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Agricultural greenhouse gas emissions and carbon sequestration from a range of perennial horticultural crops in New Zealand

McNally S, Gentile R

July 2021

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Report prepared by:

Sam McNally
Scientist, Climate Smart Systems, Cropping Systems and Environment
July 2021

Report approved by:

Paul Johnstone
Science Group Leader, Cropping Systems and Environment
July 2021

Contents

Executive summary

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McNally S[1], Gentile R[2]
Plant & Food Research: [1]Lincoln, [2]Palmerston North

July 2021

A primary sector partnership, ‘He Waka Eke Noa’, has been established with the goal of understanding, reporting and reducing agricultural emissions as outlined in the Climate Change Response Act.

Greenhouse gas (GHG) emissions caused by perennial horticultural production include emissions from fossil fuels, electricity, waste and agricultural emissions from fertiliser, and include emissions generated on-orchard, and throughout the supply chain.

In New Zealand, all emissions other than agricultural emissions are captured by the Emissions Trading Scheme (ETS).

He Waka Eke Noa is concerned with the agricultural emissions at the farm-gate. For perennial horticulture, agricultural emissions will be associated with fertiliser use and animals. For the purposes of this study, we have considered that orchardists have no animals within their systems, which is true for most orchards. Therefore only emissions from fertiliser have been considered as part of this study.

He Waka Eke Noa is also concerned with on-farm opportunities to offset agricultural GHG emissions with sequestration of carbon (C) into either woody biomass of plants or soil.

However, the emissions associated with fertiliser and the C sequestration rates for a range of perennial horticultural crops in New Zealand are not well understood.

We calculated the agricultural GHG emissions associated with fertiliser use for a range of perennial horticultural crops and explored the typical C sequestration rates in the woody biomass of the tree and shelterbelts, using a search of published literature or expert opinion.

While there was a lack of supporting literature for a ‘typical’ rate of fertiliser applied to individual perennial crops, we calculated that for every kilogram of nitrogen (N) applied, an associated GHG emission of between 4.5 and 4.8 kg CO_2-eq would occur depending on the type of fertiliser applied. Therefore, the actual emissions of an orchard would be dependent on the amount of N fertiliser applied. These application rates of fertiliser could range from as low as 5 kg N ha^{-1} to over 200 kg N ha^{-1} depending on the perennial crop and grower management. Further reduction of these fertiliser-related GHG emissions would rely on careful N management.

The C sequestration in woody biomass varied between perennial crops but occurred only for a limited lifetime of between 15 and 45 years. This time restriction influences the maximum C stock that would be obtained. On average, the C accumulation rate in woody biomass, including shelterbelts, was

670 kg C ha^{-1} y^{-1} or 2456 kg CO_2-eq ha^{-1} y^{-1} and is the value that the New Zealand Greenhouse Gas Inventory methodology applies. In addition, this inventory C accumulation rate only occurs for a maximum of 28 years. Therefore, the age of an orchard will be critical when determining the amount of C accumulation available when exploring offsetting opportunities.

Based on the fertiliser-associated emissions and the C accumulation rate of perennial horticulture, the likelihood of the woody biomass offsetting fertiliser-associated emissions over a finite timeframe and provided the orchard is recently established is high. However, caution is needed in this interpretation, as the C stock accumulated in woody biomass will be stable only for a finite period (i.e. for the lifetime of that biomass). Therefore, the main goal should be further reduction of agricultural GHG emissions of an orchard regardless of any offsetting potential and despite perennial horticulture being a relative low-emitting land use.

For further information please contact:

Roberta Gentile
Plant & Food Research Palmerston North
Private Bag 11600
Palmerston North 4442
NEW ZEALAND

Tel: +64 6 953 7700
DDI: +64 6 953 7708
Email: Roberta.Gentile@plantandfood.co.nz

1 Overview of project scope and objectives

A primary sector partnership, ‘He Waka Eke Noa’ (hewakaekenoa.nz), has been established with the goal of quantifying, understanding, reporting and reducing agricultural emissions under the Climate Change Response Act. The quantification of greenhouse gas (GHG) emissions under this He Waka Eke Noa framework will consider only agricultural emissions, or those associated with nitrogen (N), lime or dolomite fertiliser and the emissions associated with animals. The minimal requirement of the calculation of these GHG emissions under He Waka Eke Noa is that they use emission factors sourced from the National Inventory (MfE 2020) or other valid source (Journeaux et al. 2021). In the context of perennial horticulture, animal-associated emissions will be less relevant, as many of these systems do not use livestock to graze on-orchard. In addition, the He Waka Eke Noa farm level pricing option proposes to only be a requirement for enterprises above a certain threshold. The interim threshold for He Waka Eke Noa is agricultural farms and orchards greater than 80 ha. This is likely to shift to an effects based threshold for the pricing phase. Currently an effects threshold of 40 tonnes of fertiliser is being considered (hewakaekenoa.nz, March 2021) for the farm level pricing option, or no threshold for the processor level pricing option. The 80 ha or effects based threshold will exclude a large proportion of perennial horticultural enterprises; however, reduction of GHG emissions should be a key consideration for growers as this will contribute to national GHG emission reduction targets and market demands for lower carbon foods.

Agricultural GHG emissions caused by perennial horticulture production are primarily driven by the emissions associated with fertiliser use.

