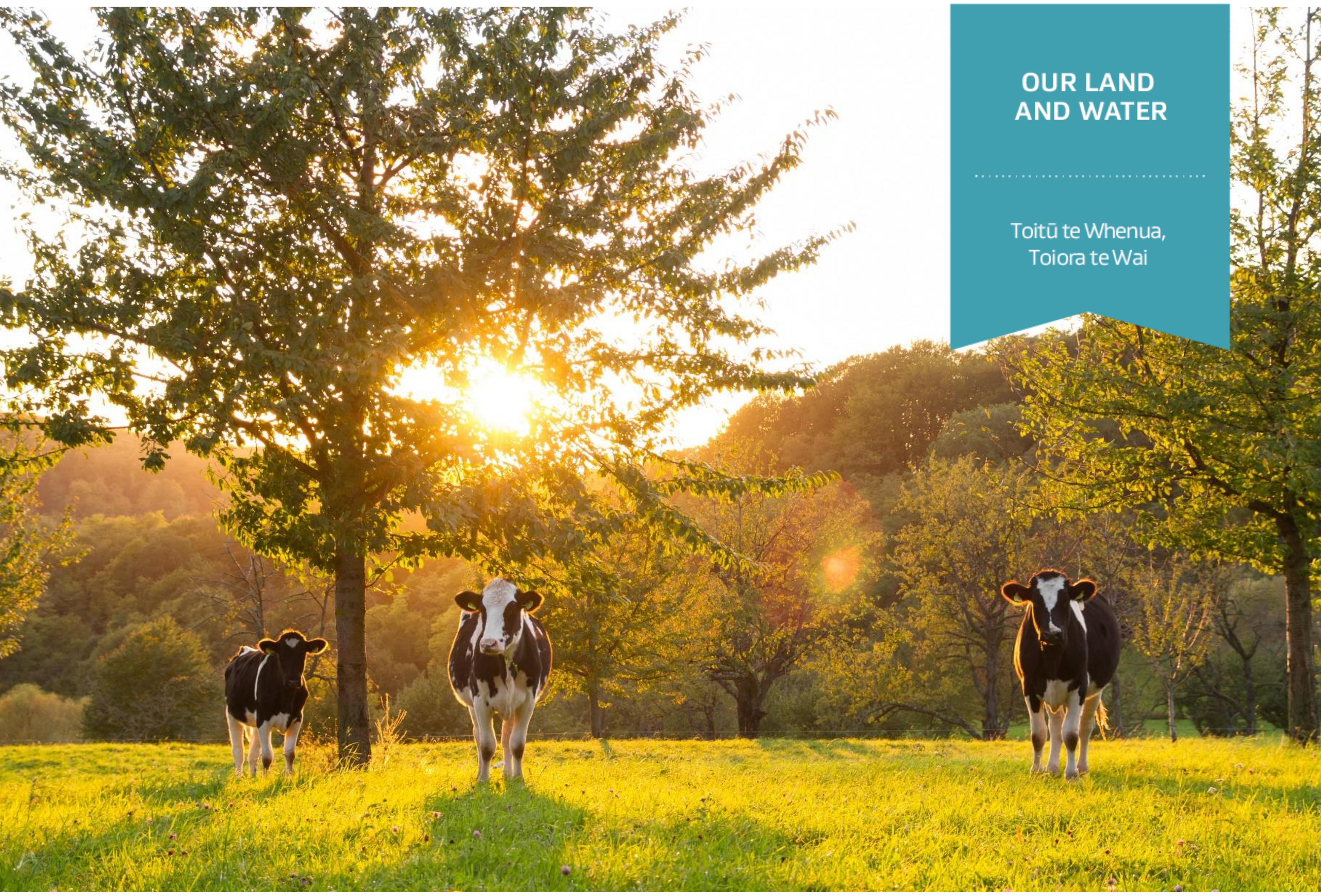

Integration of agroforestry systems within irrigated dairy farms in Waimakariri, Canterbury

January 2024

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Reviewed by:	Dr Electra Kalaugher, Aimee Dawson, Nathan Capper, Lisa Arnold	19 January 2024
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Executive summary

Project aim

This Project explores environmental and economic benefits that agroforestry systems can provide to the dryland corners of irrigated Canterbury dairy farms. Dryland corners of farms constitute over 35,000ha in Canterbury and provide a unique opportunity to diversify the dominant farming sector in this region. This project's specific aims are to:

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

Team

The project team included:

(1) The rural professional

Kyle Wills led the project. He has experience both working on dairy farms in Southland as well as working with farm decision makers throughout Canterbury to identify their key objectives and make plans to achieve them. Kyle is a trustee for Waimakariri Landcare Trust and has strong networks with farmers throughout Canterbury. Kyle is a member of WSP – Primary Industries team.

(2) The rural entrepreneurs

Sam Spencer Bower of Claxby farm and Ben Jaunay and George Mauger at Ngāi Tahu Farming offered in kind support to use one of their farms each as case study farms. Sam is the current chair of the Waimakariri Landcare Trust, which has 120 local members, and is seen as a local leader within the industry. Ngāi Tahu Farming also provided taiao and mātauranga Māori technical expertise along with Nathan Capper (WSP). Ngāi Tahu are the principal Māori iwi of the South Island.

(3) The science partner

WSP provided robust technical expertise in agriculture, forestry and mātauranga Māori, spatial data science and economic feasibility analyses, in combination with practical experience in dairy, sheep and beef, and horticultural systems. Team members included: Dr Istvan Hadju, Lisa Arnold, Dr Sandra Velarde Pajares, Nathan Capper, Aimee Dawson and Dr Electra Kalaugher.

Key findings

Barriers and enablers of change

- Based on the farmer survey (n=21), the largest barrier to adoption of agroforestry systems reported was the cost of establishment, the lack of knowledge/awareness and their perceptions of the financial viability of agroforestry systems. Factors most likely to overcome these barriers include the availability of funding options, local examples of implementation and access to practical research.

Agroforestry systems suitable for integration with Canterbury dairy farms

- The tree species considered in the dryland corner of dairy farms case studies (Claxby and Ngāi Tahu) are mulberry, poplar, honey locust and walnut. These have different growing requirements and productivity values, can be used as forage and also contribute to animal health. The choice of tree species for agroforestry systems considers both biophysical aspects and landowner's multiple goals; and these varied by case study.

- The economic assessment of agroforestry systems in the base case found internal rates of return (IRR) of 26% and 20% and annual return on investment (ROI) over 36 years of 32% and 24% for Claxby and Ngai Tahu farms respectively; and resulted in positive Net Present Values (NPV) for both farms. These results consider agroforestry as an additional system to the existing farm system and infrastructure. The core assumptions for both farms include a NZU price of $70/tC, 20% reduction in pasture production due to the integration of the trees and 5% discount rate on a 36-year horizon.
- New Zealand Emissions Trading Scheme (NZ ETS) is a major income contributor to the cashflow for both farms. Sensitivity analysis shows that without this income stream, the IRR of both farms turns negative (-7% for both case study farms). Tree distribution on the dryland corners is laid out so that they qualify for the permanent forest category (i.e. selective harvest only retaining ETS forest definition) and income from NZ ETS is only considered for the first 35 years of the system, assuming carbon sequestration values from the MPI Hardwood Exotic Carbon look up table. At a carbon price of $20/t, the NPV for Claxby farm is positive ($123,071) but Ngāi Tahu farm is negative (-$ 13,850). This difference can be explained by the higher establishment costs for agroforestry for Ngāi Tahu (that required double fencing given the farm layout).
- The net annual cashflow after the end of NZ ETS income is positive for both farm case studies, reflecting the potential economic gains from tree forage and reduced heat stress through increased milk solid production.

Research gaps

- A key knowledge gap is pasture productivity under an agroforestry system for the South Island, in particular for dryland areas. A key assumption used in the economic assessment is that pasture would only be reduced by 20% within an agroforestry system, having a 10:1 ratio influence on the IRR on both farms. That is, for every 10% pasture reduction, there is a 1% reduction in IRR. Even though the effect of pasture productivity seems to be small, the assumptions are based on best estimates adapted from studies in the North Island with different species and environmental conditions. Hence, research is needed to investigate pasture production under agroforestry systems in dryland areas of the South Island planted in rows with different tree species.
- A second key knowledge gap is the potential increase in milk solids (MS) production due to reduced heat stress. We assumed that farmers would move the cows to areas of shade during warmer days (> 250C degrees). Given current animal welfare requirements to provide shade for livestock, researching the benefits on milk production under agroforestry system is an important knowledge gap.
- We recommend setting up trials 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 a learning opportunity for both researchers and farmers, while raising farmer awareness and confidence to consider agroforestry as part of their existing land use or a new land use option.

Specific thematic findings

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.
- 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.
- Assuming there are no soil fertility limitations, in dryland Canterbury pasture production is driven by temperature (winter periods) and moisture (summer periods). To support pasture production, particularly during spring, deciduous species should be utilized 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.
- Lower evapotranspiration under trees as well as the drawing of water from depths by tree roots can enhance soil water content in the top 300mm. This has been shown under mature poplars where deeper tree roots have drawn moisture from depth making it assessable to shallower rooted pasture.

Carbon sequestration

- Agroforestry sequesters more carbon than open pasture. 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.

Soil effects

- Soils under agroforestry tend to have higher porosity, infiltration, soil aggregate stability and organic matter 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.
- Soil temperatures under tree canopies were 0.70C higher in winter and 3.30C lower in summer.

Biodiversity

- Agroforestry 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. 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 100C lower than open pasture, which cows use 40-50% of the time they are not grazing.
- New Zealand research showed a small increase in in milk solid production for cows provided shade on days where the temperature >25^{0}C. In Darfield, Canterbury this equates to approximately 45 days per year.

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Acknowledgements

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- The Our Land and Water team, 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.

List of abbreviations

Abbreviation	Definition
ADF	acid detergent fibre
C	carbon
Ca	calcium
DBH	diameter breast height
DM	dry matter
GHG	greenhouse gas
IRR	internal rate of return
K	potassium
ME	metabolisable energy
Mg	magnesium (chemical element); megagram (unit)
MJ	megajoules
MPI	Ministry for Primary Industries
MS	milk solids
NDF	neutral detergent fibre
NPS-FM	National Policy Statement for Freshwater Management
NPV	net present value
NZ ETS	New Zealand Emissions Trading Scheme
P	phosphorus
sph	stems per hectare
tCO_2-eq	tonnes of carbon dioxide equivalent

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 on dry areas of Canterbury farms, combined with existing animal welfare requirements have spurred interest in practices such as agroforestry, that can help future proof farming, addressing environmental and economic objectives. Agroforestry is the deliberate integration of trees within a livestock grazing system. Dryland corners constitute over 35,000ha in Canterbury farms and provide a unique opportunity to diversify the dominant farming sector in this region.

This project was selected for the Our Land and Water National Science Challenge 2023-24, and funded by the Rural Professionals Fund, which is aimed at funding the testing of innovative ideas which could lead to significant improvements for our food and fibre farming systems. The goal of the National Science Challenge of Wai ora, Whenua ora, Tāngata ora looks to a future in which all New Zealanders can be proud of the state of our land and water, while sharing in the economic, social and cultural values that te Taiao offers. Specifically, this project aims 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.

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, that research was conducted prior to the New Zealand Emissions Trading Scheme (NZ ETS) and without consideration of other potential tree species, and therefore likely fails to capture the market value of carbon that could be obtained today. Moreover, international research on agroforestry or silvopastoral systems shows promise for tree species with growth characteristics that differ from Pinus radiata (Jose & Dollinger, 2019; Wilson & 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 (*Kunzea* spp.) trees into sheep and beef pastoral systems, providing evidence of how strategically placed trees can affect nutrient transfer and pasture production.

This project contributes to expanding the knowledge on agroforestry through a combination of farmer engagement, literature review and case studies, to assess the potential of agroforestry systems in dryland areas of Canterbury farms, including economic analysis and visual tools to enhance communication with farming communities.

Methodology

The first stage of this project involved engaging with local farmers in the Canterbury region to determine their appetite for and knowledge of agroforestry systems; and conducting a literature review to explore different aspects of agroforestry.

The second stage of the project was supported by the findings from the surveys and literature review; and involved an agroforestry case study for each of the two participating farms, including planting plans and an economic feasibility study.

The third stage of the project involved dissemination of the project results. This includes the publication of this report, a visual implementation tool, and presentations to farming, rural professional and scientific communities.

A detailed methodology for each project component is provided below. We note some of the stages were run in parallel and informed each other. For example, an initial literature review informed the farmer survey, and the results of the survey in turn helped to focus the final literature review.

Farmer engagement

Farmers from a local Canterbury catchment group, Waimakariri Landcare Trust, were surveyed to determine their understanding of agroforestry knowledge, 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 farmers 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. The available published literature was drawn on to answer the following questions:

- What impact do agroforestry systems have on the environment (including influencing microclimates, carbon sequestration, soil, and biodiversity)?
- What impact do agroforestry systems have on measures of farm performance (including pasture production and livestock performance)?
- Which tree species could have potential for agroforestry systems on Canterbury dairy farms (focusing on those species which have forage potential and a lower impact on pasture production)?

After the interviews with case study farmers (described 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 design.

Case studies and planting plans

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

Figure 1. Location map of Ngāi Tahu – Hamua and Claxby Farms.

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 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, to be able to accurately judge necessary compromises in designing an agroforestry system. Farm key performance indicators such as pasture milk solid (MS) yield were gathered for the economic assessment component of this project.

Agroforestry planting plans and designs were developed in the open-source QGIS software and overlayed with the associated auxiliary 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 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, visually illustrating what the farms may look like once the plantings were 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 (LINZ) Data Service. The aim of this visualisation was to provide reference material and visual insights to improve the understanding of the spatial relationships to the surrounding environment.

Economic assessment

A standard discounted cashflow analysis was undertaken on the net annual revenue over 36 years. The internal rate of return, annual return on investment estimated and net present value for a base case was estimated. The core assumptions for both farms economic analysis included a carbon price of $70/tC, a 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:

- Farm key performance indicators for imported feed, winter feed, MS 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 productive production of each. 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 Solids 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 annual number of days above 25^{0}C 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.

Dissemination – Farmer Field Day

The case-study outputs were presented at a seminar which was attended by approximately 20 farmers and rural professionals and advisers at the Mandeville Sports Centre in Swannanoa on 29th November 2023. Agroforestry planting plans, future farm images and economic assessment results were presented by Kyle Wills. National and international benefits and examples of agroforestry in terms of climate and biodiversity were presented by Dr Sandra Velarde Pajares and the alignment of agroforestry with WSP's Rautaki Māori strategic values and priorities[1] was presented by Trent Tipene.

The flyer for the field day is included at the bottom of the Appendix.

Dissemination - StoryMap

An ArcGIS StoryMap was created, with the layers published to WSP's ArcGIS Online platform, to summarise the key results of farm-specific economic assessments and to display the designed planting systems through web maps. The StoryMap allows the user to explore various aspects of the developed agroforestry plans, including the key outcomes of the literature review, and the quantified as well as unquantified benefits of integrating dairy farming with agroforestry.

Link to the StoryMap:
https://storymaps.arcgis.com/stories/05b48b90174a44c59fdc5e106b417c89

Dissemination - Webinar

A webinar to present the results of this project to farmers and rural professionals is planned for late February 2024, after the time of writing this report.

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[1] See: https://www.wsp.com/en-nz/services/maori-business-and-advisory-services

Dissemination – Additional engagement

A poster will present the results of this project to rural professionals and academics at the Farmed Landscapes Research Centre Workshop in mid-February 2024.

An interview with Radio NZ near the start of the project was held to discuss the research project aims and what outcomes we were looking and a newspaper article was published on Farmer's Weekly on 6th December 2023 by Our Land and Water[2].

Farmer engagement

The survey sent to farmers in June 2023 received 21 responses (Appendix), with an average of 22 years of farming experience. Most respondents were based on dairy farms, followed by sheep & beef farms, mixed farming then arable. Overall, respondents saw the potential benefits of agroforestry being 'shade and shelter for livestock' and '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'.

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 for agroforestry'.

The largest barrier to adoption was the 'cost of establishment', closely followed by 'lack of knowledge/awareness' and 'not financially viable'. Factors most likely to overcome these barriers was 'funding options', followed by 'local examples of it working' and then 'access to practical research'.

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.

[2] See: https://www.farmersweekly.co.nz/news/project-looks-at-agroforestry-benefits-in-canterbury-plains/

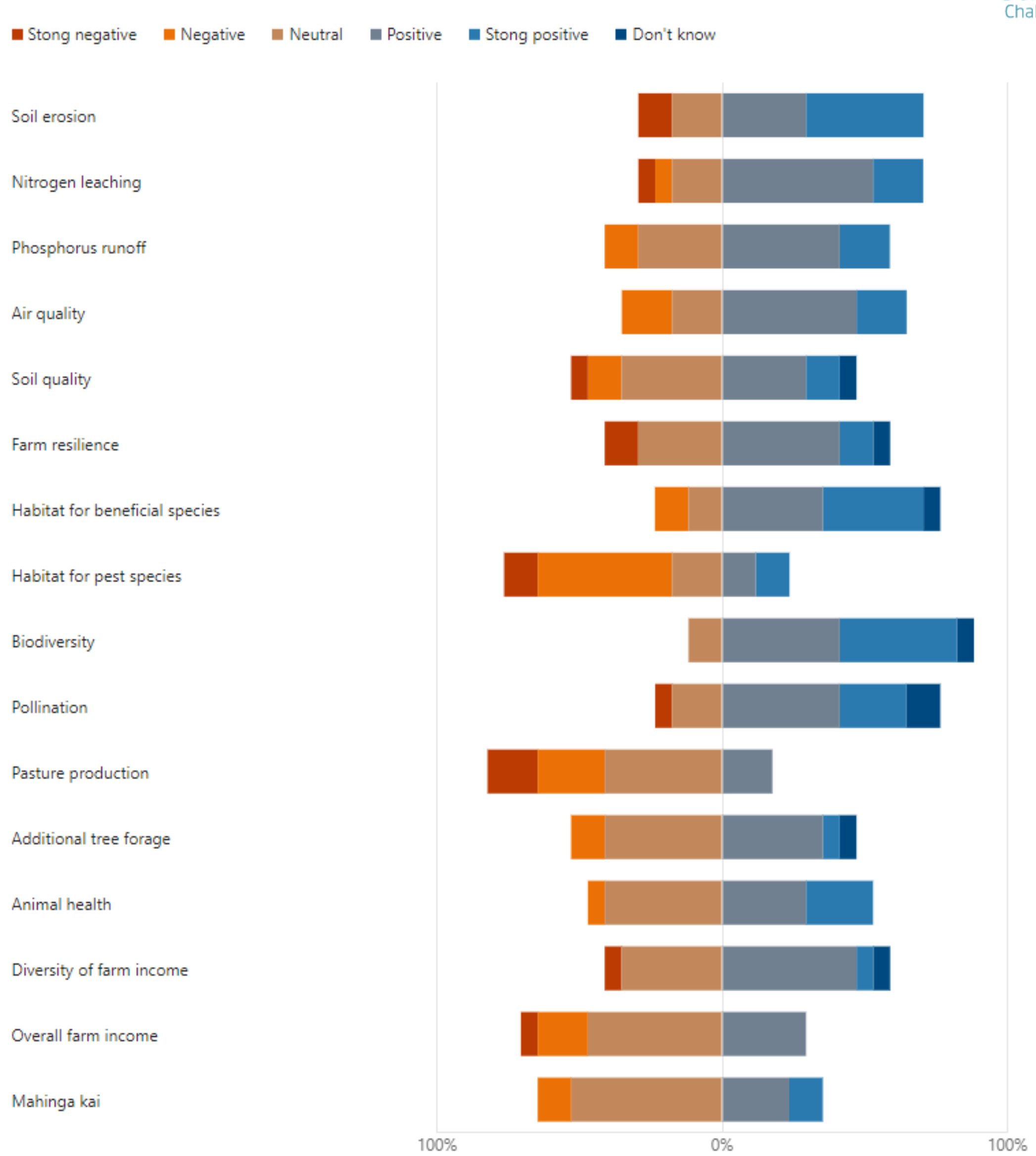

Figure 2. Responses to "What effect do you think agroforestry will have on a series of farm related factors?" from the farmer survey.

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. 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.

A follow up survey has been sent out to the original survey respondents, along with a copy of the summarised findings from this project, to determine what impact this project has had in terms of providing new knowledge and understanding, and what the perceived primary barriers to adoption of agroforestry are now. At the time of writing this report, the survey is still awaiting responses.

Literature review

Introduction

This literature review investigates potential success factors for establishing and integrating agroforestry into dryland corners of Canterbury dairy farms. It aims to inform how different agroforestry practices and species can impact profitability, biodiversity, ecosystem services and environmental effects for soil and water. The review covers New Zealand and international agroforestry sources.

The literature reviewed includes three broad areas:

1) the potential environmental impacts of agroforestry including carbon sequestration; soil quality; shading (with emphasis on pasture production); shelter/wind protection; and soil moisture, and biodiversity benefits,
2) agroforestry production, including pasture production; livestock production (shading; shelter/wind, forage); and tree production.
3) information for selected tree species (mulberry, poplar, honey locust, walnut), including growing conditions; biomass production; and chemical composition if available. As timber production was not a desired outcome for the landowners of the case studies in this report, the review targets tree species that can be used as forage.

Combined with the results of the farmer engagement, this literature review informed the assumptions of the economic analysis presented at the end of this report.

Environmental impacts of agroforestry

It is the general consensus that trees have a positive effect on the environment compared to conventional agriculture in terms of nitrogen leaching, air quality and erosion. This report has not attempted to further these claims but acknowledges that they are very important qualities.

Carbon

Agroforestry systems can sequester more carbon (C) than monocultural cropping or pastoral systems (Jose, 2009; Ramachandran Nair, et al., 2010). C sequestered by agroforestry systems is comprised of vegetative and soil C sequestration, with soil C contributing two thirds of the total C sequestration (Ramachandran Nair, et al., 2010). Total C sequestered depends on type of agroforestry system, species composition and age, environmental factors, and management practices. For example, agroforestry systems in semiarid environments are likely to sequester less C than those systems in temperate locations (Ramachandran Nair, et al., 2010).

