Submission of the Irish Apple Growers Association to the National Planning Framework “Ireland 2040 – Our Plan”

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Introduction:

The Irish Apple Growers Association is the representative organisation for apple growers in the Republic of Ireland. There are about 40 full-time commercial apple growers in Ireland, and a number of additional smaller-scale operatives, growing approx. 15,000 tonnes of apples on an annual basis. About 5% of the apples consumed in Ireland are produced in Ireland annually. The remainder are imported.

The apple sector has relevance to the Ireland 2040 plan, as from a planning perspective the production of apples is a labour-intensive rural enterprise that, in addition to the ~150 jobs it already supports, has the potential to support many more, if domestic production were increased. In addition, apple production is an activity with significant environmental benefits associated with it, as it is the only agricultural activity (forestry excluded) in Ireland that is carbon-sequestering.

As a consequence, to a certain extent here in Ireland, but more-so in countries with larger orchard areas, work is being done to quantify the ability of orchards to mitigate greenhouse gas emissions, and to act as the providers of sustainably produced raw materials and to act as locally based drivers of rural development.

Contents

Responses to ten key questions for the National Planning Framework:

In the information leaflet, a number of questions were posed. These are dealt with in the order asked, and additional comments made as they best fit into the topic question headings.

1. What should Ireland look like in 20 years?

From the perspective of apple producers, Ireland should move from its current position of about 5% self-sufficiency to 25% in the next twenty years.

This would create an extra 500 to 750 rural-based jobs in apple production, with additional employment possible in packing, processing, marketing etc.

Commercial orchards would be located in the Eastern and Southern regions, as these have the most sites that could be classified as highly suitable for the production of apples. Counties from Louth south towards Wexford, and across to Cork, with Carlow, Kilkenny and Tipperary featuring strongly are likely to be the main production centres.

Non-commercial orchards, ranging from single trees in gardens and allotments to community orchards and street plantings of apple trees can happen throughout the country, and will add resilience to our food production system, as well as an appreciation for locally produced fruits.

Some of the commercial orchards will be focussed primarily on supplying the towns and cities in their immediate vicinities with fruit, reducing the transport emissions associated with moving fruit longer distances. Production for multiple retailers, and for fruit suitable for processing into juice, cider and other apple products will also increase.

Direct sales and pick-your-own operations will probably assume greater significance than currently, as witnessed by the growing popularity of “U-pick” type operations in relative proximity to urban centres in the United States. Processing into more artisan and higher-value products will also increase. Locally produced value-added products such as juices and ciders will add to the tourism experience of people visiting Ireland.

2. How do we ensure that every place can realise its potential?

Clearly due to climatic and geographical constraints, not all locations are equally suitable to the production of apples. A clear plan for the sector will need to be developed to ensure that places can reach their potential.

3. Where will jobs be located and what will these jobs be?

Apple production requires about one FTE for every 4 hectares produced (official but now outdated figures would indicate a higher employment level per hectare). Because harvest time requires extra labour compared to the rest of the year, the two-month period in September and October results in a peak in low-skilled employees. In practice in Ireland, labour tends to move from other fruit production (e.g. Strawberries, where peak harvest is from May to September) to apples at this time.

More skilled labour is required for tree pruning and maintenance (principally November-March), and care of growing trees (April-August). Ordinarily those involved in running the enterprise would have third level (degree level 8) education.

The jobs will be located where the orchards are.

4. Where will we live and what types of housing will be needed?

In general farmers with orchards reside on their farms. Employees and their families generally reside in local towns and villages, or in rural dwellings in the immediate vicinity. By 2040 better housing stock will be needed, probably built to Passive House standards.

In addition, a certain amount of seasonal housing may be required. If orchards are located close to other enterprises (such as strawberries) that also need seasonal housing, these could work well together. It is also possible that housing used in tourism in the peak summer season will no longer be occupied in September/October, and that these might also prove suitable.

5. What are the key services people will need?

Education for families (access to schools).

Clean water

In general in rural areas, access to clean water is reliable. By 2040 climate change will be leading to significant differences in the intensity and variation in precipitation events compared with today. Extra collection and storage of water may be a feature of life in 2040, and with the exception of areas prone to flooding, rural areas are well suited to dealing with such change due to the land area available for water collection and storage, as well as ample ground water supplies.