Opportunities to offset these agricultural GHG emissions are associated with sequestration of carbon (C) into either the woody biomass of plants or soil. The sequestration of C within vegetation (i.e. indigenous and exotic trees) will be included in He Waka Eke Noa. Whether or not this will include C sequestration in tree crops and shelterbelts is not yet clear. However, the emissions associated with fertiliser and the C sequestration rates for a range of perennial horticultural crops in New Zealand are not well understood.

Although specific perennial horticultural crops (e.g. kiwifruit) will have had substantially more research conducted relating to GHG emissions and C sequestration, other crops (e.g. summerfruit) have received much less research effort. While the total emissions from these various horticultural crops may contribute a very small proportion of New Zealand’s total GHG emissions, it is important to understand the drivers of these agricultural GHG emissions and C sequestration rates, to ensure that the production of these crops has the smallest footprint possible.

Furthermore, understanding the agricultural GHG emissions of perennial horticultural crops will also contribute to the role that these crops may play in providing alternative land use opportunities to reduce GHG emissions while still providing food and nutritional security.

The objective of this report was to assess and review the typical rates of fertiliser use, the associated agricultural GHG emissions from fertiliser, and the likely C sequestration rates within a range of perennial horticultural crops in New Zealand. In addition we discussed the context of pre- and post-1990 orchards for C sequestration. We estimated the GHG emissions associated with fertiliser using New Zealand inventory methodology (MfE 2020), and estimated the C sequestration within the woody biomass and soil using data from the available literature.

2 Literature review of carbon sequestration in New Zealand perennial crops (soils, trees, vines and shelters)

The opportunities of perennial horticultural systems to sequester C depend primarily on the balance of inputs, through photosynthesis, and outputs, through decomposition and respiration. In simplistic terms, a system must capture more C than is released to achieve C sequestration.

For perennial horticultural crops, opportunities to sequester C will be in three main areas: soil C, woody biomass of the tree crop, and woody biomass of shelterbelts. A brief literature review on all three is presented in the following Sections 2.1–2.2. A brief review on typical fertiliser use is presented in Section 2.3.

2.1 Soil carbon sequestration

Soil C sequestration has received considerable attention globally because of the role it could play in GHG mitigation. The global stocks of soil C contain significantly more C than that in the atmosphere or vegetation (Lal 2004). Therefore, any change in the flux of soil C can have consequences for atmospheric carbon dioxide (CO_2) levels and consequently climate change.

Increasing soil C stocks is a potential option to sequester atmospheric CO_2. As such, a recent initiative (e.g. 4 per 1000) proposed the lofty goal of an annual increase in the global stock of soil C of 0.4%. This increase is considered enough to significantly reduce the atmospheric CO_2 concentration and help to mitigate against the effects of climate change (4p1000.org).

Increasing soil C is also beneficial as soil C affects soil quality, soil health and soil function (Lal 2016). Therefore, increasing soil C stocks, or at the very least maintaining soil C stocks, should be goal of all growers to ensure their sustainability and ensure food security. Generally, increasing soil C stocks can be achieved through increasing the net input of C to soil achieved by either increasing the total C input, or through reducing the losses of C from soil.

A recent review on management options to reduce losses from, or increase, soil C stocks in New Zealand was presented for grassland systems (Whitehead et al. 2018). While New Zealand soils are considered to already have moderate to high soil C stocks (Whitehead et al. 2018), research suggests that there is still opportunity to increase these further (Beare et al. 2014; McNally et al. 2017). However, in New Zealand, very little research effort has gone into exploring management practices that may increase soil C stocks in land uses other than grazed grasslands.

There are a limited number of studies on soil C stocks in perennial horticultural systems in New Zealand. A study by Tate et al. (2005) predicted a loss of soil C of 9±7 t C ha^{-1} when converting grazing land to perennial horticulture, based on the soil C monitoring system (CMS) model. Following this study, the loss of soil C stocks under various perennial crops was estimated using comparisons between the tree row and alleyways for apple, vineyards and kiwifruit (Deurer et al. 2008b). This study reported losses of soil C of 12±5 t C ha^{-1} for vineyards in the top 15 cm and between 7.6 t C ha^{-1} and 19.9 t C ha^{-1} in the top 30 cm of kiwifruit orchards with and without a cover crop respectively. In apple orchards a loss of 8.5±15 t C ha^{-1} and 11±7 t C ha^{-1} for organic and integrated apple orchards was reported respectively. These results were the combination of field measurements (vineyard and apples) and modelling (kiwifruit). The measured C losses used the permanent pasture in the alleyways as a reference soil C stock and calculated losses associated with the herbicide strip of the tree row. The total soil C stock loss was estimated by weighting the area under both tree row and alleyway.

An updated methodology to measure soil C stocks under kiwifruit was developed more recently (Deurer et al. 2010) which highlighted the requirements of sample collection for stock measurements. Following this methodology, a study quantifying and comparing the soil C stocks under adjacent kiwifruit and pasture at a single site suggested that C sequestration of 6.3 t C ha^{-1} y^{-1} was occurring in soil under kiwifruit (Holmes et al. 2015; Gentile et al. 2016). This figure was based on the differences, to 9 m depth, between the soil C stocks of the two adjacent land uses and the time since the kiwifruit had been converted from pasture.

