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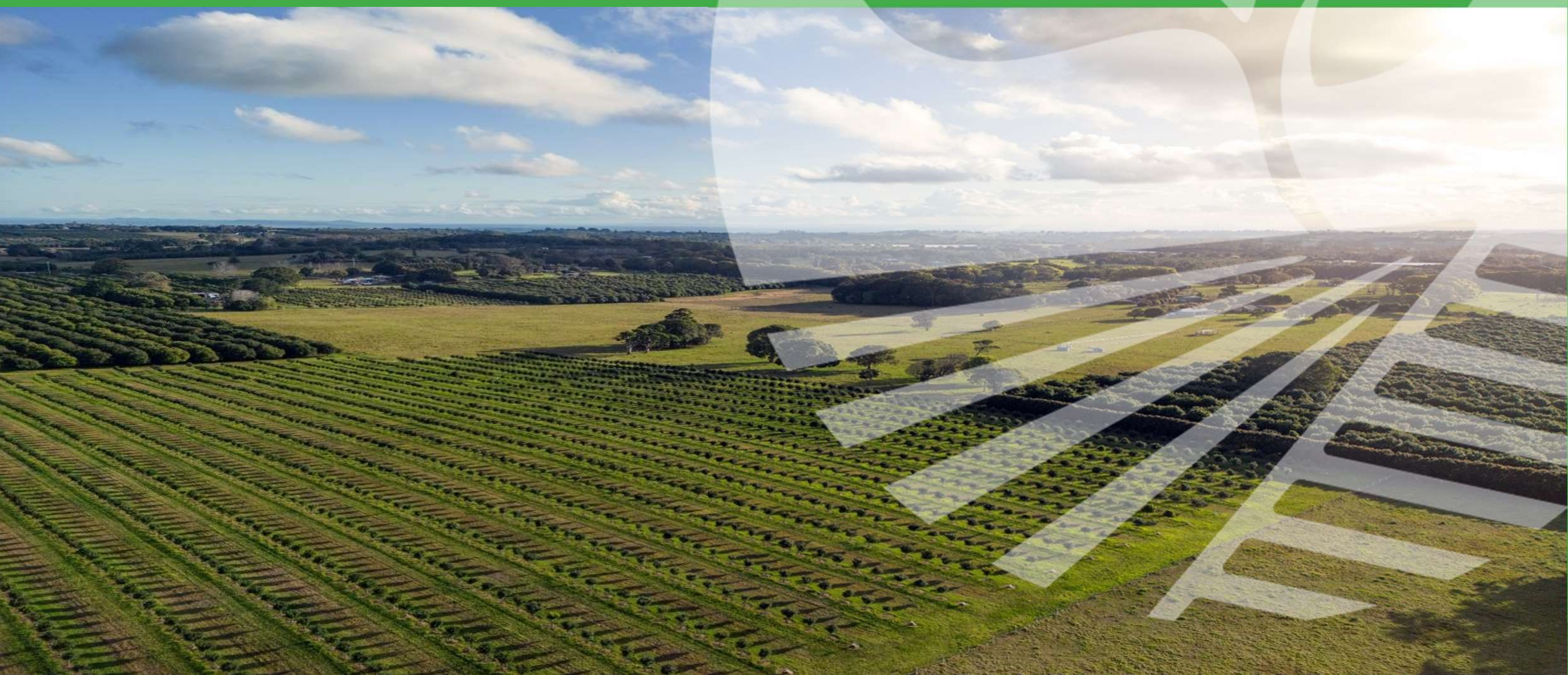
RESEARCH, DEVELOPMENT & EXTENSION SERVICES

Opportunities to sequester carbon in dryland cropping rotations

An economic review of costs and benefits – Stage 2

APRIL 2025



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Executive summary

This study follows on from a desktop study completed in January 2023 on *Opportunities to sequester carbon in dryland cropping rotations*. The earlier study found that changing crop rotations from a traditional baseline to a focus on accumulating soil carbon could be economically viable in two out of the three scenarios modelled.

With both sustainability and decarbonisation becoming a business imperative in agricultural supply chains, board governance and market access, this second stage study aimed to further investigate the extent to which participating in the Emissions Reduction Fund (ERF) with a soil carbon project could produce favourable returns to producers by completing three case studies at Douglas Station (Northern Territory), Kielli (Darling Downs in Queensland), and Blue Hills (Lower Namoi in New South Wales).

Each case study analysis found a positive net present value (NPV) and internal rate of return (IRR) from changing from a baseline practice to a carbon-focussed rotation whilst participating in an ERF soil carbon project. However, the financial results were highly sensitive to assumptions around long-term increases in cropping yields, and moderately sensitive to soil carbon sequestration assumptions. Changes in the discount rate and future ACCU prices were found to have more limited impacts on the financial results. All three case study farms were found to be either carbon neutral or net carbon sinks, owing to sequestration from non-cropped areas.

Future research may seek to investigate further sustainability combination options, including analysis on combining enhanced emissions fertiliser with organic products. The high-level findings on carbon sequestered from native vegetation also generates the prospect for more detailed species analysis on each farm. This would enable a clearer understanding of sequestration potential and an emerging area of consumer interest, biodiversity ‘scores’ of farms used to demonstrate the site stewardship and change over time.

Introduction

This study follows on from a desktop study completed in January 2023 on *Opportunities to sequester carbon in dryland cropping rotations* (referred to as the Stage 1 study from here on). The Stage 1 study found that changing crop rotations from a traditional baseline to a focus on accumulating soil carbon could be economically viable in two out of the three scenarios modelled. The Stage 1 study offered insight into the rate of change of soil carbon stores from more frequent cropping and reduced long fallow, and all scenarios modelled showed an improvement in soil carbon compared to the baseline rotation. Whilst the results of the Stage 1 study provided a useful signpost, it was clear that a more detailed investigation into the working models relied on in the analysis was required to understand both the robustness of the proposed practice change and the key sensitivities in the results.