Power

By 2040 it is to be hoped that all power will come from renewable sources, which will mean electricity will feature as the main power source. Due to improvements in efficiency in power use, provision of power will decrease on a per capita basis. The power used in apple production should be fully met by local production based on Solar PV and power storage systems.

Connectivity

The rate of change in peoples demand for connectivity is rapid. By 2040 it is likely to have increased greatly compared to today. It is to be hoped that a better effort will be made by then in securing rural connectivity, compared with the very poor situation that pertains today.

Waste collection and treatment

Initiatives such as "Zero Waste" and the development of new technologies, as well as the unacceptability of waste will mean that waste such as currently derives from packaging, will be much reduced by 2040. However, for people living in rural areas, the issue of waste water and the proper functioning of septic tanks and related waste water treatment plants will be key.

Health care

Provision of health care is a vital service. The issue of the effect of food on health will be much better appreciated by 2040. People will be healthier because dietary related illnesses such as type 2 diabetes and obesity will be almost eradicated due to better dietary choices. The confluence of peoples lifestyles, becoming involved in the production of their own food via allotments, involvement in community supported agriculture initiatives (CSA's) consumption of sustainable locally produced fresh produce like fruit and vegetables (such as apples) will lead to much improved health. Costs of drug treatments for illnesses like heart disease, alzheimer's, and certain cancers will be reduced as they will be prevented by diets lower in meats, and higher in vegetables and fruits.

6. Where will Ireland fit in a wider geographical context?

Ireland will probably have a much greater population than now, due to inward migration caused by climate change related issues in warmer and more arid countries. Our country will no longer be a net importer of calories (as it currently is), as we will have reduced our reliance on meat production (which is hugely inefficient from a perspective of calorific production on a per acre basis), and will produce more of the vegetables and fruits that we currently import. This will relate directly to apple production, which will increase in Ireland due to need, and due to increasing climate suitability.

7. What are the planning responses to key environmental challenges?

Flooding:

Re-establishment of flood plains to cope with increased flooding.

Reduced reliance on engineering "solutions" and more use of natural solutions.

Storms:

Plan to make the electricity system storm-proof by putting transmission under ground.

Greenhouse gases:

Plan for a huge reduction in fossil fuel use. This will have impact on air travel in particular, where alternatives to fossil fuel use do not exist. Many of the fresh fruit and vegetables transported to Ireland by air will no longer be able to get here by these means.

Plan for increased forestry.

Buildings will need to be net generators of power, rather than net users.

Built environment:

Plan for people to avoid frequent commuting, and to be able to access a significant proportion of their food from the local area.

8. What infrastructure is required – what are the national priorities?

For apple production, infrastructure apart from the orchards themselves is required. Buildings for cold storage of fruits, grading machines, processing equipment etc.

Within agriculture on a national basis, priority ought to be given to sectors that are demonstrably less demanding on the resources of the planet.

9. How should a National Planning Framework be implemented?

By engaging with the stakeholders and getting a commitment from all actors involved to animate the plan to bring it to fruition.

10. What will success look like?

A country with a larger population; with citizens having access to good food, having good health and living harmoniously and within their means, without huge discrepancies in wealth, in a context where demands on the planet are diminishing and climate is stabilising.

Appendix 1.

Carbon sequestration in Irish orchards and potential for offsetting CO^2 emissions.

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Summary:

Carbon sequestration in orchards has significant potential to mitigate Ireland's CO_2 emissions.

Long-term sequestration in orchards is due to increments in the mass of plant structural wood each year, and increases in soil organic carbon (SOC) in the orchard soils.

There is also short-term sequestration, principally the carbon sequestered in the fruits produced in a particular year. Short-term sequestration is not generally considered as useful from the perspective of emissions mitigation, and is not considered mitigating in this report.

Allowing for carbon inputs such as fuel and fertiliser in the growing cycle, an orchard studied in Ireland had a net annual sequestration of 3.1t C/ha/yr., equivalent to 11.4t CO_2 per ha per year.

In comparison with international research, this is less than reported in some countries, and more than in others. Because many factors contribute to net sequestration, figures will vary internationally, and even within a particular country.