A follow-up study further exploring differences between adjacent kiwifruit and pasture land uses of multiple paired sites demonstrated no significant difference in soil C stocks to a depth of 2 m (Gentile et al. 2021). This study noted modest gains in soil C stocks under kiwifruit at a depth of 1.5–2.0 m. These gains represented a C sequestration rate of 0.06 t C ha^{-1} y^{-1}, much smaller than the earlier reported 6.3 t C ha^{-1} y^{-1}. The larger estimate was based on loss on ignition estimates of C compared to the Gentile et al. (2021) study that used the more accurate dumas combustion analysis of C.

In other perennial horticultural systems in New Zealand research on soil C is scarce. A study comparing an organic and integrated apple production system demonstrated that the alley row had greater soil topsoil C stocks than the tree row, regardless of management system (Deurer et al. 2008). The organic system had slightly greater soil C stocks in both the tree row and alley than in the integrated production system.

A study measuring soil C stocks to 1-m depth in apples found there was no significant change in soil C stocks of apple orchards across a 12-year chronosequence, indicating that current apple management maintained soil C stocks (Perie 2015; Gentile et al. 2016). However, challenges with the spatial distribution of soil C within and between orchards makes measuring soil C stocks difficult unless adequate sampling methodology is used.

Despite the small amount of evidence that soil C stocks under perennial horticulture are not different from under pasture (e.g. kiwifruit, Gentile et al. 2021) and that soil C stocks are maintained (e.g. apples, Gentile et al. 2016) the New Zealand GHG Inventory (MfE 2020) assumes a loss of soil C following the conversion of pasture-based land use to perennial horticulture. This loss of soil C stock is reported to be approximately 17 t C ha^{-1} and occurs over a 20-year period, as defined by IPCC land use change guidelines, or an annual loss of 0.85 t C ha^{-1} y^{-1} in the top 30 cm of soil (MfE 2020). Whether or not an actual loss of soil C results following conversion of grassland to perennial horticulture is not clear. In some instances the conversion could result in increases in soil C stocks if management is improved. Smith et al. (2016) suggested that where irrigation increases productivity, an increase in soil C inputs and soil organic matter would result. Therefore, in semi-arid or dry areas (e.g. Central Otago), the conversion to perennial horticulture and resulting management practices such as irrigation could result in increases in soil C stocks. However, this has not been measured.

2.2 Carbon sequestration in biomass

Plants can remove CO_2 from the atmosphere through the process of photosynthesis whereby the C within CO_2 is sequestered in biomass. However, the sequestration of this C is dependent on plants that produce woody biomass. Biomass that is associated with herbaceous growth (i.e. non-woody) is considered ephemeral (i.e. short-lived) and the regeneration of this biomass is roughly balanced by the emissions from the decay of older material (IPCC 2006). Consequently, non-woody biomass is considered stable in the long term and does not contribute to C sequestration.

Woody biomass removes C from the atmosphere through its growth and will sequester the C for the lifetime of the woody biomass. For example, in exotic forest stands, C will be sequestered at a specific C accumulation rate for a certain timeframe, usually defined as a harvest cycle (MfE 2020). In the context of perennial horticulture, the use of maturity cycle might be a better terminology than harvest cycle, to avoid confusion related to the annual harvest of each fruit crop.

The New Zealand GHG Inventory uses a C accumulation rate for perennial horticultural crops of 0.67 t C ha^{-1} y^{-1} and assumes a maximum accumulation period of 28 years (MfE 2020). This gives a maximum C stock of aboveground biomass of 18.8 t C ha^{-1}. This value represents an estimate for use across general perennial horticulture. However, crop-specific values, presented in Tables 1 and 2, could be used if more representative values were wanted based on New Zealand perennial horticultural crops (Burrows et al. 2018; Kerckhoffs & Reid 2007).

Table 1. Emission factors for C accumulation rate, maturity cycle and aboveground biomass C stock for some perennial horticultural crops. Table adapted from Burrows et al. (2018). These values are used in New Zealand Greenhouse Gas inventory reporting.

	C accumulation rate (t C ha^{-1} y^{-1})	Maturity cycle[1] (y)	Above-ground biomass C stock at maturity (t C ha^{-1})
Kiwifruit	0.3–0.46	40–45	12–20.5
Grapes	0.19–0.44	20	3.8–8.7
Pipfruit	0.19–0.48	15–20	2.8–9.6
Shelter belt	0.63	30	18.9
Combined New Zealand perennial cropland[2]	0.67	28	18.8

[1] Equivalent to harvest cycle in forest systems

[2] Assumes that half of the crop area has shelter belts.

Table 2. Estimates of standing biomass and C stocks of various perennial horticultural crops. Table sourced and adapted from Kerckhoffs & Reid (2007).

	Total aboveground biomass (t DM ha^{-1})	Total C stock[1] (t C ha^{-1})
Apple	36	18
Peach/Nectarine	40	20
Orange	37	18.5
Lemon	50	25
Plums	62	31
Almond	100	50
Walnuts	75	37.5
Avocado	20-30	10-15
Kiwifruit	22	11
Grapes	4	2

[1] Assumes that the biomass dry matter contains 50% C.