Tree age and type can effect soil C accumulation in an agroforestry system. As trees age, soil C accumulation increases (Jose, 2009) with immature agroforestry systems having lower soil C pools than mature systems (Benavides, et al., 2009). This may be caused by higher contributions of organic matter (i.e., from plant litter and dead plant roots) and the modified environmental conditions beneath trees, such as lower temperature, and drying and rewetting cycles (Benavides, et al., 2009). International findings estimate that soil C can range from 1.25 Mg/ha/year in a Canadian alley cropping system to 173 Mg/ha/year for silvopasture systems in Costa Rica (Jose, 2009). In New Zealand, poplar agroforestry systems have the potential to exceed pasture soil C accumulation by 30% (Benavides, et al., 2009). Nitrogen (N) fixing tree species can further enhance soil C accumulation due to an increased supply of N (which is commonly the most limiting nutrient) increasing biomass accumulation and therefore organic C cycling (Ramachandran Nair, et al., 2010).

Above ground carbon sequestration in agroforestry systems is largely driven by biomass accumulation. Agroforestry systems with fast growing species (Ramachandran Nair, et al., 2010) and stands with greater species richness and density (Jose, 2009) have a higher potential to accumulate C. However, inclusion of slow growing species can accumulate more C over the long term (> 10 years). Jose (2009) showed that that the carbon sequestration potential of the vegetation component (both above and below ground) varied from 0.29 Mg/ha/yr in a fodder bank agroforestry system of the West African Sahel region, to 15.21 Mg/ha/yr in mixed species stands in Puerto Rico due largely due to differences in environment.

Soil quality

Agroforestry can impact soil fertility and pH, physical properties, and microbial communities. Tree species are the main driver of soil fertility changes with *Populus* species shown to increase concentrations of calcium (Ca), potassium (K), magnesium (Mg) and sodium (Na) as well as soil pH compared to open pastures (Benavides, et al., 2009; Guevara-Escobar, 1999). Trends for phosphorous (P) concentration are less clear because of the generally extended use of fertilisers that mask actual P concentration, high variation in soil type, analysis methods for P, and nutrient transfer through stock movement (Benavides, et al., 2009).

Soil physical properties can also be altered by agroforestry. 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). Enhancing these soil properties has been shown to reduce levels of surface runoff, and as a result, reduce erosion (Guevara-Escobar, 1999).

Shading

A reduction in the quantity and quality of light directly affects the physiological processes of plants, decreasing pasture carbohydrate manufacture and net dry matter production (Benavides, et al., 2009). However, a reduction in light does not lead to a proportional decrease in vegetative growth due to plant compensatory responses. Shaded plants develop longer stems and have an increased individual leaf area and chlorophyll content which can enhance sunlight interception.

Light is often the primary factor affecting pasture productivity in an agroforestry system, especially when moisture and nutrients are not limiting (Benavides, et al., 2009; Gutteridge & Shelton, 1994). Shading of the understorey can have both beneficial and/or detrimental effects on pasture growth. Leafy material is responsible for 69% of shading (Benavides, et al., 2009), the remainder of which comes from woody material such as the trunk and branches. Therefore, deciduous species give considerably less shade than evergreen species over the winter and shoulder months, an important factor to consider when designing an agroforestry system.

Tree type, density, age, and crown formation all have significant effects on the amount of light reaching pasture in the understorey of an agroforestry system (Benavides, et al., 2009). Trees with wider crown formations intercept more light and have a higher degree of canopy cover than those with narrow formations. Canopy cover generally increases with tree age, but also differs between species and cultivars depending on height, size of the crown, branch numbers and distribution, foliar density, leaf area and angle, and reflectance characteristics. Pruning trees either for the benefit of timber production or for livestock forage decreases canopy cover and therefore, the amount of light being intercepted. This can enhance pasture production.

Shading in agroforestry can lead to a reduction in soil and air temperature. Shading is inversely linked with temperature, as the proportion of shade increases (due to increased canopy cover), temperature decreases. Benavides et al. (2009) found that in *P. radiata* stands planted at 200 sph (stems per hectare) and aged 8–11 years, soil temperature was 0.7–1.5 ^{0}C cooler at 300m depth. Similarly, Douglas, et al. (2001) found that soil temperatures were 1-2^{0}C cooler on the south side of trees than the north side. Temperature changes under trees is not consistent throughout the day or the year. For example, the physical obstruction of trees between pasture and a clear night sky results in warmer soil temperatures at night compared to open pasture (Benavides, et al., 2009), an effect commonly associated with frost protection. Serrano et al., (2021) found that soil temperatures were significantly lower under evergreen species compared to open pastures over the warmer months, and significantly higher over the cooler months (Figure 3). This finding supports that tree canopy cover regulates soil temperature. Similarly, Guevara-Escobar (1999), found that deciduous species significantly lowered soil temperatures for all months except for the winter period. Differences in temperatures from underneath trees to open pasture ranged from +0.7^{0}C in June/July to -3.3^{0}C in December. In addition to shading, decreased wind speeds as a result of trees in the landscape can also reduce the effect of wind chilling, providing an additional temperature buffer (Benavides, et al., 2009). The effect of trees on wind speed is discussed in the following section.

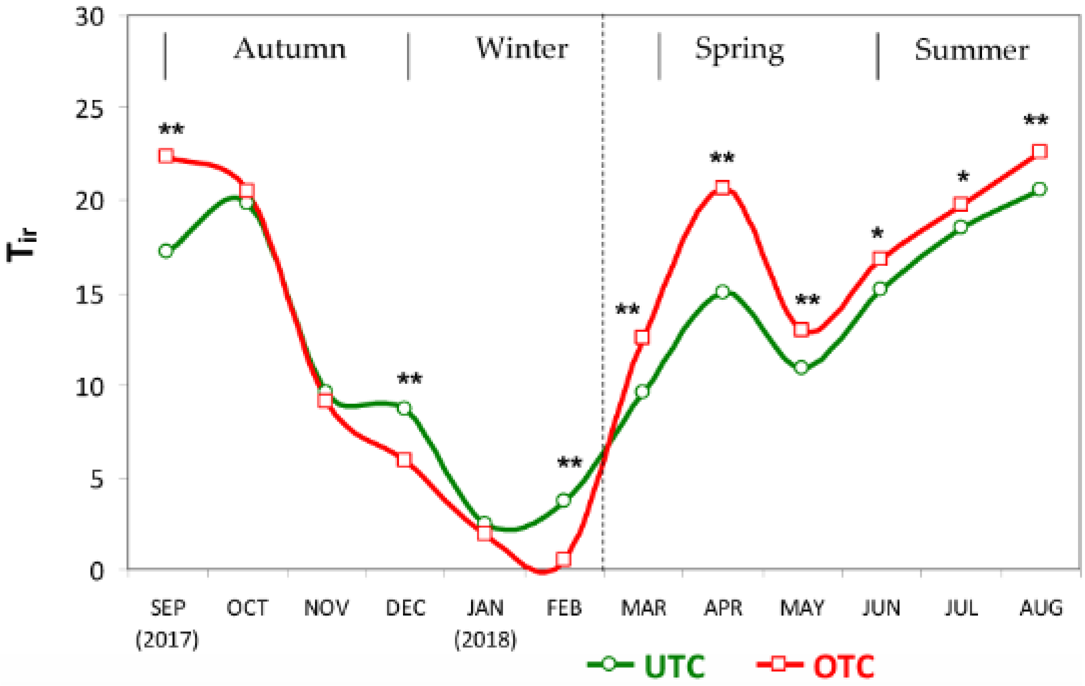

Figure 3. Northern hemisphere soil/pasture surface temperature (Tir) under tree canopy (UTC) and outside tree canopy (OTC), between September 2017 and August 2018. **—Probability < 0.01; *—Probability < 0.05 (Serrano, et al., 2021).

Shelter/wind

The presence of trees can reduce the negative effects of wind such as physical damage to farm structures and pasture as well as wind exposure for livestock (Benavides, et al., 2009; Masters, et al., 2023). The physical barrier created by trees disrupts wind currents and reduces wind speeds compared with open pasture. When compared to open pasture, stands of 8-11 year old *P. radiata* planted at 100 and 200 sph was found to reduce wind speeds by 44% and 45% respectively (Benavides, et al., 2009). Higher planting densities further decreased wind speeds with *P. radiata* planted at 400 sph reducing wind speed by 78%. Shelter from wind is not limited to directly under the tree. Tree rows or shelterbelts have been found to reduce wind speeds downwind of the row or shelterbelt by a distance of 10 to 15 times the tree height (Jose, et al., 2004) and upwind 2 to 5 times the distance of the tree height (Masters, et al., 2023).

Reduced wind speeds in a pastoral setting can have positive impacts on other factors that influence pasture growth. Shelter from wind can reduce evapotranspiration (Guevara-Escobar, 1999; Masters, et al., 2023), relative humidity (Benavides, et al., 2009) and can also improve the distribution and utilisation of irrigation and improve crop water use efficiency (Jose, et al., 2004).

Soil moisture

In temperate regions, competition for water is often a limiting factor, especially when areas are prone to periods of soil water deficit such as in summer droughts (Benavides, et al., 2009). The presence of trees can have both positive and negative effects on plant available water.

When trees are present in pasture, they have an effect on the spatial distribution and interception of rainfall (Benavides, et al., 2009). The level of rainfall intercepted by tree canopies varies from 34% under large canopy cover trees to 6% under 6 year old trees planted at 156 sph (Benavides, et al., 2009). The intercepted rainfall is evaporated from the canopy and therefore does not reach the understorey pasture. When rain falls on an angle with a prevailing wind, this effect is moved spatially. A trial at Lawrence, Otago showed that rainfall on the northern side of two trees was 10% lower (56mm) than the southern side (545mm) which has a reading similar to open pasture (Douglas, et al., 2001).

Many agroforestry systems are designed on the assumption that trees are deep rooted and access moisture and nutrients from greater depths compared to pasture (Gutteridge & Shelton, 1994). While tree roots normally develop deeper roots than pasture species (Benavides, et al., 2009) and tree legumes are able to take up moisture from deeper layers (Gutteridge & Shelton, 1994), the majority of tree roots are in the top 50cm (Gutteridge & Shelton, 1994) and therefore in direct competition with pasture. Rooting depth is not determined solely by species but is also affected by soil and climatic conditions. In acid soils, roots tend to be concentrated in the surface soil to avoid subsoil acidity, leading to higher competition with pasture.

Trees can affect soil moisture by altering evapotranspiration. 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. This was likely caused by lower evapotranspiration due to shade and deeper extraction of moisture. Similarly, Eastham & Rose (1988) showed that evapotranspiration decreases with increasing tree density. This effect was found to be more consistent in hotter and drier areas.

Biodiversity

Integrating trees into farm systems is widely accepted to have biodiversity benefits (England, et al., 2020). Establishing on-farm woody systems, such as agroforestry (even if planting exotic species), can facilitate the persistence of native vertebrates and invertebrates by providing food and habitat. A review of 83 international publications showed that scattered trees in pasture only had positive impacts on invertebrate biodiversity (England, et al., 2020). Similarly, Jose (2009) reported a greater density and diversity of insect populations in windbreaks. This could directly benefit farmers by enhancing populations of predatory insects for pest control. In general shelterbelts were shown to have lower populations of pest species and higher populations of predatory insects and spiders, with this effect flowing over into nearby pastures (Masters, et al., 2023).

Agroforestry could play an important role for indigenous biodiversity in New Zealand by providing biodiversity corridors and as a method of transition to native forests. 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). Agroforestry could be considered as transitional in ecological succession, with indigenous species planted (or allowed to germinate) in the understorey or after exotic species have been harvested, allowing the system to transition to indigenous forests over time.

Agroforestry production

A key concept of agroforestry is species utilising resources differently, either spatially or temporally, which ultimately results in a more efficient use of available resources, achieving higher net productivity (Ramachandran Nair, et al., 2010). Productivity of an agroforestry system is the net result of positive and negative interactions among the species present. Productivity is optimised when agroforestry systems are designed or managed to minimise antagonistic interactions between species, including pasture, and maximise positive or neutral interactions (Ramachandran Nair, et al., 2010).

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; Rickard, n.d.). In open pasture the availability of these resources varies over the year resulting in uneven pasture production or growth rates (Figure 4). If there are no limitations in soil fertility, the limiting factor for pasture will be soil temperature and moisture (Rickard, n.d.).

Agroforestry influences the availability of moisture and temperature both directly and indirectly and can therefore either promote or restrict pasture growth. Throughout winter months agroforestry could have a positive effect on pasture production (Figure 4 A.), by increasing soil temperature (Serrano, et al., 2021) which is the most limiting factor on growth rate at that time of year. In spring, agroforestry could have a negative effect on pasture production (Figure 4 B.), by restricting soil temperature through shading. Selecting deciduous species, that come into leaf later, will minimise this effect, as 69% of shade is a result of leaf foliage (Benavides, et al., 2009). Reduced evapotranspiration under agroforestry (Benavides, et al., 2009; Eastham & Rose, 1988) as well as lower soil temperatures (Serrano, et al., 2021) will conserve soil moisture for longer, resulting in agroforestry potentially having a positive effect on pasture production over summer months (Figure 4 C.), or other times of year where growth rates are limited by soil moisture. Agroforestry could have positive or negative effects on pasture production through autumn depending on whether soil moisture or temperature is limiting (Figure 4 D.).

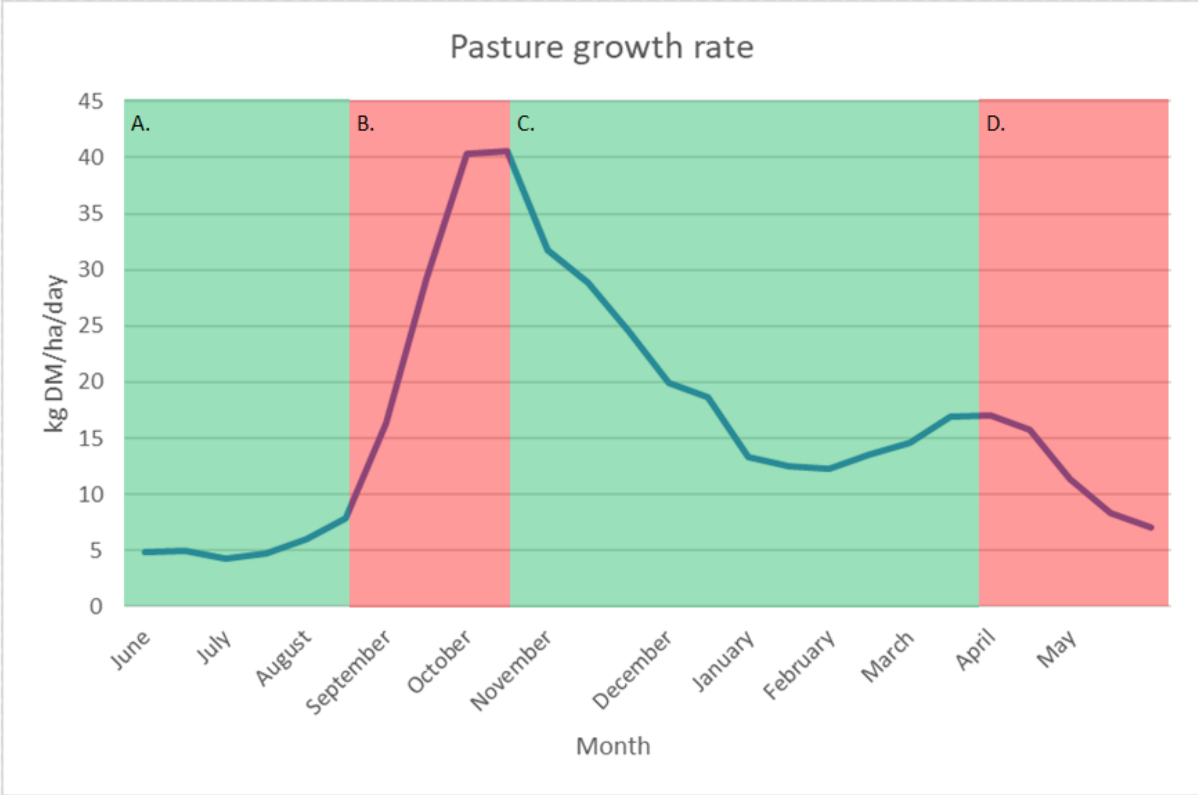

Figure 4. Dryland daily open pasture growth rate at Winchmore over 13 years. Adapted from (Rickard & Redcliffe, 1976). Green area identifies times of year where agroforestry could have a positive impact on pasture growth rate. Red area identifies times of year where agroforestry could have a negative impact on pasture growth rate.

Shade has a negative effect on pasture production (Figure 5) (Benavides, et al., 2009; Guevara-Escobar, 1999; Power, et al., 2001). 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). For example, the extinction point of pasture under deciduous species is 85% canopy cover compared to 67% for evergreen species (Benavides, et al., 2009). However, the leaf free period must be greater than four months to have a significant impact on annual pasture production (Power, et al., 2001). The negative impact of shade can be offset by the addition of nitrogen fixing trees as shown in Figure 5 by *Acacia melanoxylon* having a higher relative yield than *Eucalyptus nitens*.

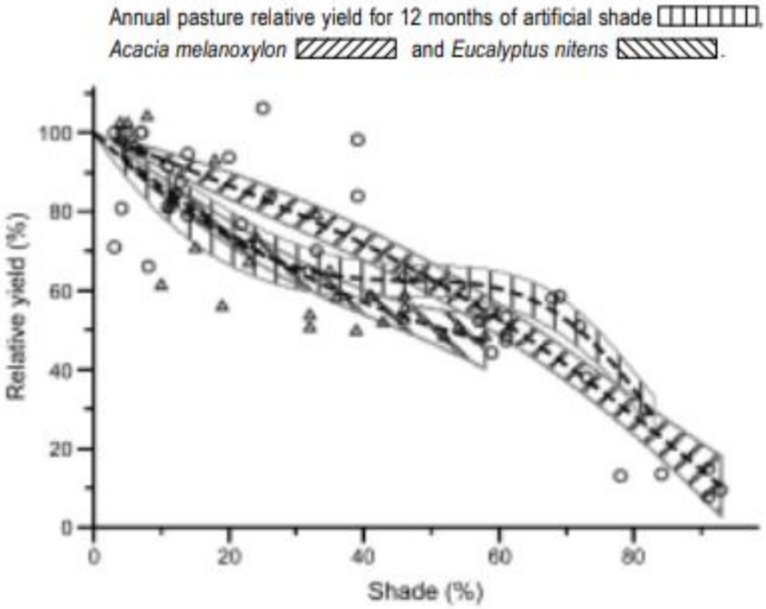

Figure 5. Annual pasture relative yield for 12 months under artificial shade for *Acacia melanoxylon* and *Eucalyptus nitens* (Power, et al., 2001).

Agroforestry systems can create microclimates resulting in improved pasture production compared to open pasture. This is more enhanced in difficult growing environments such as hot, dry or nutrient deficient areas. This is due to nitrogen availability (Gutteridge & Shelton, 1994; Benavides, et al., 2009) and soil moisture conservation (Gutteridge & Shelton, 1994; Masters, et al., 2023). When open pasture production is limited by nitrogen availability, pasture production under shade can be higher due to increased availability of nitrogen (Gutteridge & Shelton, 1994; Benavides, et al., 2009). However, in less than ideal climates most of the reviewed literature attributes increased pasture production under agroforestry to lower temperature and wind resulting in lower evapotranspiration and improved soil moisture conservation (Gutteridge & Shelton, 1994; Masters, et al., 2023; Benavides, et al., 2009). Radcliffe (1985) found that annual pasture production increased by 20% behind a shelterbelt on the Canterbury plains. Masters, et al., (2023) stated that the loss in pasture production due to competition near shelterbelts was outweighed by the gain in pasture production further out where competition was lower but the effect of the shelter remained.

The pattern in which trees are planted can have a significant effect on understorey pasture production (Benavides, et al., 2009). *P. radiata* stands with 100 sph planted in rows reduced pasture production compared to open pasture by 39% and 44% at 13 and 14 years old respectively. Stands of the same age and density planted in a grid pattern decreased pasture production by 50% and 65% respectively, compared to open pasture. These results support the assumption that planting trees in rows reduces the competiton between trees and pasture, potentially at the expense of tree growth rates (Benavides, et al., 2009).

Agroforestry has a variable effect on pasture botanical composition. The grass component in pasture under agroforestry increases over time as shade increases (Benavides, et al., 2009). This is due to grass species being more shade tolerant than clover species. However, in environments where soil moisture is the limiting factor (e.g., Australia), proportions of clover species was shown to be higher under agroforestry due to moisture conservation (Benavides, et al., 2009).

Livestock production

The presence of shade can improve livestock performance during periods of high temperature. Under extreme heat, feed intake is reduced and animals seek shade and water. Air temperatures under shade from agroforestry were shown to be 10^0C less than open pasture over summer (Betteridge, et al., 2012; Gutteridge & Shelton, 1994). The effect of heat stress on fertility in both sheep and cattle is well documented with calving rate being depressed by 15-25% for English breeds (Gutteridge & Shelton, 1994). Heat stress also affects production, with a 7% (41 minutes) decrease in grazing time for beef cows that were not offered shade on days where temperature exceeded 25^0C. This is supported by Jose, et al. (2004) who stated that cattle that were provided shade reached their target body weight 20 days earlier. In a scenario with shelterbelts rather than trees in pasture, it was found that sheep did not voluntarily utilise shading as the drive for grazing and water overrode the requirement for shade (Masters, et al., 2023). It was concluded that if grazing could be provided in the same spatial area as shade such as palatable shelterbelt species or trees in pasture then improvements in livestock could be seen (Masters, et al., 2023).

Heat stress has negative effects on dairy cow production as well (Kendall, et al., 2006). In a research project conducted at Massey University, heat stress was found to have a significant effect on milk yield with a difference of 0.5 kg/cow/day. The effect on milk solids was deemed insignificant with it averaging 0.05 kg MS/cow/day higher for cows with shade. However, this increase was with only 3.6m^2 shade per cow and over a relatively mild summer period where six out of the thirteen days had maximum temperatures under 25^0C and average daily temperatures only exceeded 20^0C once. Kendall, et al. (2006) concluded they would expect to see a further increase in milk production during hotter temperatures and where more shade is provided due to less competition between cows. Research based in Canterbury stated that cows would benefit from tree shade even under relatively mild summer conditions. It also concluded that tree shade completely eliminated any occurrences of severe heat stress (Bloomberg & Bywater, 2007). There is however evidence to suggest that reductions in milk production can be as high as 53% due to heat stress (Groeneveld, 2023).

Volunteer shading for livestock can alter nutrient transfer within a paddock. In a hill country environment where soil fertility was limiting, pasture production was 107% higher underneath kānuka trees compared to adjacent open pasture (Mackay-Smith, et al., 2022). This study concluded that nutrient transfer from open pasture to underneath kānuka trees in a grazing situation was partially the reason for higher pasture production and that trees might be able to be used as tools for nutrient transfer.