Sequestration in orchards, at 11.4t CO_2 per ha per year compares closely with forestry planted in Ireland since 1990, which over the four year period 2008-2012 had a net sequestration of 14.2 tonnes CO_2 per ha per year.

Research conducted on orchard soils in Ireland shows that they have significant capacity to sequester carbon, and compare favourably in this regard with, for instance, permanent pasture.

If Ireland were to become self-sufficient in apple production for eating apples and cider apples, this would require about 3500 ha to be converted from other farm enterprises to orchards, resulting in sequestration of almost 40,000 tonnes of CO2 annually due to the orchard uptake. In addition, if the 3500ha were diverted from grassland forage for bovines to orchards, and this led to a proportionate reduction in the national herd and emissions from same; a reduction in the order of a further 40,000 tonnes of CO2 equivalent per annum, or 0.4% of total annual agricultural emissions.

Introduction:

Orchards represent a potential carbon sink for absorbance of atmospheric CO_2, and work has been conducted around the world to begin to evaluate their potential (Lakso 2010, Guo et al. 2013, Anthony 2013). The principle areas of sequestration are fruits, plant structural wood above and below ground, and via increases in soil organic carbon (SOC) or the total soil carbon content over the lifespan of the orchard (Zanotelli et al. 2013). In operating orchards, CO_2 is also released to the atmosphere, due to natural respiration and turnover of soil carbon (Wu et al. 2012), and also due to the use of fossil fuels, agrochemicals, fertiliser and other inputs in the production cycle (Kizilaslan 2009, Saunders 2006).

Literature Review:

Studies in the USA:

Atucha et al (2011) quantified the dry weight allocation to above ground and below ground parts of a typical 9 year old apple tree growing on an old orchard site in New York State. The trees (560/ha) on M111/M9 interstem combination had 2/3 of their biomass above ground and 1/3 underground.

The mean SOC (0-20cm) from 1992 to 2000 was 2.4% while the mean SOC (0-20cm) from measurements taken in the same orchard in 2005, 2006 and 2007 was 2.9% (based on a conversion figure of 1.7:1 SOM to SOC). This was equivalent to a ten year increase of 0.5% SOC (1996-2006). Depending on BD (not given) this would be approximately 10-12 t/ha increase or 1 to 1.2t/ha increase per annum.

The average per tree below ground dry weight was 7kg and above ground was 15kg, or 3920 and 8400 kg/ha respectively. At a conversion of 2.2:1 this is equivalent to 1780kg C below ground and 3820kg per ha C above ground, or an accumulation of 178kg and 382kg C per ha per year respectively.

In a trial on apple orchards in New York State, Leinfelder et al (2010) reported that over the course of 17 years, the soil organic matter doubled from 4.5% to 9%, equivalent to a soil organic carbon increase from 2.6% to 5.2%, or 0.15% per annum on average, triple the rate reported by Atucha el al (2011).

A further report from New York state stated that dry matter increment per annum in apple orchards was 18.6 tons per hectare (excluding an additional 13.9t/ha for grass alleyways and herb/weed cover in orchards). This was made up of 6.25t/ha attributed to the apple crop, 5.0t/ha for leaves, 5.0t/ha for wood and 2.5t/ha for roots. This was equivalent to 7.8t/ha C annually (excluding 5.8 tons grass alleyway etc.),2.6t C fruit 2.1t C leaves, 2.1t C wood and 1 t C roots (Lakso 2010). This report did not attempt to quantify soil sequestration.

TerAvest (2011) reported on an apple orchard (on M7 at 1541 trees per ha) planted in the Wenatchee Valley of Washington State in 2005, the land having previously been cropped with cherry trees. Analyses were carried out in September 2007 and 2009 on the soil carbon, which increased from 10 to 14.9g C per kg of soil in the top 10cm profile, or 0.5% over the two years.

Mays et al (2014) studied an organically managed orchard planted in the Ozark Highlands area of Arkansas in 2006, planted on M26 rootstock at 1485 trees per hectare, with a fescue grass strip between the tree rows. In October 2006 SOC was measured in the top 10cm of the soil profile, and this was repeated in March 2012. Depending on the soil and groundcover management employed, the soil C sequestration rate varied from 0.9 to 2.8 tons/ha/yr. of C, a rate up to 21 times greater than reported over the same 6 year period for a native tallgrass prairie in the same area.

