Silvopastoral agroforestry systems for dryland corners in Canterbury farms

Sandra VELARDE PAJARES[1, 2*], Kyle WILLS[3], Istvan HAJDU[4], Trent TIPENE[5], and Electra KALAUGHER[6]

[1]WSP, 1105 Arawa St, Rotorua 3010, New Zealand
[2]Te Pūnaha Matatini, Centre for Research Excellence in Complex Systems, 34 Princes Street, Auckland 1010, New Zealand
3WSP, 69 Tarbert St, Alexandra 9320, New Zealand
[4]WSP, 49 Victoria Avenue, Palmerston North 4410, New Zealand
[5]WSP, 3/100 Beaumont Street, Auckland 1010, New Zealand
[6]WSP, 94B Bryce Street, Hamilton 3204, New Zealand
*Corresponding author: sandra.velardepajares@wsp.com

Abstract
Water constraints on dry areas of Canterbury farms, combined with animal welfare requirements, have spurred interest in practices such as agroforestry that can help future proof farming. Agroforestry is the deliberate integration of trees within a livestock grazing system. Farmers were surveyed to investigate their understanding of agroforestry, including enablers and barriers to change. A literature review was conducted to identify key agroforestry concepts. Agroforestry planting plans were co-developed with Ngāi Tahu Farming and Claxby Farms in Canterbury region accompanied by economic analysis of the agroforestry component of each farm. Unquantifiable benefits of integrating trees on farms were also identified. Agroforestry systems as designed had positive net present value, internal rate of return, and a positive post carbon income annual cashflow. This research demonstrated that agroforestry is potentially economically viable in Canterbury. Agroforestry systems can be designed to align with the New Zealand Emissions Trading Scheme (NZ ETS) and in turn this would provide financial incentives for establishing trees on dryland corners. The quantified economic outcomes and the identified unquantified benefits warrant further research into integrating agroforestry into dairy and other farming systems around New Zealand.

Keywords: silvopastoral system, profitability, carbon, NZ ETS, tree-pasture

Introduction
New Zealand farming is constantly adapting to changes in consumer demand, environmental and trade policies, and climate change impacts. Potential future water availability constraints in dry areas for Canterbury farms, combined with existing animal welfare requirements (Animal Welfare Act 1999) have spurred interest in practices such as agroforestry, that can help future proof farming, addressing environmental and economic objectives. Silvopastoral agroforestry is the deliberate integration of trees within a livestock grazing system (Ramachandran Nair et al. 2021). Dryland corners constitute over 35,000 ha in Canterbury dairy farms (Stats NZ 2021a; Stats NZ 2021b) and provide a unique opportunity to diversify the dominant farming sector in this region.

Currently, two species dominate the agroforestry landscape in New Zealand: poplar (*Populus spp.*) and willow (*Salix spp.*), planted historically for soil erosion management (Kemp et al. 2018). Both species are easy to propagate through coppicing and have co-benefits such as forage from twigs, leaves and bark (Kemp et al. 2001). Previous agroforestry research in New Zealand using radiata pine (*Pinus radiata*) (e.g. Tikitere trial (1973-1999) near Rotorua, North Island) (Hawke, 2011) showed undesirable economic outcomes, decreasing wood quality, pasture production and animal performance. However, that research was conducted prior to the New Zealand Emissions Trading Scheme (NZ ETS) and without consideration of other potential tree species and non-timber uses (e.g. forage, carbon sequestration), and therefore likely fails to capture the value that could be obtained today. Moreover, international research on silvopastoral agroforestry systems shows promise for tree species with growth characteristics that differ from radiata pine, such as honey locust (*Gleditsia triacanthos*), black walnut (*Juglans nigra*) and oak trees (*Quercus spp.*) (Jose and Dollinger 2019; Wilson and Lovell 2016). Barriers to the adoption of agroforestry include establishment cost, landowner's lack of experience with trees, and the time and knowledge required for management (Wilson and Lovell 2016).

Recent New Zealand publications have identified multiple values relevant to land managers for the integration of nut trees on farm (Holt et al. 2019), and the positive impact on pasture production from integrating kānuka trees (*Kunzea* spp.) into sheep and beef pastoral systems (Mackay-Smith et al. 2022). The latter

ISSN 2463-2872 (Print) ISSN 2463-2880 (Online) https://doi.org/10.33584/jnzg.2024.86.3691

provides evidence of how strategically placed trees can affect nutrient transfer and increase pasture production. The most recent silvopastoral systems study in New Zealand proposed five key principles to be considered in silvopasture design, including holistic management, local people's views, values and experiences, locally specific decisions, and understanding of ecological processes, to underpin all management decisions; and use of high-resolution data and tools (Mackay-Smith et al. 2024).

This paper expands the knowledge on agroforestry systems by focusing on these objectives:

- Understand the perceived barriers to integration of agroforestry in an irrigated dairy farm context and enablers of change to agroforestry.
- Assess the economic potential of agroforestry systems that are suitable for integration with Canterbury irrigated dairy farms.
- Identify research gaps in agroforestry for New Zealand.

Methods

A targeted literature review was conducted to explore different aspects of agroforestry and in parallel, local farmers were engaged with in the Canterbury region to determine their appetite for and knowledge of agroforestry systems. Case studies were developed for two participating farms, including a planting plan and economic assessment for each farm. Results were disseminated to a range of audiences, including the public, rural professional and scientific communities.

Literature review

A targeted literature review was conducted to understand the impacts of agroforestry on farm performance measures, on the environment, and potential tree species to be used in the case studies. The literature review was revisited after interviewing the case study farmers with a focus on specific tree species and qualities that made them desirable for the case study farms. Findings from the literature review then supported the agroforestry planting design.

Farmer survey

Farmers from a local Canterbury catchment group, Waimakariri Landcare Trust, were surveyed to determine their understanding of agroforestry, challenges and barriers to adoption. This survey was also intended to refine the scope and focus of the literature review to meet the perceived needs of local farmers. The survey was created in Microsoft Forms and consisted of 19 questions to determine local farmers' knowledge of agroforestry, as well as barriers and motivation for adoption. The survey was emailed to a potential total of 50-100 farmers and rural professionals in June 2023, with responses received within a month. The survey was sent through direct email, via a newsletter article, and some participants forwarded it to an unknown number of contacts, hence the total number of people who received the survey is an approximation only.