Shading

Cattle will utilise shade when temperatures get too high. Bloomberg & Bywater (2007) stated that cows in Canterbury will benefit from shade under even relatively mild summer conditions. However, significant reductions in production have been found when average daily temperatures exceed 20˚C. On average Darfield, Canterbury is expected to receive 45 days per year with a maximum temperature >25^0C and 8 days >30^0C (Macara, 2016). It is common consensus that climate change will increase the number of hot days as well as the maximum temperature (Macara, et al., 2020).

Shade has a significant effect on the body temperature of cows. Shade reduced the maximum ambient temperature underneath trees by 10˚C (Betteridge, et al., 2012). Thus, average temperature on the cows back at 2 PM was 40.8˚C for no shade and 36.8˚C for cows with shade. Skin temperature corresponded with internal temperature with Kendall, et al. (2006) stating that shade had a significant effect on vaginal temperature. This was most evident between 10:00am and 3:00pm.

It was shown that the cows voluntarily utilised shade 40-50% of the time when they were not grazing (Betteridge, et al., 2012). Cows with access to shade preferred using it mainly during the mid-afternoon, while, in contrast, cows with no shade grazed more at this time (Betteridge, et al., 2012). While improvements in production were experienced with shade, temperature extremes during the course of this research was not large enough to have a significant effect on feed intake. It is assumed that more significant increases in production with shade could be experienced when heat stress starts to limit daily intake. It was also noted that the cooling effect at nighttime may have been sufficient to limit reductions in temperature (Betteridge, et al., 2012).

Shelter/wind

In temperate regions, trees can ameliorate the 'wind chill factor' and greatly reduce mortality of vulnerable livestock (Gutteridge & Shelton, 1994). With shelter, mortality of twin born lambs dropped on average of 17.5%. However, the need for water and forage often override the voluntarily use of shelter (Masters, et al., 2023). There is an opportunity to increase the voluntary use of shelter by using palatable and desirable forage tree species, keeping hungry livestock in sheltered areas for longer.

No literature could be found on the effect of shelter from agroforestry increasing milk solid production on dairy farms due to reduced exposure during cold weather events, specifically cold, wet and windy.

Forage

It is common practice in New Zealand to feed willow (*Salix* spp.) and poplar (*Populus* spp.) forage to livestock in summer, as these species have a similar forage value to open pasture, and crude protein levels similar to lucerne hay (Benavides, et al., 2009). The effect of higher nutritive value compared to open pasture is even more pronounced under drought conditions (Kemp, et al., 2003). A more detailed review of the forage ability of poplar, mulberry (*Morus* spp.) and honey locust (*Gleditsia triacanthos*) is presented in following sections of this review.

Tree production

Agroforestry is the integration of trees into agricultural systems. The impact of agroforestry systems on livestock production is largely influenced by the role of the tree species in the system (Gutteridge & Shelton, 1994). If the tree species used are primarily to promote positive outcomes for livestock e.g., by providing a source of fodder, then the potential for improved animal production is high. However, if the primary focus of the system is on tree production (for timber, carbon) then the potential to have a positive impact on livestock production is relatively low (Gutteridge & Shelton, 1994). Table 1 displays this trade off whereby systems with high crop and forage outputs come at the expense of timber outputs, and vice versa.

Table 1. The potential productivity of agroforestry systems, by component (Gutteridge & Shelton, 1994).

System	Component/productivity				
	Crop	Forage	Animal	Timber	Fuelwood
Silvopastoral systems					
Natural Silvopastoral					
without edible browse	–	M	M/L	M	M
with edible browse	–	M/H	M	M	M/H
Plantation crops	H	M/L	M/L	L	M/L
Forestry systems	–	L	L	H	M/H
Horticultural systems	H	L	L	–	L
Tree legume hedgerows	–	H	H	L	M
Agrosilvopastoral systems					
Trees in crops	H/M	M/L	M/L	M	M
Alley farming	H	M	M/L	–	M
Three strata system	H	H	M	M	M
Trees in crops	H/M	M/L	M/L	M	M

H—high; H—medium; L—low

As the case study farms used in this project have opted for a simple agroforestry system that complements their current farming system, we focused the remainder of this literature review on tree species with a high forage output. Where appropriate, we have given a small amount of information on other aspects such as timber and carbon.

Species

Species described in the remainder of this review were selected for their combined forage potential and impact on pasture production. The following species have been selected with the expectation that they should be able to survive in the challenging environment described in earlier sections of this report.

Mulberry

Mulberry (*Morus* spp.; Figure 6) is a tree species originating in China that has been the traditional feed for silkworms (*Bombyx mori*) for the last 5,000 years (Sánchez, 2000). Mulberry is a very versatile tree, with its presence on all continents, except Antarctica. There are numerous species (black, red and white most common in New Zealand) and varieties of mulberry in a range of different environments, from sea level to 4,000m elevation, and hot and humid tropics to semi-arid lands with as little as 250mm annual rainfall (Sánchez, 2000).

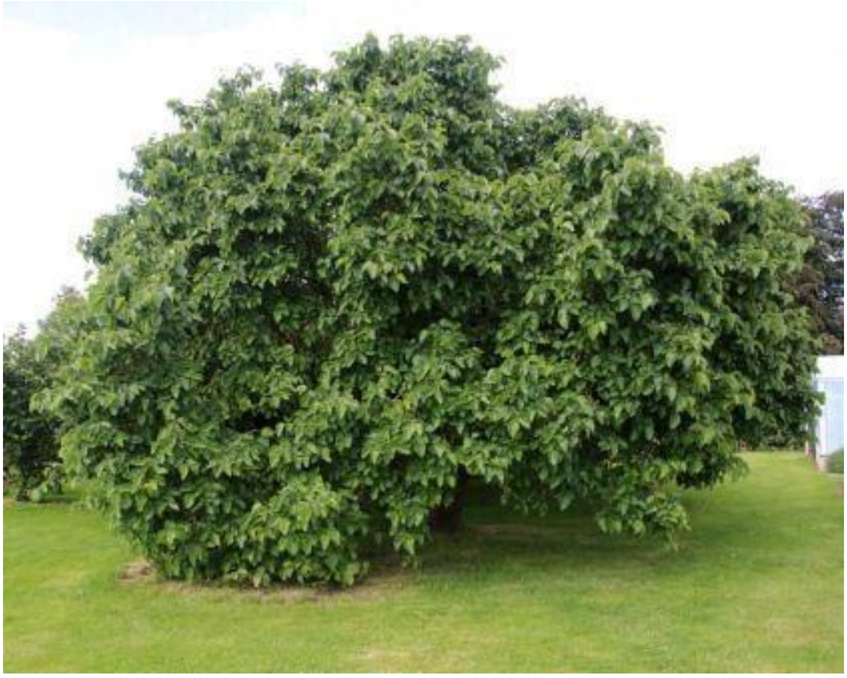

Figure 6. Black mulberry (*Morus nigra*). Image source: www.theplantstore.co.nz

Mulberry leaves and fruit are used all around the world as a feed source for ruminant animals such as cattle and sheep (Talamucci, et al., 2000). It is traditionally used as a mixed forage feed in countries such as India, China, Afghanistan and Italy. Mulberry benefits from the companion planting of other nitrogen-fixing species and nutrient cycling of livestock, reducing the competition for resources during spring for clover growth (Talamucci, et al., 2000).

In Italy, mulberry was recommended to be interplanted with clover to supply high quality summer forage for both grazing cattle and sheep (Sánchez, 2000). The combination of mulberry and clover produced more forage over a longer period than individual pure stands of either mulberry or clover species (Sánchez, 2000). Mulberry leaves can be conserved by traditional cutting and storing, letting them to ferment to silage.

Mulberry also has additional uses worldwide, including being used for furniture and fenceposts due to the nature of the soft wood and its rot resistant properties (Wood Thrive, 2023). In other parts of the world, mulberry leaves are used for their medicinal properties (Sánchez, 2000).

Mulberry can grow from stem cuttings, and it is the preferred form of establishment internationally (Sánchez, 2000). However, individuals grown from seeds have deeper roots with greater capacity to find water and nutrients.

Sánchez (2000) reported that maximum mulberry yields of edible material (leaves and young stems) and total biomass of intensive stands were 15.5 and 45.2 tons DM/ha/year respectively. In a kikuyu grass-based dairy system, mulberry was used to replace 75% of its grain-based concentrates, resulting in no significant decrease in milk yield (Sánchez, 2000). Likewise, in a beef system, both the total feed intake and weight gains increased with the amount of mulberry offered as supplement, in sorghum silage.

Table 2 shows the mean dry matter production of mulberry (*Morus alba*) and clovers (*Trifolium* spp.).

Table 2. Mean dry matter production (t/ha) of mulberry (*Morus alba*) and clovers (*Trifolium* spp.) (Talamucci, et al., 2000). Values having different letters are significantly different (P < 0.05).

Treatment	*Morus alba*	Clovers	Total
Cattle - Winter cutting	9.5b	5.5c	15.0c
Cattle - Summer cutting	7.5c	4.5c	12.0d
Sheep - Winter cutting	10.5a	7.5b	18.0a
Sheep - Summer cutting	8.5b	8.5a	17.0ab
Cattle + sheep - Winter cutting	10.3a	6.3b	16.6b
Cattle + sheep - Summer cutting	8.2b	7.9a	16.1b

One of the main features of mulberry as a forage is its high palatability, with livestock being observed preferentially grazing mulberry over other forages (Sánchez, 2000). Mulberry is a useful resource for feeding livestock as it possesses high protein and energy with a relatively high digestibility (Hassan, et al., 2020). Rich flavonoids in mulberry increased fibre digestion and utilisation, leading to enhanced milk production in ruminants. This was shown by an increase in milk protein of 36.7% in dairy cattle after feeding of mulberry leaves for 60 days (Hassan, et al., 2020).

Table 3 shows a large variation in leaf quality across the many species and varieties used in different locations globally under a wide range of soil and environmental conditions.

Table 3. Chemical analysis of mulberry (*Morus spp.*) forage.

Chemical parameters	Unit	Average	Minimum	Maximum	Reference
Digestibility - leaf	%	85.2	78.4	95	(Sánchez, 2000)
Digestibility - stem	%	40.5	37.0	44.0	(Sánchez, 2000)
Dry matter	% as fed	28.4	24.2	35.1	(Trinidad & Tobago Goat & Sheep Society, n.d.)
Crude protein - leaf	% DM	18.9	11.5	25.3	(Trinidad & Tobago Goat & Sheep Society, n.d.) (Sánchez, 2000)
Crude protein – leaf & stem	% DM	20.6	8.0	27.6	(Sánchez, 2000)
Crude fibre – Leaf	% DM	13.5	5.9	20.2	(Trinidad & Tobago Goat & Sheep Society, n.d.) (Sánchez, 2000)
Crude fibre – Leaf & stem	% DM	13.5	10	15.3	(Sánchez, 2000)
NDF - leaf	% DM	28.4	24.6	32.3	(Sánchez, 2000)
NDF – leaf & stem	% DM	23.3	22.0	24.7	(Sánchez, 2000)
ADF – leaf	% DM	22	20.8	23.1	(Sánchez, 2000)
ADF – leaf & stem	% DM	22.5	20.6	24.5	(Sánchez, 2000)
Ether extract	% DM	5.3	3.0	7.4	(Trinidad & Tobago Goat & Sheep Society, n.d.) (Sánchez, 2000)
Ash	% DM	13.4	4.5	22.2	(Trinidad & Tobago Goat & Sheep Society, n.d.) (Sánchez, 2000)
Gross energy	MJ/kg DM	18.1	17.4	18.1	(Trinidad & Tobago Goat & Sheep Society, n.d.)

NDF – neutral detergent fibre
ADF – acid detergent fibre

Poplar

Poplar trees (Populus spp.; Figure 7) are grown extensively across the world, with their native range spanning from North America, Africa, Europe and Asia (Wilkinson, 1995). Poplars were first grown in New Zealand in the 1830s. They were brought in as ornamental trees and for shelter. The early poplar introductions were the Lombardy poplar (*Populus nigra* 'Italica'), eastern cottonwood (*P. deltoides*) and silver poplar (*P. alba*).

Poplar species can tolerate a range of environmental conditions ranging from elevation between 0-500m above sea level, 750-1250 mm rainfall per annum and deep to moderately deep soil. They can also tolerate free draining to moderately poor drained soils, warm to cold climates (10-14^{0}C annual mean temperature) and strong winds (New Zealand Farm Forestry Association, 2023). Poplars can grow rapidly at a rate of 1m to 1.5m per year, maturing after 25 years in ideal conditions. Poplar is an exotic hardwood and has the ability to store carbon roughly three times faster than indigenous forest and about 80% as fast as *P. radiata* (New Zealand Farm Forestry Association, 2023).

From the 1950's, poplars have been used in New Zealand for slope stabilisation and erosion control, particularly in central and eastern North Island. They have become increasingly popular across New Zealand due to their versatility in a grass-based farming system (New Zealand Farm Forestry Association, 2023). Poplars help to reduce slips, provide shade, shelter and fodder for stock while having little impact on pasture growth. Poplars are one of the few timber species that can support a grazing pasture understorey throughout the rotation, hence their popularity for use in pastoral based farms in New Zealand (Hawkes Bay Regional Council, n.d.)

Poplar production is related to the size of the tree. Poplar shows an increase in predicted forage dry matter with increasing diameter at breast height (DBH), greater than 1.4m above the ground (Kemp, et al., 2003). Available forage from Veronese poplar (*P. euramericana*) started at 0.9 kg DM/tree at 5 DBH and increasing up to 23.4 kg DM/tree at 24 DBH (Kemp, et al., 2003)

Poplar foliage contains high levels of condensed tannins. Although this does have some effect on reducing consumption by livestock it also has some potential to benefit livestock. Condensed tannins have been shown to increase lambing percentage when fed as a supplementary feed to drought pasture (Kemp, et al., 2003).

Figure 7. Veronese poplar (Populus euramericana). Image source: www.theplantstore.co.nz

Poplar forage is of similar nutritional value to summer pastures but higher quality than drought pastures, making poplars an effective supplementary feed to balance out summer feed deficits (Kemp, et al., 2003). Soil pH in poplar agroforestry systems were consistently 0.5-1.2 units higher than adjacent pastures (Guevara-Escobar, 1999). This is assumed to be a joint effect of the decomposition of the poplar leaf litter, reduced leaching and nitrogen fixation of surrounding legumes. In a study by Guevara-Escobar (1999), the liming effect of poplar leaf litter was calculated to be the equivalent of applying 150kg lime/ha annually.

Nutrient transfer via grazing animals was considered to have a significant impact on fertility, with animals observed preferentially grazing open pasture before camping underneath the trees (Guevara-Escobar, 1999).

Table 4 shows a large variation in leaf quality across the many species and varieties used in New Zealand under a wide range of soil and environmental conditions.

Table 4. Chemical analysis of poplar (*Populus* spp.) forage.

Chemical parameters	Leaf foliage (% DM)	Range	Reference
Digestibility	69.7	62.4-78.6	(Kemp, et al., 2003)
Dry matter	90		(Taranaki Regional Council, n.d.)
Crude protein	17.6	14.9-19.6	(Guevara-Escobar, 1999) (Kemp, et al., 2003)
Neutral Detergent Fiber (NDF)	36.1	33-39	(Guevara-Escobar, 1999) (Kemp, et al., 2003)
Acid Detergent Fiber (ADF)	23.6	23.6-26.1	(Guevara-Escobar, 1999) (Kemp, et al., 2003)
Ash	24.8	7.3-9.5	(Guevara-Escobar, 1999) (Kemp, et al., 2003)
ME	10.5 (MJ kg)	9.2-11.5	(Guevara-Escobar, 1999) (Kemp, et al., 2003)

Honey locust

Honey locust (*Gleditsia triacanthos;* Figure 8) is a deciduous tree in the *Fabaceae* family, originating from the North American continent. The climatic conditions in these areas are typically humid to subhumid with an average rainfall between 510mm and 1520mm (Gold, 1997), therefore the shade intolerant honey locust thrives in these conditions. Honey locusts have a strong taproot and can survive in drought-like conditions. They have been shown to survive in areas with as little as 355 mm rainfall per annum (Csurhes & Kriticos, 1994). Honey locust grows naturally up to 760 m above sea level, but plantings have been successful from sea level to 2,500m in subtropical highlands (Gold, 1997). In cold, snowy, winter conditions honey locusts may suffer frost damage or even die back.

Honey locust trees can survive in a range of environmental conditions, including poorer soils and both alkaline and acidic soils, however they prefer soils with a pH between 6 and 8 (Gold, 1997). Honey locust originates from areas with limestone or rich alluvial floodplains with growth being limited on gravel or heavy clay. The tree has a strong taproot, penetrating about 3 to 6m in deeper soil profiles (Blair, n.d.). The fruit of the honey locust tree is a flat legume (pod), approximately 15-20cm in length. Pods are first produced when the tree is about 3 to 5 years old.

Figure 8. Honey locust (*Gleditsia triacanthos*). Image source: www.blackbridgenurseries.co.nz

Honey locust has been widely used in North America for a range of different purposes. It has been used as fodder tree to provide shade, soil enrichment and stabilisation, in a wide range of systems, including forages, grains, vegetables, woody perennials and animal-based systems (Gold, 1997). Honey locust trees provide sources of feed from both their pods and leaves. The pods fall in autumn and winter, producing a high-quality supplementary feed for livestock (Arthurs Point Farm, 2022). The tables below provide a nutrient analysis for honey locust foliage (Table 5), and pods (Table 6). The leaves drop in early autumn and have minimal impact on pasture production due to their small size and number. The leaves come out later in spring, therefore reducing any production competition with pasture in the critical spring period.

Honey locust trees are part of the Fabaceae family, and therefore they are nitrogen-fixing (Arthurs Point Farm, 2022). Although honey locust lacks nodules on its roots, there is evidence to support that nitrogen-fixing Rhizobium bacteria exist within the roots themselves. Research shows that the soil surrounding honey locust is significantly higher in nutrients and quality compared to conventional pastures and surrounding other tree species. Improved soil quality means better pasture production, erosion control, water retention and carbon sequestration (Arthurs Point Farm, 2022).

When planting honey locust, the widely spaced overstorey trees provide some shade for livestock and can also act as a wind break (Gold, 1997). Honey locust provides enough shade to benefit livestock while minimising the direct shading of understorey pastures. As honey locust timber is strong, hard, durable and resistant to shock, the wood is considered an excellent fuel, and it is often used for fence posts (Gold, 1997).

Table 5. Chemical analysis of honey locust (*Gleditsia triacanthos*) foliage.

Chemical parameters	Average values (% DM)	Range	Reference
Digestibility	62.8	0	(Luske, et al., 2017)
Crude Protein	14.2	11.2-20%	(Luske, et al., 2017) (Gold, 1997) (Csurhes & Kriticos, 1994) (Blair, n.d.)
Neutral Detergent Fiber	48.5	0	(Luske, et al., 2017)
Acid Detergent Fiber	28.1	0	(Luske, et al., 2017)
Lignin	12.5	0	(Luske, et al., 2017)

Table 6. Chemical analysis of honey locust (*Gleditsia triacanthos*) pods (Bruno-Soares & Abreu, 2003).

Chemical parameters	Average values (% DM)	Standard deviation
Dry matter (DM)	77.9	5.89
Ash	3.9	0.49
Crude Protein	7	1.68
Ether extract	1.1	0.08
Neutral Detergent Fiber	31.0	0.73
Acid Detergent Fiber	23.1	0.81
Total sugars	29.2	0.84
Gross energy (MJ kg DM−1)	18	0.38
Condensed tannins	5.4	0.55

Both the pods and the leaves of honey locust are a great source of feed for livestock. The trees begin bearing seed at 10 years of age with optimum production occurring between 25 and 75 years of age (Blair, n.d.). A good crop can exceed 20kg/tree of clean seed, with an appropriately managed 10-year-old tree producing around 40kg/tree of pods (Gold, 1997). There is a wide range in yield depending on plant. They generally bear seed pods every year with abundant yields every two years (Blair, n.d.). Once a tree is over 12 years of age, it can produce over 500kg of pods per tree (Csurhes & Kriticos, 1994). These pods contain up to 42% carbohydrates and the beans in the pods can contain up to 12-13% protein. In addition to the pods, the leaves are also used as forage for livestock. The leaves are also a high-quality feed with low lignin and high crude protein between 14.3% and 17.3%, even up to 20% (Gold, 1997).

Honey locust trees have an influence on the soil quality and nutrient status of the surrounding environment. A study by De Bruyne (2009) identified that microbial and organic matter under honey locust trees were higher when compared to the open pastures. Soil bulk density was measured to be highest around the honey locust trees and this will be influenced by the high soil carbon levels and high organic matter levels. The fertility, including total N, total K and most other cations were higher under the honey locust trees. The exception to this was total P, which was similar under the honey locust and the open pasture. As a result, it was concluded that the soils surround the honey locust trees increased in fertility.

Walnut

Black walnut (*Juglans nigra;* Figure 9) is a deciduous tree, originating from North America. Typical climatic conditions for black walnuts in North America range between 640 mm to 1780 mm rainfall per annum (Williams, n.d.). However, the optimum annual temperature for black walnut trees is 13C˚, with at least 170 days frost free and an annual rainfall of approximately 900mm. Black walnuts have large edible nuts that drop with the leaves in autumn. They start producing nuts as early as 4-6 years old, but large seed crops are not achieved until at least 20 to 30 years. Under ideal conditions, black walnut saw logs can be produced in 30-35 years, however, it is often much longer until harvest (Williams, n.d.).

Figure 9. Black walnut (*Juglans nigra*). Image source: www.theplantstore.co.nz

Black walnut trees grow best on deep, well drained soils with a neutral pH (Williams, n.d.). Soil conditions are typically moist and fertile. The rooting structure of a black walnut tree is dependent on the surrounding environmental conditions, but they tend to have well developed taproots as well as lateral roots (Williams, n.d.).

Black walnut trees are not typically grown for the benefit of livestock; their primary target market is the veneer wood market. The average price for black walnut veneer (in 2009) was \$1,749 NZD/m^3 and \$498 NZD/m^3 for saw timber (De Bruyne, 2009).

Agroforestry case studies

The following case study farms incorporated some of the findings from the literature review, as well as understanding of individual farm drivers for the incorporation of agroforestry into their farm systems. Initial farm meetings occurred to understand the farmer needs, farm system constraints and drivers for change.