Studies in Japan:

Using data from a rolling national survey conducted in Japan from 1979 to 1998, Leon at al (2015) reported on soil organic carbon changes in orchards of apples, oranges, peaches and pears, as well as tea gardens. In general warmer sites had soils with lower carbon contents. The average increase over the 20 years was 0.2% per annum, which in the soils with lower starting SOC was equivalent to a doubling, and in soils with the highest starting SOC, going from 89 to 132 g C per kg soil.

Sekikawa (2005) also reported on soil carbon and net primary productivity of orchards in Japan. For peach orchards the measured SOC to 1m depth was 66.3t/ha. The biomass C was measured at 18.5t/ha. The net primary productivity of the trees was 4.7t C/ha/yr. and that of the orchard was 11t C /ha/yr., a value according to the author, "equal to the highest value in temperate forests". Net soil C sequestration on an annual basis was 5.9t/ha and net ecosystem productivity (net soil sequestration plus incremental growth) was 7.35t/ha/yr.

Study in Bhutan:

The carbon stocks in orchard soils of the Paro Valley in Bhutan (Eastern Himalayas – altitude 1700 to 5500m) were measured (Dorji et al. 2014). In area sections measuring 8100m^2 the SOC stocks were as follows:

Table 1: Soil Organic Carbon (SOC) figures for orchard soils in Bhutan.

Depth	T/8100m^2 SOC	Equivalent T/ha SOC
0-5cm	12.3	15.2
5-15cm	22.4	27.7
15-30cm	22.1	27.3
30-60cm	22.2	27.4
60-100cm	28.6	35.3
Total	107.6	132.9

Study in Korea:

Lee et al (2013) reported findings for a fifteen year old pear orchard in Korea, planted at 670 trees per hectare. Carbon in the top 60cm of soil profile was measured at 138.3t/ha. Carbon in trees totalled 17.7t/ha, made up on a per tree basis of 2.3kg trunk. 6.4kg main branches, 6.4kg lateral branches, 6.5kg roots, 1.7kg leaves and 6.7kg fruits, equivalent to 10 tons per ha C in above ground woody mass, 4.4 tons per ha in roots, and 3.3 tons in leaves and fruits.

Studies in New Zealand:

A report reviewed a number of publications in an attempt to quantify the standing biomass of orchards in New Zealand. Because this work was confined to orchards similar to those in New Zealand, the authors did not assess data for soil sequestration. Their estimate for total standing dry weight for an apple orchard was 36t/ha, which they calculated was equivalent to 18t/ha sequestered carbon in the standing above-ground plant biomass (Kerckhoffs 2007).

Another research study was undertaken to quantify total sequestration of carbon and also to quantify emissions directly from the orchard soil, as well as emissions due to the production inputs associated with fruit production (Page 2011). For apples in New Zealand the total annual sequestration figure was 7.1 tons of carbon per hectare. Soil emissions were 4.5 tons of carbon per hectare per year, and emissions due to orchard inputs were 1.3 tons per hectare per year, indicating a net sequestration of 1.3 tons C per hectare per year.

Studies in China:

In work on fruit ecosystems in Shanghai, China Guo et al (2013) found that for peach orchards carbon storage was 118t/ha, made up of 15.8t in tree biomass, 1.2t cover crop on orchard floor, and 101.3t/ha in soils. The net productivity reported was 4.9t C/ha/yr. (Guo et al. 2013).

Also in China, Song at al (2014) reported on response ratios in soil organic carbon due to the conversion of cropland to forest and orchard. In the 0-20 cm layer SOC increased by almost 1/3 in 14 years, and by 1/10 in the 20-40cm and 40-60cm soil layers (Song et al. 2014).

Wu and colleagues examined sequestration in orchards of different ages in China. Taking orchards of 5, 18 and 22 years of age into account, the average annual sequestration was calculated as 14t C/ha/yr., equivalent to 4.5% of the total net C sink in terrestrial ecosystems in China (Wu et al. 2012)

Hu et al (2014) compared carbon storage in orchard ecosystems and evergreen broad-leaved forests in Guangzhou, China. Vegetative C storage in orchards was 77.2 t C/ha/yr., with orchard soils storing 83.1 t/ha (56% in top 40cm, 44% in next 60cm). Comparing orchards with climax zonal vegetation, carbon storage in the upper 40cm of soil was 67% that of forests (Hu et al. 2014).