With both sustainability and decarbonisation becoming a business imperative in agricultural supply chains, board governance and market access, this second stage study (referred to as the Stage 2 study from here on) aimed to further investigate the extent to which the Emissions Reduction Fund (ERF) can produce favourable returns to producers by completing three case studies at Douglas Station (Northern Territory), Kielli (Darling Downs in Queensland), and Blue Hills Aggregation (Lower Namoi in New South Wales). As with the Stage 1 study, the DRCA was seeking to identify and analyse economic opportunities to sequester carbon under alternative carbon farming scenarios to positively contribute to their members' land-use sustainability and provide opportunities to participate in carbon markets.

Our aim, therefore, in the Stage 2 study, was to further explore the potential for DCRA members to utilise their landholdings to optimise agronomic and commercial opportunities from crop rotations through three broadly relevant case studies, while simultaneously capturing any benefits from participating in carbon markets and positively contributing to internal sustainability objectives.

This study is organised as follows:

1. A short synopsis of carbon market participation in agriculture and soil carbon research which provides background context to the study.

2. This is followed by a short description of the study method and the general model inputs, as well as a description of each case study location and the associated, case study location specific, input assumptions.

3. Finally, the results are presented for each location, findings are discussed, and proposed recommendations for the next steps are outlined.

Background

Agriculture is responsible for a significant portion of emissions in Australia, but also and has a substantial opportunity for emissions mitigation through for example landscape management and improved on-farm practices. One way that dryland cropping farmers can potentially mitigate emissions is through increased carbon sequestration in the soil and creating a soil carbon project under a carbon crediting scheme to generate an additional revenue stream.

Emissions in cotton production come from soil, transport, on-farm energy use, and from material inputs such as fertilisers and pesticides. Crops like cotton can also emit and sequester carbon, and the net change in soil carbon is a factor of the relative amounts of emissions released from, and immobilised into, soil in each time frame. Small changes in soil carbon can have a potentially big impact on the emissions of a cropping system.

This chapter highlights relevant background information across soil carbon dynamics, yield impacts from carbon farming, vegetation and carbon balance, and the Emissions Reduction Fund (ERF).

Soil carbon dynamics

Stable management of a given site means that soil organic matter reaches a steady-state equilibrium. In Australia this is primarily determined by the amount of rainfall. However, when inputs (or outputs) are changed the system moves to a new steady-state. One can project through process modelling the potential rates of change of soil carbon in different regions under different types of land management. The following table shows an estimate of potential carbon sequestration for several project management activities, including sustainable intensification. Sustainable intensification can involve for example new irrigation, fertiliser, liming, or pasture renovation. This is based on the Full Carbon Accounting Model (FullCAM) (White, et. al. 2021).

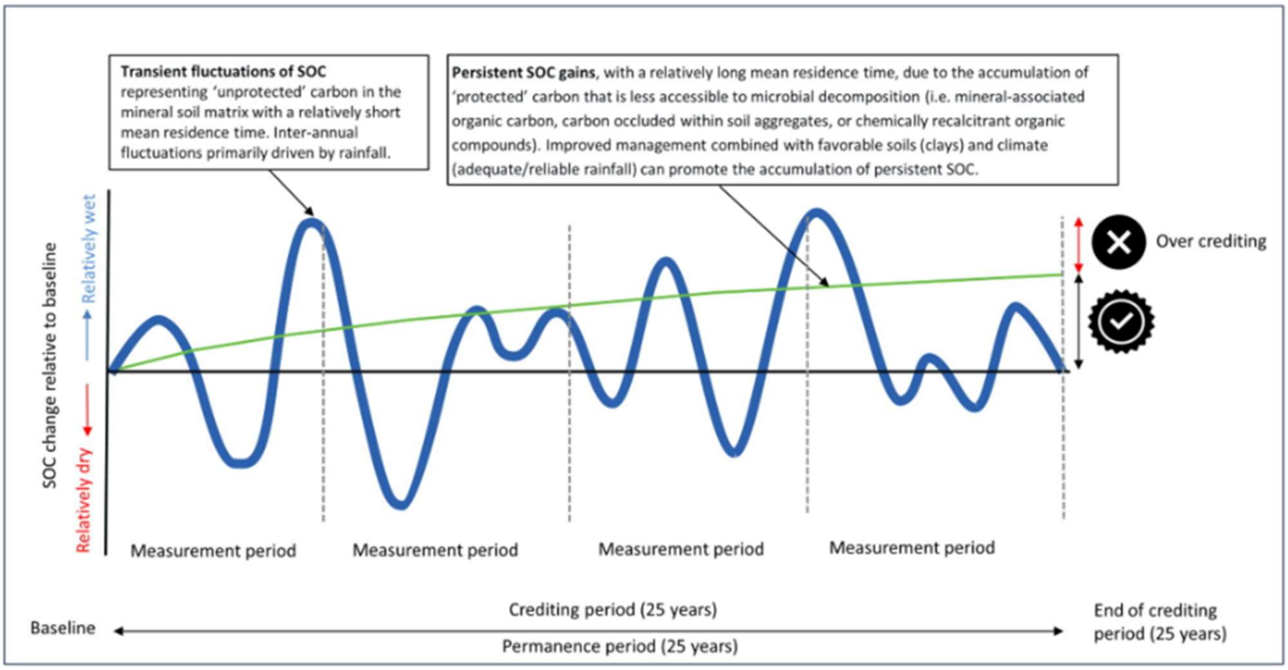
Table 1: Modelled sequestration values (t CO2-e/ha/year) for a given management activity in regionals of different sequestration potential

Project management activity	Categories of sequestration potential			
	Ineligible land (no modelled)	Marginal benefit	Some benefit	More benefit
Sustainable intensification	No value	0.11 (0.03)	0.59 (0.16)	1.65 (0.45)
Stubble retention	No value	0.07 (0.02)	0.29 (0.08)	0.73 (0.020)
Conversion to pasture	No value	0.22 (0.06)	0.44 (0.12)	0.84 (0.23)

The capacity of soil to retain additional C inputs will largely depend on the ability of the soil to “protect” added organic material, which in turn depends on clay content and mineralogy, soil structure, location within the soil profile, chemical nature and composition of organic matter inputs, the occupancy of mineral surfaces by pre-existing carbon compounds. Due to the influence of soil physicochemical properties on the retention of more stable Soil Organic Carbon (SOC), the ability to retain carbon inputs will likely vary between soil carbon projects, given their different soil properties and pedoclimatic environments.