The C accumulated in the woody biomass of various types of shelterbelts was summarised in a report by Burrows et al. (2018). In the context of shelterbelts used for perennial horticulture, the values presented for low hedges or medium-tall hedges are probably more relevant. These values suggest that shelterbelts act as a sink of C in addition to the benefits they provide for wind protection and biodiversity (Table 3). However, in recent management of some perennial crops, shelterbelts are being removed and replaced by artificial shelter. Therefore, the removal of a natural shelterbelt would act as a loss of C, resulting in an emission of CO_2 which would need to be accounted for. While there may be benefits to the use of artificial shelter (e.g. greater wind protection or maximising effective canopy area), the trade-off will be a loss of a C sequestration option.

Table 3. Suggested maximum values of C stock, age and C sequestration rate for various types of shelterbelt. Table adapted from Burrows et al. (2018).

	Maximum stock* (t C ha^{-1})	**Age**	**C sequestration rate* (t C ha^{-1})**
Non-woody/shrubs	60.5	28	2.2
Untopped trees	140-220	28-40	3.5-7.9
Low hedges	60.5	28	2.2
Medium-tall hedges	99.2	28	3.5

* To convert to CO_2 equivalent, multiply values by 44/12, or 3.67.

A study measuring woody biomass of a 12-year-old apple orchard in New Zealand calculated a total C stock of 9.2 t C ha^{-1} (Perie 2015). This would equate to a C accumulation rate of 0.77 t C ha^{-1} y^{-1}. This study was carried out on a research trial and it was noted that the planting density and age of the trees would be key considerations when extrapolating woody biomass to commercial orchards. Perie (2015) also presented a summary of woody biomass in the literature for apple trees on the same rootstock (‘M9’ rootstock) and demonstrated that the C stock accumulation rate for woody biomass in apples was between 0.28 and 1.5 t C ha^{-1} y^{-1} with an average of 0.87 t C ha^{-1} y^{-1}. The woody biomass C stock accumulation rate is similar, although slightly higher, to the average rate used in New Zealand’s Greenhouse Gas Inventory methodology for land use change (i.e. 0.67 t C ha^{-1} y^{-1}) (MfE 2020).

2.3 Typical fertiliser use in perennial horticulture

The actual quantity of fertiliser applied to perennial systems will vary with crop, cultivar, management system, soil type and growing region. There is a paucity of published data on typical rates of fertiliser used across the various perennial horticultural crops in New Zealand. Many growers would have records on their actual fertiliser use that would allow calculation of on-orchard GHG emissions from fertiliser to be more accurately quantified.

The emission of GHG in the context of He Waka Eke Noa would only be due to that of fertiliser-applied N, lime or dolomite. These emissions are calculated using inventory methodology where emission factors are multiplied by the quantity of fertiliser applied.

The range of nutrients applied to kiwifruit orchards has been summarised by Carey et al. (2009). Here application rates from fertiliser were typically between 60 and 120 kg N ha^{-1} for N, 170–300 kg Ca ha^{-1} for calcium, and 20–80 kg Mg ha^{-1} for magnesium. However, these rates were based on orchard production (maximum 9300 trays ha^{-1}) and cultivars from the mid-2000s, so are likely to be outdated.

The N application for kiwifruit was later reported by Morton (2013) to range between 100 and 226 kg N ha^{-1}. These rates were also compared with those for apples (~30 kg N ha^{-1}) and grapes (~5 kg N ha^{-1}).

A more recent report summarising the value of N to the New Zealand economy (Journeaux et al. 2019) ran modelling scenarios using baseline average N application rates for kiwifruit (140 kg N ha^{-1}), avocado (100 kg N ha^{-1}), summerfruit (120 kg N ha^{-1}), apples (40 kg N ha^{-1}) and grapes (5 kg N ha^{-1}). However, an average application rate for kiwifruit of 110 kg N ha^{-1} is considered to be more appropriate (Jayson Benge, Zespri, pers. comm. 2021).

Information relating to the quantity of lime or dolomite applied to perennial crops is even scarcer. However, we can assume the amounts of Ca and Mg reported by Carey et al. (2009) represent typical application rates (e.g. 170–300 kg Ca ha^{-1} and 20–80 kg Mg ha^{-1}). Therefore, if these rates are met through the use of only lime and dolomite, which is unlikely, then to reach 300 kg Ca ha^{-1} would require approximately 750 kg lime ha^{-1} (assuming lime = 40% Ca) or around 1300 kg dolomite ha^{-1} (assuming dolomite = 23% Ca). To supply 80 kg Mg ha^{-1} using only dolomite would require approximately 727 kg dolomite ha^{-1} (assuming 11% Mg). However, it should be noted that both Ca and Mg can be supplied through sources other than lime and dolomite and often are applied through the main fertiliser suppliers as blends with other nutrients.

3 Estimates of agricultural greenhouse gas emissions from fertiliser

The GHG emissions from fertiliser are a function of the rate and the type of fertiliser applied. Field-based fertiliser emissions are primarily dominated by the direct and indirect emissions of nitrous oxide (N_2O) associated with the N within the fertiliser. However, any urea-based fertiliser will have an additional CO_2 emission associated with its breakdown in the field (Table 4). There will also be a field-based emission of CO_2 associated with the application of lime or dolomite (Table 5).