Study in Italy:

A study on orchards in the Sud Tyrol region of Italy reported very high carbon use efficiencies (Zanotelli et al. 2013). The SOC in the top 60cm of the soil profile was 128t/ha. In addition, the tree biomass carbon for the 11 year old trees measured in 2009 was 12t/ha, with 72% accounted for by above ground biomass, and 28% below the ground. In this very productive orchard about 50% of the carbon sequestered was allocated to fruit in 2009. The carbon use efficiency figure of 0.71 reported for this orchard was said to be of “a comparable magnitude with respect to deciduous forests growing in similar climatic conditions”.

Studies in Ireland:

In 2009 samples of soil from an orchard soil in Co. Tipperary which had been in situ since 1985 were taken for analysis (Greaney 2009). Prior to that the field was in tillage since about 1970, having been tilled annually.

Table 2: % SOC in an orchard in Tipperary 23 years after planting.

Depth	BD (g/cm3)	Mass of soil per depth (t/m2)	Mass of soil (t/ha) for this 5cm	SOC %	SOC (t/ha)	Litter (t/ha)
0-5	0.84	0.04	420	7.64	32.1	0.99
5-10	1.09	0.05	545	5.87	32.0	
10-15	1.03	0.05	515	5.32	27.4	
15-20	1.18	0.06	590	4.15	24.5	

Excluding litter, the total SOC in the top 20cm of soil profile was 116t.

In 2013 Moriarty conducted a trial to establish baseline levels of soil organic carbon in an orchard which was newly planted in that year, adjacent to that tested by Greaney. The land used for the orchard had been planted in grass the year previously, and prior to that had been in fallow with a wild vegetation cover for two years, while prior to that had mostly been tilled annually for a number of years and had also been used to grow strawberries, which meant it had been untilled for a 4 year period (Moriarty 2014). As such the %SOC in the baseline was probably higher than would be expected in a typical tillage field, but lower than in permanent pasture.

Table 3: % SOC in an orchard in Tipperary in the year of planting.

Depth	BD (g/cm3)	Mass of soil per depth (t/m2)	Mass of soil (t/ha) for this 5cm	SOC %	SOC (t/ha)
0-5	1.25	0.0625	625	3.12	19.5
5-10	1.25	0.0625	625	3.07	19.2
10-15	1.28	0.064	640	2.97	19.0
15-20	1.21	0.061	610	2.82	17.2
20-25	1.35	0.067	670	2.56	17.2
25-30	1.38	0.069	690	2.09	14.4

Because the data collected by Moriarty and Greaney are from two orchards in the same field, but with these orchards planted at different times, it is possible to use Moriarty's figures as a baseline, and to compare the figures reported by Greaney with them. Moriarty's figures were recorded in the first year that particular orchard was planted, and in the top 20cm of soil profile the SOC was 74.9t/ha. In an orchard which was 23 years old, Greaney found that in the top 20cm of soil profile the SOC was 116t/ha. This is equivalent to an annual soil C increase (in top 20cm) of 1.8t per ha per annum over the 23 years.

In addition, work conducted by this author in 2009 sought to quantify the carbon sequestered in the more permanent above-ground tree structure of the 23 year old orchard sampled by Greaney. After pruning, two trees were removed from the orchard by cutting at soil level, and weighed. The average above ground mass was 36kg. A sub-sample revealed that the moisture content was 31%, so the above ground dry weight was 24.8kg. Based on the conversion in Table 4 below this is 11.3kg C per tree C. Over the 23 years this is equivalent to 0.5kg per tree per year of about 1200kg per ha per year.

Other relevant work:

(Kizilaslan 2009) measured energy inputs into production of apples in Turkey. The total energy input bearing in mind agrochemical inputs, fertiliser inputs, labour, machinery write-down, diesel, electricity and irrigation water was 4.1MJ per m2 on an annualised basis. Based on a yield of 4.5 kg per m2 this worked out at 0.91MJ per kg of fruit. This is quite similar to the 0.95MJ per kg reported by for New Zealand grown apples (Saunders 2006), which in this case equated to 60.1kg of CO_2 emissions per tonne of apples, or 16.4 kg of C emissions per tonne of apples.