Case studies: Planting plans and economic assessment

Planting plans

Agroforestry designs and planting plans were created for two case study farms. Claxby Farms and Ngāi Tahu Hamua farm (Table 1) were selected based on landowner interest, their proximity to each other and their location within the Waimakariri Catchment. Initial interviews were conducted with decision makers of both farms to understand the farming enterprise values, challenges and opportunities where agroforestry could help achieve farm goals. The interviews focused on understanding how each enterprise valued factors such as indigenous biodiversity, farm management complexity and accuracy as well as diversification, to be able to accurately judge necessary compromises in designing an agroforestry system. Farm key performance indicators such as milk solids yield were gathered for the subsequent economic assessment.

Agroforestry planting plans and designs, including species, spacing and layout of trees on the dryland corners of the farms, were developed in the open-source QGIS software and overlayed with the associated geospatial information such as farm boundary layers. Agroforestry planting plans were proposed based on information gathered from the literature review, expert knowledge, and insights gained from the case study farmer meetings. Once the agroforestry designs had been completed, the datasets were imported into ESRI ArcGIS Pro to generate enhanced 2D and 3D versions of the planting systems. The representation of different tree species considered the proportions of the tree species and anticipated tree dimensions (height and width) at the fully grown stage. These parameters were used to create future farm images, illustrating how the farms may look once the plantings are fully grown. Additionally, a semi-realistic 3D building layer in real-world units was generated using the publicly available building footprint layers from the Land Information New Zealand Data Service. This visualisation aimed to improve the understanding of the spatial relationships to the surrounding environment.

Economic assessment

The economic assessment consisted of a standard discounted cashflow analysis on the net annual revenue of the agroforestry system for each farm. The internal rate of return, annual return on investment and net present value for a base case were estimated. The

Table 1 Case study farm data.

	Total effective area	Irrigated percentage	Cows/ha (effective)
Claxby Farms	647 ha	93.5%	2.99
Ngāi Tahu Hamua	335 ha	95.6%	3.06

core assumptions for both farms economic analysis included a carbon price of $70/tC which was the price at the time of completion (My Native Forest, 2024), an assumed 20% reduction in pasture production due to the integration of the trees and 5% discount rate on a 36-year horizon. Sensitivity analysis was conducted for carbon price and pasture production.

The economic analysis was informed by information provided by farm managers, literature reviewed and industry quotes, as follows:

- No evidence of pasture production under non-pine, spaced agroforestry systems in the Canterbury plains, was found. Therefore, a maximum reduction in pasture production of 20% was assumed based on literature from Power et al. 2001; Gutteridge and Shelton, 1994; Benavides et al. 2009; Radcliffe, 1985. It is assumed that the proportion of shade increased at the same rate as carbon accumulated for hardwood exotics in the Ministry for Primary Industries (MPI) Hardwood Exotic Carbon look up table: (MPI carbon look up table).
- Farm key performance indicators for imported feed, winter feed, milk solids and pasture production were provided by the farm managers on a per hectare basis based only on effective irrigated area. These values were then split between irrigated and dryland area based on the relative productivity of each. This resulted in total, per hectare and per cow values for tons of dry matter pasture eaten (t DM) and milk solids production (kg).
- The cost of establishing agroforestry was calculated from industry quotes for purchasing trees, individual tree protectors, fencing materials and paying contractors for planting, maintenance and fencing. These quotes were extrapolated by the number of trees, tree protectors and linear meters of fencing required for each agroforestry plan. The cost of establishment was assumed to be incurred in year 0.
- Per hectare and total loss in pasture production was calculated from productive area lost to individual tree protectors, mature tree trunks and fenced protection and decreased pasture production under the agroforestry area.
- Milk solids production from tree forage was calculated using farm specific feed conversion efficiency values. Tree forage per hectare was assumed to increase annually at the same rate as carbon accumulated in the carbon look up table.
- Total additional milk solids production per hectare was calculated based on the annual number of days above 25^0C, with the gain increasing annually as available shade increased (Kendall et al. 2006).
- Total and per hectare carbon from trees in the agroforestry systems was calculated from the MPI carbon look up table for hardwood exotics.

Results

Literature review

Impacts of agroforestry on farm performance

Pasture production. Pasture production or growth rate is largely the net result of the availability of resources, namely sunlight, temperature, moisture, and fertility (Benavides, et al. 2009). In ideal pasture growing conditions, pasture production under agroforestry is limited by shading (Wall et al. 2006). This is shown in numerous agroforestry trials with pasture production and or livestock carrying capacity decreasing as shade increases from increasing canopy cover (Gutteridge and Shelton 1994; Benavides, et al. 2009). Deciduous tree species tend to have less of a negative impact on pasture production due to their leaf free period over winter (Power et al. 2001; Ramachandran Nair et al. 2010). In particularly difficult growing environments, such as hot, dry or nutrient deficient areas, the moderating effect of agroforestry on local microclimate and pasture growing environment means pasture production under trees may be similar to open pasture or even possibly higher, due to nitrogen availability (Gutteridge and Shelton 1994; Benavides, et al. 2009) and soil moisture conservation (Gutteridge and Shelton 1994; Masters et al. 2023; Benavides et al. 2009).

Livestock performance. Heat stress is a real risk in Canterbury, with cows benefitting from shade under relatively mild summer conditions (Bloomberg, M. & Bywater, A. C., 2007). Air temperature under shade by agroforestry was shown to be 10^0C lower than open pasture (Betteridge et al. 2012; Gutteridge and Shelton 1994), which cows use 40-50% of the time they are not grazing (Betteridge et al. 2012). Cows provided shade on days where temperature $>25^0$C had a higher milk solid production than cows that did not have shade (Kendall et al. 2006).