Farm details

The case study farms, Claxby Farms and Ngāi Tahu – Hamua, are dairy farms located in Waimakariri, Canterbury. Both properties are flat system 2-3 dairy farms (Dairy NZ, 2024) stocking approximately 3 cows/ha. The dairy farms are run in conjunction with other properties which act as support blocks for young stock and provide supplement to the dairy farm. A summary of the farm details is provided in Table 7. Further detail on the case study farms is provided in the following sections.

Table 7. Agroforestry case study farm details.

	Claxby Farms	Ngāi Tahu - Hamua
Total farm area (ha)	715	363
Effective area (ha)	647	335
Effective irrigated area (ha)	605	320
Effective dryland area (ha)	42	15
Cows/ha	2.99	3.06

Both properties have similar soil types, as detailed in Table 8. All soil types are silt textured, with predominantly moderate profile-available water. The acidic orthic brown soil is extremely gravely, which can limit plant rooting depth. However, the other two soil types have no limitations to 100cm depth.

Table 8. Soil types for Claxby Farms & Ngāi Tahu–Hamua (Manaaki Whenua Landcare Research, 2019).

Soil Classification	Sibling name	Texture	Rooting barrier & depth (cm)	Profile Available Water (PAW) (0-30, 0-60, 0-100 cm)
Pallic firm brown soil	Lismore_2a.1	silt	Unlimited to 100	mod-mod-mod
Acidic orthic brown soils	Balmoral_10a.1	silt	Extremely gravelly	mod-low-mod to low
Pallic firm brown soils	Lismore_1a.1	silt	Unlimited to 100	high-high-mod

mod=Moderate

Weather data from Darfield was used for the case study farms. Historic average annual rainfall is 756mm (Macara, 2016). Monthly distribution is relatively consistent with the highest rainfall months (10% of annual rainfall) being July and August, and the lowest rainfall months (7% of annual rainfall) being January, April and September. Average wind speed for Darfield peaks in November at 14.6 km/h. Wind can be strong, with nine days annually having an average daily wind speed exceeding 30 km/ha, with the majority of these days occurring in spring and summer. Christchurch average daily temperature peaks in February at 16^0C, with Darfield having 45 days/year having a maximum temperature over 25^0C and eight days a year with a maximum temperature over 30^0C. Christchurch average daily temperature troughs in July at 5^0C with Darfield having 34 days annually dropping below 0^0C.

For these case study farms, rainfall is the most limiting factor for the agroforestry plantings survival and productivity. Even though rainfall distribution is relatively even, significant periods of soil moisture stress can occur over summer from increased evapotranspiration. This is not only caused by decreased rainfall but also high wind speed and temperature. Climatic information was used to inform the species selected for the agroforestry design.

Claxby Farms

Claxby Farms is family owned. It is 715 ha, with 647 ha effective milking 1,934 cows through two sheds. Claxby Farm is mainly irrigated with pivot irrigators. Five pivots are used to irrigate 605ha of the property. Three large pivots and one small pivot complete a full 360^0 and an additional pivot completes 180^0 (Figure 10). Paddocks under the 360^0 west pivot are half wedge-shaped with a circular lane splitting paddocks, avoiding the narrow end of the wedge. Paddocks under the remaining 360^0 pivots are long and skinny rectangular shapes with a straight central lane accessing both sides for the middle and east pivot and a lane along the southern end of paddocks under the north pivot. Paddocks under the remaining 180^0 pivots are semi-irregular in shape, utilising both irrigated and dryland area.

Figure 10. Claxby Farms aerial map.

The dryland area makes up 6.5% of the Claxby Farms effective area. This is split between dryland paddocks, corners, and strips between pivots. Most of the dryland area is in five fenced paddocks situated around the miking sheds and staff accommodation. The second largest component of the dryland area is irregular shaped corners between pivots, usually in the back of the paddocks. The remaining dryland area is strips between pivots, primarily comprising of north-south strips between the east, west and middle 360^0 pivots.

Profitability is the primary goal for Claxby Farms, with optimisation of the farm system the main strategy to achieve this. A focus on environmental outcomes, driven by the introduction of fertilizer limits through the National Policy Statement for Freshwater Management (NPS-FM), has been a catalyst for change at Claxby Farms. Although the farm has made significant improvements in environmental outcomes over recent years, primarily driven by regulation, Claxby Farms have become aware of the need to further prioritise reducing their environmental footprint. Their target is an efficient and profitable system, simple to operate, with as small an environmental footprint as possible.

Either regulation or profitability has historically driven change for Claxby Farms' system management. A change would occur on the farms either when required to do so by regulation, or when it would provide better economic outcomes. However, Claxby Farms would like to begin transitioning towards a more proactive farming system where they can front-foot future regulation change.

Claxby Farms is family owned. Succession has been ongoing for several years and is steadily making progress transitioning the farm between generations. They intend to continue to integrate future generations where possible. They also want to develop a system to improve staff outcomes, keeping the right people on farm and allowing them to grow.

Claxby Farms are aware they have low numbers of trees, bushes, and shrubs on the farm as well as limited biodiversity plans. They have begun planting for shelter and privacy around the farm, as well as amenity plantings around the houses and staff accommodation. They strive for an attractive farm with more trees. However, they acknowledge that the time and cost of maintenance is a real hindrance.

Ngāi Tahu – Hamua

Hamua farm is Ngāi Tahu Iwi owned, 363 ha, of which 335 ha is effective. Hamua milks 1,142 cows through one shed. Hamua is irrigated by three center pivots (Figure 11). Irrigated paddocks are rectangular, not as long and narrow as for Claxby Farms, except for paddocks at the start and end of lanes which form irregular shapes in the remaining area.

Just over 4% of Ngāi Tahu – Hamua effective area is dryland, split between dryland paddocks and strips/edges between pivots and outside pivots. The majority of the total dryland area is in six fenced paddocks located around the miking shed, staff accommodation, and corners between pivots. The remaining dryland area is small strips between pivots and edges or corners of paddocks where the pivot end gun does not reach. There are small strips between pivots and edges or corners of paddocks where the pivot end gun does not reach.

Like all farming enterprises, Ngāi Tahu Farming must farm according to local and national regulations. However, they also must meet Iwi expectations. They are expected to remain profitable while following Ngāi Tahu principles of Whanaungatanga (family), Manaakitanga (looking after our people), Tohungatanga (expertise), Kaitiakitanga (stewardship), Tikanga (appropriate action) and Rangatiratanga (leadership) in day-to-day operations. Ngāi Tahu Iwi expects Ngāi Tahu Farming to be environmental leaders and embrace new technology related to their enterprise. An example of farming to meet Iwi expectations is their plan to plant 30,000 natives across Whenua Hou. Within the dairy farms, native planting has been undertaken underneath pivots along fence lines and planting whole dryland corners.

Ngāi Tahu also has goals to address climate change. Te Kounga Paparangi is Ngāi Tahu's ambitious climate change action plan, influencing every part of their operations. They are experimenting with innovative solutions across industries to mitigate climate change, build resilience, and promote sustainable business practices to make meaningful change.

Te Kounga Paparangi is grounded in eight pou:

1. Operations emit no greenhouse gases.
2. Marae and Whanau resilience.
3. Water use is environmentally responsible and follows the principles of Te Mana o Te Wai.
4. Operational emissions do not harm the people or the environment.
5. Operations work synergistically with the natural environment and do not encroach on ecosystems or communities.
6. Optimising resources.

Ngāi Tahu – Hamua has significantly increased production in the last three years. They would like to maintain this production level in the future while tweaking other inputs to achieve better environmental and social outcomes. When commercial performance targets are met or expected to be met, farm decisions above and beyond this prioritise better environmental outcomes. Economic returns at the expense of lowered environmental outcomes are always unacceptable.

Figure 11. Ngāi Tahu – Hamua aerial map.

Agroforestry design

Case study farm system considerations

Interviews with the case study farmers provided an overview of important farm system considerations for the integration of agroforestry:

- Integrating agroforestry would increase the complexity of farm management. Both Claxby Farms and Ngāi Tahu – Hamua have stated that complexity should be minimised where possible to simplify the farming system.

- When considering minor land use changes on farms (<10% area), both farms preferred to transition into something that complements the current farming system rather than diversifying into something such as tree nut crops as explained in Holt, et al. (2019). However, Ngāi Tahu has a greater appetite for diversification of other farm types as they have more dryland area available.
- Both businesses are happy to invest significant capital into diversification if it achieves acceptable financial performance. The amount of capital available for investment depends on the business's current and future indicative financial performances as well as the level of the return potentially achieved by the diversification. The interaction becomes more fluid when investment is directed towards more environmentally beneficial outcomes. Ngāi Tahu – Hamua is willing to voluntarily invest money into environmental outcomes with little to no economic return, whereas Claxby Farms will do so, but to a much lower degree. Investing in non-economic environmental outcomes, such as native planting, is primarily limited by financial surplus. This is felt in the farmer decision-making process, where they need to be confident in the future of their farm as a viable enterprise to be willing to commit to the necessary investment required to achieve suitable and sustainable outcomes for the farming business and the environment.
- Animal health is a priority and is actively managed on farm for the benefit of the cows. Managing animal health well often has a direct effect on productivity and therefore directly affects productivity and financial performance. Heat stress for cows is acknowledged as an issue, each farm have addressed it differently, including the planting of natives along fence lines for future shade at Ngāi Tahu – Hamua and the installation of fans in the milking shed at Claxby Farms.
- Dryland paddocks currently play a role on farms for storage, silage pads, calf paddocks, carryover paddocks, holding paddocks and winter grazing runoff areas. Although these areas struggle to deliver a financial return, the essential role they play in the farming enterprise would have to come from more productive areas of the farm, if they were unable to continue in some capacity under new diversified land use. Ngāi Tahu Farming has planted dryland areas in native tree species for biodiversity outcomes. Claxby Farms have considered planting exotic trees but are wary of changes in the NZ ETS, a large contributor to the financial performance of this potential diversification.
- Both farms have investigated extending irrigation into dryland corners of irrigated paddocks through sprinklers/fixed grids. Both concluded that the relative return on investment was lowest for these areas and often unviable. They also concluded that the intensification from extending irrigation would exceed self or regulation-imposed current or future nutrient loss limitations. Feed grown on dryland corners is often poor quality and unreliable; as such, it is not considered in feed calculations and is treated as a bonus.

Agroforestry design considerations

The following are features or design considerations that have been incorporated into the agroforestry design based on discussions with both Ngāi Tahu and Claxby Farms, and the literature review:

Pasture productivity

Pasture productivity under and around agroforestry is the net result of factors that can both have a positive or negative effect on pasture production, depending on several variables such as climate, design and management etc.

- In general, shade provided by trees directly decreases pasture production due to reduced photosynthesis. However, in less ideal pasture growing conditions, shade can have only a minor or even a positive effect on pasture production due to trees moderating local microclimate. We have selected honey locust and poplar as a species, partially because they have light and medium-density canopies, allowing more sunlight. In addition, tree rows were oriented north-south where possible, to maximise sunlight penetration.

- Shade cast by trees can decrease soil temperature. This can negatively affect pasture production in spring and autumn, when pasture production is temperature-limited. However, this effect is diminished or even reversed in summer where soil temperature is decreased by the presence of trees, alleviating one of the limiting factors on pasture production at that time of year. We have selected all deciduous tree species to minimise negative interactions on pasture production in spring and autumn. Species selected tend to begin leafing out in mid-late September and finish in November. This will largely avoid adverse effects on pasture production through August, which is crucial for grazing during September (generally the tightest feed pinch of the growing season).
- Shade increases moisture availability by reducing temperature and, thus, evapotranspiration. This could have a particularly positive impact on pasture production in dryland corners, which in Canterbury are often limited by soil moisture availability for several months of the year. However, this could result in more mud when planted adjacent to farm tracks. This was considered and minimised where possible, although other benefits were considered likely to outweigh this factor.

Trees

- Planting plans are predominantly exotic hardwoods, designed with the intent for the trees to be able to be registered in the NZ ETS. Planting density is 50 trees/ha, 20m between rows and planted at 10m intervals along the row, achieving 40% canopy cover with 10m diameter tree canopies at maturity. This design minimises shade and gives a 10% buffer above the NZ ETS requirement of 30% to allow for replacing trees without falling below 30% canopy cover. This is essential for the trees to remain in the permanent forest category.
- Trees compete with pasture for moisture and nutrients. The majority of tree roots are within the topsoil layer competing with pasture. However, some of the tree species selected are more taproot dominant, extracting relatively more moisture and nutrients from the soil below where pasture species roots can reach, therefore reducing competition.
- Trees physically reduce wind speed. This directly benefits pasture species by reducing physical wind damage. Reducing wind and soil temperature decreases soil evapotranspiration and may result in soil moisture content being as high or higher than open pasture. This is another good reason to orientated trees north south, to be semi-perpendicular to the predominant northwest wind. Trees should provide shelter 225-250m downwind of rows and 60-80m upwind of rows.
- Trees can regulate soil temperature in winter. This is due to the physical barrier a tree canopy creates, keeping frosts off the ground. This effect may be reduced but potentially still present to some degree for the deciduous species selected for the case study farms.
- N fixing trees increase N availability, increasing adjacent pasture production. This is partially why honey locust was selected for the case study farms.
- Poplars can significantly increase soil pH, one reason for their selection.

- Soils under agroforestry tend to have higher porosity, infiltration, soil aggregate stability and organic matter than open pasture.
- Widely spaced trees on the Canterbury plains are not particularly suitable for growing quality timber due to high wind and lack of shade, resulting in trees that are not straight. Therefore, the agroforestry system has been designed to minimise negative impacts on infrastructure and pasture production while maximising returns from carbon via the NZ ETS and milk production.

Animals

- Reduced wind speed decreases exposure for livestock during windy and cold and or wet weather events.
- Shade provided by trees reduces heat stress for livestock during hot times of the year. This can increase livestock productivity and reproductive performance. Where possible agroforestry was incorporated into the back of paddocks to shift the intensity of stock camping from the front of paddocks. This may have some impact on reversing nutrient transfer from the front of the paddock towards the back and allow for improved grazing control in the back of the paddock.
- Leaves and young stems of trees can have positive or negative effect when consumed by livestock depending on species and even time of year. Some species, like mulberry, provide high-quality forage for livestock with no implications or negative side effects. Other species can be toxic to livestock when consumed in large amounts or at particular times of year. All primary tree species selected for case study farmers have high forage potential, particularly mulberry, to maximise the opportunity of forage potential and minimise any negative tree/livestock interactions.

Infrastructure

- Trees have not been proposed to be planted within reach of powerlines or critical farm infrastructure such as staff houses, irrigation dams or center pivots. Trees have been proposed to be planted next to farm tracks to provide forage and generate carbon credits on previously unproductive areas. It was assumed the positive impacts of planting trees would outweigh any negative impacts on the farm track such as mud and soil being pushed up by tree roots.

Biodiversity

- Agroforestry can improve biodiversity by creating habitat and food sources for flora and fauna. These areas can be used as habitat corridors to connect indigenous species between native forest remnants. There is also the possibility of incorporating native tree species into agroforestry or succeeding in the exotics with native species to create more beneficial habitats and connectivity for indigenous species. To improve indigenous biodiversity outcomes at Ngāi Tahu – Hamua, 1 in 4 planting sites are planted with two natives 2.5m apart. As exotic trees die or are removed, they will be replaced with native species, slowly transitioning to a native agroforestry over future generations.

Tree-animal interaction

- Claxby Farms elected for more individual tree protectors rather than fencing off rows as they are cheaper and provide more management freedom, allowing livestock and equipment to pass between trees with ease.

- At Ngāi Tahu – Hamua, trees are protected via fenced rows for whole dryland paddocks, to create more subdivision for improved pasture management and options regarding calf paddocks etc. Fenced-off tree rows also allow regenerating seedlings to be established without being grazed, assisting in Ngāi Tahu's vision of transitioning this to native agroforestry.

Planting plans

Claxby Farms

Figure 12 shows a birds' eye view of the Claxby Farms agroforestry planting plan. Areas highlighted in orange contain the agroforestry design and any area that should be able to be included in the NZ ETS. Other details are visible but quite small and will be explained further in this report. Claxby Farm's agroforestry comprises three dryland paddock areas, one each around the two milking sheds and one next to the irrigation pond, with the remaining area being dryland corners and under the end gun of the pivot.

Figure 12. Birds eye view of Claxby farms agroforestry planting plan.

Figure 13 shows the agroforestry planting plan for the south-west corner of Claxby Farms. Green circles are the predicted future tree canopy with a 10-meter diameter, yellow circles are trees that individual tree protectors will protect and white lines are new fences that need to be erected to protect other trees. Individual tree protectors have been prioritised to allow livestock and vehicles to move through agroforestry areas largely unaffected. Fences have been used where already against an existing fence, effectively halving the cost of more permanent protection.

The orange area eligible for the NZ ETS connects the two left-hand planting areas as it will utilise existing tree rows. Trees are planted underneath the irrigator end gun but far enough away from the pivot so not to connect. This is essential for a number of small dryland corners to >1ha, which is required for the NZ ETS.

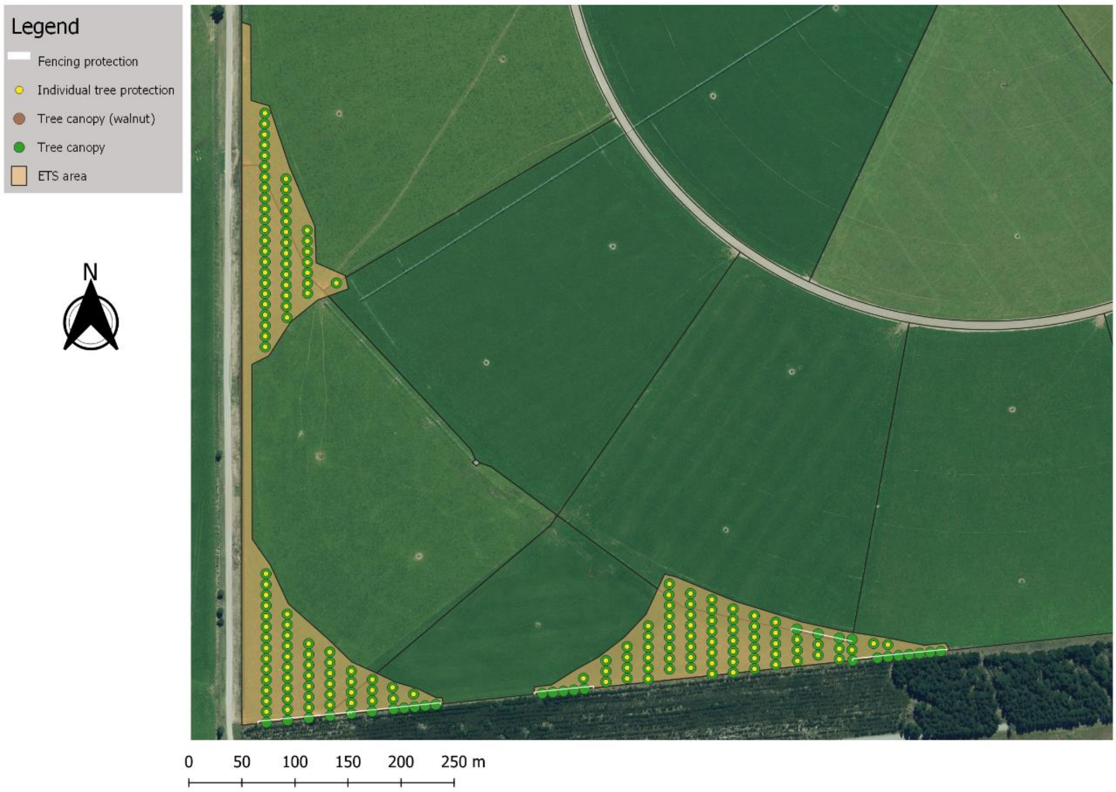

Figure 13. Claxby Farms agroforestry planting plan, south-west corner.

Figure 14 shows the planting plans for the areas between the west and middle 360^0 pivots and the dryland corners of a small 180^0 pivot. This shows two paddocks where agroforestry is in the front of paddocks. Although this is not ideal from an environmental perspective with stock camping and point source nutrient loss, it was an economic decision that can be reversed if it proves too troublesome. North of that is the area between the west and middle 360^0 pivots, where 2-3 tree rows provide significant downwind shelter of the middle pivot area. Although these trees may shade the track somewhat, it was deemed that effective light would still penetrate through, especially in wet times of year, such as winter and early spring when the trees are still leafless.

Figure 14. Claxby Farms agroforestry planting plan, between west and middle 360⁰ pivots.

Figure 15 shows the agroforestry planting plan around the shed, yards and houses for the West dairy farm. Brown circles are planting sites for black walnuts, primarily grown for timber. However, it has been stated that this site is not ideal for growing timber trees. Adding a small number of black walnut in the most sheltered and 'forest-like' areas is a high risk, high reward diversification with very small exposure. If successful black walnut timber is very valuable, if it fails, they can be replaced with forage-type species at minimal cost.

In Figure 15 there are two instances where the orange area encompasses long thin strips of areas with no green circles, stating planted trees. This is because existing trees rows are already planted there. Previously these trees were not eligible for the NZ ETS because they were < 1 ha and had an average width of < 30m. In the plan, because they will be connected to the large agroforestry area, the collective area will be > 1ha and > 30m wide, making these areas eligible for the NZ ETS and directly able to generate revenue. Similarly, NZ ETS revenue is now able to be generated from some of the area around the staff housing, due to their close proximity to the trees.

Claxby Farms has elected to leave an area around the silage pits free of trees for flexibility of management. A diagonal row of trees is also missing, running from the lefthand house to the shed, to allow space and avoid conflict with the power lines.

Figure 15. Claxby Farms agroforestry planting plan, west dairy yards, houses and sheds.

Figure 16 shows the agroforestry planting plan for a dryland paddock next to the storage pond. The majority of the tree protection will be fencing to allow for more subdivision for calf paddocks, etc. Although this is more expensive than individual tree protection, additional subdivision is expected to result in improved grazing control and management efficiencies for separating stock.

Figure 16. Claxby Farms agroforestry planting plan, dryland pond paddock.

Further close-ups images of the planting plans for the remaining agroforestry areas can be found in the Appendix (Figure 31-38).

Ngāi Tahu – Hamua

Figure 17 shows the birds eye view of the Ngāi Tahu – Hamua agroforestry planting plan. This agroforestry plan is made up of five dryland paddocks, two of which are used for staff housing, with the remainder being dryland edges and under the pivot end guns. Note, some orange NZ ETS areas are <1ha and on their own would not be able to be accepted into the NZ ETS. However, these areas are adjacent to dryland areas on other Ngāi Tahu farming properties. Therefore, it is assumed that sufficient area from neighboring properties would also be planted, allowing the area to be added to the NZ ETS.