Direct emission relates to the fertiliser as it is applied in the field, and indirect emission relates to the emission occurring from leaching or volatilisation of applied fertiliser. Using inventory methodology (MfE 2020), both direct and indirect GHG emissions associated with fertiliser application can be calculated. This is achieved simplistically by multiplying the amount of fertiliser by an emission factor and then converting through to a CO_2 equivalent using a Global Warming Potential (GWP) value. As an example, the direct emission of N_2O following N fertiliser application is calculated as:

$$N_2O_{Direct} = \frac{44}{28} \times N \times EF$$

where:

N_2O_{Direct} = the direct N_2O emission from N applied (kg N_2O),
44/28 = the molecular conversion to convert N to N_2O,
N = the total amount of N applied (kg N) and EF is the emission factor, or the proportion of N_2O emitted per kilogram of N applied (kg N_2O-N/kg N) for urea (0.0059) and non-urea N sources (0.01).

To convert N_2O_{Direct} to CO_2-eq value”
$CO_2 - eq = N_2O_{Direct}$ x GWP

where the GWP for N_2O = 265 kg CO_2-eq per kg N_2O.

Please refer to the inventory methodology (MfE 2020) for a comprehensive breakdown of the various calculations and emission factors required to calculate the GHG emission.

The conversion of a CO_2-eq to C can be achieved by multiplying the CO_2-eq value by 12/44, and to convert C to CO_2-eq multiply the C value by 44/12. For example, 100 kg CO_2-eq would be the same as 27kg C (i.e. 100*12/44) and 100 kg C would be equivalent to 367kg CO_2 (i.e. 100*44/12).

Using the inventory methodology, the total GHG emission associated with 1 kg of N applied through either urea or non-urea products equates to between 4.5 and 4.8 kg CO_2-eq. It is important to note that these values of emission are dependent on the choice of GWP value used for N_2O. We used the up-to-date and recommended GWP for N_2O (GWP = 265) presented in the fifth activity report (AR5, Box 3.2, Table 1) of the IPCC report (IPCC 2014). If the previous GWP of 298 were used, the total emissions presented in Table 1 would increase to between 4.9 to 5.4 kg CO_2-eq for each kg of N applied as fertiliser. The use of urea with a urease inhibitor resulted in the lowest emission owing to the reduction in volatilisation losses using the inhibitor coating.

The proportion of N-applied fertiliser among the three generic sources presented in Table 4 for different perennial horticultural crops is not known. Therefore, all total emissions based on fertiliser application have been calculated assuming that the source of N is applied as a non-urea-based product (e.g. CAN or similar). This will give the most conservative GHG estimates because this source of N has the largest total GHG emissions per unit N applied (Table 4).

Table 4. Total carbon dioxide equivalent emission (kg CO_2-eq) for the use of 1 kg of N fertiliser applied as urea, with and without a urease inhibitor (UI) and other synthetic nitrogen (N) sources. The nitrous oxide (N_2O) emission includes indirect emissions associated with leaching and volatilisation. All emissions calculated using inventory methodology and emission factors. The values are calculated using the 100-y global warming potential of 265 (IPCC AR5 2014).

	Urea fertiliser No UI*	Urea fertiliser With UI*	Other N fertiliser
N_2O emission including indirect emission	3.1	2.9	4.8
CO_2 emission	1.6	1.6	n/a
Total emission	4.7	4.5	4.8

UI refers to Urease inhibitor.

Table 5. The field-based emission of CO_2 from the application of 1 tonne of lime or dolomite.

	kg CO_2 per tonne applied
Lime	440
Dolomite	477

Owing to the large variability and uncertainty in the fertiliser application rates across perennial horticultural crops, we have presented a summary of the GHG emissions associated with increasing rates of fertiliser application of N between 25 and 200 kg N ha^{-1} (Table 6). This table assumes that N fertiliser is applied as non-urea and accounts for direct and indirect emissions.

Table 6. Field-based emissions (kg CO_2-eq ha^{-1}) for non-urea applied nitrogen (N) applied at different rates. Emissions represent both direct and indirect associated emissions.

Application rate (kg N ha^{-1})	Greenhouse gas (GHG) emission (kg CO_2-eq ha^{-1})
25	120
50	240
75	360
100	480
125	600
150	720
175	840
200	960

4 Implications for agricultural emissions neutrality at the orchard gate

An estimate of C neutrality at the orchard gate was carried out based on the difference between on-orchard agricultural GHG emissions from N fertiliser use and the reasonable offsetting potential of C sequestration that would occur in the woody biomass of perennial orchards.

We note this only refers to the neutrality in terms of agricultural emissions at the orchard gate, for informing the likely cost the Horticultural sector will be exposed to by He Waka Eke Noa. This concept is not comparable, to the concept of C neutrality accounting for all sources and emissions of GHG (e.g. fuel from vehicles, leaf fall residues).

We have presented the C accumulation rate in woody biomass, the maximum C stock of that biomass, and the annual GHG emission related to N fertiliser use for a range of perennial crops in New Zealand (Table 7). Based on these results, the C accumulation in the woody biomass would offset a significant amount of GHG emission from fertiliser over several years. However, the accumulation of C in woody biomass is finite, whereas the emissions from fertiliser will continue to occur, annually, for as long as fertiliser is applied. Therefore, over a long enough timeframe a perennial orchard crop will cease its offsetting potential and become a source of GHG emissions. Therefore, it would be difficult to quantify the C neutrality of existing orchards unless exceptional record keeping of management information exist and C sequestration in woody biomass can be measured for that specific orchard. However, any change in land use (e.g. from pasture to perennial) that occurs, from now on, would have the ability to track and report the offsetting potential of C sequestered in woody biomass up until that biomass reaches maturity.

