CCF-2708 Final Report Appendix III: Tree Carbon Calculations

Contents

Leith Community Crops in Pots

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Introduction and Summary

In early 2016, 175 fruit rootstock saplings were obtained, of five varieties, and these were planted for grafting on 6 March of that year. This document lays out how the expected carbon savings associated with this were calculated. Altogether the fruit from these trees (to be distributed throughout Leith and also grown out on Leith Community Croft) is estimated to save over 617 tonnes of CO_2-equivalent. Furthermore, the trees at their peak maturity were estimated to sequester nearly 6 tonnes CO_2-equivalent.

Carbon Savings at Tree Maturity

The carbon savings associated with the mature trees were calculated as shown in Table 1 and Figure 1. Note the difference between carbon sequestered in the mature trees themselves and the annual carbon savings from fruit. Estimates of carbon sequestered are probably conservative as the formula provided on the Broward website assumes that carbon represents 50% of the dry weight of a tree, whereas Kumar et al. (2011)[1] use a figure of 55.75% for fruit trees (23,000 MT of carbon in 40,000 MT dry mass of trees).

[1] Kumar, G.P., Murugan, M.P., Ashutosh, A and Singh, S.B. (2011) 'A Carbon Sequestration Strategy Involving Temperate Fruit Crops in the Trans-Himalayan Region'. *Journal of Horticultural Science and Biotechnology* 85 (5).

Table 1: Carbon sequestration in and annual CO_2 savings from mature trees.

			Mature height (feet)[1]			Mature diameter (inches)[2]	$kgCO_2$ sequestered/ mature tree[3]	**Total $kgCO_2$ sequestered in all mature trees**	Annual fruit yield/mature tree				Total annual fruit yield from mature trees (kg)	**Total annual CO_2 savings from fruit from mature trees (kg)[7]**
fruit	no. trees	type	from	to	mean			**(= no. trees x $kgCO_2$ seq. /mature tree)**	from lb/kg	to lb/kg	kg[5]	figures used in our calculations (kg)	(= no. trees x fruit yield/tree)	
apple	25	M26	8	10	9	2	6.51	**162.77**	30/13.5[4]	80/36[4]	≤ 30	24.5	612.50	**949.38**
apple	75	MM106	12	15	13.5	3	21.97	**1648.01**	50/23[4]	100/56[4]	25 - 50	37	2775.00	**4301.25**
apple	25	M25	15	18	16.5	5	74.60	**1865.03**	200/90[4]	400/180[4]	≤ 200	135	3375.00	**5231.25**
pear	25	Quince A	13	16	14.5	4	41.96	**1048.94**				88[6]	2188.92	**3392.83**
plum	25	St Julien A	12	15	13.5	4	39.06	**976.60**				88[6]	2188.92	**3392.83**
Totals								**5701.35**						**17267.53**

[1]Deacon's Nursery.

[2]Estimated by Tom Watson, Leith Community Crops in Pots Community Education Officer.

[3]Calculated according to the formula provided at http://www.broward.org/NaturalResources/ClimateChange/Documents/Calculating%20CO2%20Sequestration%20by%20Trees.pdf using mean height and mature diameter.