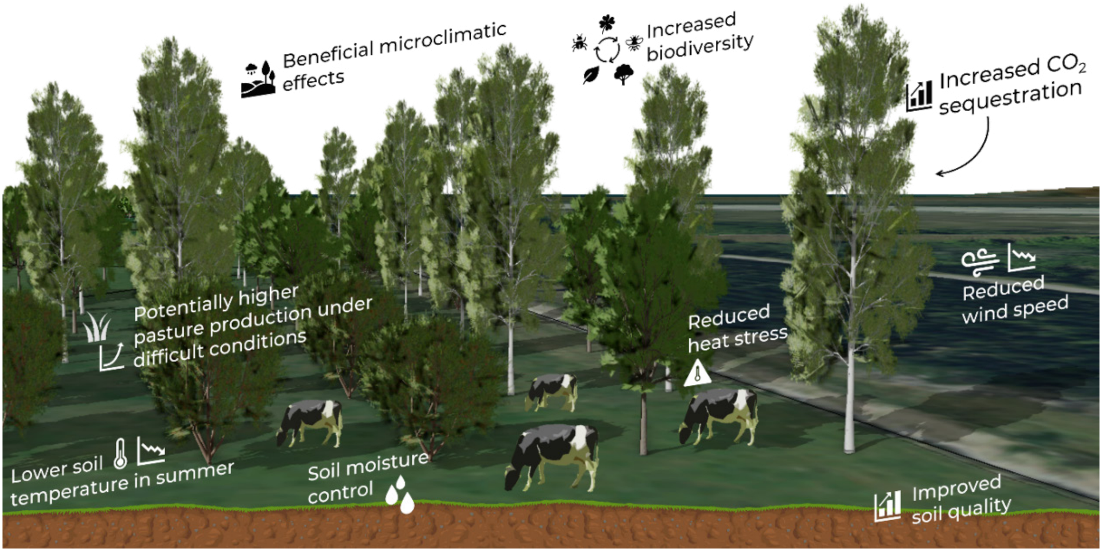

Figure 1 Example of the benefits agroforestry could provide a farming system in dryland Canterbury based on the literature review.

Impacts of agroforestry on the environment

Microclimate. Trees can reduce wind speed downwind 10-15 times the height of the tree (Jose et al. 2004), and upwind 2-5 times the height of the tree (Masters et al. 2023). Benavides et al. (2009) demonstrated that soil water content was similar or higher under mature poplar species (down to 300mm soil depth) compared with open pasture.

Carbon sequestration. Agroforestry sequesters more carbon than open pasture (Jose 2009; Ramachandran Nair et al. 2010). Poplar based agroforestry systems, similar to New Zealand poplar pole planting for soil erosion, are likely to sequester 30% more carbon over the lifetime of the trees (Benavides et al. 2009).

Soil effects. Soils under agroforestry systems consistently show increased infiltration (Guevara-Escobar 1999; Jose 2009), as well as having higher porosity and improved soil aggregate stability (Jose 2009), and increased levels of organic matter (Benavides et al. 2009). Some tree species impact soil pH: For example, mature poplars were shown to increase soil pH by 0.9-1.2 (Guevara-Escobar 1999). Soil temperatures under tree canopies were 0.7^{0}C higher in winter and 3.3^{0}C lower in summer (Benavides et al. 2009).

Biodiversity. Integrating trees into farm systems is widely accepted to have biodiversity benefits (England et al. 2020). Evidence from 72 studies and 143 study sites in the Brazilian Atlantic Forest found that agroforestry systems can provide 45% more biodiversity benefits than conventional production systems (Santos et al. 2019). Similarly, Jose (2009) reported a greater density and diversity of insect populations in windbreaks. Shelterbelts were shown to have lower populations of invertebrate pest species and higher populations of predatory insects and spiders, with this effect flowing over into nearby pastures (Masters et al. 2023). Trees within a landscape, particularly more dense agroforestry plantings, can provide habitat for bird species as well as act as a transport corridor between remnant vegetation (Masters et al. 2023). On the other hand, a meta-analysis of European agroforestry studies between 1991-2019 did not find a benefit to biodiversity from silvopastoral agroforestry systems when compared to forests and pastures of abandoned silvopastures (Mupepele et al. 2021). In response to these findings, Boinot et al. (2022) argued for the need to develop rigorous experimental designs with adequate controls to assess the impacts of agroforestry on biodiversity.

The key findings of the literature review are highlighted in Figure 1.

Tree species with potential on Canterbury farms

The tree species considered in the dryland corner of dairy farms case studies (Claxby and Ngāi Tahu) focused on those species which have forage potential and are deciduous or nitrogen fixers, to lower the impact on pasture production. Primary tree species are wind and drought tolerant.

The choice of tree species for agroforestry systems considers both biophysical aspects and landowner's