The year that an orchard was established will be important for the C sequestration and C accumulation. Any orchard established pre-1990 will have reached its ‘maturity’ and not considered to have any C accumulation still occurring based on the data presented in Tables 1–3. Orchards that have been established post 1990, may still have some C accumulation occurring providing the establishment period is more recent than the maturity age (i.e. established within the last 28 years using the NZ inventory maturity value). Therefore, as a rough rule of thumb, any orchard established after 1994 (i.e. within the last 28 years) would theoretically have some C sequestration occurring in the woody biomass. However, any removal of that woody biomass (i.e. change in shelter or removal of orchard trees without replacement), would be considered to be a loss of C. Temporary removal and re-grafting might be considered a loss of C, followed by a renewed phase of accumulation of C, depending on the inventory accounting rules used. In the context of He Waka Eke Noa, a framework to allow sequestration of C in the woody biomass could be developed. The total C sequestration available for a given orchard could be achieved, for example, by multiplying the sequestration rate by the years remaining up to an agreed maturity cycle (i.e. the difference between the agreed maturity age and current orchard age, Equation 1).

$$C\ sequestration_{\ Available} = C\ sequestration\ rate\ \times (Maturity\ age - Current\ age) \ldots\text{..(}\textit{Equation 1}\text{)}$$

Newly established orchards would have the sequestration of C in woody biomass available. However, the land area under various perennial horticultural crops over the past 30 years has not changed considerably with the exception of wine grapes which had a large increase in land area up until 2010 (Figure 1). Based on these figures, many orchards across New Zealand will have likely reached their maturity and hence maximum C stock. If a baseline year was agreed for He Waka Eke Noa, the

C sequestration available would need to factor this baseline year in when calculating the orchard age relative to the maturity age. As a rule of thumb, if the difference between the baseline year and the establishment year is less than the maturity age, then a proportion of the total C sequestration would still exist. Any orchard established since that baseline year would theoretically be able to account for all the total C sequestration available up until it reaches its maturity.

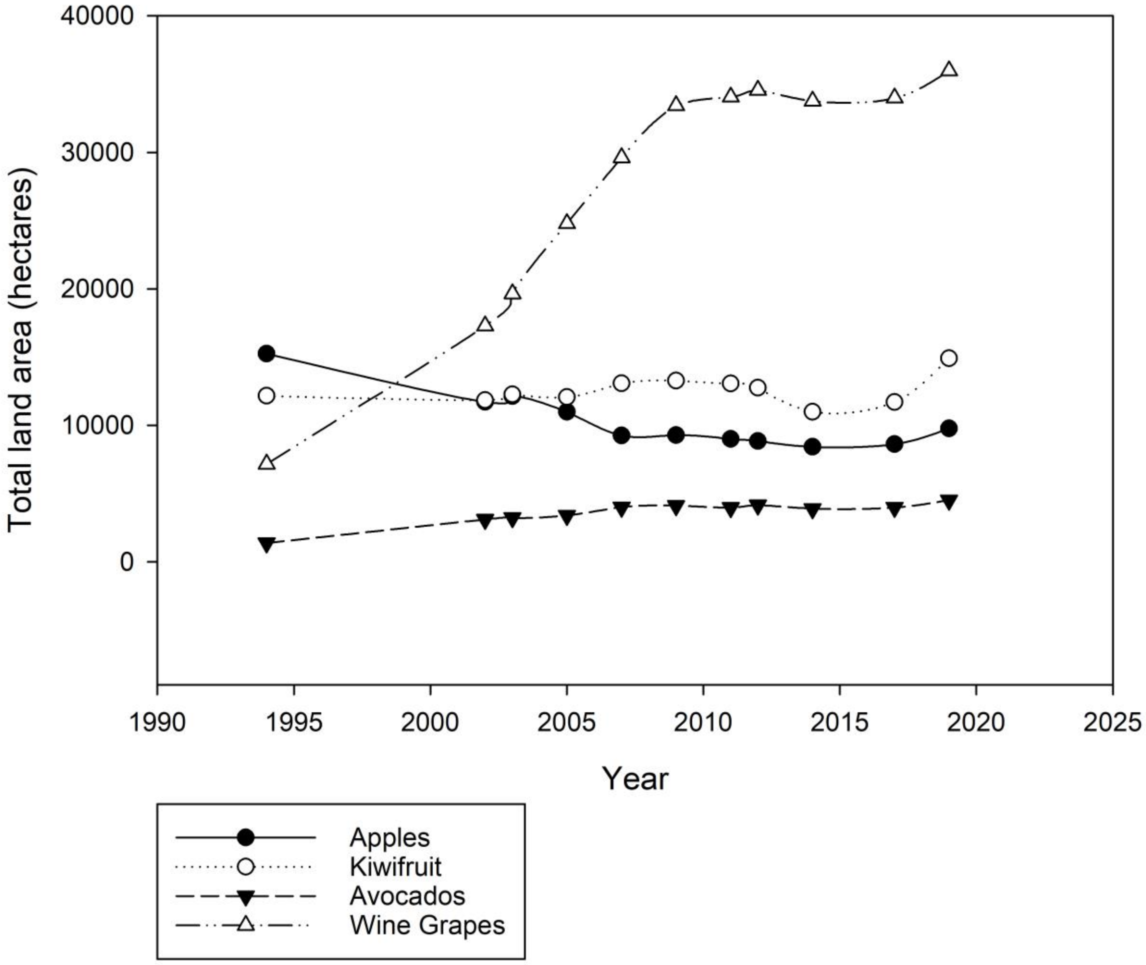

Figure 1. The change in total land area (hectares) under various perennial horticultural crops across New Zealand. Data obtained from Statistics New Zealand (https://www.stats.govt.nz/information-releases/agricultural-production-statistics-june-2019-final).

