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INTEGRATION OF AGROFORESTRY SYSTEMS WITHIN IRRIGATED DAIRY FARMS IN WAIMAKARIRI, CANTERBURY

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Abstract

The opportunity of integrating agroforestry within irrigated dairy farms in Waimakariri, Canterbury, was investigated via farmer surveys, a literature review and two desktop case studies including economic assessments. Agroforestry has the potential to alter the understory microclimate, providing a buffering effect for extreme weather conditions. Some tree species can alter soil chemistry such as poplars increasing pH by up to 1.2. Species such a mulberry are used around the world to as animal fodder due to forage attributes such as high crude protein (18.9% DM) and high digestibility (>85.2%). The presence of trees in the back of dairy paddocks can provide shade and reduce heat stress for cows, potentially increasing milk production. Mature agroforestry systems can improve biodiversity by creating habitat and food sources for fauna. These areas can be used as habitat corridors to connect indigenous species between native remnants. Native tree species can be incorporated into agroforestry or succeed the exotics to create more beneficial habitat and connectivity for indigenous species.
Economic assessments of the two case study farms agroforestry plans showed that establishment cost $3,974/ha and $5,017/ha for the two farms. Annual cashflow started out negative before quickly peaking in year 7 at $2,730/ha for both properties. Annual cashflow trended downwards to $119 and $195/ha respectively at year 36 after carbon income stopped. Agroforestry had an internal rate of return (IRR) of 26% and 20% and a net present value (NPV) of $19,549/ha and $17,007/ha respectively.

Introduction

The New Zealand farming sector is constantly adapting to changes in consumer demand, environmental pressures, trade policies, and climate change impacts. Moisture availability constraints on non-irrigated dryland areas of Canterbury dairy farms, combined with existing animal welfare requirements has stimulated interest in diversifying on farm practices such as agroforestry, that can help future proof farming, addressing environmental and economic objectives. Non-irrigated corners constitute over 35,000ha in Canterbury farms, providing a unique opportunity to diversify the dominant farming sector in this region.

Agroforestry is the deliberate integration of trees within an agricultural system, with silvopasture specifically being the integration of trees into a livestock grazing system. Agroforestry has been previously researched in New Zealand using *Pinus radiata*, showing undesirable economic outcomes (e.g. Tikitere trial near Rotorua, North Island; Hawke, 2011).

However, international research on agroforestry shows promise for tree species with growth characteristics that differ from *Pinus radiata* (Jose & Dollinger, 2019; Wilson & Lovell, 2016).

This project was selected by the Our Land and Water National Science Challenge 2023-24, and funded by the Rural Professionals Fund, which aims at funding the testing of innovative ideas which could lead to significant improvements for our food and fibre farming systems. This project specifically aimed to:

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

Methodology

Farmer engagement

Farmers from the Waimakariri Landcare Trust catchment group, Canterbury, were surveyed to determine their understanding of agroforestry, their perceived challenges and barriers to agroforestry adoption. The survey created in Microsoft Forms, consisted of 19 questions and it was also used to refine the scope of the literature review. The survey was emailed in June 2023, with responses received within a month.

Literature review

A literature review was conducted to understand the impacts of agroforestry on the environment, farm performance measures, and potential tree species suitable for dryland corners of Canterbury. After the interviews with the case study farmers (detailed below), the literature review was revisited with a focus on specific tree species and qualities that made them desirable for the case study farmers. Findings from the literature review then supported the agroforestry planting designs.

Case studies and planting plans

Two case-study farms within the Waimakariri Catchment were used to create agroforestry designs and planting plans. Claxby Farms and Ngāi Tahu – Hamua were selected due to landowner interest, their close proximity to each other (Figure 1).

Initial meetings with decision makers of Ngāi Tahu – Hamua and Claxby Farms were undertaken to understand the farming enterprise values, challenges and opportunities where agroforestry could help achieve their farm goals. A valuable part of these interviews was understanding how each enterprise valued indigenous biodiversity, farm management complexity and accuracy as well as diversification. This information was used for the design phase of their specific agroforestry systems. Key performance indicators such as pasture milk solid (MS) yields were gathered for the economic assessment component of this project.

