly for Cox. Starch degradation, fruit colour and fruit firmness were significantly affected by the compost treatments. Based on these parameters, fruit maturity was advanced by around two weeks by the compost treatment.

The implication of this is that compost treated fields need to be treated separately from fields which have not received compost. Fruit analysis is necessary to confirm storage potential and maturity tests need to be conducted regularly to determine optimum harvest dates for compost treated fields. Failure to do so would result in the harvesting of fruit at an incorrect time with the consequent reduction in fruit quality when the fruit is removed from store. Also the application of fertilizers and foliar feeds need to be made bearing this in mind as differences in fruit nutrient content could be compounded through inappropriate applications. Nutrient availability is also altered by the compost treatment, possibly through changes to soil organic matter content and structure and through increased biological activity. It is difficult to compare with published data on the effect of mulches on tree nutrient status due to the wide range of mulches tested. The effect of straw for example will be very different to the effect of green waste compost.

The effect of compost on soil moisture content was recorded by Enviroscan probes. In 2009 the compost treatment resulted in significantly greater soil moisture content than the control treatment and it seems likely that this caused the increase in growth and fruiting in the compost treatment. However, because rainfall was greater in 2010, differences between treatments in soil moisture content were less obvious. In 2011 the lack of rainfall early in the growing season resulted in much lower soil moistures than in previous years. Combined with this was the effect of tree size on water usage. Because the compost treated trees were so much larger, water demand would have been much greater in the compost treatment than the no compost control treatment. Where in 2010 the compost treatment caused significantly greater levels of soil moisture, in 2011 soil moisture was similar in both treatments and only at certain times were differences apparent. That there were still similar differences in growth and fruiting in 2009, 2010 and 2011 must be due to the tree size being greater in the compost treatment. Growth and yield potential would have been greater simply due to the tree size. The main difference in the soil moisture levels occurred early during the season where rainfall in May was able to increase soil moisture at the lower soil levels in the compost treatment, but not in the no compost control treatment. This is a trend that has been observed in previous years and relates to improvements in soil structure along with the soil surface becoming hard and impenetrable to rain in the no compost control treatment.

As in previous years, the increase in yield arose due to the increase in shoot growth. Increased shoot length allowed a greater number of fruiting sites to develop, thereby increasing fruit number. The increase in yield was a factor of both increased fruit numbers and increased fruit size in both varieties. That the fruit size was greater, even though fruit number was higher, may mean that fruit number can be increased intentionally in compost treated orchards. As fruit size is increased with the use of compost, more fruit could be left on the tree at thinning, without any detrimental effect on fruit size being seen. This means that compost treated orchards need thinning differently to orchards which have no compost.

The effect of compost was again significant. Compost does offer potential to improve growth and yield of apple trees. However, what is important here is that key effects are still being seen even seven years after the initial compost application. Compost causes significant increases in shoot growth, possibly through improved moisture availability and altered nutrient content. The potential of this is shown by the fact that, in addition to fruit number per tree being increased by compost, fruit size was also increased, resulting in improved yields. However, the effect on fruit nutrient content was significant and did reduce potential storability. In addition the compost treatment advanced maturity by around two weeks.

However, in orchards where growth is poor and is restricting yields, the benefits of the use of compost mulch far outweigh any reduction in the potential storability of fruit and the advanced maturity, as the use of compost would result in significant improvements in tree establishment and cropping over a long period. As the project continues the effect of compost on growth, yield, and fruit development and quality will be examined further.

Conclusions

- The use of compost as mulch can increase fruit number per tree and in 2011 increases in fruit size were seen in both varieties tested.
- Careful management of soil nutrient balance is needed. Applications of foliar feeds in particular need to be made in response to leaf and fruit analysis as significant effects on fruit and leaf nutrient content were seen.
- Growth was significantly increased through the use of compost and this requires careful tree management to maintain fruiting/growth balance.
- Differences in fruit maturity times need to be taken into consideration when planning the harvesting schedule. Compost treated orchards will need harvesting at a different time to untreated orchards.
- The differences described here show the potential of the effects of compost on apple growth and fruiting but this does mean that compost treated fields do need to be treated differently to those not treated with compost. This will affect all management practices from pruning to fruit management and fertilizer applications.

Recommended follow-up activities

2012 will be the last season of the project and it would be useful for growers to visit the site to see the effects. An open day could be held.

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