Soil C can contribute to C sequestration or GHG emissions. However, there is still uncertainty in the soil C change under perennial horticulture. Currently, a large loss of soil C is associated with the conversion of grassland to perennial horticulture, and will have implications for C neutrality and GHG inventory accounting. This is despite evidence that soil C may be maintained following conversion for some perennial horticultural crops. Therefore, there is a requirement for more targeted and representative measurements to track changes in soil C in perennial horticulture.

In the context of the He Waka Eke Noa initiative, only emissions related to synthetic fertiliser use would be relevant to most perennial horticultural crops, with limited livestock used across these sectors. A reduction of fertiliser-related GHG emissions would rely on careful N management, or using alternative sources of N (e.g. organic N supplied through composts). However, it is important to note that alternative sources of N would also have GHG emissions associated with their use, but there is currently no way of accounting for these using the New Zealand inventory methodology.

Another point to highlight would be that the use of biomass to offset GHG emissions will work only for the lifetime of that biomass. For example, once that biomass is removed, any C that had been sequestered will be released back into the atmosphere, depending on the disposal method. One particular management practice that would affect this is removal of trees/vines due to pest and disease damage. There has also been an increasing trend of natural shelterbelts being replaced by artificial shelter. This would result in a loss of C associated with the woody biomass of natural shelterbelts and a loss of C sequestration opportunity for newly established orchards.

Overall, perennial horticultural crops have the ability to sequester C into woody biomass for a finite period of time and have relatively low GHG emissions. However, agricultural GHG emissions will continue to occur while fertiliser application and other associated management practices occur.

Table 7. The C sequestration of woody biomass and the greenhouse gas emissions using ‘average’ rates of N fertiliser for kiwifruit, pip fruit, grapes, summerfruit and avocados. Please note the GHG emission excludes lime and dolomite use. The conversion of CO_2-eq to C uses a multiplication factor of 12/44.

	C accumulation ($t\ C\ ha^{-1}\ y^{-1}$)	**Maturity (y)**	**Maximum C stock ($t\ C\ ha^{-1}$)**	**Average annual N application rate [c] ($kg\ N\ ha^{-1}$)**	**Annual GHG emission, ($t\ CO_2$-eq ha^{-1})**	**Annual GHG emission, ($t\ C\ ha^{-1}$)**
Kiwifruit[a]	0.38	42.5	16.2	110	0.53	0.14
Pip fruit[a]	0.34	17.5	6.0	40	0.19	0.05
Grapes[a]	0.32	20	6.4	5	0.024	0.007
Summerfruit[b]	0.71	28	20	120	0.58	0.16
Avocado[b]	0.45	28	12.6	100	0.48	0.13
Average perennial crop[e]	0.67	28	18.8	75[d]	0.36	0.1

[a] The C accumulation rates and maturity derived from averages presented earlier in the report in Table 1. [b] Maximum C stock derived from Table 3 earlier in report, C accumulation rate calculated assuming a 28 year maturity. [c] The average N application rate based on Journeaux et al. (2019) report or updated recommendation (e.g. for Kiwifruit). [d] A non-weighted average of fertiliser application rates for all perennial crops listed. [e] C accumulation rate accounts for shelterbelt as per Burrows et al. (2018) and New Zealand inventory methodology for LULUCF.

5 References

Beare MH, McNeill S, Curtin D, Parfitt R, Jones H, Dodd M, Sharp J 2014. Estimating the organic carbon stabilisation capacity and saturation deficit of soils: A New Zealand case study. Biogeochemistry 120:71–87.

Burrows L, Easdale T, Wakelin S, Quinn J, Graham E, Mackay A 2018. Carbon sequestration potential of non-ETS land on farms. Manaaki Whenua – Landcare Research report prepared for the Ministry of Primary Industries. Contract Report: LC3161.

Carey PL, Benge JR, Haynes RJ 2009. Comparison of soil quality and nutrient budgets between organic and conventional kiwifruit orchards. Agriculture, Ecosystems and Environment 132:7–15.

Deurer M, Sivakumaran S, Ralle S, Vogeler I, McIvor I, Clothier B, Green S, Bachmann J 2008a. A new method to quantify the impact of soil carbon management on biophysical soil properties: the example of two apple orchard systems in New Zealand. Journal of Environmental Quality 37: 915–924.

Deurer M, Clothier BE, Greven M, Green S, Mills T 2008b. Soil carbon stocks and their change in orchards and vineyards in New Zealand. Report to Landcare Research. HortResearch Client Report No. 25805. HortResearch. Contract No. 22723.