Figure 17. Ngāi Tahu – Hamua agroforestry planting plan, birds-eye view.

Figure 18 shows the agroforestry planting plan for the south-west house. Ngāi Tahu has elected not to plant trees to the north-west of staff accommodation so as not to block their view of the Southern Alps. Tree rows have been offset from the paddock boundary, given the legal requirement of 10m set back from the irrigation dam. Area from farm track, driveway, backyard and water race can now potentially generate revenue from the NZ ETS.

Figure 18. Ngāi Tahu – Hamua agroforestry planting plan, south-west house.

Figure 19 shows the agroforestry planting plan for the north-east dryland paddock. Tree rows have been fenced off for additional subdivision within the paddock. However, the trees are individually protected when the rows are not sufficiently long enough to warrant fencing. The row of trees within the irrigated paddock are under the pivot's end gun and follow the paddock's end as it curves around to remain uniform instead of being strictly north-south orientated.

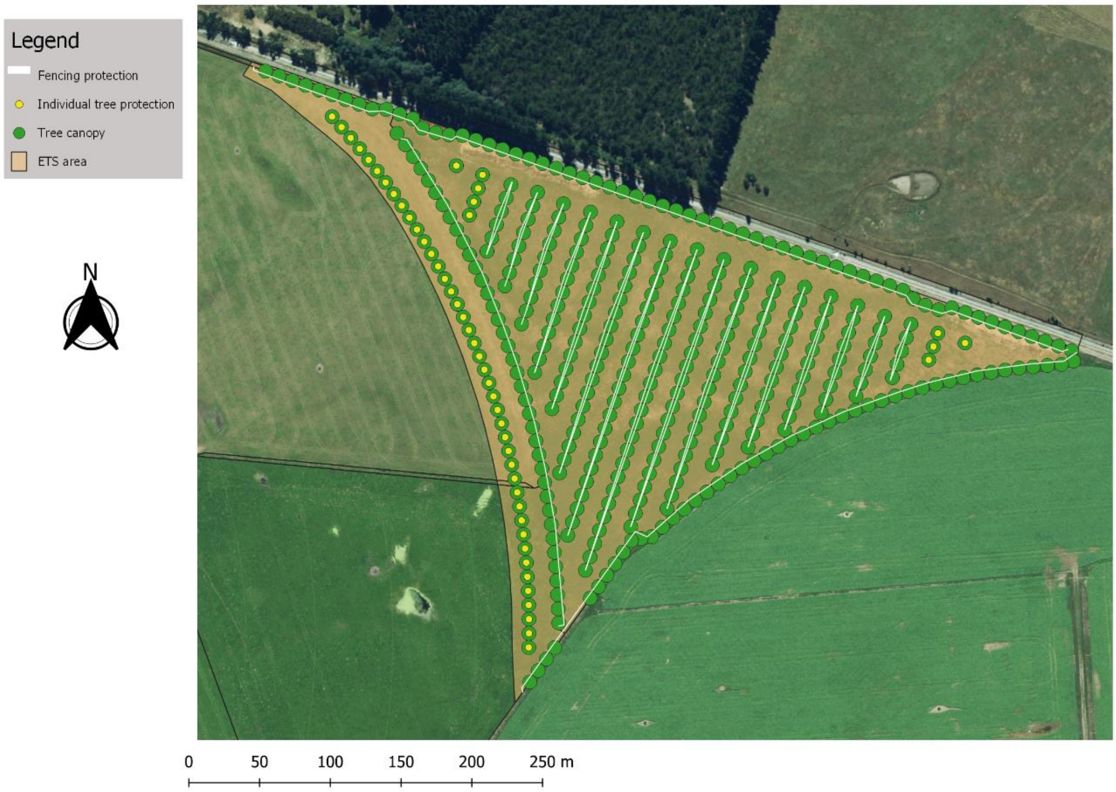

Figure 19. Ngāi Tahu – Hamua agroforestry planting plan, north-east dryland paddock.

Figure 20 shows the agroforestry planting plan for the north-west dryland edge. The row of trees within the irrigated paddocks is under the end gun and follows the edge of the paddock for uniformity. Trees are to be planted in existing native rows at either end of the highlighted area. Although there are already natives here, they will not reach 5m in height and are not eligible for the NZ ETS.

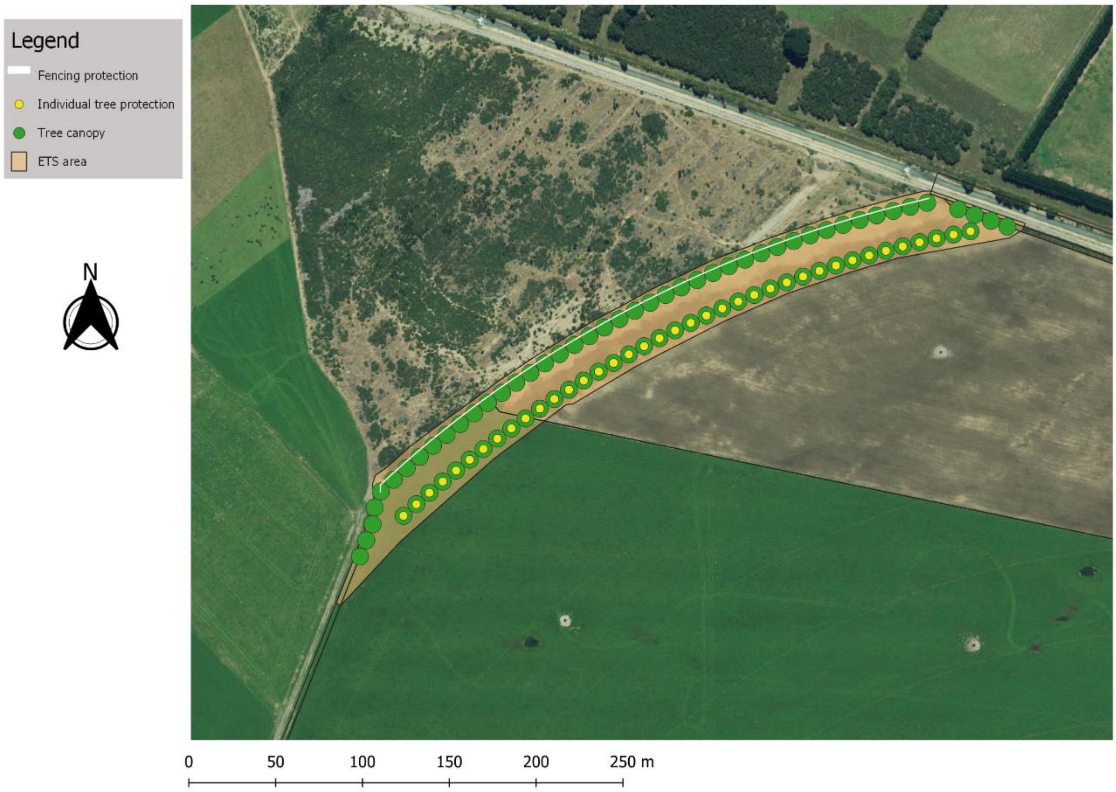

Figure 20. Ngāi Tahu – Hamua agroforestry planting plan, North-west dryland edge.

Further close-up images of the planting plans for the remaining agroforestry areas can be found in the Appendix (Figure 39-43).

Agroforestry future farm images

Claxby Farms

From the agroforestry planting plans, tree height and canopy widths, we randomly distributed the correct proportions of each species to indicate what the agroforestry system at Claxby Farms may look like when mature.

Figure 21 gives a view from the west pivot looking east. This view highlights the span of trees between the pivots providing shelter as well as what the farm may look like from the air in 40-60 years. Figure 22 gives a high level view of the agroforestry system around the East dairy shed, this shows the space between the rows and an indication of shading from a late afternoon sun. It also shows how the curved tree rows at the end of paddocks may look as well as maximum shading on the farm track.

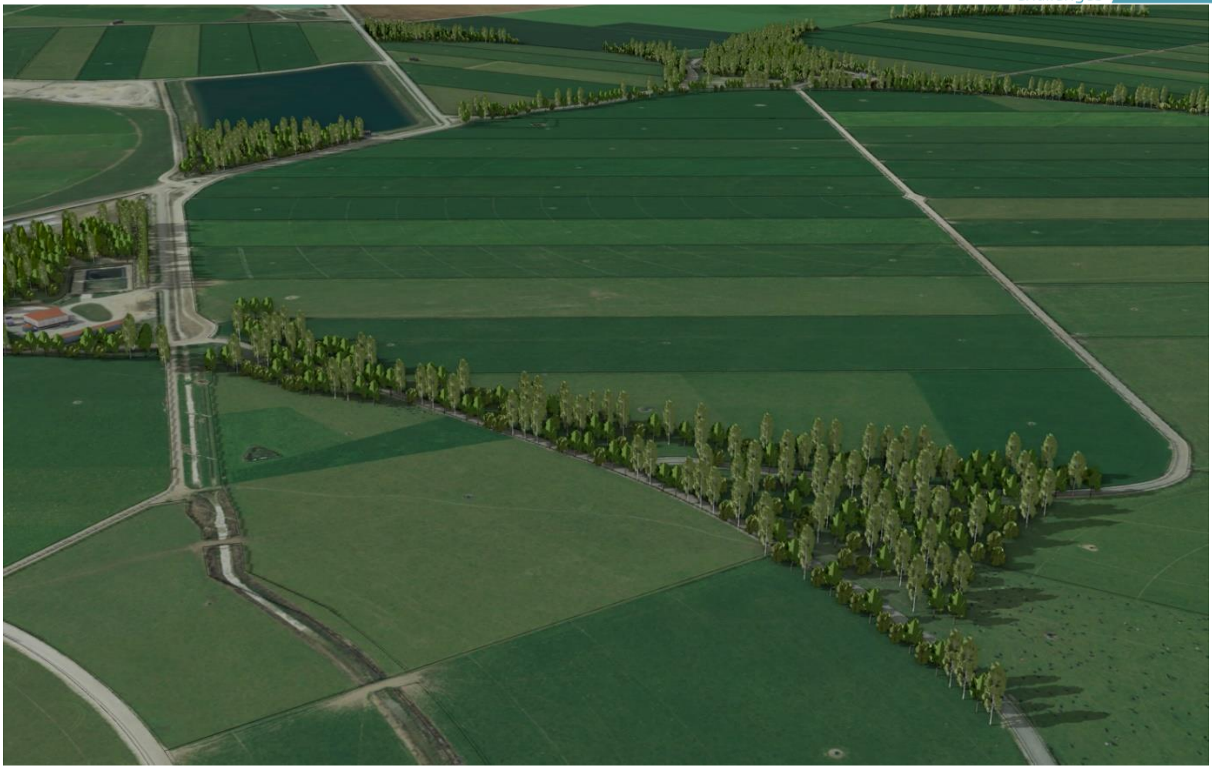

Figure 21. Claxby Farms future farm image.

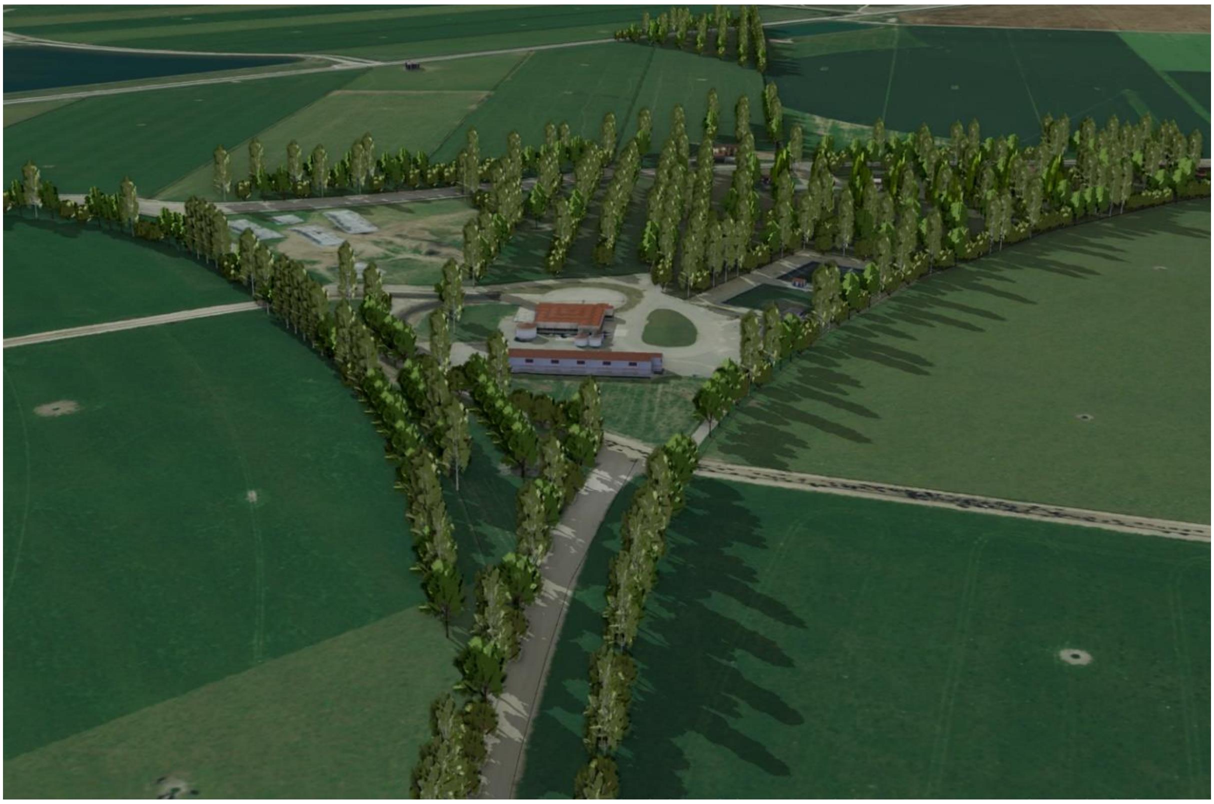

Figure 22. Claxby Farms future farm image.

Figure 23 shows the agroforestry in a dryland corner, giving another view of the space between the rows and maximum shade from the late afternoon sun. Figure 24 shows a close-up view of mature trees at the West dairy shed. From this image, they may wish to increase the buffer between the trees and the effluent ponds to avoid any potential negative implications. Further future farm images are available in the Appendix (Figure 44-55).

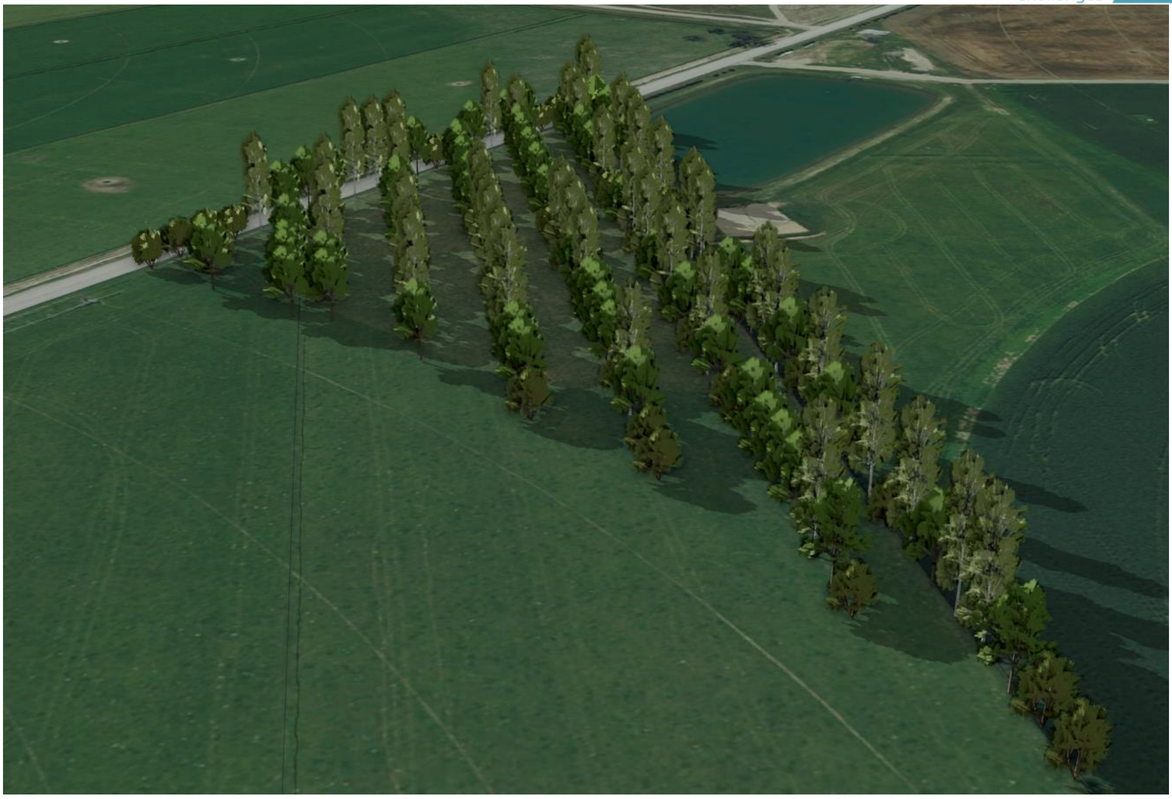

Figure 23. Claxby Farms future farm image.

Figure 24. Claxby Farms future farm image.

Ngāi Tahu – Hamua

From the agroforestry planting plans, tree height and canopy widths we were able to randomly distribute the correct proportions of each species to indicate what the agroforestry system at Ngāi Tahu – Hamua may look like when mature.

Figure 25. Ngāi Tahu – Hamua future farm image.

Figure 25 gives a bird's eye view of the agroforestry planting around the north-east pivot. This constitutes three dryland paddocks and one dryland corner with adjoining tree rows under the pivot end gun. From this image you can see the other interlocking dryland areas of neighbouring properties and imagine how the whole Ngāi Tahu Farming system may look when all interconnected. Figure 26 gives a view of what the trees around staff accommodation may look like when mature. To retain their view, we kept an empty space to the north-west of the houses.

Figure 26. Ngāi Tahu – Hamua future farm image.

Figure 27 shows what a mature agroforestry system in a dryland paddock may look like. It highlights the space between canopies and maximum shading during the late afternoon. Figure 28 shows a planted dryland edge. The boundary trees are in true dryland with the inner row of trees under the pivot's end gun. From this view it is possible to perceive how livestock may utilise these areas in the back of paddocks. More future farm images are in the Appendix (Figure 56-66).

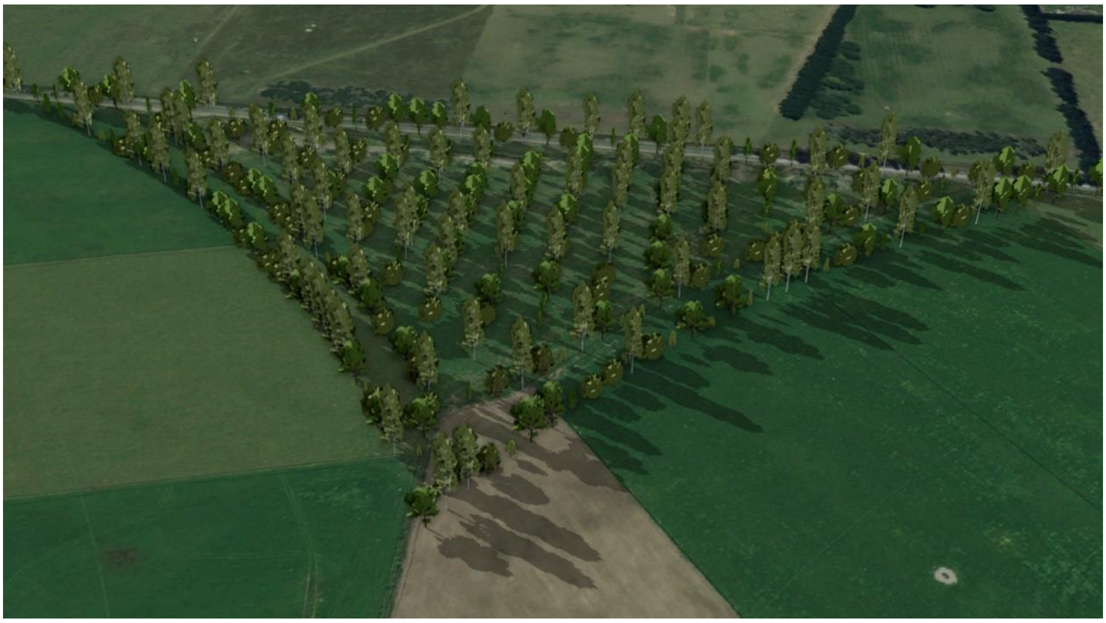

Figure 27. Ngāi Tahu – Hamua future farm image.

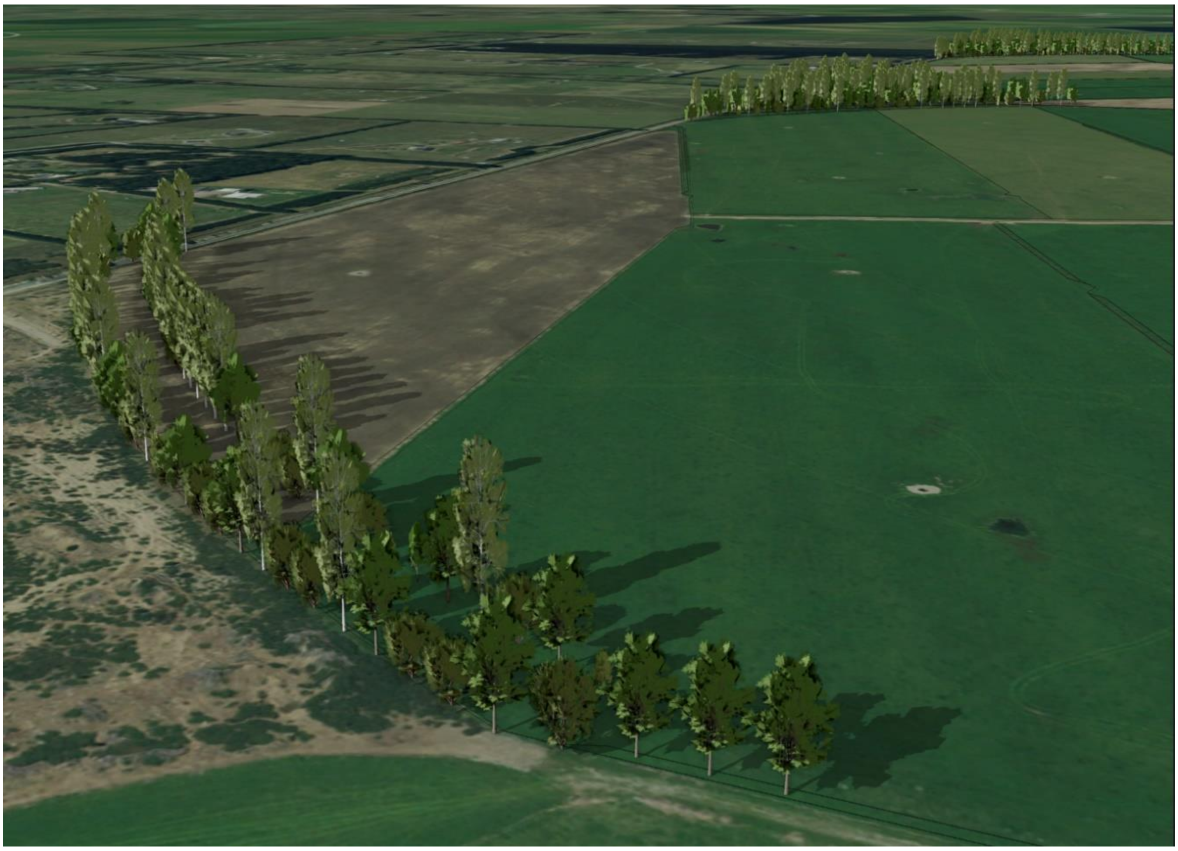

Figure 28. Ngāi Tahu – Hamua future farm image.