Figure 1. Farm location map of case study farms, including both Ngāi Tahu – Hamua and Claxby Farms, Waimakariri District

Agroforestry planting plans and designs were developed in the open-source QGIS software and overlayed with the associated supporting geospatial information such as farm boundary layers. Agroforestry planting plans were the net result of information gathered from the literature review, expert knowledge, and insights gained from the case study farmer meetings. Once the agroforestry designs were completed, the datasets were imported into 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 both the weight and width tree dimensions when they are fully grown. These parameters were used to create future farm imagery, visually illustrating what the farms may look like once the plantings were fully established.

Economic assessment

Cost of planting establishment was calculated from the agroforestry planting plans for each case study farm. Revenue was calculated in addition or subtraction from the farm revenue based on carbon, pasture and milk solid production under agroforestry. The core assumptions for both farms economic analyses included a carbon price of $70/t and a 20% reduction in pasture production under the agroforestry system. A standard discounted cashflow analysis was undertaken on the net annual revenue over 36 years with a 5% discount rate. The internal rate of return (IRR), annual return on investment estimated and net present value (NPV) were estimated.

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

- Key farm performance indicators for imported feed, total winter feed, MS and pasture production were provided by the farm managers on a per hectare basis based only on the effective irrigated area. These values were then split between irrigated and dryland areas based on the relative productive production. This resulted in total, per hectare and per cow values for pasture eaten (t DM) and MS production (kg).

- The cost of establishing agroforestry was calculated from industry quotes for purchasing trees, individual tree protectors and 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 all 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 as well as decreased pasture production under the agroforestry area. It was assumed that the effect of trees reducing pasture production was increased annually at the same rate as carbon in accumulated in the MPI Hardwood Exotic Carbon look up table.

- Milk solid production from tree forage was calculated with farm specific feed conversion efficiency values. Tree forage per hectare increased annually at the same rate as carbon in accumulated in the MPI Hardwood Exotic Carbon look up table.

- Total additional MS production per hectare was calculated based on the annual number of days above 25^0C, with the gain increasing annually as available shade increased. Shade increased at the same rate as carbon in accumulated in the MPI Hardwood Exotic Carbon look up table.

- Total and per hectare carbon was calculated from the MPI Hardwood Exotic Carbon look up table.

Results

Literature Review

Pasture productivity

- In particularly difficult growing environments, the moderating effect of agroforestry on local microclimates means pasture under trees may potentially have higher production than open pasture, due to nitrogen availability and soil moisture conservation (Benavides, et al., 2009; Gutteridge & Shelton, 1994; Masters, et al., 2023).
- Trees planted in rows have less of a negative impact on pasture production than trees planted in a grid pattern (Benavides, et al., 2009).
- In ideal pasture growing conditions, pasture production under agroforestry is limited by shading. This ranges from a 30-45% decrease depending on species, agroforestry system and planting density (Benavides, et al., 2009; Guevara-Escobar, et al., 2007; Power, et al., 2001).
- Assuming there are no limitations in soil fertility, pasture production in dryland Canterbury is driven by variations in temperature (winter periods) and moisture (summer periods). To support pasture production, particularly during spring, deciduous tree species should be utilised to reduce the effect of shading.

Microclimate

- Trees can reduce wind speed downwind 10-15 times the height of the tree, and upwind 2-5 times the height of the tree (Jose, et al., 2004).
- Lower evapotranspiration under trees (Benavides, et al., 2009; Guevara-Escobar, et al., 2007; Masters, et al., 2023)as well as the drawing of water from depths by tree roots can enhance soil water content in the top 300mm of the soil profile (Benavides, et al., 2009). This has been shown under mature poplars, where deeper tree roots have drawn moisture from a depth, making it assessable to shallower rooted pasture.

Carbon sequestration

- Agroforestry sequesters more carbon than an open pasture environment. 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 tend to have higher porosity (Jose, 2009), infiltration (Guevara-Escobar, et al., 2007; Jose, 2009), soil aggregate stability (Jose, 2009) and organic matter (Benavides, et al., 2009) than open pasture.
- Some tree species impact soil pH: For example, mature poplars were shown to increase soil pH by 0.9-1.2 units (Guevara-Escobar, et al., 2007).
- Soil temperatures under tree canopies were 0.7^0C higher in winter and 3.3^0C lower in summer (Serrano, et al., 2021).