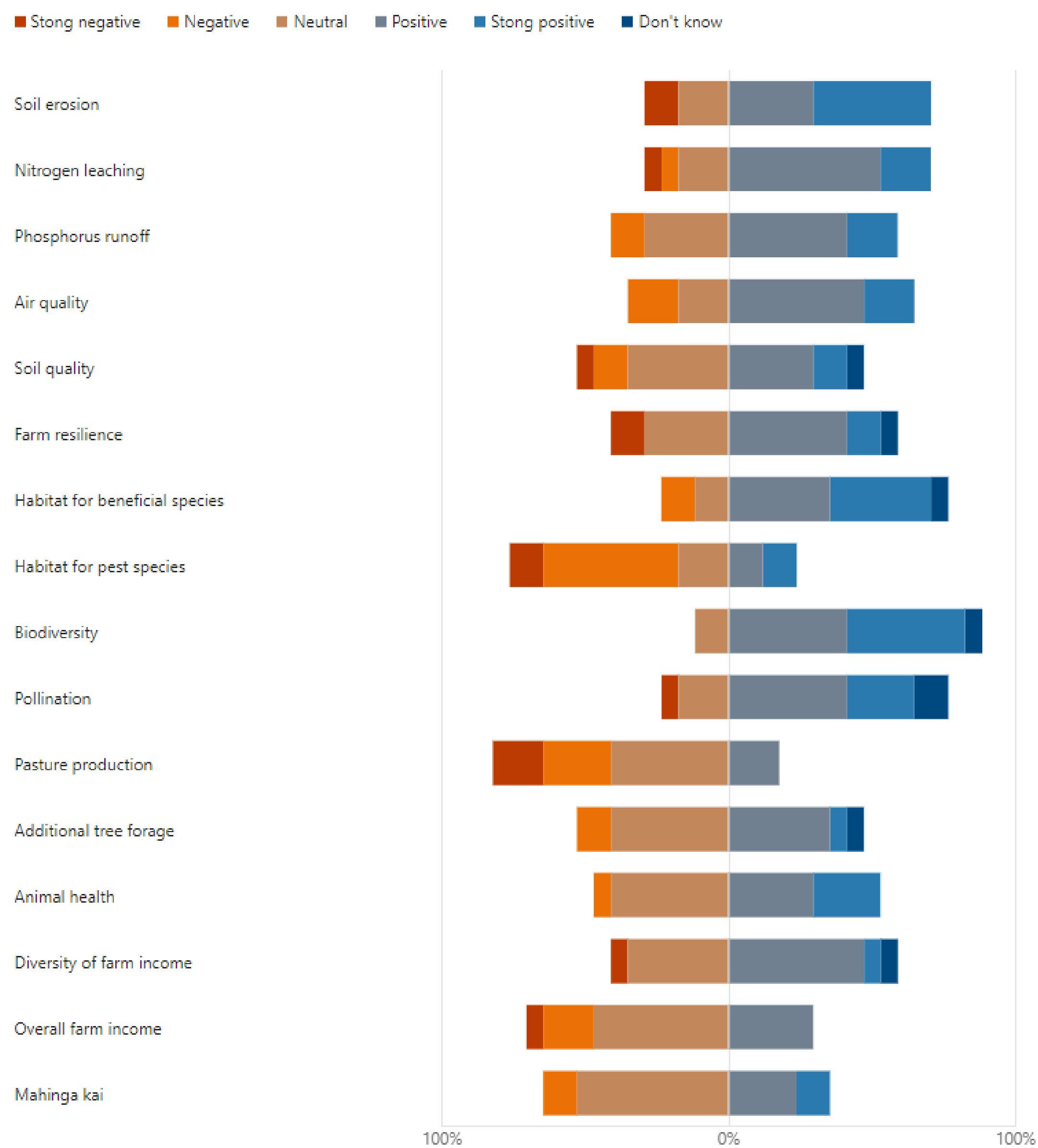

Figure 2 Responses to "What effect do you think agroforestry will have on a series of farm related factors?" from the farmer survey.

multiple goals; and these varied by case study. Forage species considered include mulberry (*Morus* spp.), poplar and honey locust. These species have different growing requirements and productivity values, can be used as forage and contribute to animal health.

Farmer survey

The farmer survey elicited 21 responses, with an average of 22 years of farming experience. Most respondents were dairy farms (40%), followed by sheep and beef farms (21%), mixed farming (21%) then arable (11%) and other (7%). Based on the farmer survey, the largest barrier to adoption of agroforestry systems reported was the 'cost of establishment' (16 of 21 responses), closely followed by their perception of the system being 'not financially viable' (13 of 21 responses) and 'lack of knowledge/awareness' (12 of 21 responses). Factors most likely to overcome these barriers include the availability of funding options, local examples of implementation and access to practical research.

Overall, 52% respondents saw the potential benefits of agroforestry being 'shade and shelter for livestock' and 29% of respondents seen benefits in 'offsetting greenhouse gas (GHG) emissions via the New Zealand Emissions Trading Scheme (NZ ETS)'. When asked about the potential negative impacts of agroforestry the most common response was 'reduced productivity in the form of pasture or food production' followed by 'limitations to farm management'. Because a negative impact on pasture production was highlighted as a concern, this helped focus the literature review on understanding the potential impact that agroforestry has on pasture production and how negative impacts could be minimised. Some farmers specifically mentioned low pasture production under pines, but they did not mention any specific case information.

When asked "how likely they would be to implement agroforestry on their farm?" the average response was 5.2 out of 10. Reasoning for their answers was evenly split between positive and negative responses ranging from 'they don't believe it will work' to 'they are already doing some form of agroforestry'.

When asked "what effect do you think agroforestry has on a series of farm related factors?", 'habitat for pest species' had the strongest negative rating (Figure 2) followed by 'pasture production' and 'overall farm income'. 'Biodiversity' has the strongest net positive response followed by 'habitat for beneficial species', 'soil erosion', 'nitrogen leaching' and 'pollination'.

When asked whether they thought that agroforestry spoke to mātauranga Māori or to cultural values, 35% of responded with yes (primarily mentioning biodiversity) and 18% responded no, with 47% unsure.

The findings from this survey and case study farmer interviews also highlighted the importance of minimising the potential impacts from agroforestry on farm infrastructure and management practices.

Case studies: Planting plans and economic assessment

Planting plans

Both case study farms (Claxby and Ngāi Tahu) wanted an agroforestry system to complement their current farming system, with minimum complexity and conflict with animals, infrastructure and farm management. Extending irrigation to dryland areas is not a possibility for either farm due to return on investment and nutrient loss limitations. In the planting plans for each case, tree rows were set 20m apart with trees 10m apart along the rows, except for 1 in 4 sites at Ngāi Tahu farm, in which are planted with two natives 2.5m apart. Importantly, canopy cover is maintained at 40%, making it eligible for the New Zealand Emissions Trading Scheme (NZ ETS) permanent forest category, maximising their opportunity for carbon capture under the MPI carbon look up tables for exotic hardwoods. Where some agroforestry areas were initially <1ha, trees were planted within the irrigated area of the pivot end gun, but not physically under the pivot, to make them >1ha and NZ ETS eligible.

Where possible, tree rows are orientated north to south, to minimise pasture shading and maximise wind obstruction. The majority of trees are planted in the back of paddocks to incentivise livestock camping in the back of paddocks rather than the front. This may reverse nutrient transfer and improve pasture management.

The key differences between species choice for each case study farm were due to the preference for native biodiversity and fencing requirements from Ngāi Tahu Hamua. When exotic trees are replaced at Ngāi Tahu Hamua farm, they will be replaced with natives, systematically transitioning to a native agroforestry system over time. They preferred more fencing as they had more whole dryland paddocks that fenced rows effectively creating more subdivision. The restricted grazing provided by fenced tree rows allows for unhampered regeneration and longer grass, providing more suitable habitat for indigenous species. On the other hand, Claxby Farms preferred more individual tree protectors rather than fencing off rows as they are cheaper and provide more freedom of management. The agroforestry species, their role in the system and proportion planted at each farm is presented in Table 2. In addition to the forage species (poplar, mulberry and honey locust), black walnut was chosen by Claxby Farms as a timber species, whereas the New Zealand native species, kowhai (*Sophora microphylla*) and Ribbonwood (*Plagianthus regius*) were favoured by Ngāi Tahu Hamua for their biodiversity potential.