The figures of Page (2011) and Saunders (2006) actually agree quite closely as at a yield of 50t/ha, as Saunders and her colleagues assumed in her work, the figures indicate a per hectare emission of 820 kg of carbon, not so far removed from the 1300kg calculated by Page.

Also of relevance is C saturation in soils, and how in different land use scenarios, saturation levels are different, with forest soils showing the highest saturation levels, and continuously tilled soils the lowest (Kimetu et al. 2009). Stewart et al, also working on measuring soil C saturation found that more degraded soils had better potential for extra C accumulation than soils already high in carbon (Stewart et al. 2008).

Conversion Figures Used:

In the course of the review above a number of conversion figures had to be used in order to make data comparable. For instance, in some publications soil organic matter was reported, whereas in others, soil carbon was the unit used. The conversion figures used (and their origin) are given in table 4 below:

Table 4: Conversion figures used in the review of literature.

Conversion	Conversion applied	Authority
Soil Organic Matter % : Soil Organic Carbon %	1.7:1	Spink
CO_2:C	3.67:1	Based on atomic mass
Dry Weight apple tree woody tissue: C content	2.2:1	Wu, Zanotelli
Dry Weight apple tree leaf tissue: C content	2.1:1	Zanotelli
Dry Weight apple fruit tissue: C content	2.5:1	Zanotelli
Dry Weight apple tree fine roots: C content	2.25:1	Zanotelli

Discussion of highlighted literature:

Carbon sequestration by fruits:

Sequestration by fruits differed between studies where this was reported. For New York (Lakso, 2010) the figure of 2.6t C per ha per year was given. In Korea (Lee at al, 2013) a figure of 1.9 t per ha per year was reported. In Italy (Zantonelli et al 2013) a higher figure of 4.7t per ha per year was reported, but this was for an extremely high yielding orchard, which meant the figure was much elevated.

While no data were presented for Ireland, on the basis of a typical crop of 40t/ha, at a dry weight of 16.5%, carbon sequestration in fruits would be 2.6t/ha.

Although these are significant figures, it is generally felt that carbon sequestered in fruits should not be considered as permanently sequestered, as the majority is emitted back to the atmosphere upon consumption of the fruits.

Therefore for the purpose of this report, no sequestration will be attributed to fruits.

Carbon sequestration by plant structural wood:

Sequestration in plant structural wood is longer-term than in fruits. In forest timber, sequestration could be considered more permanent if, for example, wood is subsequently used as a building material. Nonetheless, wood from forests is also used as a “carbon-neutral” fuel source, and wood from orchards at the end of their productive lifespans is typically used for the same purpose, and can be considered accordingly.

In the reviewed literature carbon in structural wood is reported for trees of different ages and species. In Ireland apple orchards tend to be left in situ for longer than in the examples reported, which would mean higher levels of sequestered carbon both in total, and on an annual basis if averaged over the longer orchard lifespan. In addition, most cider apple orchards have larger trees than culinary or dessert orchards which represent the tree type reported on, so these would also have higher levels of sequestered carbon, something that would warrant further study to quantify.

In general reports of the carbon sequestered above and below ground indicated that about 2/3 of the total was attributable to above-ground biomass and 1/3 to below-ground biomass (Atucha et al, 2011; Lakso 2010 and Lee at al, 2013).

There were quite a few publications which gave total biomass carbon data, but were not specific as to the age of the trees studied. Therefore it was decided to focus only on data which stated the annual increments or average sequestration over a given period.

Sequestered carbon on a per annum basis was variously measured as an annual average of 0.6 t/ha/yr. for 10 year old trees, (Atucha et al, 2011), 1.0t/ha/yr. for 15 year old trees (Lee et al, 2013), 1.1t/ha/yr. for 11 year old trees (Zantonelli et al, 2013) and 3.1t/ha/yr. for trees whose age was not stated (Lakso, 2010). A figure calculated for a 23 year old dessert apple orchard in Ireland in 2009 was 1.2t C per ha/yr. for above-ground biomass, and based on this a further 0.6t C per ha/yr. could be attributed to below-ground biomass accumulation, making the total 1.8t C per ha per year.