Biodiversity

- Agroforestry can improve biodiversity by creating habitat and food sources for fauna (England, et al., 2020). These areas can be used as habitat corridors to connect indigenous species between native remnants (Masters, et al., 2023). There is also the possibility to incorporate native tree species into agroforestry or succeed the exotics with native species to create more beneficial habitat and connectivity for indigenous species.

Animal welfare

- Heat stress is a real risk in Canterbury, with cows benefitting from shade under relatively mild summer conditions. Air temperature under shade by agroforestry was shown to be 10^0C lower than open pasture, which cows use 40-50% of the time they are not grazing (Betteridge, et al., 2012).
- New Zealand research showed a small increase in in milk solid production for cows provided shade on days where the temperature >25^0C (Kendall, et al., 2006). In Darfield, Canterbury this equates to approximately 45 days per year (Macara, 2016).

Case studies – Agroforestry 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 isn't a possibility for both farms due to return on investment and nutrient loss limitations in their catchment.

Design considerations:

- Tree rows are north-south where possible, to minimise pasture shading and maximise wind obstruction. Rows are 20m apart with trees 10m apart along the rows, except for one in four sites at Ngāi Tahu, in which are planted with two natives 2.5m apart.

- Canopy cover is 40%, making it eligible for the NZ ETS permanent forest category, maximising their opportunity for carbon capture under the MPI carbon look up tables for exotic hardwoods.

- Trees should provide 225-250m of downwind shelter under the pivot when mature.

- Trees planted under pivot end gun where possible. This is required in some areas to make them >1ha and NZ ETS eligible as well as provide shade for livestock.
- Majority of trees are planted in the back of paddocks to promote stock camping in the back of paddocks rather than the front, where nutrient transfer is more prevalent. This may reverse nutrient transfer and improve pasture management in the back of paddocks.
- Previously unproductive areas such as tracks and yards can now claim carbon in the NZ ETS as they are underneath tree canopies.
- Majority of tree species are palatable and deciduous, with some nitrogen fixers to minimise negative impacts on pasture and optimise forage potential (*Table **3***).
- All tree species selected perform a role in the agroforestry (Table 2). Primary tree species are wind and drought tolerant to improve establishment.
- When 3.6m^2 shade/cow is provided on days where maximum temperature >25^{0}C, there is a small increase in MS production due to reduced heat stress.
- Ngāi Tahu elected for more fencing as they had more whole dryland paddocks that fenced rows effectively create more subdivision. The restricted grazing provided by fenced tree rows allow for unhampered regeneration and longer grass providing more suitable habitat for indigenous species. When exotic trees are replaced at Ngāi Tahu, they will be replaced with natives, systematically transitioning to a native agroforestry system over time.