Economic assessment

A discounted cash flow was employed to determine the financial viability of the two agroforestry systems designed for Claxby Farms and Ngāi Tahu – Hamua. The discounted cash flow considers only what agroforestry adds or subtracts from the current farm economics. This study does not investigate whole farm analysis in any form.

Net Present Value (NPV) and Internal Rate of Return (IRR) were key financial indicators of the discounted cash flow. This analysis was deigned to highlight the economic potential of agroforestry in the dryland corners of Canterbury Dairy farms with sufficient research to determine assumptions. Follow-up research and assessments could consider a monetary value on some of the unquantified benefits highlighted in the Economic assessment – Unquantified benefits section.

Key assumptions and inputs

Pricing

1. Milk price of $8/kg MS.
2. Carbon price of $70/tCO2-eq.

Costs

3. Bulk rates are used for costs
4. Tree establishment is contracted out at $12/tree for site prep and planting and $10/tree for maintenance.
5. Cost of clearing windfall of $10/ha in year 10, increasing to $50/ha in year 35.
6. 10% of plantings are required to be replaced in years 2, 3 and 5, totalling 30% replacement for plant deaths.
7. Assumed no value for timber (including black walnut planted for timber), firewood value covers the cost of removal and replacement at end of tree life.
8. Fencing costs $4.88/m, including contractor and materials for 3 wire electric fence.
9. Individual tree protector and stakes are $60 each. Assumed 100% of them are brought in year 1. However, planting would occur over several years, and protectors could be used multiple times.

Agronomic

10. Trees reduce pasture production by 20% at year 35 (maturity). This value was determined by five key factors:
    - 20% increase in dryland pasture production at Winchmore, downwind of the shelterbelt due to physical shelter and reduced evapotranspiration from less wind.
    - Pasture production improves by 10% with nitrogen fixing tree species when compared to non-nitrogen fixing species.
    - 40% decrease in pasture production at 50 eucalyptus trees/ha in Te Kuiti, Waikato, under irrigation.
    - Decreases in pasture production under agroforestry are lower in more extreme areas (drier, colder and hotter), due to the buffering effect of trees on the local microclimate.
    - Deciduous species tend to have less of a negative impact on pasture production.

11. Negative impacts of trees on pasture growth ranges from 0% in year 1 to 20% reduction in year 35. This occurs at the same rate as the MPI Hardwood Exotic Carbon look up table accumulate carbon for hardwood exotics.
12. Productive area is lost to tree protection in the form of fences and individual tree protectors from year 1.
13. Assuming 1t DM/ha from tree forage at a similar quality to dryland summer pasture. This equals 20 kg DM/tree/year that livestock can reach or falls down while green.
14. Savings in MS production due to reduced heat stress is on days with average temperature above 20 degrees based on literature. Days with an average temperature above 20 degrees is closely linked to days where the maximum temperature exceeds 25 degrees. Hot days with maximum temperature >25 degrees for Darfield are 45 (closest site used as proxy).
15. Climate modelling of temperature increases is using RCP4.5 where mean surface air temperature increases by 1.4 degrees by 2031-2050. This is conservative because our model would finish by 2058 if planting occurred next year, potentially seeing at least a further 8 years of warming. Results in a mean increase of 15 days above 25 degrees by year 35 in the model.
16. Assume farmers graze paddocks with shade on hot days.
17. Assume Claxby farms are split into 4 herds and Ngāi Tahu are split into two herds.
18. 3.6m^2 per cow is the minimum shade requirement based on literature.
19. Livestock benefit from shade is not limited to shaded area. If 100% of the herd has access to volunteer shade, then the per hectare benefit is felt across 100% of the paddock. Of paddocks that have significant shade 97% and 96% of cows could access shade at once for Claxby Farms and Ngāi Tahu – Hamua respectively.
20. Feed conversion efficiency is back calculated from farm input data.
21. Assume all dryland area is milked off growing 8t DM/ha for calculations. However, much of these areas provide other farm functions that are not as valuable as calculated.
22. If cut at the correct time of year, most of selected species can grow from the stump, saving replacement cost.

Emissions trading scheme

23. Trees are registered in the NZ ETS under the permanent forest category with canopy cover of 40%. With canopy cover not able to fall below 30% under the permanent forest category, this allows for 9.3% buffer for tree replacement.
24. Small number of trees are replaced each year to maintain at least 30% canopy cover.
25. No requirement to submit carbon credits when transitioning from exotic to native.
26. Proposed government admin charges of $30.25/ha are included.
27. Cost of registering for the NZ ETS is included.
28. After 35 years in the NZ ETS, trees remain in place to ensure no liabilities are ensued.

Unquantified benefits

Non-Economic

- Reducing the intensity of stock camping in the front of paddocks by providing shade in the back of paddocks. This would result in less or even reverse nutrient transfer from the back to the front of paddocks. This would create less point source nutrient loss from very high fertility in the front of paddocks.
- 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 by being around trees.
- Improved erosion control by tree roots if on unstable land.
- Habitat and food for pollinators. This 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.

Economic

- Increase in milk solid production when shade is provided is assumed to be nonlinear with increasing air temperature. Therefore, at temperatures above 30^0C (8 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 >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 (Appendix; Figure 67 Figure 68).
- 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.
- Shifting the intensity of stock camping from the front to the back of paddocks could Improve grazing management in the back of paddocks as it is frequented more often.
- If biodiversity credits, as proposal for consultation by government stated, came into effect, this could potentially provide another revenue stream depending on how the scheme is implemented.

Economic assessment results

The results of the economic assessment from the two case study farms is presented side by side for comparison (Table 9).

Table 9. 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 areas 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 ($119.63/ha)	$4,969 ($195.01/ha)

Claxby Farms is roughly twice the size of Ngāi Tahu – Hamua. However, it has proportionally more agroforestry area due to relatively more dryland corners and a higher willingness to plant trees near unproductive areas such as houses, tracks and water races. This is shown by the relatively higher unproductive area under agroforestry.

Total establishment costs for the agroforestry are significantly higher at Claxby Farms, largely due to the significantly higher agroforestry area. However, the establishment cost per hectare was significantly higher at Ngāi Tahu – Hamua. This is primarily due to a higher proportion of fencing which is roughly twice the cost of individually protecting trees (when fencing both sides). Although the cost of this additional protection was factored in, no additional revenue was included in the NPV or the IRR.

The IRR is an indicator of the financial viability of an investment. Some investors or businesses require a higher IRR depending on their preferences and risk or perceived risk. The IRR reflects a discount rate where the NPV of a cashflow equals zero.

The IRR over 36 years of establishing agroforestry in the dryland corners for Claxby Farms and Ngāi Tahu – Hamua are 26% and 20% respectively (Table 9). This is driven almost entirely by the lower cost of establishment per hectare at Claxby Farms compared to Ngāi Tahu – Hamua with relatively comparable returns per.

NPV is a measure of a project's profitability, it is the calculated sum of all discounted costs and revenues for a project over the investment period. The discount code commonly applied is the investors required rate of return. For this project we used the 2023 NZ Treasury default discount rate of 5%[3]. The NPV for Claxby Farms is $19,549/ha and $17,007/ha for Ngāi Tahu – Hamua.

Figure 29 and Figure 30 show the proportion of revenue (or costs) derived from carbon and agroforestry revenue for Claxby Farms and Ngāi Tahu – Hamua. Agroforestry revenue is the net result of milk solid gain from shade and loss in MS from a decrease in productive area due

[3] See: https://www.treasury.govt.nz/information-and-services/state-sector-leadership/guidance/reporting-financial/discount-rates

to tree protection. Both figures show losses in revenue from agroforestry until years 21-23 before becoming positive. This is due to lost productive area in tree protection from year 1 and gain in MS production increasing over time as shade increases. At year 36, after no more carbon can be earned from the NZ ETS, the post carbon cashflow is $119/ha and $195/ha for Claxby farms and Ngāi Tahu – Hamua respectively (Table 9). This figure is higher at Ngāi Tahu – Hamua due to a lower feed conversion efficiency, calculated from farm input data.

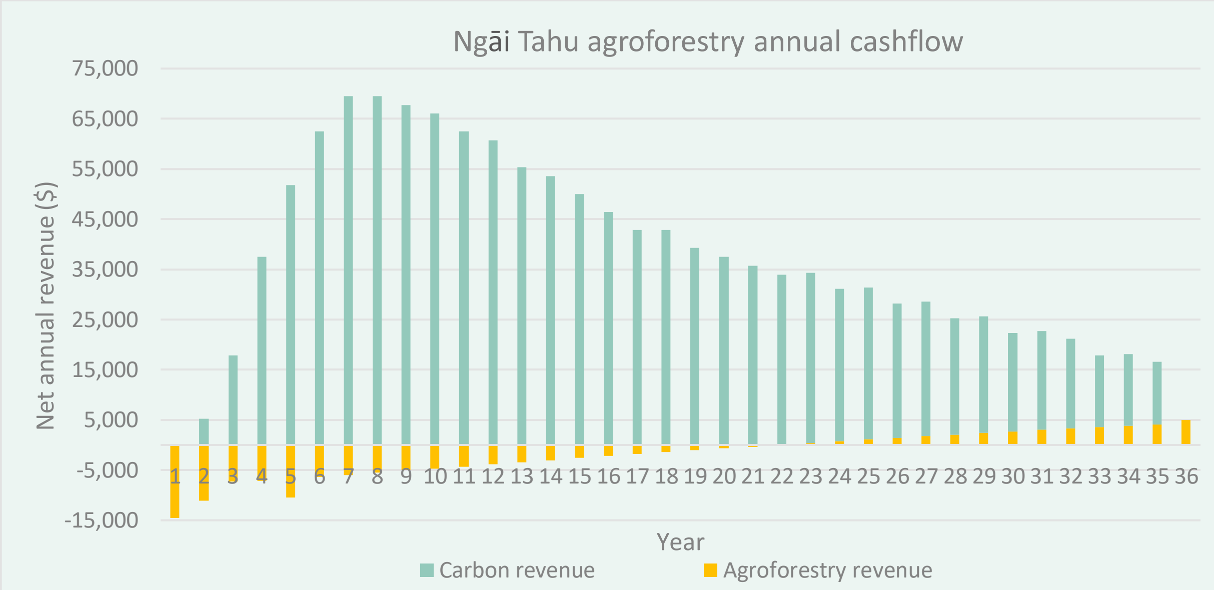

Figure 29. Net modelled cashflow of Ngāi Tahu – Hamua agroforestry.

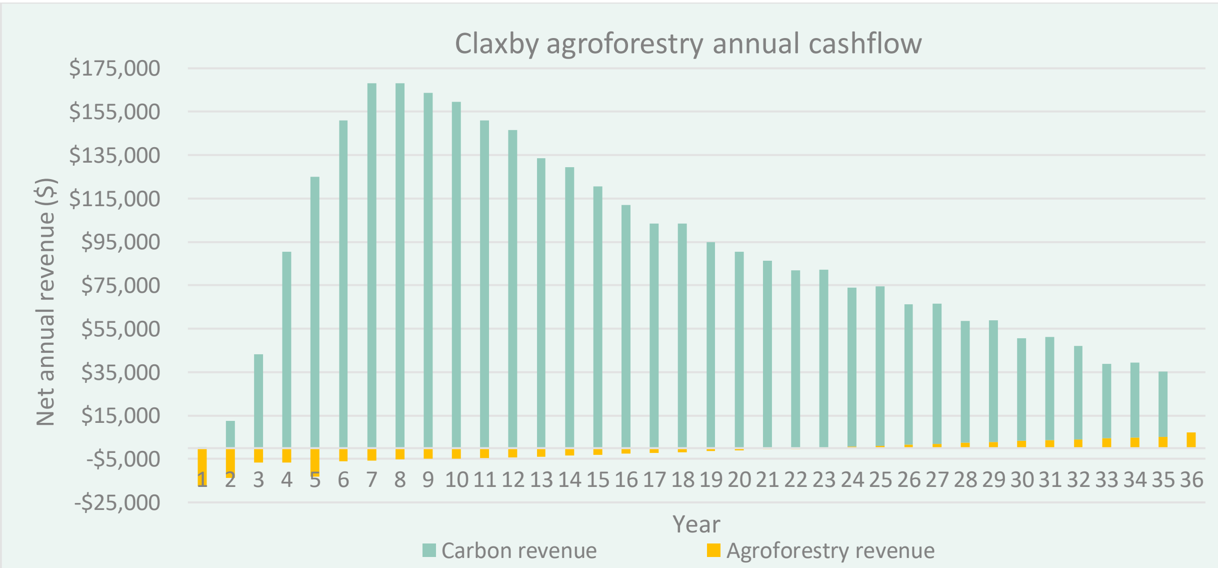

Figure 30. Net modelled cashflow of Claxby Farms agroforestry.

Sensitivity analysis

The financial performance of agroforestry in our calculations is largely dependent on variables, such as carbon price and pasture production.

Claxby Farms

A sensitivity analysis was undertaken to determine the effect of a variable carbon price on IRR and NPV Table 10) if Claxby Farms invested in agroforestry. The price of carbon has a significant effect on the financial performance of agroforestry at Claxby Farms. At a carbon price of $150 per NZU, IRR increased to 42% and NPV increased to $2,933,107. In a scenario where the price of carbon falls to $0, IRR would decrease to -7% and NPV would be -$309,242. At $20/NZU, the IRR would be 8% and the NPV would be $123,071.

Table 10. Sensitivity analysis of carbon price on NPV and IRR for Claxby Farms agroforestry.

Carbon price (NZD)	$0	$20	$50	$70 (base case)	$150
IRR (%)	-7%	8%	20%	26%	42%
NPV (NZD)	-$ 309,242	$ 123,071	$ 771,541	$ 1,203,854	$ 2,933,107

A sensitivity analysis on the effect of pasture production under agroforestry indicated that pasture production under agroforestry does not have a large impact on financial viability (Table 11). If pasture production under agroforestry decreased by 30% then the IRR would only drop 1% from its normal value of 26%. However, the NPV would decrease to $939,732. If pasture production was 10% less than open pasture then IRR would only increase 1% and NPV would increase $264,122 from the baseline estimates.

Although pasture production under agroforestry does not have a significant impact on the financial viability of the investment during the investment term. We assume that if the investment term were to increase then pasture production would have relatively more impact on overall financial performance. This is due to revenue from carbon running out after 35 years in the NZ ETS. After this, it is expected that pasture production will have a significant effect on annual cashflow. Therefore, as investment term increases, overall revenue directly associated with pasture production will increase making it relatively more important to the financial viability of the investment.

Table 11. Sensitivity analysis of pasture production on NPV and IRR for Claxby Farms agroforestry.

Pasture production	-10%	-20% (base case)	-30%
IRR	27%	26%	25%
NPV	$ 1,467,976	$ 1,203,854	$ 939,732

Ngāi Tahu – Hamua

A sensitivity analysis was undertaken to determine the effect of a variable carbon price on IRR and NPV (Table 12) if Ngāi Tahu – Hamua invested in agroforestry. The price of carbon has a significant effect on the financial performance of agroforestry at Ngāi Tahu – Hamua. At a Carbon price of $150 per NZU, IRR increased to 34% and NPV increased to $1,148,868. In a scenario where there the price of carbon falls to $0, IRR would decrease to -7% and NPV would be -$192,730. At $20/NZU the IRR would be 4% and the NPV would be -$13,850.

Table 12. Sensitivity analysis of carbon price on NPV and IRR for Ngāi Tahu – Hamua agroforestry.

Carbon price (NZD)	$0	$20	$50	$70 (base case)	$150
IRR (%)	-7%	4%	15%	20%	34%
NPV (NZD)	-$ 192,730	-$ 13,850	$ 254,469	$ 433,357	$ 1,148,868

A sensitivity analysis on the effect of pasture production under agroforestry determined that pasture production under agroforestry does not have a large impact on financial viability (Table 13). If pasture production under agroforestry decreased by 30% then IRR would only drop 1% from the base estimate of 20%. NPV however, would decrease to $336,477. If pasture production increased from -20% to -10% then IRR would only increase 1% and NPV would increase $96,864 from their respective norms.

Table 13. Sensitivity analysis of pasture production on NPV and IRR for Ngāi Tahu – Hamua agroforestry.

Pasture production	-10%	-20% (base case)	-30%
IRR	21%	20%	19%
NPV	$ 530,221	$ 433,357	$ 336,477

Comparison

Claxby Farms IRR is 8% higher than Ngāi Tahu – Hamua at $150 carbon price. At a carbon price of $0 Claxby Farms IRR is the same as Ngāi Tahu – Hamua (-7%). This is due to Claxby Farms having a significantly lower establishment cost and its post carbon annual cashflow only being $75/ha less than Ngāi Tahu – Hamua.

Discussion & knowledge gaps

In this project, agroforestry in the dryland corners of Canterbury dairy farms was shown likely to be financially viable, and warrants further investigation, including assessing the economic value of the unquantified benefits (see section: Unquantified benefits). Further research should also investigate a diverse set of tree species based on land managers' goals and environmental conditions. Pasture production under Pinus radiata is unlikely to compete with 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.

The carbon returns from the NZ ETS are the primary revenue source for agroforestry and a potential incentive for uptake. However, it is likely that the greatest uptake will come from other long term ecosystem services (e.g. animal welfare) and revenue streams (e.g. fodder). Once carbon has been claimed under the permanent forest category under the NZ ETS, the forest owner must maintain canopy cover so not to incur any pay back obligations. 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. Sequestering carbon from hardwood exotics in the MPI carbon look up tables 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 value farming systems could potentially derive great benefit from agroforestry systems, as they are more likely to benefit from the additional tree forage. It is likely that the more extreme the farming system, in terms of temperature extremes that trees can moderate, the greater potential return on investment; as long as enough trees can survive and grow to 5m in height.

We have identified the following knowledge gaps and recommend research to address them:

- A key knowledge gap is the productivity of pasture production under an agroforestry system for the South Island, and in particular dryland areas. A key assumption used in the economic assessment is that pasture would only be reduced by 20% within an agroforestry system, having a 10:1 ratio influence on the IRR on both farms. That is, for every 10% pasture reduction, there is a 1% reduction in IRR. Even though the effect of pasture productivity seems to be small, the assumptions are based on best estimates adapted from studies in the North Island with different species and environmental conditions. Hence, research is needed to investigate pasture production under agroforestry systems in dryland areas of the South Island planted in rows with different tree species.
- A second key knowledge gap is the potential increase of milk solids production given reduced heat stress. We assumed that farmers would move the cows to areas of shade during warmer days (> 25^0C). Given current animal welfare requirements for providing shade for livestock, researching the benefits on milk production under agroforestry system is an important knowledge gap.
- We recommend setting up trials 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.

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Appendix

Additional planting plan and future farm images

Figure 31. Claxby Farms agroforestry planting plan, north-west corner.

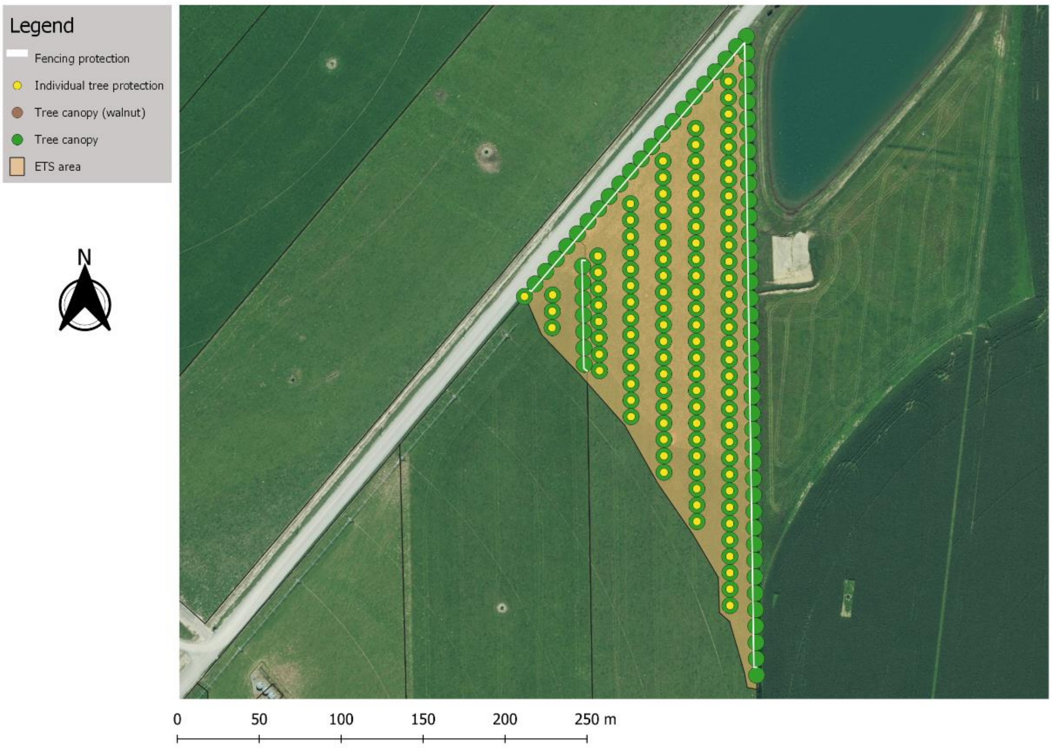

Figure 32. Claxby Farms agroforestry planting plan, north corner.