Carbon sequestration in orchard soils:

Total sequestration:

Sequestration in soils has the capacity to keep large amounts of carbon dioxide out of the atmosphere on a long-term basis. Different soils have different saturation capacities with regard to soil carbon, depending on soil type, climate, and land use. Forest soils are considered to be those with the highest saturation capacity. Orchard soils, because fruit trees are essentially managed mini-forests, also offer significant sequestration capacity, with, for example Hu et al (2014) reporting orchard soils holding about 2/3 of the amount of carbon in the top 40cm of soil profile when compared with evergreen broad-leafed forest soils in the same area.

In the same way that saturation figures vary, soil sequestration figures for orchards depend on climate and location, soil type, orchard age, as well as orchard management. Reported total SOC figures are given in Table 5 below:

Table 5: SOC (soil organic carbon) figures reported for orchard soils to various depths.

Country	Orchard Crop	Orchard Age (years)	Reported by	SOC (t/ha)	Measured to depth (cm)
Bhutan	Apple	Mixed	Dorji et al	132.9	100
Korea	Pear	15	Lee et al	138.3	60
China	Peach	Mixed	Guo et al	101.3	100
China	Various	Mixed	Hu et al	83.1	100
Japan	Peach	Not stated	Sekikawa	66.3	100
Italy	Apple	11	Zantonelli et al	128.0	60
Ireland	Apple	23	Greaney	116.0	20

Orchard soils Worldwide were found to hold substantial reserves of carbon. Figures for soils in an Irish orchard were broadly in line with figures reported for other countries. Unfortunately the SOC for the 23 year old Irish orchard was only measured to 20cm deep, giving a significant underestimate of the total SOC. A simple proportionate addition for the SOC expected in the 20-30cm soil profile as per the results reported by Moriarty would suggest a total SOC in the top 30cm of soil of about 165 t/ha. While further carbon would be stored deeper in the soil profile, since no research was conducted to quantify this, it will not be included in calculating sequestration figures.

While this figure is higher than any of the other reported figures in the studies on orchards, it is not particularly surprising. It is much lower than the figure attributed to forest soils in Ireland (approx. 450t/ha). However, it is worth bearing in mind that this figure includes peat soils, and that typical figures for SOC under forestry in mineral soils range from 100 to 140t/ha in the top 30cm of soil profile (Black et al. 2014). Areas of greater rainfall have higher SOC than areas of lower SOC, and, for instance, precipitation in Ireland exceeds that in Italy, where the reported figure was 128t/ha. Areas with moderate average soil temperatures (around 11^{o}C) show reduced respiration, and consequently greater net accumulation of carbon in soils, than, for instance areas with soils temperatures of 15^{o}C, where respiration rates were much higher. The average annual soil temperature at 10cm deep in the region of Ireland where the orchards was studied is 11^{o}C, which is an ideal from the perspective of reducing soil respiration, and is considerable lower than, for instance, Korea, where soil temperatures in fruit growing areas are higher. Lastly, soils with higher clay contents support higher SOC than soils with lower clay content, and the soil in the orchard in question in Tipperary has relatively high clay content in the range 30-40%.

Annual net sequestration to soil:

While it is interesting to know total SOC, what is of greater use is an assessment of annual C sequestration where a particular crop is grown. This is a difficult figure to obtain, requiring either long-term studies which assess changes over significant periods, or complex studies which measure carbon being incorporated into the soil and deduct soil respiration to calculate net sequestration. In the case of orchards studies have been undertaken using both methods, and results are comparable. Figures for annual sequestration to soils are presented in Table 6.

Table 6: Annual sequestration of carbon to orchard soils (t/ha/yr.)