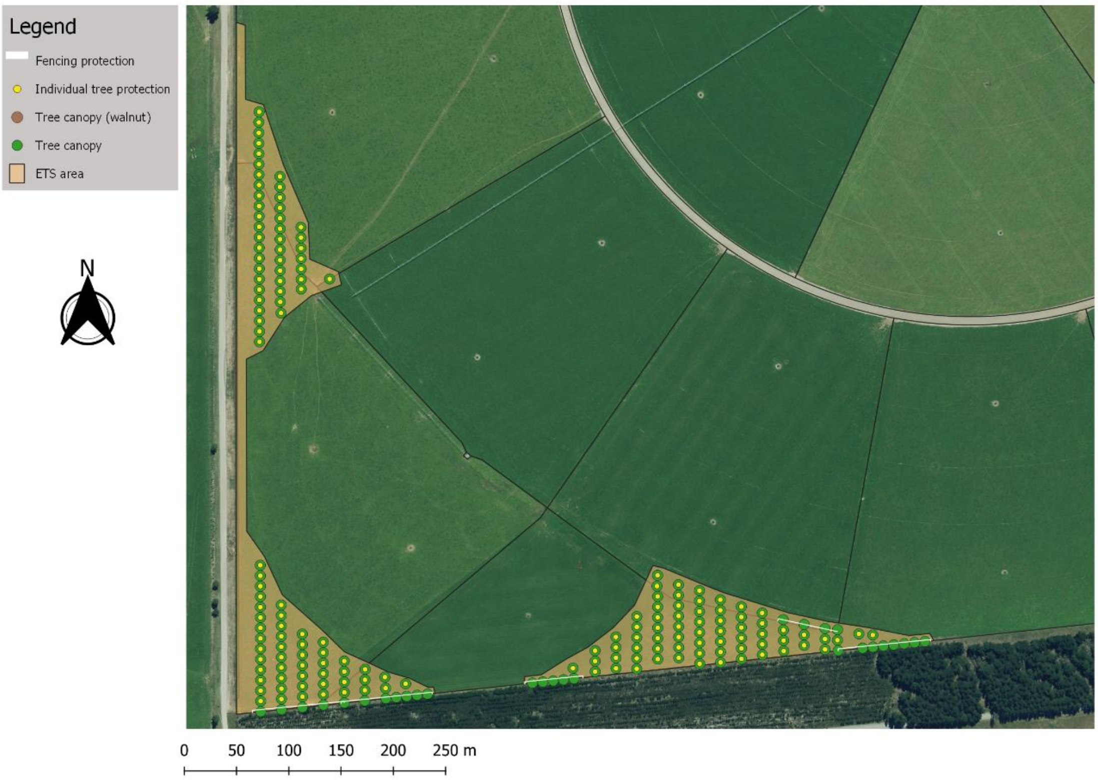

Figure 2. Example of agroforestry planting plan on Claxby Farm, south-west corner.

Table 1. Agroforestry species, their role in the system and proportion planted at each farm.

Species	Claxby Farms	Ngāi Tahu	Role in Agroforestry
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*

Table 2. Agroforestry forage species quality analysis of digestibility, DM %, crude protein, neutral detergent fibre, acid detergent fibre, ash content and metabolizable energy.

Species	Digestibility (%DM)	Dry matter (%)	Crude protein (% DM)	NDF (%DM)	ADF (%DM)	Ash (% DM)	ME (MJ/kg/DM)
Poplar	69.7	90	17.6	36.1	23.6	24.8	10.5
Mulberry	85.2	41	18.9	28.4	22.0	13.4	18.1
Honey locust (leaf)	62.8		14.2	48.5	28.1		
Honey locust (pod)		77.9	7	31.0	23.1	3.9	18

Example of future farm imagery

Figure 4 and Figure 3 give a visual representation of what agroforestry systems may look like when mature with average heights and widths of each species. Selected tree specie have been randomly distributed along planting sites to reflect their overall proportion in table 2.