Figure 33. Claxby Farms agroforestry planting plan, north edge of middle pivot.

Figure 34. Claxby Farms agroforestry planting plan, east dairy shed, house and yards.

Figure 35. Claxby Farms agroforestry planting plan, between middle and east pivots.

Figure 36. Claxby Farms agroforestry planting plan, south edge of middle and east pivots.

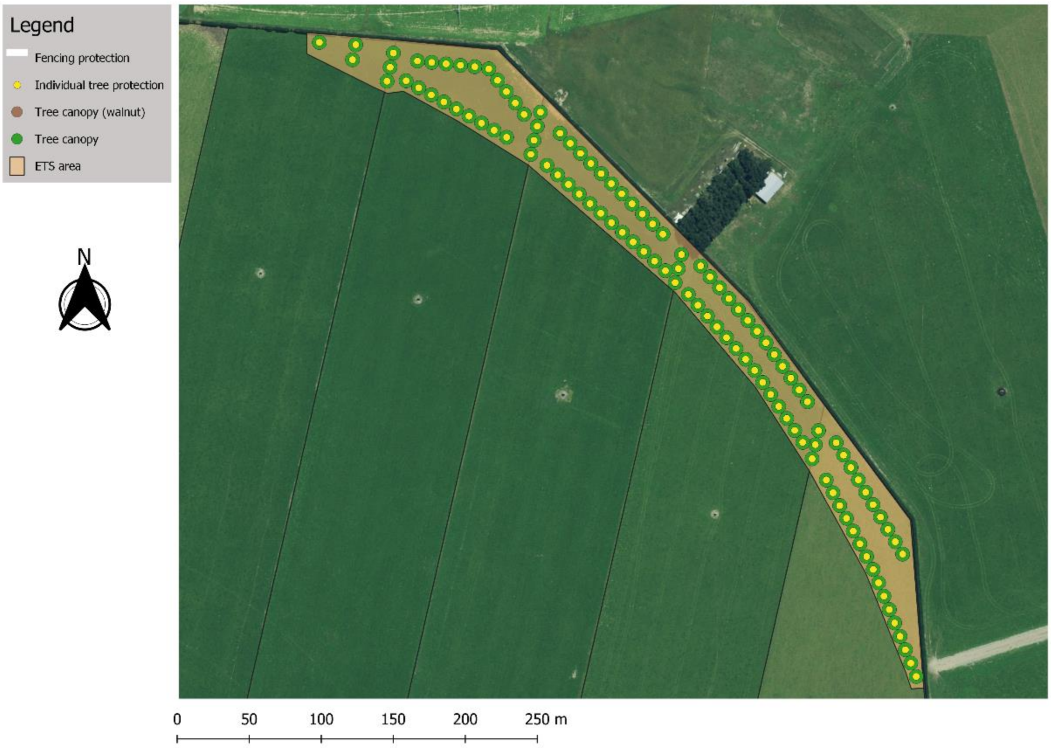

Figure 37. Claxby Farms agroforestry planting plan, north edge of east pivot.

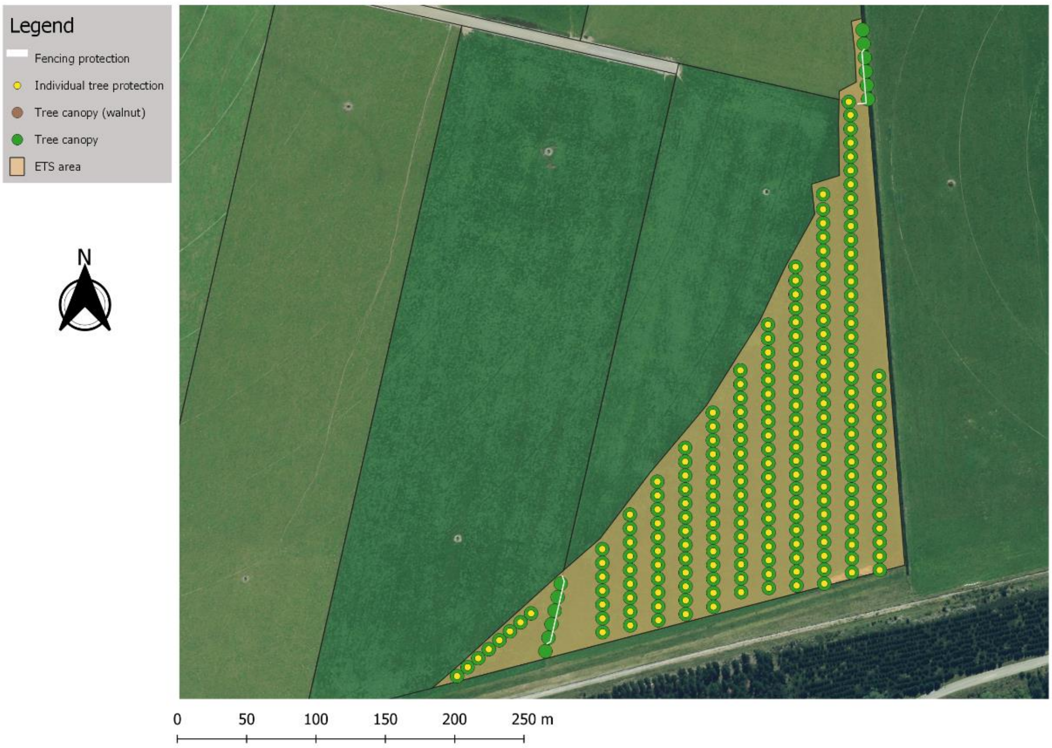

Figure 38. Claxby Farms agroforestry planting plan, south-east corner of east pivot.

Figure 39. Ngāi Tahu – Hamua agroforestry planting plan, dry corner between south and north east pivot.

Figure 40. Ngāi Tahu – Hamua agroforestry planting plan, dryland edge of north east pivot.

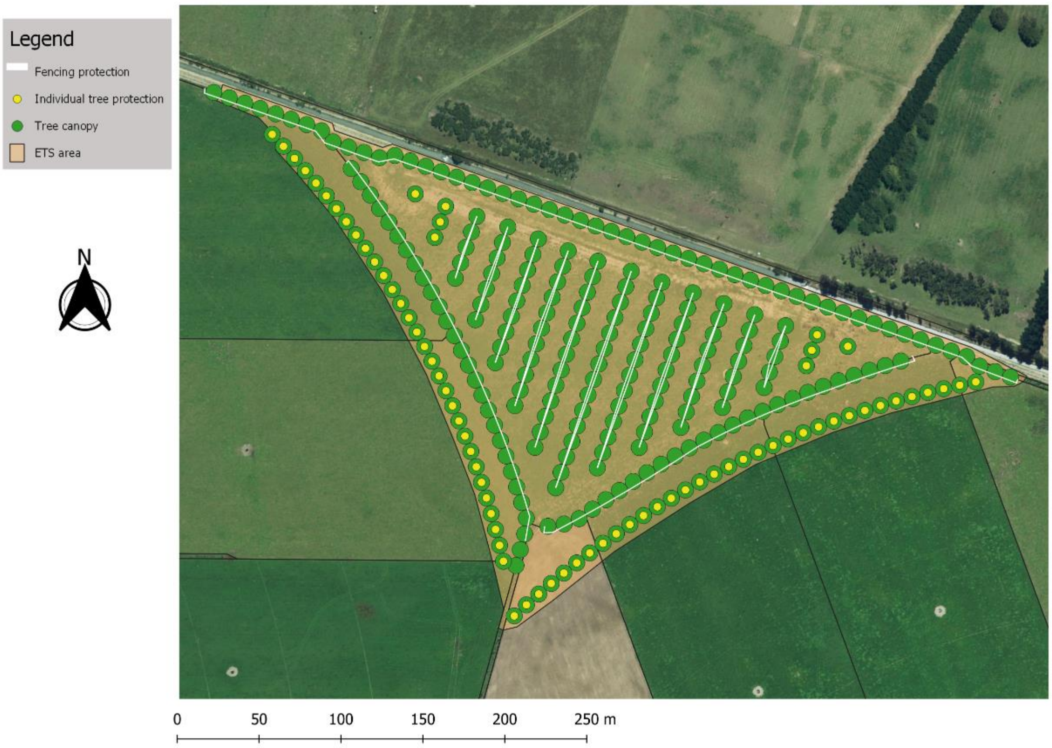

Figure 41. Ngāi Tahu – Hamua agroforestry planting plan, north dryland corner between north east and west pivots.

Figure 42. Ngāi Tahu – Hamua agroforestry planting plan, west dryland edge of north west pivot.

Figure 43. Ngāi Tahu – Hamua agroforestry planting plan, dryland corner between all three pivots.

Figure 44. Claxby Farms future farm image.

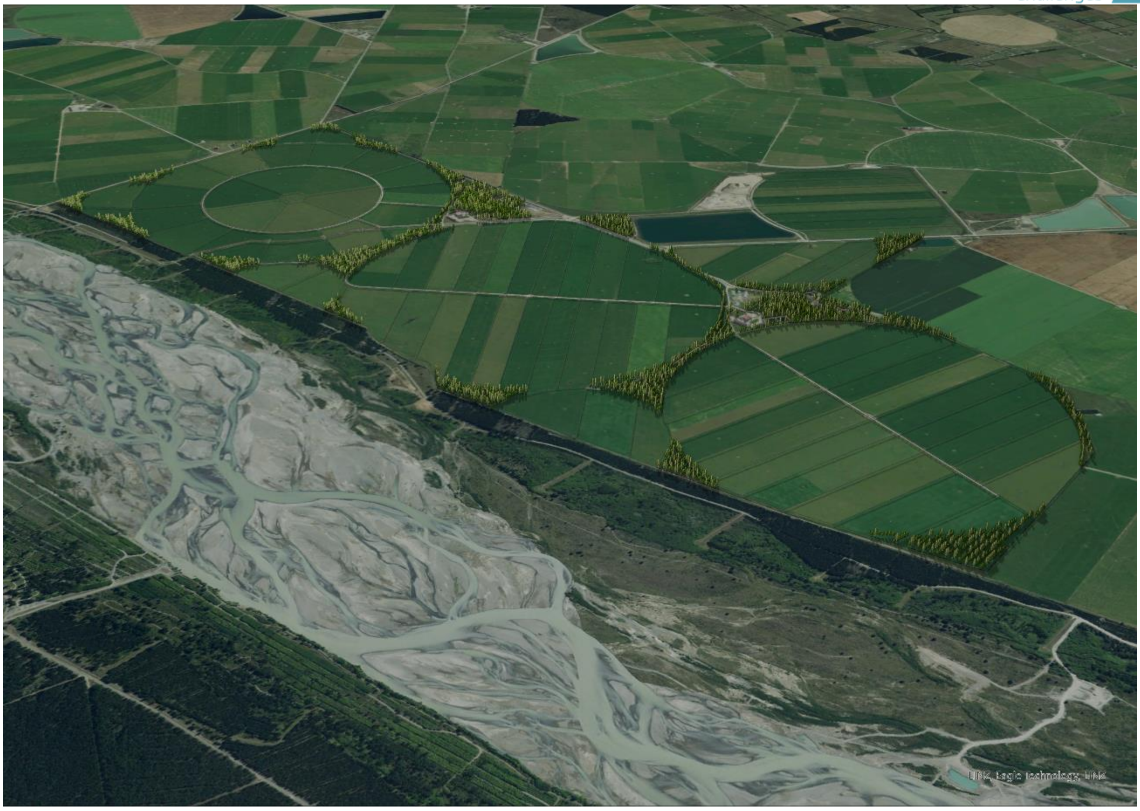

Figure 45. Claxby Farms future farm image.

Figure 46. Claxby Farms future farm image.

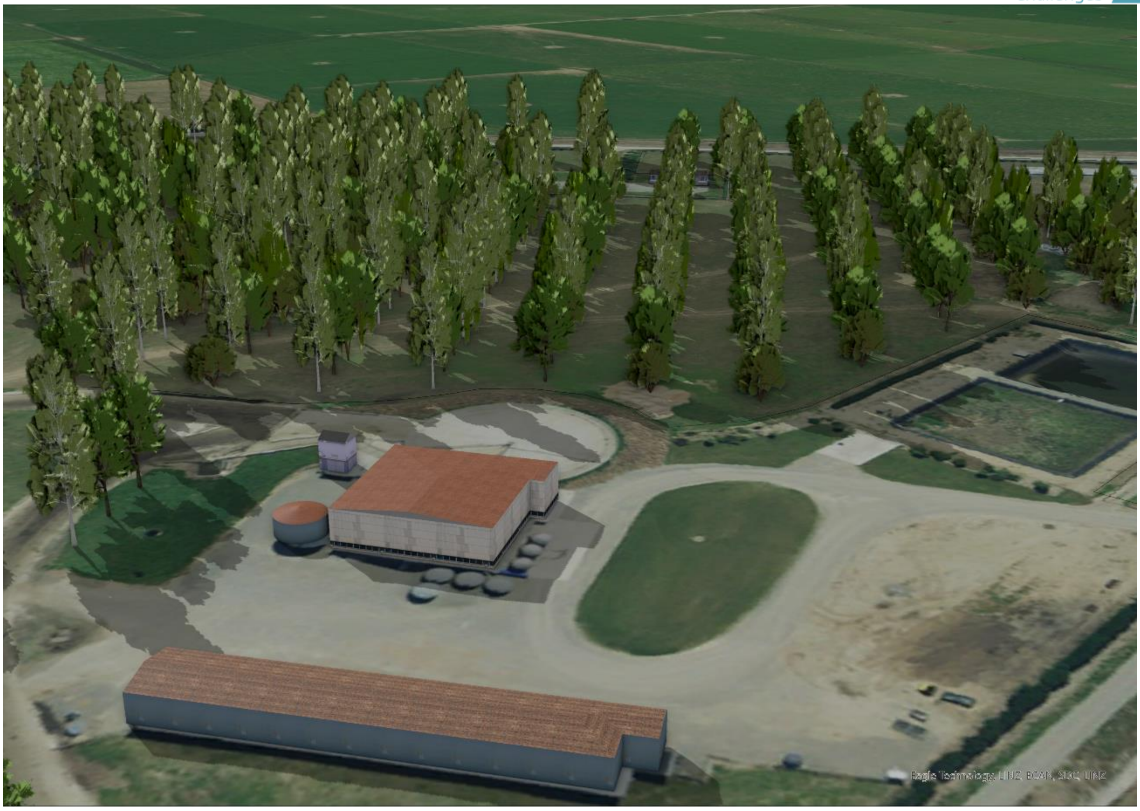

Figure 47. Claxby Farms future farm image.

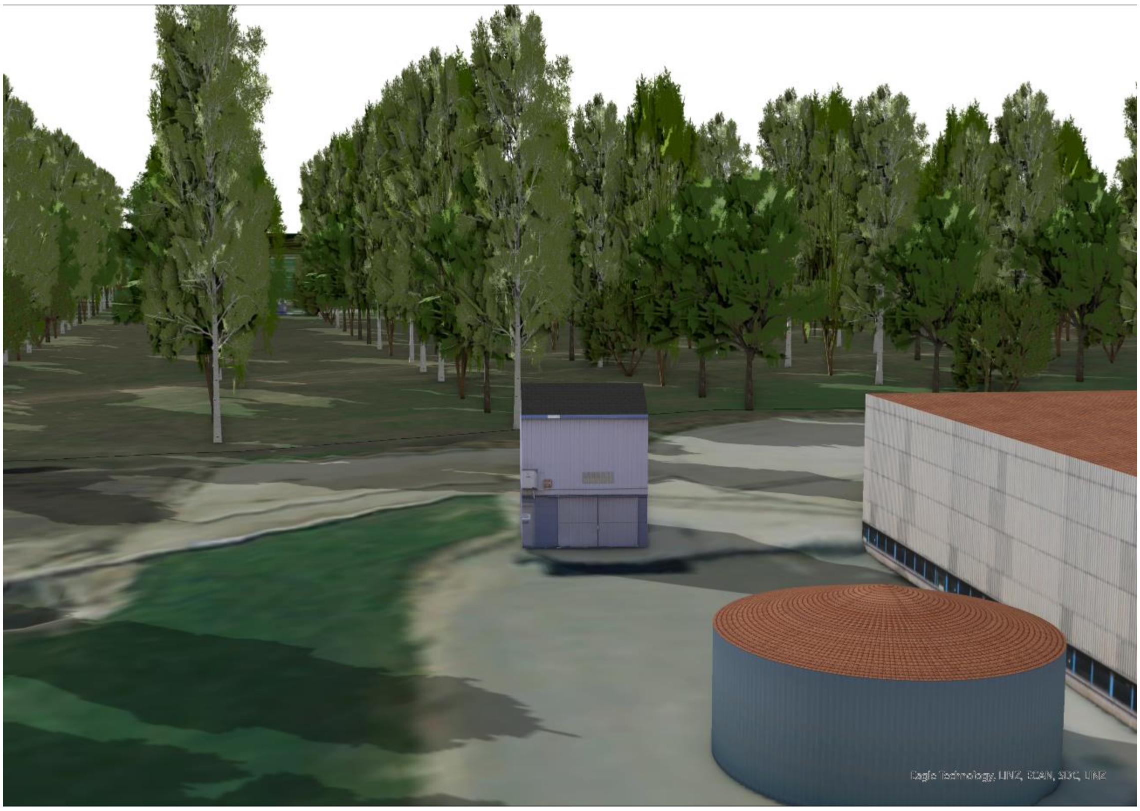

Figure 48. Claxby Farms future farm image.

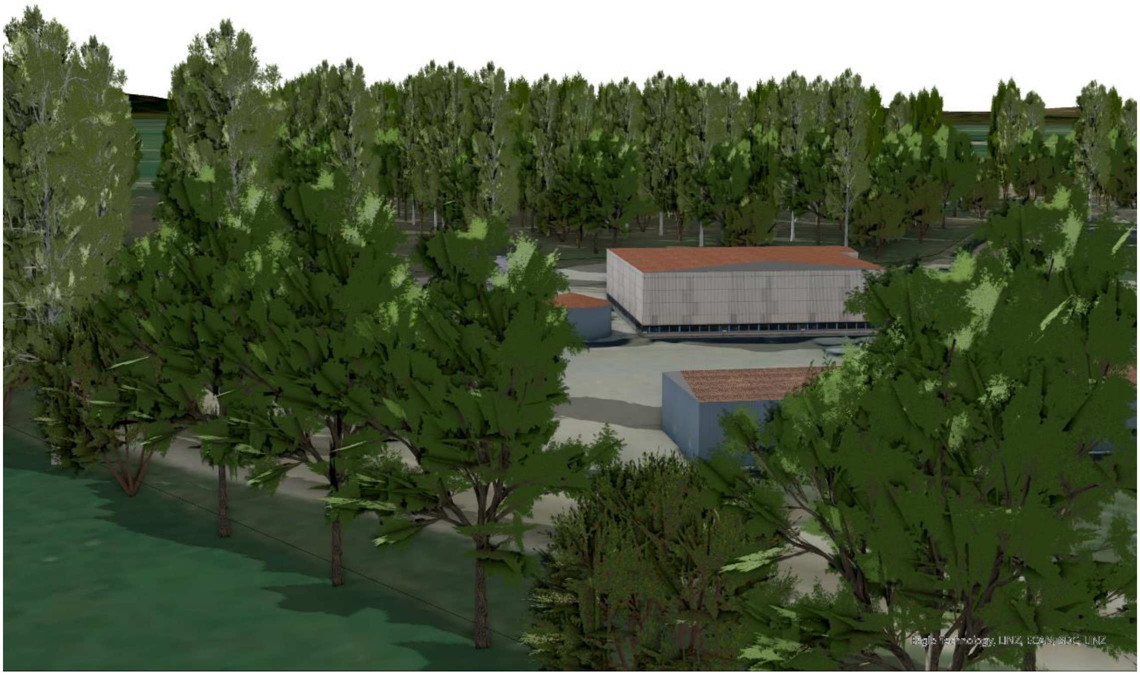

Figure 49. Claxby Farms future farm image.

Figure 50. Claxby Farms future farm image.

Figure 51. Claxby Farms future farm image.

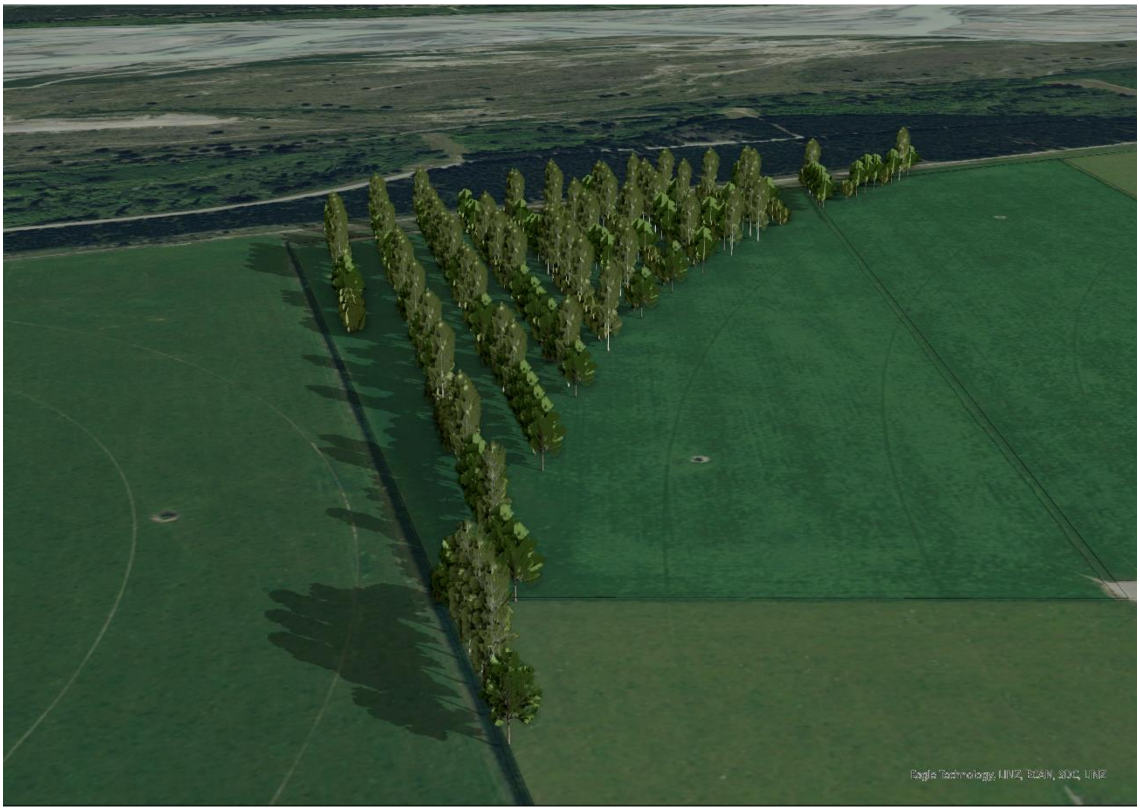

Figure 52.Claxby Farms future farm image.