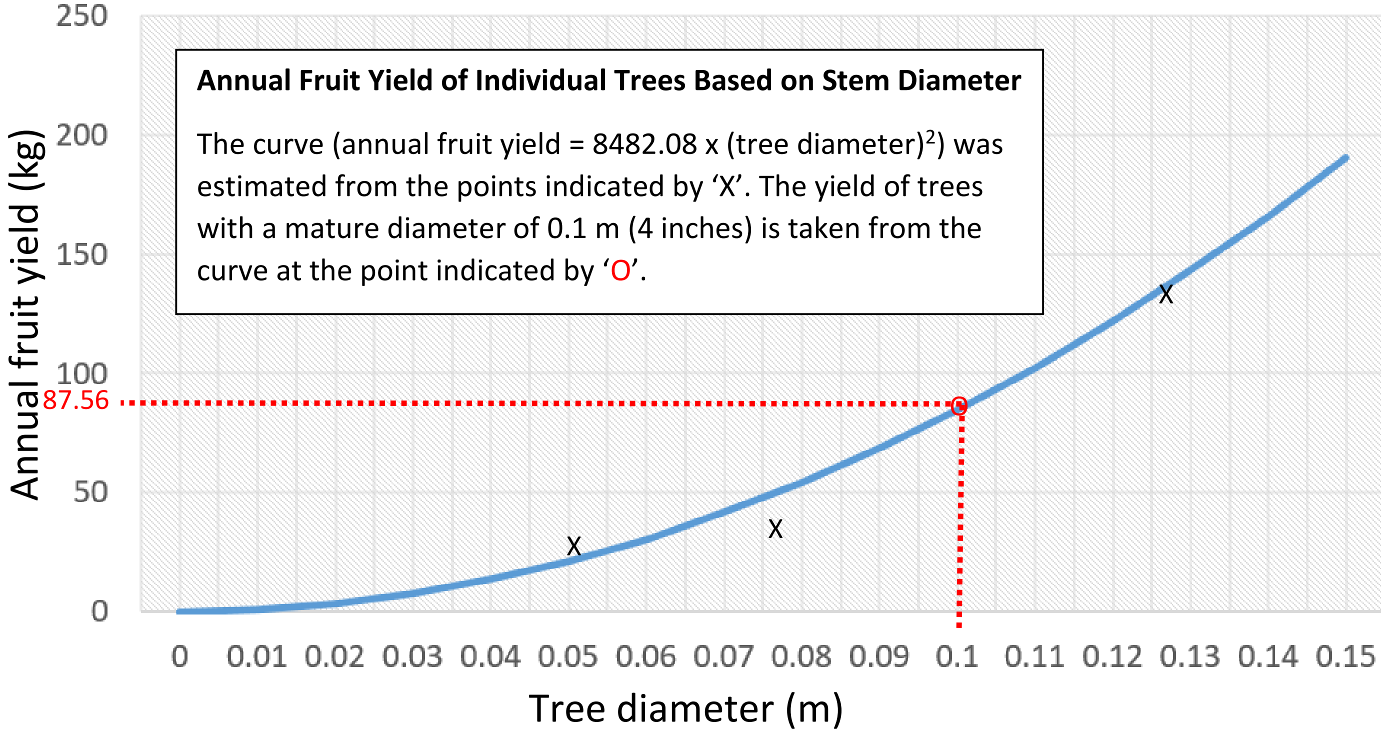
[4]According to http://aeronvale-allotments.org.uk/factfiles/Fact-File_Fruit_trees_rootstock_guide.htm#Apple.

[5]Tweed Valley Fruit Trees.

[6]Estimate based on regression of fruit yields for M26, MM106 and M25 on diameter squared. See Figure 1.

[7]Calculated on the basis that an average figure for embodied carbon for allotment-grown fruit and vegetables is only 0.54 $kgCO_2e$/kg (according to Keep Scotland Beautiful), whereas for shop-bought fruit and vegetables it is 2.09 $kgCO_2e$/kg (according to Audsley et al., cited in *A Low Carbon Route Map. Planning and Measuring Emission Savings for Climate Challenge Fund Projects. 2011, version 1.0)*. We assume that the fruit grown from our trees will displace shop-bought produce. Therefore, by subtracting 0.54 from 2.09 and multiplying the result by the mass of fruit produced, we can estimate greenhouse gas savings.

Figure 1: Relationship between diameter of mature trees and annual fruit yield.