Rainfall has a significant influence on the accumulation and depletion on carbon stores. If a project was baselined under lower-than-average rainfall and completed in 2019 under higher-than-average rainfall, likely resulting in a corresponding positive trajectory in SOC (even if no management change was implemented). Similarly, if a carbon project was baselined in 2022 under higher-than-average rainfall conditions (scenario 2) and completed in 2023 (a drier year), there was a downward trajectory in rainfall. The fluctuations of carbon stores are illustrated in Figure 1 below (Mitchell, et. al. 2024).

Figure 1: Soil carbon stores fluctuate over time, depending on rainfall and seasonal conditions (blue line). Source: Mitchell, et. al. (2024)



Estimating yield impacts from carbon farming

Sustainable intensification has the potential to improve crop yields over time. A wide review of impacts on crop yield from carbon farming suggested a material positive impact, as per Table 2 below.

Table 2: Review of yield impacts from carbon farming

Author	Journal	Study focus	Findings
Vendig et. al. (2022)	Nature Sustainability	US meta-analysis	0-20.2% yield increase. Yields increased 60% of the time.
Vendig et. al. (2023)	Nature Sustainability	Global meta-analysis	Yield response depends on SC %. Range 0-24.3%
Ma, J et. al. (2023)	Advanced Earth and Space Science	Global meta-analysis	7% increase in soil carbon, 2% increase in production
Oldfield, E.E., et. al. (2019)	European Geosciences	Global meta-analysis	Yield increases 10-37% when soil carbon levels reached 2% grains slowed.
Devereux, A.F. et. al. (2014)	Agronomy Australia Proceedings	Cotton yields following corn	Up to 25% cotton yield increase.

Vegetation and carbon balance

Carbon yield from vegetation in non-cropped areas can vary greatly, depending on species assumptions (Smith et. al. 2014, Smith and Reid, 2013). Riparian River Redgum can sequester around 7 t CO2e per hectare annually, with perennial grass species yielding around 1 t CO2e per hectare annually.

Table 3: Vegetation and carbon balance

Vegetation type	Structure	t CO2-e / ha / year
Riparian River Redgum	Old growth, some thinning	7.60
Coolibah woodland	Mature and regenerating trees	1.84
Brigalow	Pockets of dense regen	2.39
Poplar box and brigalow	Open brigalow	2.20
Tropical pasture	Bambasti, Rhodes grass etc	0.99
Native grasses	Mix of species	0.99

Emissions Reduction Fund

Farmers and land managers can benefit financially from increasing the amount of carbon in their soil through participating in carbon markets. The major carbon crediting schemes that have provisions for soil carbon projects include the Emissions Reduction Fund (ERF) in Australia, as well as international credit schemes, such as the Verified Carbon Standard (VCS) and Gold Standard (GS). It is also possible to participate in carbon markets through obtaining a sustainability certification that results in a price premium.

The price premium approach was the focus of the Stage 1 study, however, soil carbon projects through the ERF are the focus of this Stage 2 study. The ERF provides the opportunity to run new projects in Australia that reduce or remove emissions from the atmosphere. The scheme is administered by the Clean Energy Regulator (CER). Running a project allows a participant to earn Australian carbon credit units (ACCUs) and sell them to the Australian government, to companies, or other private buyers. Projects can include, for example, using new technology, upgrading equipment, changing business practices to improve productivity or energy use, or changing the way vegetation is managed.

One of the agricultural ACCU methods available for growers involves estimating soil organic carbon sequestration using measurement and models method. This method involves demonstrating an increase in soil carbon above a baseline level by testing and sampling soil. Farmers or landowners can be eligible to run a soil carbon project if their land is used for pasture, cropping, perennial horticulture or is bare fallow during a base line period, if soil carbon can be increased through new land management activities, if it is possible to sample the soil, and there is at least 30 cm of soil.

The method credits ACCUs for increasing soil carbon through for example using a legume species in a cropping or pasture system, applying nutrients to the land in the form of a synthetic or non-synthetic fertiliser to address a material deficiency, using a cover crop to promote vegetation cover or improve soil health. The eligible management activity needs to be new or materially different from what was already being done.

There are costs associated with a soil carbon project, including monitoring, record-keeping, sampling, reporting and audit costs, and the way that carbon abatement is calculated can be complex, including credit discounts to ensure issued carbon credits do not overestimate stored carbon. The minimum period which carbon must be stored to participate in an ERF project is 25 years.

Method

A **discounted cash flow** (DCF) modelling approach was used to assess the net present value (NPV) of future cash flows comparing a baseline and an alternative scenario for each case study location. A DCF can better represent the time value of money [10]. Is it suitable as it can capture future agronomic land use changes from yield and carbon stores, the five yearly ERF project costs for maintenance and monitoring, and future appreciation of ACCUs (Diaz, et. al. 2018). Whilst the ERF project was assumed to last 25 years, a 10-year time horizon was used in modelling.

The **alternative scenario** for each case study was established with the following principles in mind:

- Comply with carbon farming principles, as set out in Farrel, et al (2021)
- Satisfy additionality criteria as defined by the Clean Energy Regulator (2024)
- Offer a realistic and practical alternative to the baseline scenario (AMPS Agribusiness Research, 2025)

The **revenues, costs, and gross margins** for the baseline and alternative scenarios were established together with managers of each case study location. The revenues, costs, and gross margins were assumed to remain constant in real terms over the modelling horizon and are summarised in the following chapter for alternative scenarios (Case study locations).

The **changes in crop yields** per year were determined with reference to detailed desktop research (see Table 2). The crop yield changes were specific to each case study location and are detailed in the next chapter (Case study locations).