Country	Orchard Crop	Reported by	Age of orchard (years)	Annual sequestration (t C/ha/yr.)
USA	Apples	Atucha et al	9	1.1
USA	Apples	Leinfelder et al	17	3.0
USA	Apples	May et al	5-6	0.9 – 2.8
Japan	Peach	Sekikawa et al	Not stated	5.9
New Zealand	Apples	Page	Not stated	2.6
China	Peach	Guo et al	Mixed	4.9
Ireland	Apples	Greaney	23	1.8

As can be seen from the table, the figures for peach orchards are higher than apple orchards. Typically peach orchards are left in situ for longer than apple orchards. In addition, the figures for apple orchards are generally lower for younger orchards, which is probably due to the lesser leaf fall and lower levels of litter from trees being incorporated into soils when trees are young. According to Wu at al (2012), the orchards they were studying in China became net C absorbers (taking into account C inputs due to fertiliser applications etc. when growing the crop) at some point after the 5th year, which would concur with what is observed here. From the point of view of ongoing annual net sequestration, it is difficult to estimate at what point in the future annual net sequestration would begin to decline due to a saturation effect. At the moment this is an unknown for Irish orchard soils, and requires further study.

Carbon inputs in the growing cycle:

Thus far the focus of discussion has been the sequestration of carbon by orchards and orchard soils. In order to complete the calculation, it is also necessary to take into account all carbon inputs in running the orchard.

For apples a very comprehensive case study was completed in New Zealand by Saunders (2006) which indicated a figure of 16.4 kg of C emissions per tonne of apples, or 0.8t/ha/yr. based on a yield of 50 t/ha. A very similar figure was arrived at by Kizilaslan (2009) for apples grown in Turkey, while Page (2011) came up with a higher figure for New Zealand-grown apples of 1.3t/ha/yr.

In Ireland comprehensive data is also available, based on the methodology of Saunders (2006), which takes into account all inputs. Such a calculation is completed in Table 7, for an orchard in Co. Tipperary, using data collected there as part of the Bord Bia Origin Green Program.

Table 7: Carbon inputs as measured for a 14.1ha apple orchard in Co. Tipperary in 2014

Input	Total	CO2 equivalent (kg)	CO^2 per ha (kg)	C per ha (kg)
Direct & Indirect:				
Diesel	3568 litres	9527	676	184
Electricity	12000kWh	4632	329	90
Agrochemicals		3906	277	75
Fertiliser		2390	169	46
Capital (write-off)				
Farm Buildings			7	2
Tractors			100	27
Bins			40	11
Other equipment			100	27
Tree posts etc.			20	5
Irrigation equipment			3	1
Total			1721	468

This shows that in 2014, the carbon inputs were 468kg per ha. The reasons these figures for Ireland were lower than reported by Saunders (2006) for New Zealand is that in the interim growers have been attempting to lower the carbon footprint of production, and, for instance, have purchased more fuel-efficient tractors, have been mowing the orchard less frequently, making less passes with spraying equipment, using plant protectant chemicals which have a lower carbon footprint, and reducing fertiliser use. For instance, on this particular Tipperary farm, in 2011 the per ha diesel use was 40% higher than in 2014 and CO^2 associated with agrochemicals was 44% higher.

Overall net sequestration – completing the calculation:

Only the research paper by Page (2011) calculated an overall net sequestration due to orchards, taking into account the carbon inputs involved, and ignoring sequestration by fruits. This indicated a net sequestration for apples of 1.3 tons C per hectare per year. This is most likely an underestimate of net sequestration achieved in New Zealand orchards nowadays, as it assumed 36 spray passes and 619 litres per ha per year of fuel use, this difference alone overestimating today's C input by about 0.3t C/ha/yr.

A number of papers calculated sequestration excluding inputs, and these figures showed a net ecosystem productivity for peaches in Japan of 7.35t/ha/yr. (Sekikawa 2005), and 4.9 t/ha/yr. for the same crop in China (Guo et al. 2013). Wu et al (2012) calculated apple orchard sequestration at 14 t C/ha/yr., but this included fruit sequestration (probably about 3t/ha/yr.), and also did not take into account carbon inputs.

To come to a conclusion for net sequestration in Irish grown apples is possible by calculating as follows:

Annual carbon sequestered in tree structural wood + annual increase in SOC minus annual carbon inputs.

Plant structural wood:	1.8		
SOC increment:	1.8		
	3.6		
Carbon inputs:	0.5		
Net annual sequestration	3.1	(t C/ha/yr.)	or 11.4t CO_2/ha/yr.

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