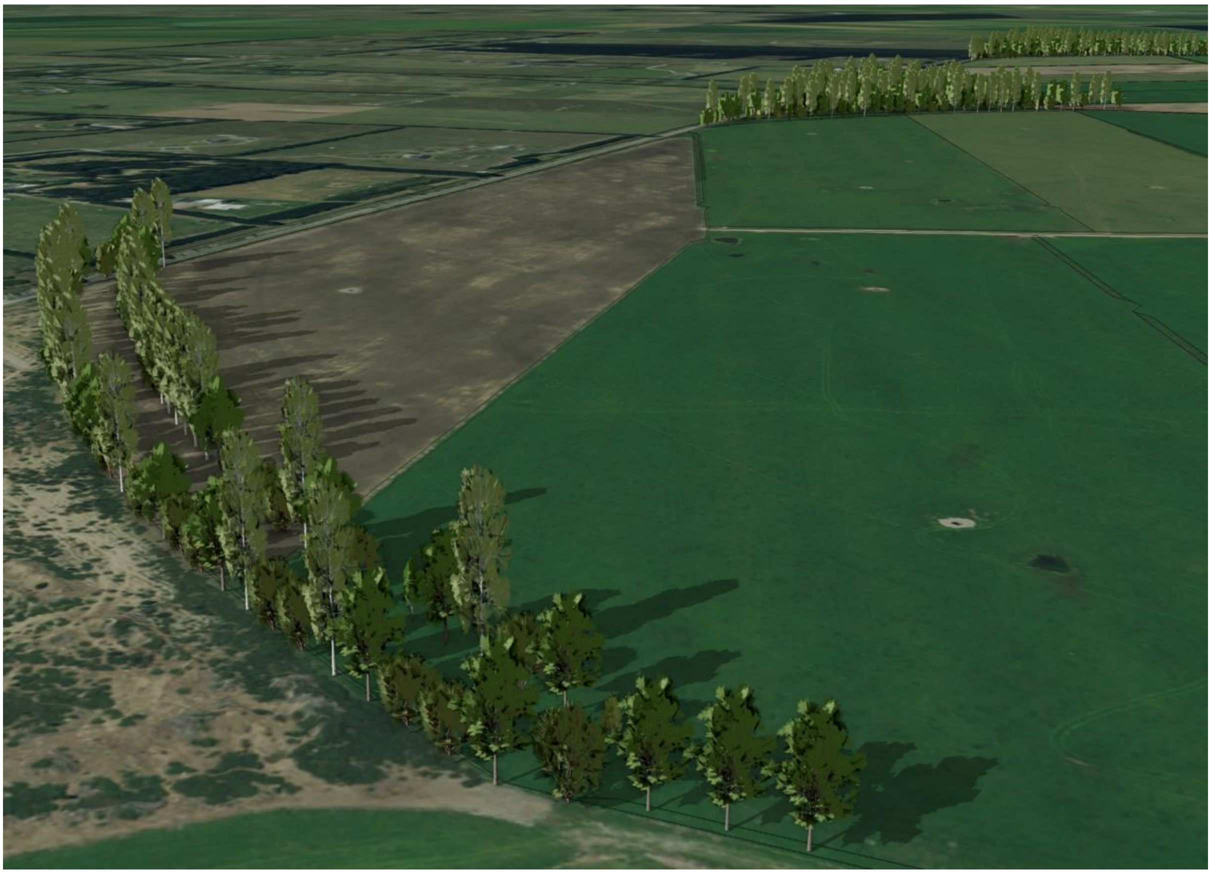

Figure 4. Ngāi Tahu – Hamua future farm image.

Figure 3. Claxby Farms future farm image.

Net effect of agroforestry on farm economics

The total effective area, agroforestry area and unproductive area under agroforestry of Claxby Farms is significantly larger than Ngāi Tahu – Hamua (*Table **3***). The overall establishment costs of Claxby Farms are higher than Ngāi Tahu – Hamua due to being 36.1 ha larger, but $1,043/ha cheaper due to relatively more individual tree protection than Ngāi Tahu – Hamua, which is roughly half the price of fencing both sides of the tree rows.

Agroforestry had a positive economic effect on both Claxby Farms and Ngāi Tahu – Hamua. Agroforestry at Claxby Farms had a NPV of $1,203,854 ($19,549/ha) with an IRR of 26% (Table 4). Agroforestry at Ngāi Tahu – Hamua had a NPV of $433,357 ($17,007/ha) with a IRR of 20%. The differences between the financial performance of agroforestry at Claxby Farms and Ngāi Tahu – Hamua is primarily driven from the lower cost of establishment per hectare at Claxby Farms with relatively comparable returns per hectare between the two farms.

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 costs	$244,767 ($3,974/ha)	$127,846 ($5,017/ha)
NPV	$1,203,854 ($19,549/ha)	$433,357 ($17,007/ha)
IRR	26%	20%
Post carbon annual cashflow	$7,367 ($119.632/ha)	$4,969 ($195/ha)

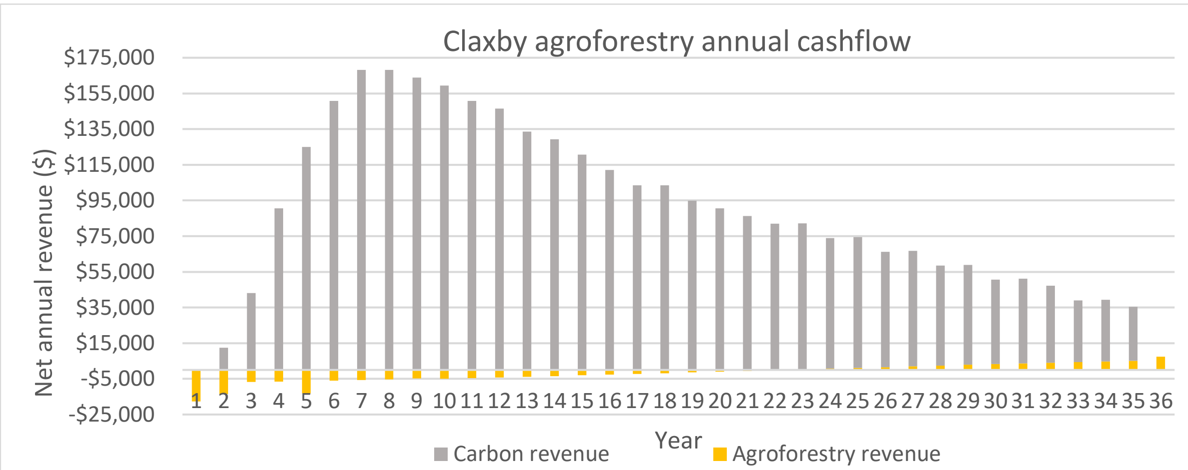

Figure 5. Net modelled cashflow of Claxby Farms agroforestry.