Carbon Savings Over Trees' Lifespans

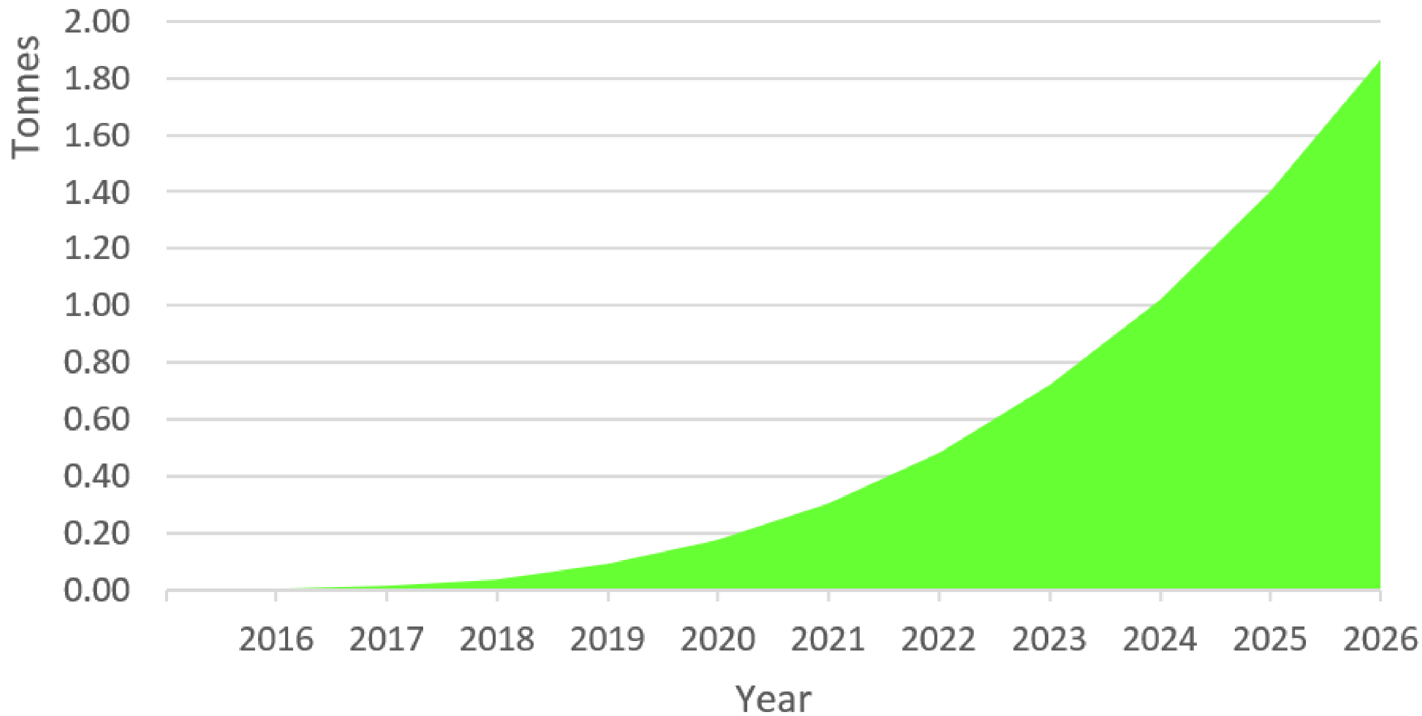
The carbon sequestered by trees at various stages of their lives were also calculated as was the annual production of fruit over their lifespans.

Carbon Sequestered at Various Ages

In order to do this, assumptions had to be made about the trees' rate of growth. According to http://walcotnursery.co.uk/rootstocks.htm, trees reach their mature size when ten years old. The conservative assumption was made that this refers to the age of grafts and not the age of rootstock. Year zero, then, was assumed to be 2016 and year ten 2026, although the rootstocks are one or two years of age in early 2016.