The **change in soil carbon** per year was determined with reference to modelled sequestration values achieved through sustainable intensification as detailed in the previous chapter (Background). It was assumed that for dryland cropping sustainable intensification 0.59 tCO_2-e per hectare per year was yielded. The methods considered to increase soil carbon included millet cover cropping, which is a proven method to build carbon stores cheaply and efficiently per millimeter of rainfall (Erbacher, et al 2020). Adding organic fertiliser at planting with a lower emissions factor (EF) than synthetics (see Table 4) was also considered to increase soil carbon (Walling & Vaneeckhaute, 2020 and Paini et al 2024). The below summary shows the nutrient profiles of each product and the costs applied to the Gross Margins.

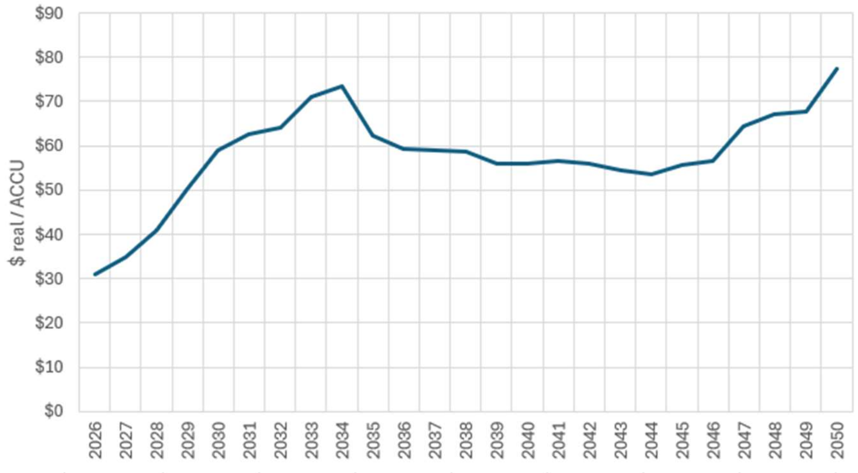
Table 4: Organic fertiliser inputs. Terrus Pro was used in the analysis

Product	N-P-K-S	% carbon	Bulk cost $/t	Moisture
Terrus Pro	3-1-4-2	28	$600	10-12%
Terrus	3-2-1-1	31	$550	10-12%
Terra Firma	4-2-3-1	37	$300	5-10%

Increases in **annualised average project emissions** resulting from the rotation or practice changes were subtracted from the soil carbon yield, consistent with ERF carbon abatement calculations.

Participants can earn an ACCU for every tonne of carbon dioxide equivalent (tCO_2-e) emissions stored or avoided by a project. The future **price of an ACCU** was determined with reference to a central estimate established by Ernst & Young Australia (2023) (see Figure 2). The relevant temporary withholding discounts and permanence discounts were applied to the number of ACCUs generated.

Figure 2: EY Australia central estimate for ACCU prices



The upfront and ongoing ERF project costs were determined with reference to a 2023 study comparing major carbon offset standards for soil carbon projects in Australian grazing lands Pudasaini, et. al (2024). The costs for baseline sampling and measurement, and maintenance and monitoring in this study were scaled to reflect the cropping hectares in each case study location. All costs have been included regardless of if they typically fall to an agent or a landholder. The project implementation costs were assumed to be part of the gross margin costs.

Table 5: ERF soil carbon project costs

Item	Cost	Occurrence
Project certification (fixed)	$5,000	Establishment
Baseline sampling and measurement	$114/ha	Establishment
Maintenance and monitoring	$150/ha	Every five years for 25 years

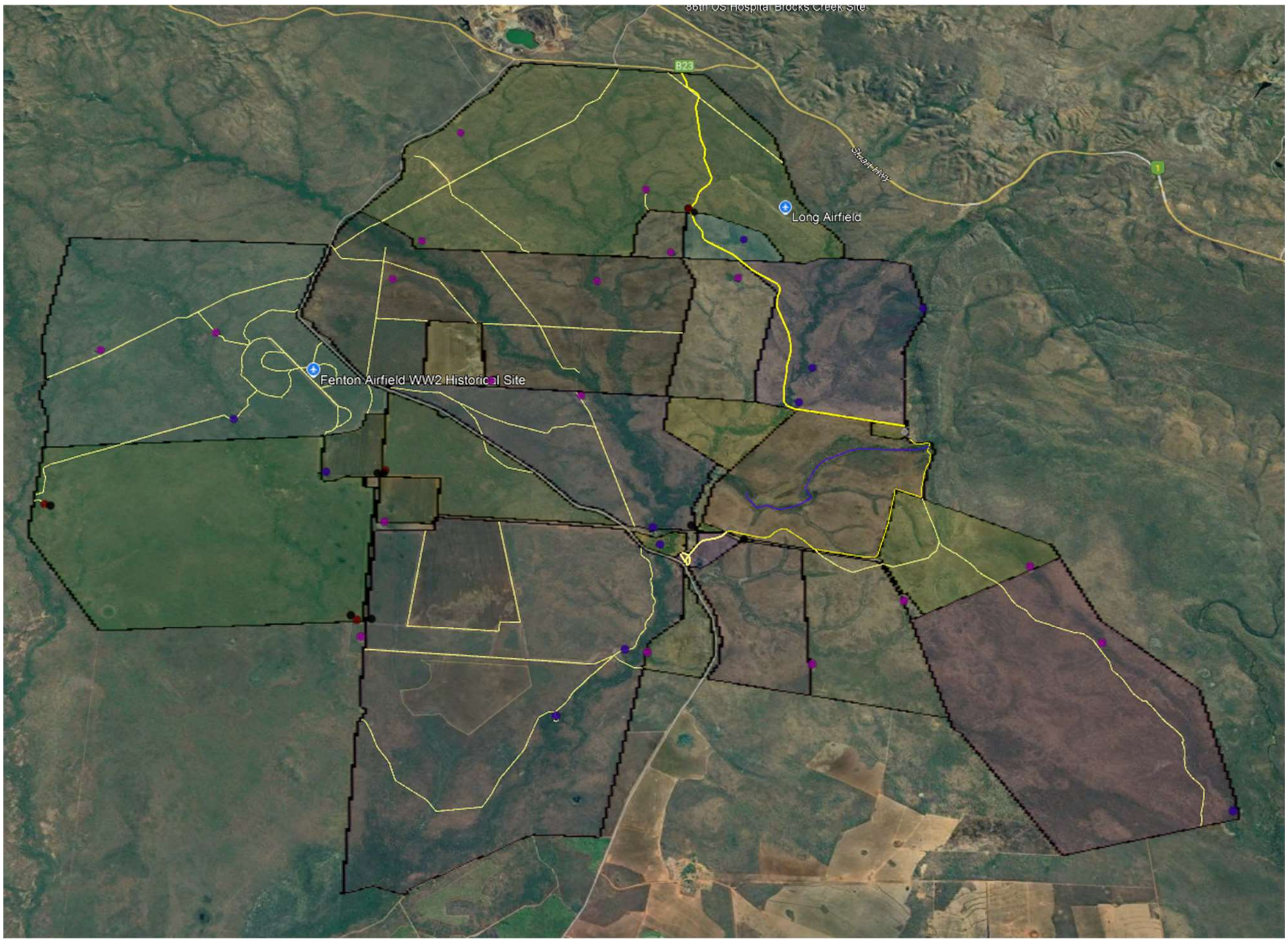
The analysis utilised a **discount rate** of 8 per cent, derived from the current interest rate to account for the time value of money.