Agroforestry revenue is the net result from loss in productive farm area and increase in MS production from shade and shelter for livestock. Modelled annual cashflow of both Claxby Farms and Ngāi Tahu – Hamua is negative in years one and two (Figure 5 & Figure 6). This is due to a decrease no milk solid production from productive area lost to tree protection and minimal carbon credits earned in the early years not making up the shortfall. Agroforestry revenue becomes positive in in year 22 for both farms and reaches $119/ha and $195/ha for Claxby Farms and Ngāi Tahu – Hamua respectively. This revenue is higher at Ngāi Tahu – Hamua due to a lower feed conversion efficiency, calculated from the farm input data.

Annual carbon returns start off very low and peak in years seven earning $168,119 for the total agroforestry area for Claxby Farms and $69,563 for Ngāi Tahu – Hamua. The annual carbon returns then trend downwards, finishing at $30,175 and $12,486 for Claxby Farms and Ngāi Tahu – Hamua respectively. Currently the NZ ETS only accepts the carbon sequestering potential for hardwood exotics for 35 years. From year 36 onwards revenue is limited to efficiency gains form the agroforestry.

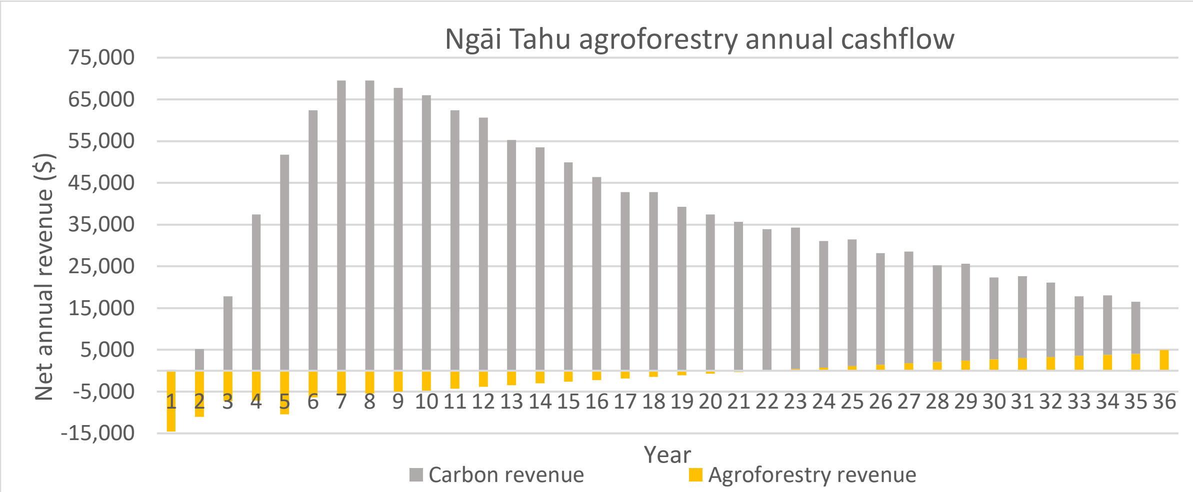

Figure 6. Net modelled cashflow of Ngāi Tahu Hamua agroforestry.

Unquantified benefits of agroforestry not included in the economic analysis

Non-economic benefits

- Reduction of stock camp intensity in the fronts and gateways of paddocks by providing shade in the back of paddocks. This would result in more nutrient transferred to the back of the paddocks, reducing high fertility at the fronts of the paddocks, improving grazing management and reducing the potential nutrient loss from these areas.
- Increased habitat for some indigenous species through agroforestry systems that include natives or mature exotic trees.
- Tree species intercepting leached nutrients from below the roots of pasture species.
- Improved air quality.
- Improvement in staff mental health with more trees on farm.
- Improved erosion control by tree roots if on unstable land.
- Habitat and food source for pollinators, resulting in improved pollination on farm.
- Habitat for biological control agents (and some pests). May result in improved pasture or crop yields and or longevity.