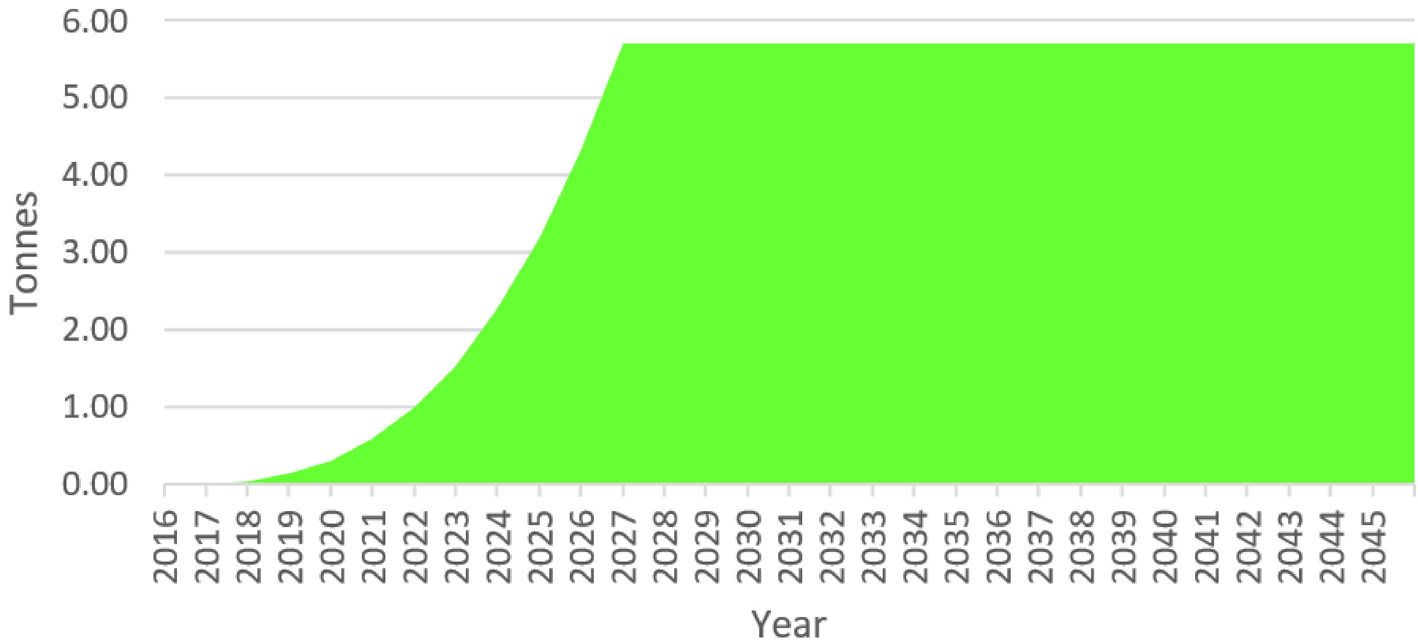
The next assumption, a simplifying one, was that there would be linear growth of height and stem diameter over ten years until mature dimensions are reached. The rootstocks are currently about two feet tall (0.61 m) and 0.39 inches in diameter (0.01 m). The mature height and diameter are listed in Table 1 above. It was therefore possible to interpolate intermediate heights and diameters for all rootstocks for years between 2016 and 2026, and then use the formula provided on http://www.broward.org/NaturalResources/ClimateChange/Documents/Calculating%20CO2%20Sequestration%20by%20Trees.pdf to calculate sequestered carbon (carbon dioxide equivalent) for each year until full size was reached. This leads to a hyperbolic mass (and carbon) curve, with growth abruptly stopping at maturity in 2026 (Figure 2). In fact, it is likely that height and diameter growth patterns would be sigmoidal rather than linear, with growth tailing off as mature size is reached, which might then lead to a little less carbon being sequestered in early years, and more as maturity is approached. This has no effect, of course, on how much carbon is ultimately sequestered.

Figure 2: Estimated cumulative CO_2-equivalent sequestered in M25 trees.



Peak sequestration was calculated to be 5.70 tonnes of CO_2e, which would be reached in 2026 (Figure 3). How long this carbon will remain 'locked up' depends on the life of the trees (a topic dealt with below) and what happens to their wood when the trees come to the end of their productive lives. However even the trees with the shortest estimated lives would last until 2045, so peak sequestered carbon should persist until then.

Figure 3: Estimated cumulative CO_2-equivalent sequestered in all trees (peak of 5.70 tonnes reached in 2026).



A further consideration is what happens to leaves shed in autumn. If these are used to contribute to soil carbon then the sequestered carbon might be significantly greater, as suggested by Kumar et al. (2011) (see previous footnote for reference).

In summary, the amount of CO_2-equivalent estimated to be sequestered in the years immediately before maturity is reached is likely to be conservative, because the growth curve for mass (carbon) is probably sigmoidal rather than exponential, and the peak estimated (5.70 tonnes) is also likely to be conservative because:

- a conservative carbon-from-dry-mass coefficient was used and
- leaves were not accounted for.