Economic assessment

The economic assessment considered agroforestry as an additional system to the existing farm system and infrastructure. In the base case internal rates of return (IRR) were 26% and 20% and annual return on investment (ROI) over 36 years was 32% and 24% for Claxby and Ngāi Tahu-Hamua farms respectively; resulting in a positive Net Present Value (NPV) for both farms (Table 3).

Income from NZ ETS is only considered the first 35 years of the system, assuming carbon sequestration values from the MPI carbon look up table. Income from carbon sequestration through the NZ ETS was a major contributor to the cashflow for both farms (Figure 3 and Figure 4).

Sensitivity analysis showed that without the carbon income stream, the IRR of both farms was negative

Table 2 Agroforestry species, their role in the system and proportion planted at each farm.

Species	Claxby Farms (planted)	Ngāi Tahu (planted)	Role of in agroforestry system
Poplar	32.7%	25%	Forage, soil conditioner, medium canopy
Mulberry	32.7%	25%	Forage, medium to dense canopy
Honey locust	32.7%	25%	Forage, Nitrogen fixer, sparse canopy
Black walnut	2%		Timber, high risk high return timber opportunity with small exposure
Kowhai*		12.5%	Behave as an island for indigenous flora and fauna to be attracted to, encouraging reforestation. Nitrogen fixer
Ribbonwood*		12.5%	Behave as an island for indigenous flora and fauna to be attracted to, encouraging reforestation

*Semi deciduous species.

Table 3 Farm information and economic performance of agroforestry at Claxby Farms and Ngāi Tahu Hamua.

	Claxby Farms	Ngāi Tahu Hamua
Total effective area	647 ha	335 ha
Agroforestry area	61.58 ha	25.48 ha
Unproductive area under agroforestry	4.14 ha	1.54 ha
Establishment cost	$3,974/ha	$5,017/ha
Net Present Value (NPV)*	$19,549/ha	$17,007/ha
Internal Rate of Return (IRR)	26%	20%
Annual Return on Investment (ROI)	32%	24%
Post carbon annual cashflow	$119.63/ha	$195/ha

*5% discount rate, 36 year horizon

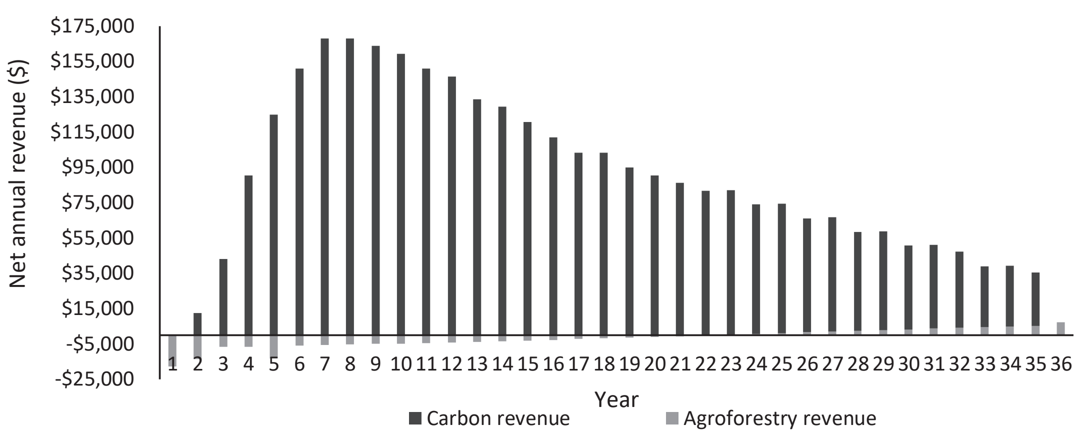

Figure 3 Net modelled annual cashflow of Claxby Farms agroforestry.

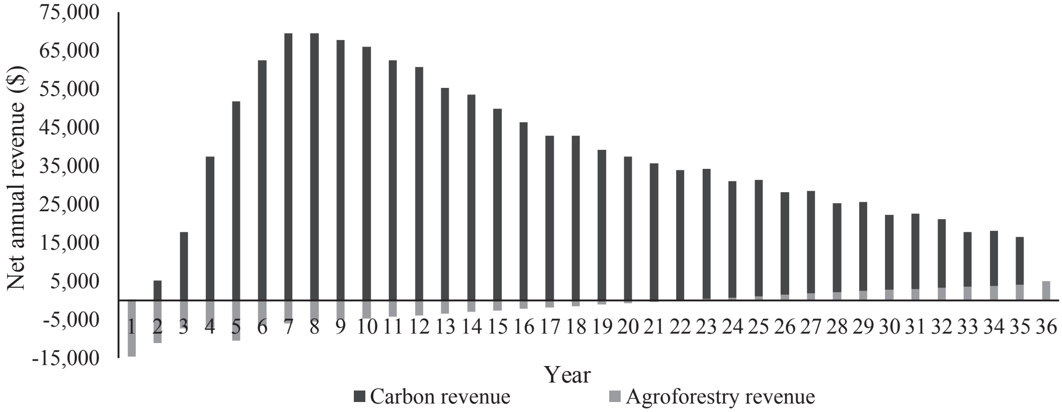

Figure 4 Net modelled cashflow of Ngāi Tahu Hamua agroforestry.

Table 4 Sensitivity analysis of carbon price on NPV and IRR for each case study.