Case study locations

Douglas Station, Northern Territory

Case study location 1 was Douglas Station in the Northern Territory (see Figure 3). The location has the Köppen classification Savanna, a mean annual rainfall of 1,146 mm, and an altitude of 189 meters. The total holding was 23,152 hectares, with 500 hectares of cropping, 2,500 hectares of riparian scattered woodlands, and 20,000 hectares of grasslands.

Figure 3: Map of Douglas Station, Northern Territory



The baseline rotation at Douglas Station was cotton – cotton. The alternative rotation was cotton – cotton – corn, with 300 kg/ha Terrus Pro fertiliser added alongside the corn. The introduction of corn was aimed at increasing the carbon in the soil. It was assumed that the cotton yield in the baseline rotation decreased by 2 per cent per year over 10 years (Constable and Bange, 2015), and that the yield across the crops increased by 5 per cent following corn and 2 per cent in every other year in the alternative scenario. The total scope 1, 2, and 3 emissions decreased because of the practice change (not including soil carbon).

Table 6: Gross margins at Douglas Station for alternative scenario

	Cotton	Corn
Revenue	$3,200	$1,750
Costs	$1,811	$1,044
Gross margin	$1,389	$706

Kielli, Darling Downs in Queensland

Case study location 2 was Kielli in Darling Downs in Queensland (see Figure 4). It has the Köppen classification temperate (hot summer), a mean annual rainfall of 589 mm, and an altitude of 377 meters. The total holding was 635 hectares, with 500 hectares of cropping and 135 hectares of scattered riparian woodlands and grasslands.

Figure 4: Map of Kielli, Darling Downs in Queensland

The baseline rotation at Kielli was cotton – millet. The alternative rotation was cotton – millet also, but with 300 kg/ha Terrus Pro fertiliser biannually alongside the millet. It was assumed that the yield across the crops increased by 2 per cent each year in the alternative scenario. The total scope 1, 2, and 3 emissions increased marginally because of the practice change (not including soil carbon), and this was reflected in the carbon project revenues.

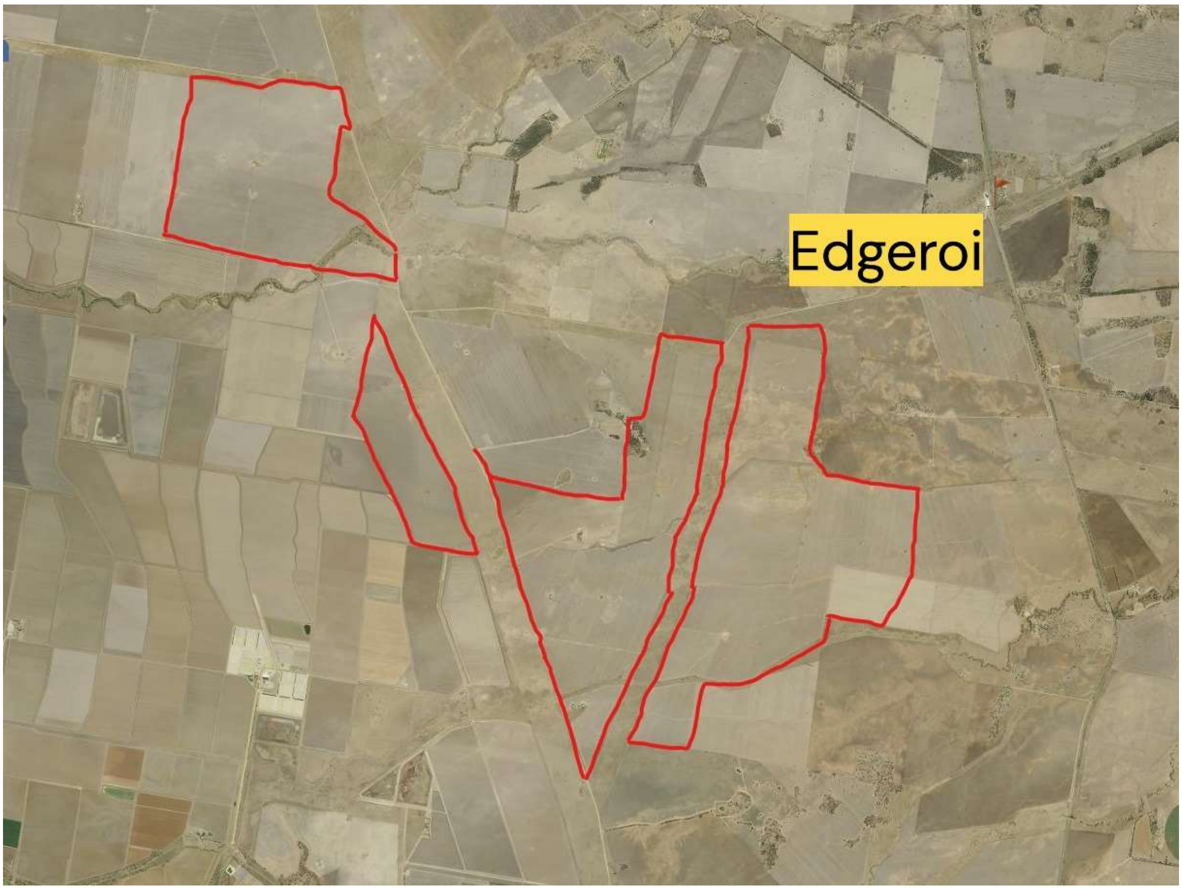
Table 7: Gross margins at Kielli for alternative scenario