Figure 53. Claxby Farms future farm image.

Figure 54. Claxby Farms future farm image.

Figure 55. Claxby Farms future farm image.

Figure 56. Ngāi Tahu – Hamua future farm image.

Figure 57. Ngāi Tahu – Hamua future farm image.

Figure 58. Ngāi Tahu – Hamua future farm image.

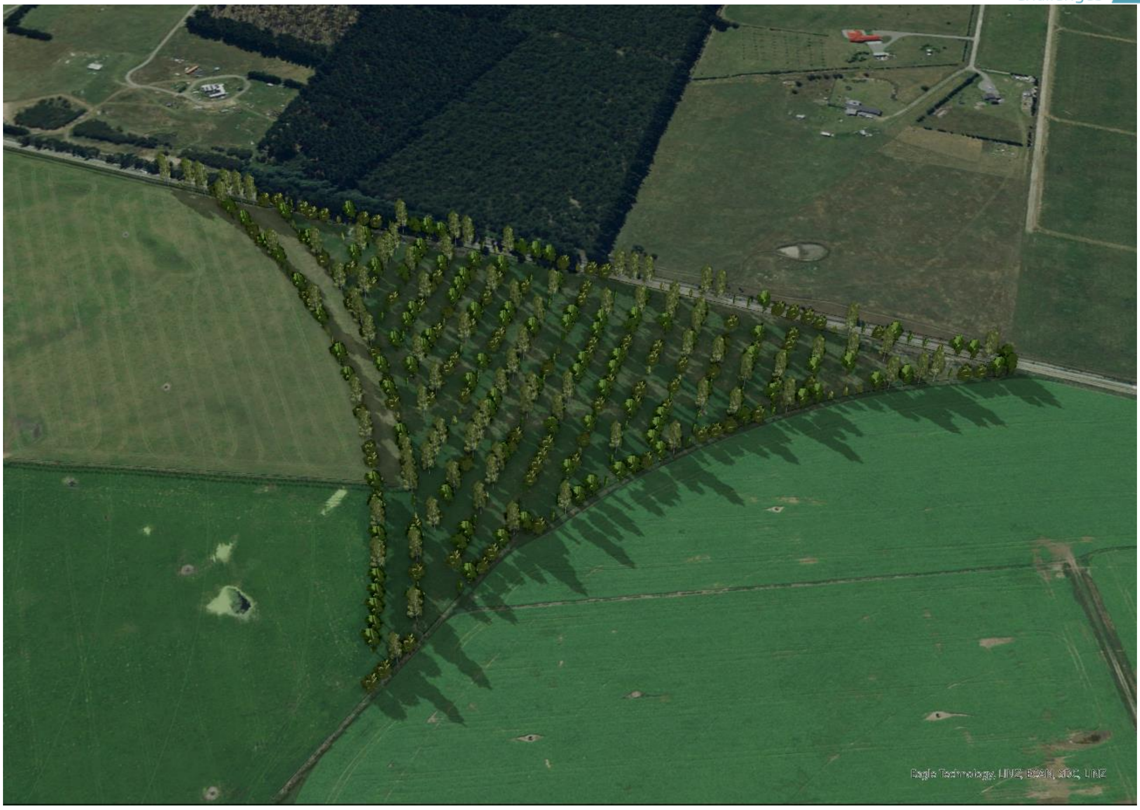

Figure 59. Ngāi Tahu – Hamua future farm image.

Figure 60. Ngāi Tahu – Hamua future farm image.

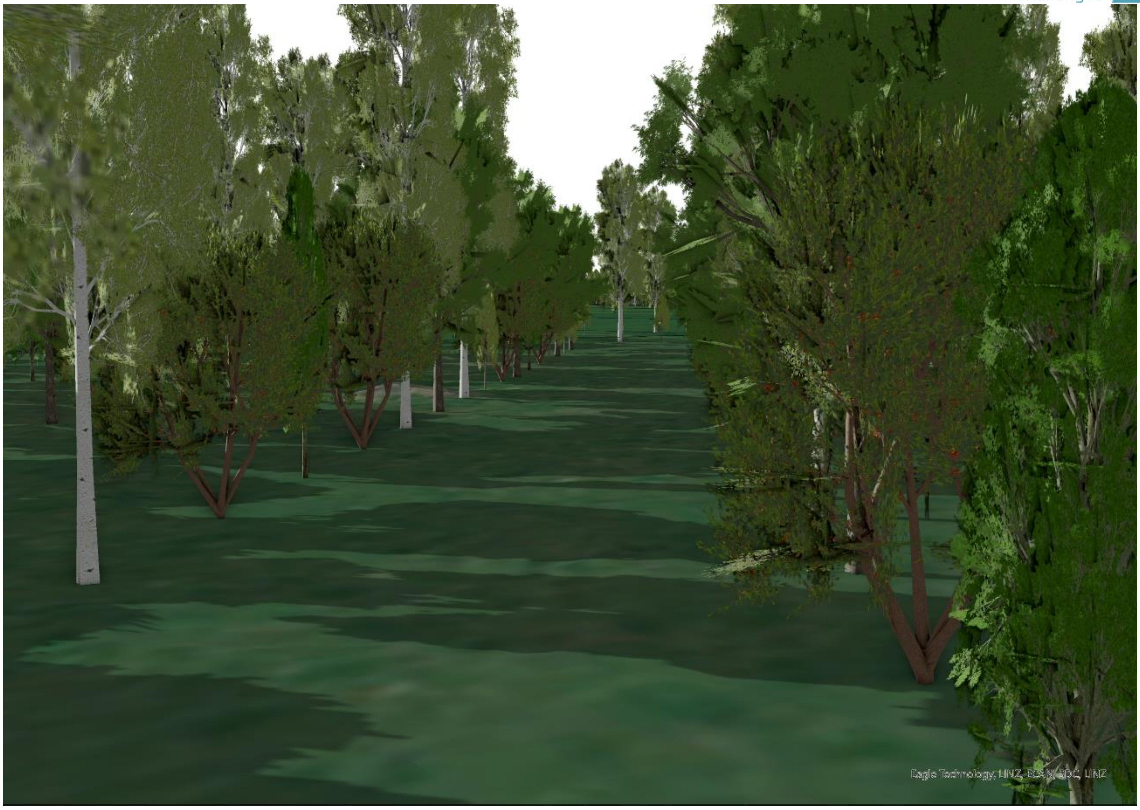

Figure 61. Ngāi Tahu – Hamua future farm image.

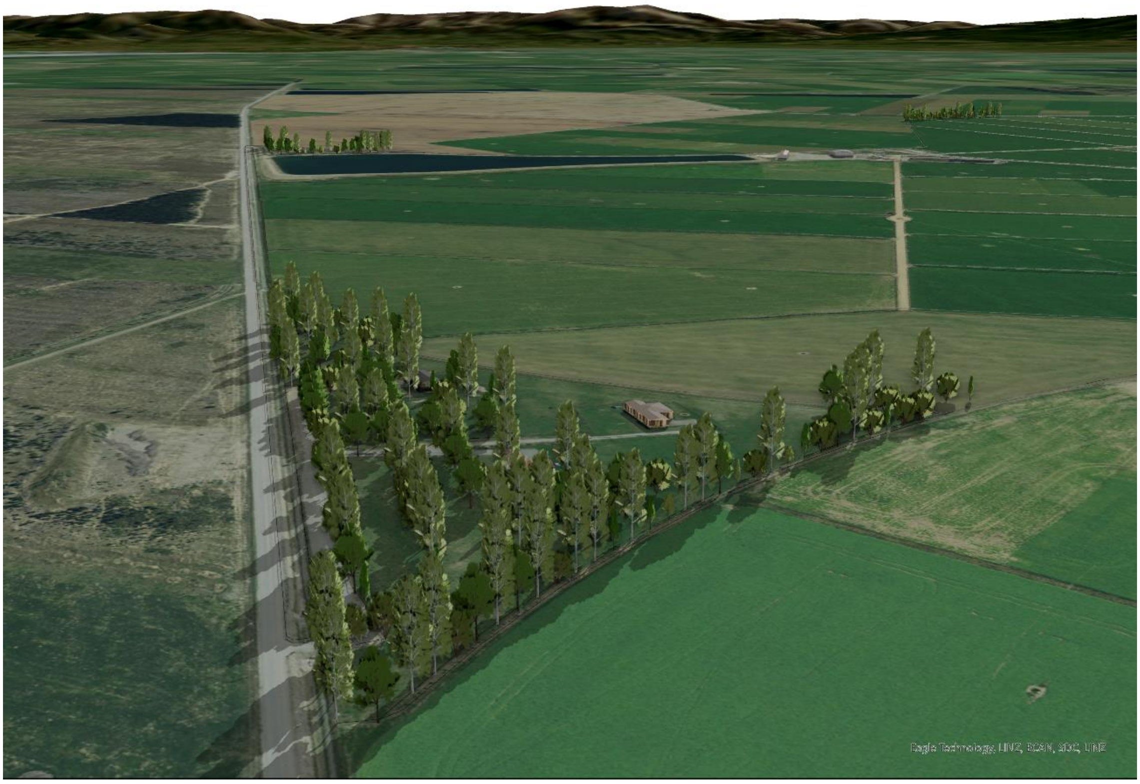

Figure 62. Ngāi Tahu – Hamua future farm image.

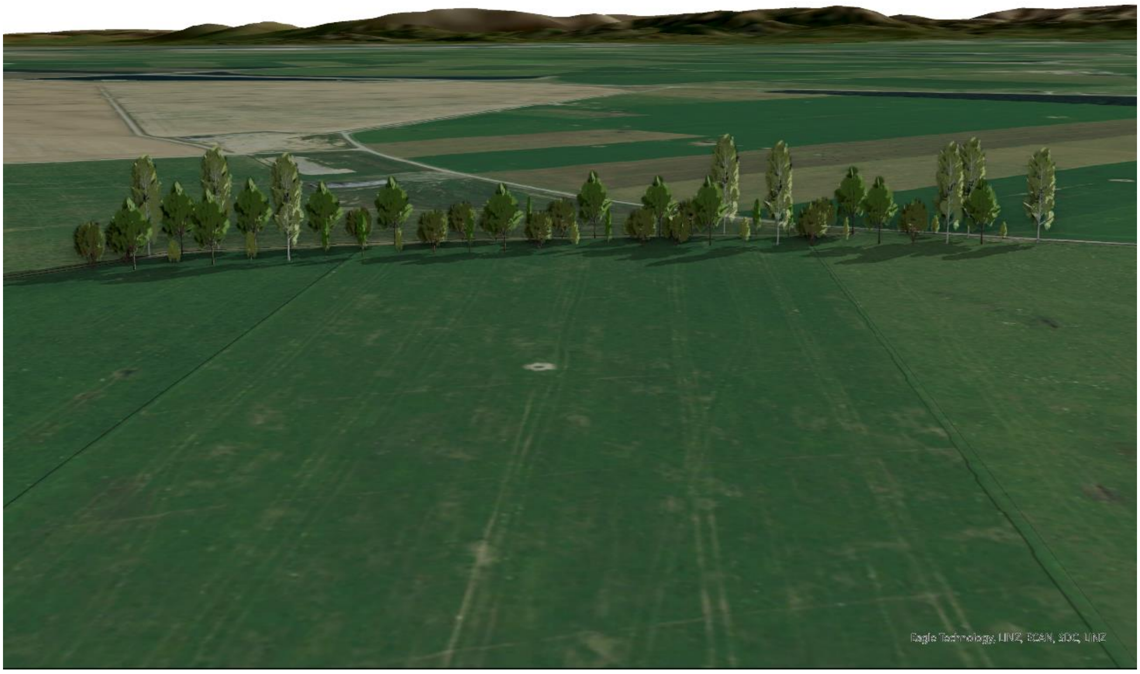

Figure 63. Ngāi Tahu – Hamua future farm image.

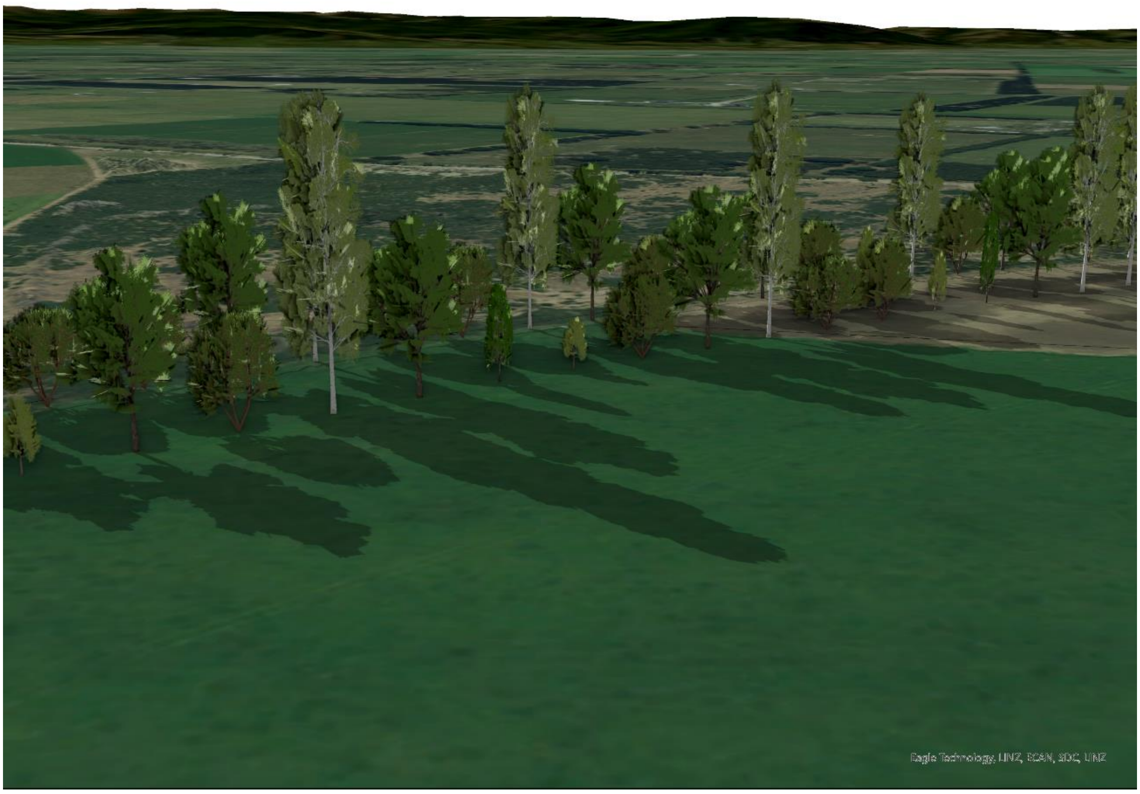

Figure 64. Ngāi Tahu – Hamua future farm image.

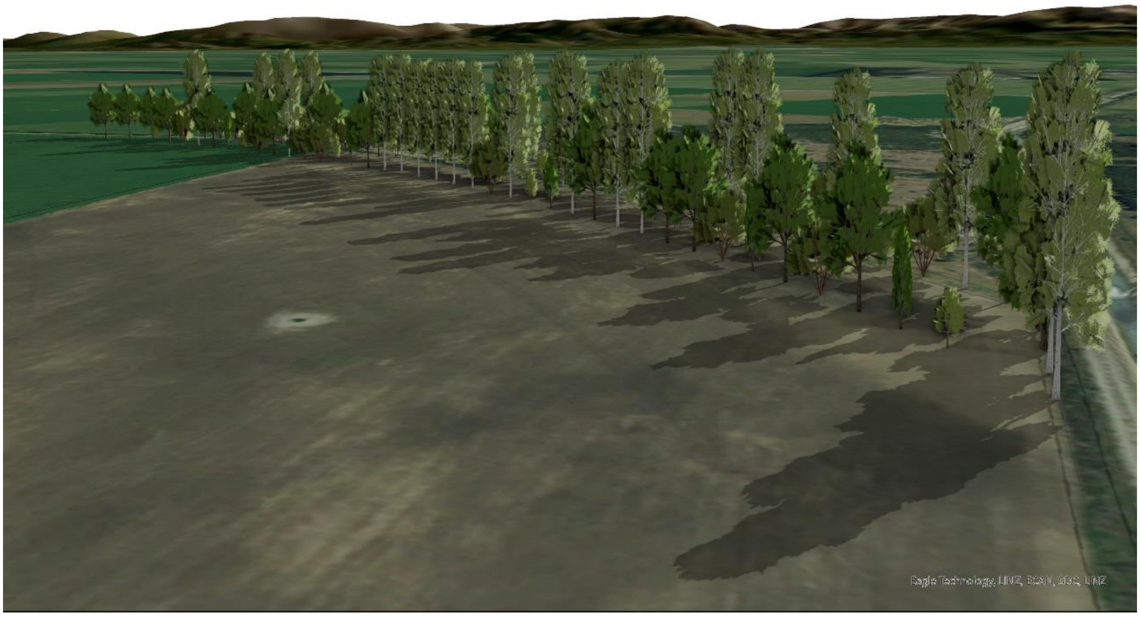

Figure 65. Ngāi Tahu – Hamua future farm image.

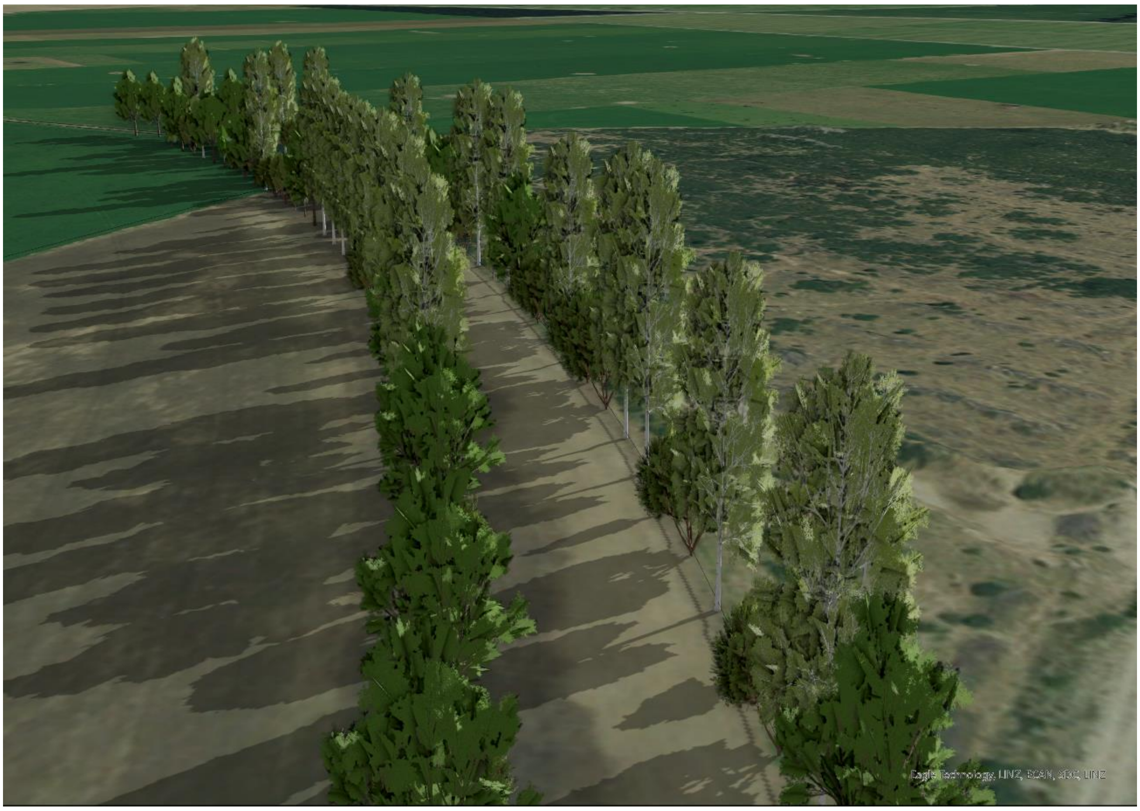

Figure 66. Ngāi Tahu – Hamua future farm image.

Figure 67. Claxby Farms downwind shelter from agroforestry.

Figure 68. Ngāi Tahu – Hamua downwind shelter from agroforestry.

Field Day flyer

Farmer survey questions

1. Are you a farmer in the Waimakariri area?
2. How old are you?
3. How long have you been farming?
4. What farm type are you currently run?
5. Do you currently have trees on your farm? if so, tell us a bit about them. For example, how many are there, what species, when and why were they planted etc?
6. What is your level of knowledge of agroforestry or silvopasture?
7. In your own words, what do you think agroforestry or silvopasture is and do you know of any examples?
8. Agroforestry is the deliberate integration of trees or shrubs into agricultural land. Silvopasture is a subset of agroforestry and refers to the integration of trees and shrubs in a pastoral grazing setting.
9. What potential benefits do you think could be achieved from the integration of trees and shrubs into agricultural systems?
10. What potential negative effects do you think might occur with the integration of trees and shrubs into agricultural systems?
11. How likely would you be to implement agroforestry on your farm in the future?
12. Please explain your answer to question 11.
13. What barriers or challenges do you anticipate in adopting agroforestry?
14. Which factors would reduce perceived barriers and motivate you to adopt agroforestry practices on your farm?
15. What effect do you think agroforestry will have on the below factors? i.e. Nitrogen leaching may reduce which is positive for your farm or habitat for pest species may increase which is negative for your farm.
16. Based on your current understanding, do you think agroforestry speaks to mātauranga Māori or to cultural values? If yes, how? If not, why not?
17. Is there anything else you would like to know more about regarding agroforestry?
18. At the conclusion of this project near the end of the year, we will be sharing the project report which will share the case studies, and address some of the barriers and motivators that you have identified in this survey. Along with this report we would like to ask some follow up questions to determine the level of impact our project has had and what next steps need to be taken. Would you be interested in receiving our project report and answering our follow up questions?
19. If you answered yes to question 18, please provide your email address. Your contact details will not be shared further and will be deleted at the conclusion of the project.