Economic indicator	**Carbon price (NZD)**				
	0	20	50	70 (base case)	150
Claxby Farms					
IRR (%)	(7)	8	20	26	42
NPV (NZ$)	(309,242)	123,071	771,541	1,203,854	2,933,107
Ngāi Tahu Hamua					
IRR (%)	(7)	4	15	20	34
NPV (NZ$)	(192,730)	(13,850)	254,469	433,357	1,148,868

Table 5 Sensitivity analysis of pasture production on NPV and IRR for each case study

Economic indicator	Pasture production		
	-10%	-20% (base case)	-30%
Claxby Farms			
IRR (%)	27	26	25
NPV (NZ$)	1,467,976	1,203,854	939,732
Ngāi Tahu Hamua			
IRR (%)	21	20	19
NPV (NZ$)	530,221	433,357	336,477

(-7% for both case study farms) (Table 4). At a carbon price of $20/t, the NPV for Claxby farm was positive ($123,071) but Ngāi Tahu Hamua farm was negative (-$ 13,850) (Table 4). A sensitivity analysis on the effect of pasture production under agroforestry indicated that this did not have a large impact on financial viability, resulting in a 1% reduction in IRR per every 10% reduction in pasture production (Table 5).

Dissemination

Dissemination of this research to date has included a radio interview, a newspaper article, a field day, a conference presentation, a webinar and an illustrated story. In the field day, conference and webinar, visualisation tools were used to show how the planting plans would look for in the case study farms. An ArcGIS StoryMap summarising

Figure 5 Claxby Farms visualisation of the future farm with inclusion of agroforestry.

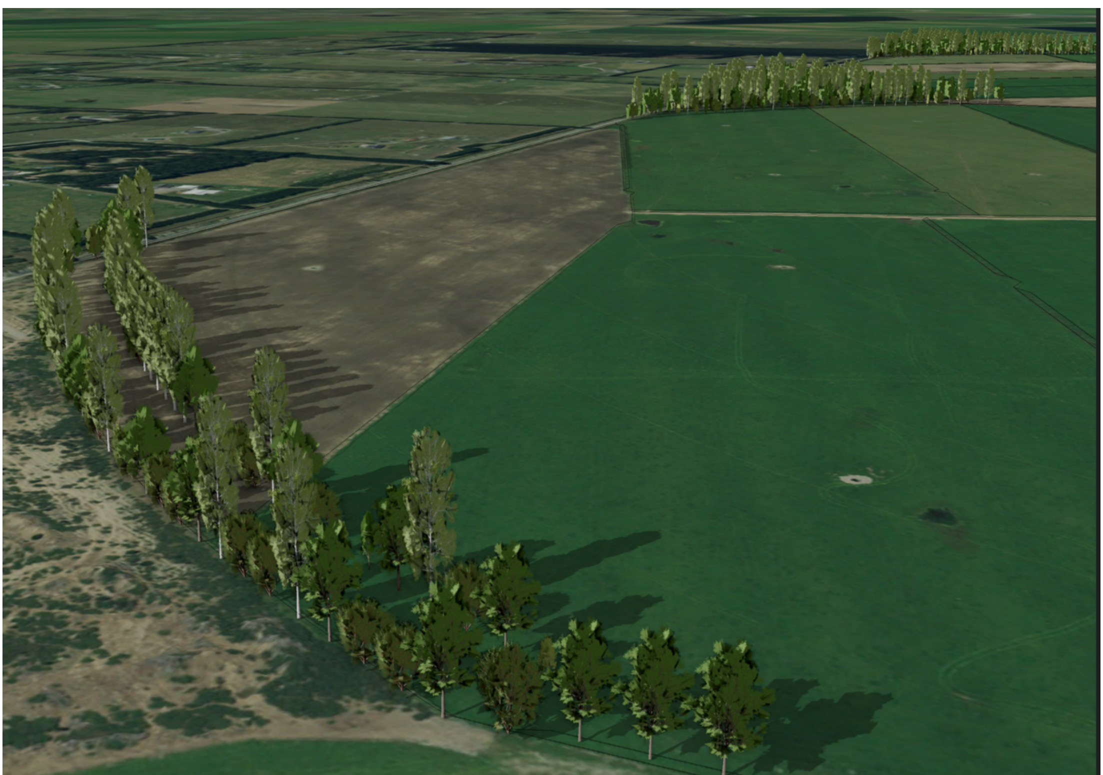

Figure 6 Ngāi Tahu Hamua visualisation of the future farm with inclusion of agroforestry.

key results was created and published to WSP's ArcGIS Online platform: https://storymaps.arcgis.comstories/05b48b90174a44c59fdc5e106b417c89. This includes a 3D model that allows do a virtual online tour of each farm. Example visualisations are shown in Figure 5 and Figure 6. A short story based on this was digitally illustrated and animated for further dissemination: https://www.tepunahamatatini.ac.nz/2024/05/24/the-surprising-benefits-of-planting-trees-on-farms/ (Te Pūnaha Matatini, 2024).

Discussion

The case studies presented in this paper have helped to better understand and highlighted ways to address the barriers to integrating agroforestry into systems. Results from the farmer survey agreed with known barriers to agroforestry adoption such as establishment costs (Wilson and Lovell 2016; Mackay-Smith et al. 2024) and lack of knowledge/know-how, and awareness (Mackay-Smith et al. 2024). These barriers were addressed by designing tailored agroforestry systems and cashflows that include income generated from carbon sequestration through the NZ ETS. Effectively, the guiding agroforestry system design question was: *"How could we make agroforestry work under current legislation so that the system benefits from NZ ETS income?"*. Lessons learned from previous agroforestry experiences with negative results (e.g. Hawke 2011) were effectively incorporated by including profitability as a key consideration in the analysis.

This study was limited to the components that could be readily accounted for. Multiple environmental and economic benefits of agroforestry were identified, but several could not be integrated in the economic assessment. Some of the potential environmental benefits identified but not included are:

- Nutrients: The impacts on point source nutrient loss from reducing the intensity of stock camping in the front of paddocks (by providing shade in the back of paddocks), as well as the impacts of tree species intercepting leached nutrients from below the roots of pasture species.
- Biodiversity: Increased habitat for some indigenous species through agroforestry systems that include natives or mature exotic trees; and increased habitat and food for pollinators that may result in improved pollination on farm. Habitat for biological control agents (and some pests) may result in improved pasture or crop yields and/or longevity.
- Other benefits: Improved air quality; improved aesthetics and potentially staff mental health (and possibly retention) through a better-quality environment with more trees; improved erosion control by tree roots if on erosion-prone land.