	Cotton	Millet
Revenue	$2,572	$0
Costs	$1,228	$335
Gross margin	$1,344	-$355

Blue Hills Aggregation, Lower Namoi in New South Wales

Case study location 3 was Blue Hills in Lower Namoi in New South Wales (see Figure 5). It has the Köppen classification subtropical (dry winter), a mean annual rainfall of 624 mm, and an altitude of 260 meters. The total holding was 6,578 hectares, with 5,060 hectares of cropping, 710 hectares of native woodlands, and 808 ha of grasslands.

Figure 5: Map of Blue Hills, the western part of the aggregation, Lower Namoi in New South Wales



The baseline rotation at Blue Hills was wheat – canola – fallow – cotton – chickpea. The alternative rotation was wheat – canola – fallow – cotton – chickpea - millet, with 100 kg/ha Terrus Pro fertiliser alongside the chickpea, cotton, and canola. It was assumed that the yield across the crops increased by 2 per cent each year in the alternative scenario. The total scope 1, 2, and 3 emissions increased marginally because of the practice change (not including soil carbon), and this was reflected in the carbon project revenues.

Table 8: Gross margins at Blue Hills for alternative scenario

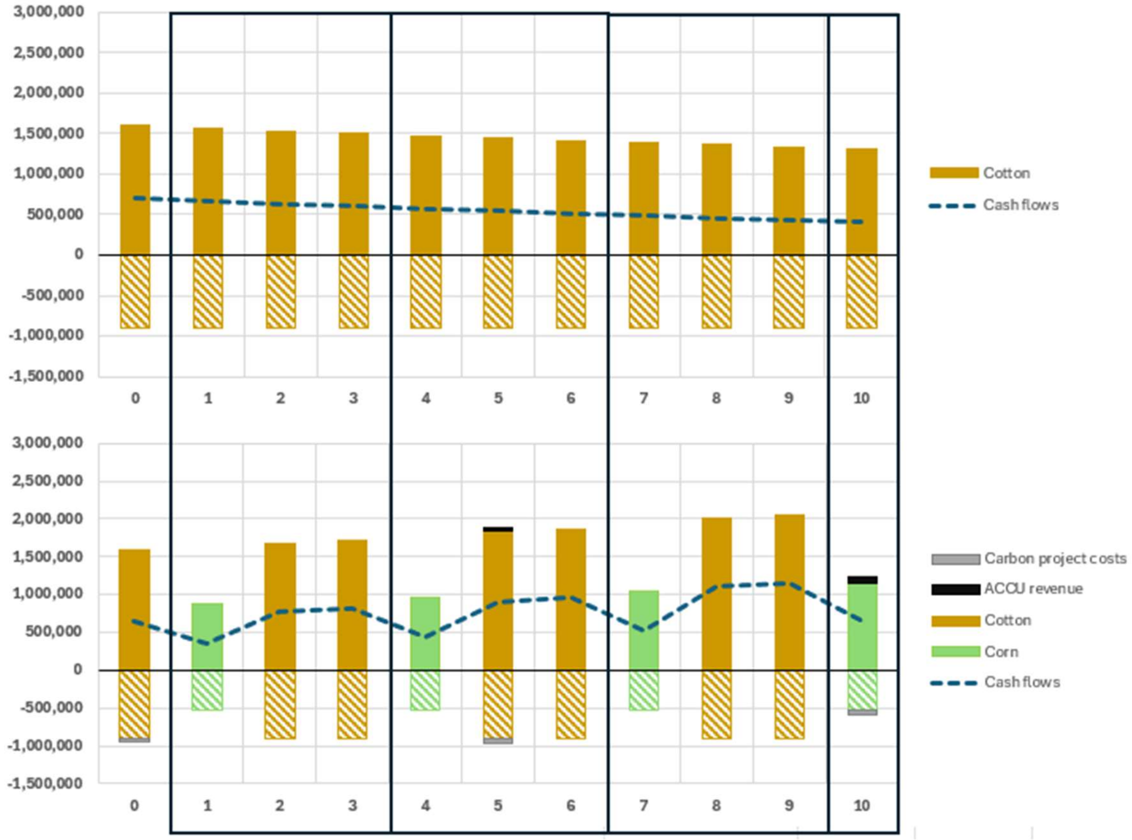
	Wheat	Chickpea	Cotton	Millet	Canola
Revenue	$1,120	$1,600	$2,251	$0	$1,296
Costs	$693	$648	$1,205	$148	$890
Gross Margin	$427	$952	$1,046	-$148	$406

Results

Douglas Station, Northern Territory

The baseline rotation at Douglas Station was cotton – cotton (top of Figure 6). The alternative rotation was cotton – cotton – corn, with 300 kg/ha Terrus Pro fertiliser added alongside the corn (bottom of Figure 6). The net benefits associated with the carbon project were small relative to the overall project economics (black/grey bars), and the agronomic assumptions (e.g. yield increases over time) were a key driver of the returns. The NPV was $1.2 million, and the internal rate of return (IRR) was 48%.