Deurer M, Rahman H, Holmes A, Saunders S, Clothier B, Mowat A 2010. Quantifying soil carbon sequestration in kiwifruit orchards: development of a sampling strategy. In*:* Farming's future: Minimising footprints and maximising margins. (Eds L.D. Currie and C.L. Christensen). Occasional Report No. 23. Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand.

Gentile RM, Malepfane NM, van den Dijssel C, Arnold N, Liu J, Muller K 2021. Comparing deep soil organic carbon stocks under kiwifruit and pasture land uses in New Zealand. Agriculture, Ecosystems and Environment 306:107190. https://doi.org/10.1016/j.agee.2020.107190.

Gentile RM, Périé E, Müller K, Deurer M, Mason K, van den Dijssel C, Clothier BE, Holmes A, Hardie M, McLaren SJ 2016. Quantifying the potential contribution of soil carbon to orchard carbon footprints. Acta Horticulturae 1112:461–466. https://doi.org/10.17660/ActaHortic.2016.1112.62.

He Waka Eke Noa 2021. Greenhouse gases: farm planning guidance, Edition 2: March 2021. ISBN No: 978-0-473-55945-8 (online). hewakaekenoa.nz/wp-content/uploads/2021/03/GHG-Farm-Planning-Guidance-March.pdf.

Holmes A, Müller K, Clothier B, Deurer, M 2015. Carbon sequestration in kiwifruit orchard soils at depth to mitigate carbon emissions. Communication in Soil Science and Plant Analysis 46: 122–136 http://dx.doi.org/10.1080/ 00103624.2014.988583.

IPCC 2006. Guidelines for National Greenhouse Gas Inventories. Volume 4: Agriculture, Forestry and Other Land Use. Chapter 2: Generic Methodologies Applicable to Multiple Land-Use Categories. www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_02_Ch2_Generic.pdf.

IPCC 2014. Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, Pachauri RK, Meyer LA (eds.)]. IPCC, Geneva, Switzerland, 151 pp. www.ipcc.ch/site/assets/uploads/2018/02/SYR_AR5_FINAL_full.pdf.

Journeaux P, Batley L, van Reenen E 2021. Review of models calculating farm level GHG emissions #2. AgFirst report prepared for He Waka Eke Noa. hewakaekenoa.nz/wp-content/uploads/2021/05/Review-of-Models-Calculating-Farm-Level-GHG-Emissions-2-June-2021.pdf.

Journeaux P, Winton J, Archer L, Ford S, McDonald G 2019. The value of nitrogen fertiliser to the New Zealand economy. AgFirst report prepared for the Fertiliser Association, www.agfirst.co.nz/wp-content/uploads/2020/03/Value-of-N-Fertiliser-Report-2.pdf.

Kerckhoffs LHJ, Reid JB 2007. Carbon sequestration in the standing biomass of orchard crops in New Zealand. Report prepared for Horticulture New Zealand Ltd. March 2007.

Lal R 2004. Soil Carbon Sequestration Impacts on Global Climate Change and Food Security. Science 304(5677):1623–1627.

Lal R 2016. Soil health and carbon management. Food and Energy Security 5(4): 212–222.

McNally SR, Beare MH, Curtin D, Meenken ED, Kelliher FM, Calvelo Pereira R, Shen Q, Baldock J 2017. Soil carbon sequestration potential of permanent pasture and continuous cropping soils in New Zealand. Global Change Biology 23(11):4544–4555.

MfE 2020. New Zealand’s Greenhouse Gas Inventory 1990-2018. Volume 1, Chapters 1-15. Publication number: ME 1496. ISSN: 1179-223X (electronic). Ministry for the Environment, Manatū Mō Te Taiao PO Box 10-362, Wellington, New Zealand environment.govt.nz/assets/Publications/Files/new-zealands-greenhouse-gas-inventory-1990-2018-vol-1.pdf.

Morton AR 2013. Kiwifruit (*Actinidia* spp.) vine and fruit responses to nitrogen fertiliser applied to the soil or leaves. PhD Thesis. Massey University.

Perie E 2015. Carbon dynamics in apple orchards in New Zealand and their integration into Life Cycle Assessment. PhD Thesis. Massey University.

Tate KR, Wilde RH, Giltrap DJ, Baisden WT, Saggar S, Trustrum NA, Scott NA, Barton JP 2005. Soil organic carbon stocks and flows in New Zealand: System development, measurement and modelling. Canadian Journal of Soil Science 85:481–489. https://doi.org/10.4141/S04–082.

Smith P, House JI, Bustamante M, Sobocka J, Harper R, Pan G, West PC, Clark JM, Adhya T, Rumpel C, Paustian K, Kuikman P, Cotrufo MF, Elliott JA, McDowell R, Griffiths RI, Asakawa S, Bondeau A, Jain AK, Meersmans J, Pugh TAM 2016. Global pressures on soils from land use and management. Global Change Biology 22(3):1008–1028.

Whitehead D, Schipper LA, Pronger J, Moinet GYK, Mudge PL, Calvelo Pereira R, Kirschbaum MUF, McNally SR, Beare MH, Camps-Arbestain M 2018. Management practices to reduce losses or increase soil carbon stocks in temperate grazed grasslands: New Zealand as a case study. Agriculture, ecosystems and Environment 265:432–443.

4p1000.org. The 4 per 1000 initiative. www.4p1000.org, Accessed 23 July 2021.

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