Economic benefits

- Increase in MS production when shade is provided is assumed to be nonlinear with increasing air temperature. Therefore, at temperatures above 30^0C (eight days per annum in Darfield) we expect to see relatively higher MS production compared to open pasture than we did at 25^0C.
- When shade is greater than 3.6m^2 per cow, milk production could be higher than anticipated due to less competition for shade.
- Gains in production from providing shelter and reducing exposure for livestock during cold weather events.
- Gains or losses in reproductive performance from livestock association with shade, shelter, forage or unforeseen health complications from trees.
- Shelter from wind for livestock and pasture as well as reduced evapotranspiration 60-80m upwind of tree rows and 225-250m downwind of tree rows.
- Reduced or reversed nutrient transfer could result in higher fertility in the back of paddocks, saving on capital fertiliser applications and potentially increasing pasture production.
- If biodiversity credits, as proposal for consultation by government stated, came into effect, this could potentially provide another revenue stream.

References

Benavides, R., Douglas, G. B. & Osoro, K., 2009. Silvopastoralism in New Zealand: review of effects of evergreen and deciduous trees on pasture dynamics. *Agroforestry systems,* pp. 327-350.

Betteridge, K. et al., 2012. *Impact of shade trees on angus cow behavior and physiology in summer dry hill country: Grazing activity, skin temperature and nutrient transfer issues.,* Palmerston North: AgResearch.

Dairy NZ, 2024. *Fundamentals overview.* [Online]
Available at: https://www.dairynz.co.nz/feed/fundamentals/fundamentals-overview/

England, J. R. et al., 2020. Trees on farms to support natural capital: An evidence-based review for grazed dairy systems. *Science of the Total Environment,* Volume 704.

Guevara-Escobar, A., Kemp, P. D., Mackay, A. D. & Hodgson, J., 2007. Pasture production and composition under poplar in a hill environment in New Zealand. *Agroforestry Systems,* Volume 69, pp. 199-213.

Gutteridge, R. C. & Shelton, H. M., 1994. Animal Production Potential of Agroforestry Systems. *Australian Centre for International Agricultural Research,* pp. 7-16.

Holt, L. et al., 2019. *The case for a novel agroforestry system and cross-sector collaboration.* Palmerston North, Nutrient loss mitigations for compliance in agriculture.

Jose, S., 2009. Agroforestry for ecosystem services and environmental benefits: an overview. *Agroforestry systems,* 76(1), pp. 1-10.

Jose, S., Gillespie, A. R. & Pallardy, S. G., 2004. Interspecific interactions in temperate agroforestry. *Agroforestry systems,* 61(1-3), pp. 237-255.

Kendall, P. E. et al., 2006. The effects of providing shade to lactating dairy cows in a temperate climate. *Livestock Science,* 103(1-2), pp. 148-157.

Macara, G. R., 2016. *NIWA Climate and Weather of Canterbury 2nd edition.* [Online]
Available at:
https://niwa.co.nz/sites/niwa.co.nz/files/Canterbury%20climate%20FINAL%20WEB_0.pdf
[Accessed 31st August 2023].

Mackay-Smith, T. H., Lopez, I. F., Burkitt, L. L. & Reid, J. I., 2022. Kānuka Trees Facilitate Pasture Production Increases in New Zealand Hill Country. *Agronomy,* 12(7), pp. 1-17.

Masters, D. G. et al., 2023. Shelter and shade for grazing sheep: implications for animal welfare and production and for landscape health. *Animal Production Science*, 63(7), pp. 623-644.

Power, I. L., Dodd, M. B. & Thorrold, B. S., 2001. Deciduous or evergreen: Does it make a difference to understorey pasture yield and riparian zone management?. *New Zealand Grassland Association,* 63(1), pp. 121-125.

Serrano, J. et al., 2021. Floristic Composition: Dynamic Biodiversity Indicator of Tree Canopy Effect on Dryland and Improved Mediterranean Pastures. *Agriculture,* 11(11), pp. 1128-1153.