Figure 6: Results for Douglas Station



The results are sensitive to the input assumptions made in the analysis. The following tables show how changes in the key input assumptions change the returns. The baseline assumption from the above results is highlighted yellow.

Table 9: Discount rate sensitivity

		5%	8%	10%
NPV	$	1,557,048	1,233,279	1,057,537
IRR	%	48%	48%	48%

Table 10: ACCU price sensitivity

		Flat $18	Flat $35	EY central estimate
NPV	$	1,187,456	1,205,589	1,233,279
IRR	%	47%	48%	48%

Table 11: Soil carbon sensitivity

		Marginal benefit	Some benefit	More benefit
NPV	$	1,180,380	1,233,279	1,350,097
IRR	%	47%	48%	50%

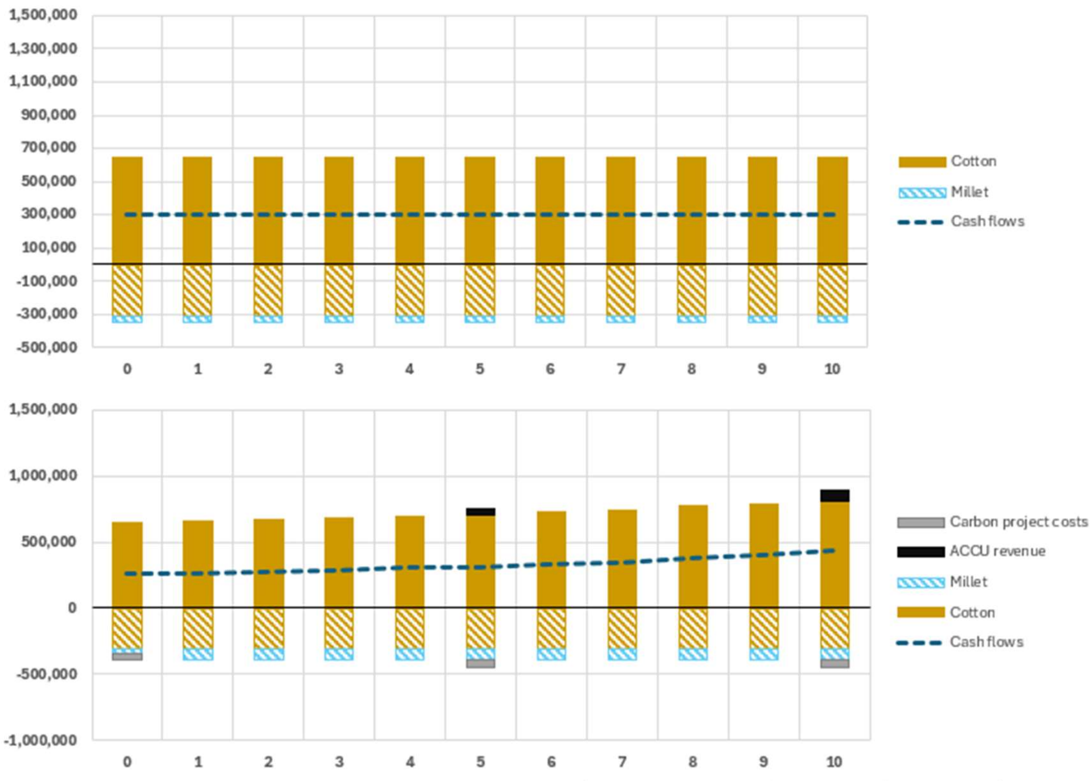
Table 12: Yield change sensitivity

		0%	As described
NPV	$	20,413	1,233,279
IRR	%	9%	48%

Kielli, Darling Downs in Queensland

The baseline rotation at Kielli was cotton – millet (top of Figure 7). The alternative rotation was cotton – millet also, but with 300 kg/ha Terrus Pro fertiliser biannually alongside the millet (bottom of Figure 7). The net benefits associated with the carbon project were small relative to the overall project economics (black/grey bars), and the agronomic assumptions (e.g. yield increases over time) were a key driver of the returns. The NPV was $124,955, and the IRR was 21%.

Figure 7: Results for Kielli



The results are sensitive to the input assumptions made in the analysis. The following tables show how changes in the key input assumptions change the returns. The baseline assumption from the above results is highlighted yellow.

Table 13: Discount rate sensitivity

		5%	8%	10%
NPV	$	181,523	124,955	95,077
IRR	%	21%	21%	21%

Table 14: ACCU price sensitivity

		Flat $18	Flat $35	EY central estimate
NPV	$	75,232	94,975	124,955
IRR	%	16%	18%	21%

Table 15: Soil carbon sensitivity

		Marginal benefit	Some benefit	More benefit
NPV	$	65,334	124,955	256,616
IRR	%	15%	21%	30%