Other potential economic benefits may require further research to fully integrate and assess them, for example:

- Potential further increase in milk solid production when shade is provided at temperatures above 30°C and shade is > $3.6m^2$ per cow, as milk production could be higher than anticipated due to less competition for shade; as well as potential gains in production from providing shelter and reducing exposure for livestock during cold weather events.
- The impact of reduced or reversed nutrient transfer that could result in relatively higher fertility in the back of paddocks, saving on fertiliser applications and potentially increasing pasture production.
- Alternative future revenue streams, such as biodiversity credits (Ministry for the Environment 2023).

While these case studies were developed before learning about the five agroforestry principles proposed by Mackay-Smith et al. (2024), these principles were applied in practice: This was achieved by carefully designing a system that could be integrated seamlessly under current farming management, by listening to farmers' views, values and perspectives through the survey and interviews which resulted in different species choice and profitability outcomes, and understanding of ecological processes as reflected in species selection. Results were delivered using high-resolution data and tools to visualise the farms in a 3D tool and the publication of the Story Map and dissemination of results.

Assumptions about the impact of trees on pasture production are based on best estimates adapted from studies in the North Island with different species and environmental conditions, including planting orientation. Pasture production under radiata pine is likely to be lower than under deciduous species, due to excessive shading; and pasture production under poplars in the North Island will likely have very different results to summer dry areas of the South Island due to the trees' microclimate effect. Hence a key knowledge gap is pasture productivity under a deciduous agroforestry system for the South Island, in particular for dryland areas.

A second key knowledge gap is the potential increase in milk solids production given reduced heat stress. It was assumed that farmers would move the cows to areas of shade during warmer days (> 25^0C). Understanding the benefits on milk production under agroforestry system could contribute to current animal welfare requirements for providing shade for livestock.

Conclusions and Recommendations

Agroforestry in the dryland corners of Canterbury dairy farms was shown likely to be financially viable, and warrants further investigation, including assessment of the economic value of its unquantified benefits. Further research should also investigate a diverse set of tree species based on land managers' goals and environmental conditions.

For the two farm case studies, carbon returns from the NZ ETS were the primary revenue source for agroforestry and a potential incentive for uptake. However, future uptake may come from other long term ecosystem services (e.g. animal welfare) and revenue streams (e.g. fodder). Farming is often an intergenerational business, and subsequent generations must farm these agroforestry systems long after the revenue from the carbon is gone. This means that non carbon revenue must remain positive or near positive, and not erode revenue earned from carbon too quickly, for farmers to be willing to take the risk of diversifying.

Agroforestry may also provide an excellent opportunity for other farming systems around New Zealand, such as sheep and beef. Although the post carbon returns are expected to be higher in more extreme climates due to the microclimate buffering effect of trees, the revenue earned from carbon can provide significant opportunity for other land uses. Calculations of carbon sequestered from hardwood exotics in the MPI carbon look up tables or Tane's Tree Trust Carbon Calculator (Tane's Tree Trust, 2024) do not consider land use differences (e.g. whether it is on a high performing dairy farm or a low intensity sheep and beef farm). However, lower intensity farming systems could potentially derive greater benefit from agroforestry systems, as they are more likely to benefit from the additional tree forage.

More research is required to quantify the forage potential of selected tree species and their impacts on pasture and animal productivity, including economic assessment. These trials could also provide an opportunity to learn for both farmers and researchers, while raising farmer awareness and grow confidence to consider agroforestry as part of their existing land use, or as a new land use option.

ACKNOWLEDGEMENTS

New Zealand Ministry for Business, Innovation and Employment's Our Land and Water (Toitū te Whenua, Toiora te Wai) National Science Challenge Rural Professionals Fund (Contract 23.24RPF112) in particular, Michelle Van Rheede, for the opportunity to carry out this research and providing support throughout the project. Claxby Farms (Sam Spencer Bower) and Ngāi Tahu (Ben Jaunay, George Mauger, Monique Daulton, and Logan Robertson) for supporting this research, sharing their farming knowledge and providing their farm information for the agroforestry case studies. Waimakariri Landcare Trust, in particular Erin Harvie, for their support and help with organising the Farmer Field Day, and the participants of the Farmer Field Day for their time and feedback on the preliminary results.

REFERENCES

Animal Welfare Act 1999. Version as of 30 April 2023. Retrieved 18 April 2024 from: https://www.legislation.govt.nz/act/public/1999/0142/latest/whole.html

Benavides R, Douglas GB, Osoro K. 2009. Silvopastoralism in New Zealand: review of effects of evergreen and deciduous trees on pasture dynamics. *Agroforestry systems 76(2)*: 327-350. doi:10.1007/s10457-008-9186-6

Betteridge K, Costall D, Martin S, Reidy B, Stead A, Millner I. 2012. Impact of shade trees on angus cow behaviour and physiology in summer dry hill country: Grazing activity, skin temperature and nutrient transfer issues. In: Currie LD, Christensen CL (Eds). *Advanced Nutrient Management: Gains from the Past - Goals for the Future*. http://flrc.massey.ac.nz/publications.html. [Occasional Report No. 25]. Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand. 10p.

Bloomberg, M. & Bywater, A. C., 2007. Estimating the Effect of Shade on Heat Stress in New Zealand Dairy Cows Using Two Published Models. *Land, Water and Environmental Management*, pp. 420-426

Boinot S, Barkaoui K, Mézière D, Lauri P-E, Sarthou J-P, Alignier A. 2022. Research on agroforestry systems and biodiversity conservation: what can we conclude so far and what should we improve? *BMC Ecology and Evolution 22*: 24. https://doi.org/10.1186/s12862-022-01977-z

My Native Forest. (2024). Carbon Price NZ. My Native Forest. Retrieved 16 July 2024. https://www.mynativeforest.com/carbon-price-nz

England JR, O'Grady AP, Fleming A, Marais Z, Mendham D. 2020. Trees on farms to support natural capital: An evidence-based review for grazed dairy systems, *Science of The Total Environment 704*: 135345. https://doi.org/10.1016/j.scitotenv.2019.13534

Guevara-Escobar A. 1999. *Aspects of a poplar-pasture system related to pasture production in New Zealand.* [Doctoral thesis, Massey University].