Cumulative and Total Carbon Savings from Fruit for the Lifespan of All Trees

Age at maturity (ten years for all rootstocks), mature annual fruit yield and the carbon dioxide savings associated with 'allotment-grown' fruit and vegetables are discussed above. For simplicity, trees are assumed to stay at peak production for their 'mature productive life' and then to cease production altogether. In order to estimate cumulative and total carbon savings from fruit for the lifespan of all trees, the following additional pieces of information are required:

- age at first fruiting;
- the amount of fruit produced from this age annually up to the age of peak production (maturity);
- the length of mature productive life.

Age at first fruiting

The age at first fruiting, as listed on a website (http://aeronvale-allotments.org.uk/factfiles/Fact-File_Fruit_trees_rootstock_guide.htm#Apple), is shown in Table 2.

Table 2: Age at first fruiting ('bearing age').

Rootstock	Bearing age

M26	2-3 years
MM106	3-4 years
M25	5-6 years
Quince A	4-5 years
St Julien A	4-5 years

It is unclear whether these ages referred to the ages of the rootstocks or to the ages of the grafts (time since grafting). The conservative decision was taken to assume that they refer to time since grafting. In other words, although the rootstocks we are using are one or two years of age in early 2016, for the purposes of calculating future fruit production we are assuming the trees are at 'zero years' in early 2016, that they will come into production in 2016 + the lengths of time listed in Table 2, and that they will reach peak production in 2026.

Fruit produced annually from age at first bearing to the age of peak production

We have already estimated by interpolation the stem diameter at various ages (see 'Carbon Sequestered at Various Ages', above) and we have calculated, for mature trees, the relationship between stem diameter and annual yield of fruit (Figure 1). We assume that there is no fruit production before the minimum bearing age listed in Table 2, and that the same relationship as for mature trees relates the yield to stem diameter from the maximum age listed in Figure 1. In order to take account of the fact that ranges for initial bearing ages are given, however, we decided to use the established relationship between diameter and yield for trees at the lower end of the age range but multiply the estimate by 0.5. Another way of looking at this would be to imagine that all trees starting to bear fruit produce a crop in accordance with the curve shown in Figure 1, but only half the trees start to bear at the lower end of the range given for their bearing age. To make this clear, trees based on rootstock M26, for example, are assumed not to bear fruit until 2018, and in that year their total yield was assumed to be half what one would estimate from the curve in Figure 1 (0.5 x 2.8 kg/tree = 1.4 kg/tree, based on an estimated stem diameter of 0.018 m). After that, and until maximum yield is reached, their yield is calculated on the basis of Figure 1 (in 2024 it is 15.4 kg/tree, based on an estimated stem diameter of 0.0426 m).

Mature productive lives (years at maximum production)

The mature productive lives of the various rootstocks used were estimated as in Table 3.

Table 3: Length of mature productive life of fruit rootstocks.

Rootstock varieties	Stem diameter at maturity in inches	Length of mature productive life (years), estimates in red	Conservative length of mature productivity used for further calculations (years)
M26	2	20[1]	**20**
MM106	3	26.67[2]	**26**
Quince A, St Julien A	4	33.34[2]	**33**
M25	5	40[1]	**40**

[1]Figures provided by Leith Community Crops in Pots Community Education Officer Tom Watson, who states 'Estimates vary, but assume 20-40 years at "mature yield". Smaller trees (M26) will be at the lower end of the range (about 20 years) and larger trees (M25) at the higher end (about 40 years).'

[2]Estimates interpolated from M26 and M25, assuming a linear relationship between mature productive life and diameter. In the absence of further data this seems as reasonable a way of estimating this as any.

All the above information enabled the cumulative CO_2-equivalent saved, from all fruit produced (398.18 tonnes), to be estimated (Figure 4). The last year of production would be 2095, and the total CO_2-equivalent saving due to fruit production over the lives of all the trees is estimated to be **617.18 tonnes**.

Figure 4: Estimated cumulative CO_2-equivalent saved from all fruit produced