Gutteridge RC, Shelton HM. 1994. Animal production potential of agroforestry systems. In: Copland JW, Djajanegra A, Sabrani M (Eds). *Agroforestry and Animal Production for Human Welfare: proceedings of an international symposium held in association with the 7th AAAP Animal Science Congress*, Bali. Indonesia, 11-16 July 1994. ACIAR Proceedings No. 55, 125p. Australian Centre for International Agricultural Research, pp. 7-16.

Hawke, M. 2011. *Agroforestry – the Tikitere experience*. New Zealand Tree Grower May 2011. Retrieved 12 December 2023 from: https://www.nzffa.org.nz/farm-forestry-model/resource-centre/tree-grower-articles/may-2011/agroforestry-the-tikitere-experience/

Holt L, Renwick A, Johnstone P, Dynes R, King W. 2019. The case for a novel agroforestry system and cross-sector collaboration. In: Currie LD and Christensen CL (Eds) *Nutrient loss mitigations for compliance in agriculture*. http://flrc.massey.ac.nz/publications.html. [Occasional Report No. 32]. Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand. 10 pages.

Jose S, Dollinger J. 2019. Silvopasture: a sustainable livestock production system. *Agroforestry Systems 93*:1-9. https://doi.org/10.1007/s10457-019-00366-8

Jose S, Gillespie AR, Pallardy SG. 2004. Interspecific interactions in temperate agroforestry. *Agroforestry systems 61(1-3)*: 237-255. https://doi.org/10.1023/B:AGFO.0000029002.85273.9b

Jose S. 2009. Agroforestry for ecosystem services and environmental benefits: an overview. *Agroforestry systems 76(1)*:1-10. doi:10.1007/s10457-009-9229-7

Kemp PD, Hawke MF, Knowles RL. 2018. Temperate agroforestry systems in New Zealand. In: Gordon AW, Newman SM, Coleman BRW, editors. *Temperate agroforestry systems*. Oxfordshire: CAB International, p. 224-236. https://doi.org/10.1079/9781780644851.0224

Kemp PD, Mackay AD, Matheson LA, Timmins ME. 2001. The forage value of poplars and willows. *Proceedings of the New Zealand Grassland Association 63*: 115-119. https://doi.org/10.33584/jnzg.2001.63.2444

Kendall PE, Nielsen PP, Webster JR, Verkerk GA, Littlejohn RP, Matthews L. 2006. The effects of providing shade to lactating dairy cows in a temperate climate. *Livestock Science 103(1-2)*: 148-157. https://doi.org/10.1016/j.livsci.2006.02.004

Mackay-Smith TH, Lopez IF, Burkitt LL, Reid, JI. 2022. Kānuka trees facilitate pasture production increases in New Zealand hill country. *Agronomy 12(7)*: 1-17. https://doi.org/10.3390/agronomy12071701

Mackay-Smith TH, Spiekermann RI, Richards DR, Harcourt N, Burkitt LL. 2024. An integrative approach to silvopastoral system design: perspectives, potentials and principles, *New Zealand Journal of Agricultural Research*: 1-41. https://doi.org/10.1080/00288233.2023.2298922

Masters DG, Blache D, Lockwood AL, Maloney SK, Norman HC, Refshauge G, Hancock S. 2023. Shelter and shade for grazing sheep: implications for animal welfare and production and for landscape health. *Animal Production Science 63 (7)*: 623-644. https://doi.org/10.1071/AN22225

Ministry for the Environment. 2023. *Helping nature and people thrive – Exploring a biodiversity credit system for Aotearoa New Zealand.* Retrieved 12 December 2023 from: https://consult.environment.govt.nz/biodiversity/nz-biodiversity-credit-system/

Mupepele AC, Keller M. Dormann CF. 2021. European agroforestry has no unequivocal effect on biodiversity: a time-cumulative meta-analysis. *BMC Ecology and Evolution 21*: 193. https://doi.org/10.1186/s12862-021-01911-9

Power IL, Dodd MB, Thorrold BS. 2001. Deciduous or evergreen: Does it make a difference to understorey pasture yield and riparian zone management? *Proceedings of the New Zealand Grassland Association 63*: 121-125. https://doi.org/10.33584/jnzg.2001.63.2443

Ramachandran Nair PK, Vimala DN, Mohan Kumar B, Showalte JM. 2010. Carbon sequestration in agroforestry systems. *Advances in Agronomy 108*: 237–307. https://doi.org/10.1016/S0065-2113(10)08005-3

Ramachandran Nair PKR, Mohan Kumar B, Nair VD. 2021. Definition and Concepts of Agroforestry. In: Ramachandran Nair PKR, Mohan Kumar B, Nair VD. *An Introduction to Agroforestry. Four Decades of Scientific Developments.* Springer, Cham. 21-28. https://doi.org/10.1007/978-3-030-75358-0

Santos PZF, Crouzeilles R, Sansevero JBB. 2019. Can agroforestry systems enhance biodiversity and ecosystem service provision in agricultural landscapes? A meta-analysis for the Brazilian Atlantic Forest, *Forest Ecology and Management 433*: 140-145. https://doi.org/10.1016/j.foreco.2018.10.064

Stats NZ. 2021a. Agricultural and horticultural land use. Statistics New Zealand. https://www.stats.govt.nz/indicators/agricultural-and-horticultural-land-use

Stats NZ. 2021b. Irrigated land. Statistics New Zealand. https://www.stats.govt.nz/indicators/irrigated-land/

Tane's Tree Trust. 2024. Carbon calculator. https://toolkit.tanestrees.org.nz/carbon-calculator/

Te Pūnaha Matatini. 2024. The surprising benefits of planting trees on farms. Retrieved 25 July 2024.

https://www.tepunahamatatini.ac.nz/2024/05/24/the-surprising-benefits-of-planting-trees-on-farms

Wall AJ, Kemp PD, Mackay AD. 2006. Predicting pasture production under poplars using canopy closure images. *Proceedings of the New Zealand Grassland Association 68*: 325-330. https://doi.org/10.33584/jnzg.2006.68.2625

Wilson MH, Lovell ST. 2016. Agroforestry –The Next Step in Sustainable and Resilient Agriculture. *Sustainability 8*: 574. https://doi.org/10.3390/su8060574