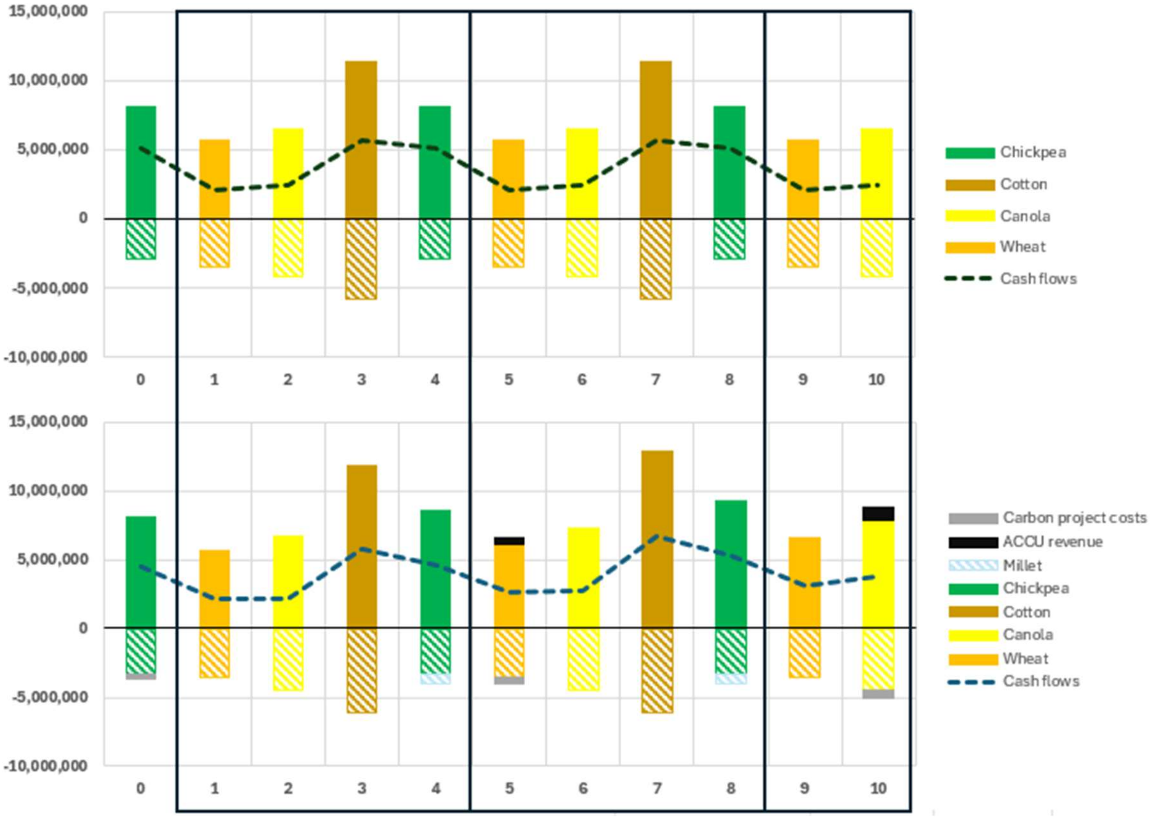
Table 16: Yield change sensitivity

		0%	As described
NPV	$	-353,445	124,955
IRR	%	-	21%

Blue Hills Aggregation, Lower Namoi in New South Wales

The baseline rotation at Blue Hills was wheat – canola – fallow – cotton – chickpea (top of Figure 8). The alternative rotation was wheat – canola – fallow – cotton – chickpea - millet, with 100 kg/ha Terrus Pro fertiliser alongside the chickpea, cotton, and canola (bottom of Figure 8). The net benefits associated with the carbon project were small relative to the overall project economics (black/grey bars), and the agronomic assumptions (e.g. yield increases over time) were a key driver of the returns. The NPV was $932,905, and the IRR was 17%.

Figure 8: Results for Blue Hills



The results are sensitive to the input assumptions made in the analysis. The following tables show how changes in the key input assumptions change the returns. The baseline assumption from the above results is highlighted yellow.

Table 17: Discount rate sensitivity

		5%	8%	10%
NPV	$	1,445,718	932,905	661,884
IRR	%	17%	17%	17%

Table 18: ACCU price sensitivity

		Flat $18	Flat $35	EY central estimate
NPV	$	392,636	606,489	932,905
IRR	%	12%	14%	17%

Table 19: Soil carbon sensitivity

		Marginal benefit	Some benefit	More benefit
NPV	$	276,896	932,905	2,381,591
IRR	%	11%	17%	27%

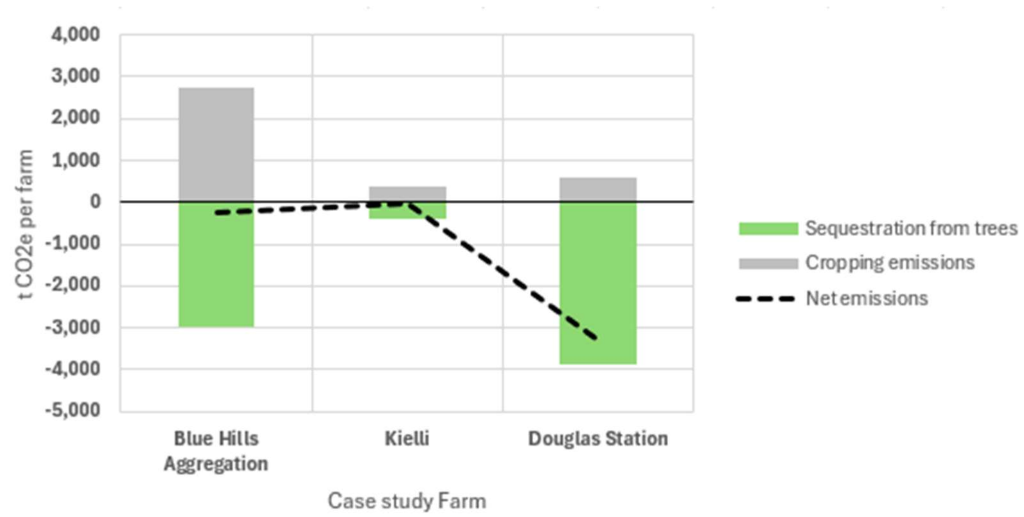
Table 20: Yield change sensitivity

		0%	As described
NPV	$	-3,225,200	932,905
IRR	%	-	17%

Vegetation and carbon balance

A G-GAF tool analysis of cropping emissions found all sites were carbon positive or neutral, meaning emissions from cropping enterprises were offset by vegetation carbon sinks (see Figure 9). In the cases of Blue Hills Aggregation and Douglas Station, large areas of standing woodlands and grass areas sequestered considerable carbon. However, emissions from livestock enterprises were not considered in the analysis.

Figure 9: Vegetation and carbon balance



Discussion and conclusion

The study showed that an ERF soil carbon project has limited economic opportunities due to high start-up and compliance costs and uncertain carbon sequestration outcomes. The analysis showed that the potential agronomic benefits, e.g. improved crop yields through improved soil health, from increased soil carbon drive the returns. The modelled returns were highly sensitive to yield increases over the 10-year analysis period in all case study locations. The discount rate assumption was tested and was found to be the least sensitive input variable in the model analysis. ACCU price forecasts and soil carbon benefits generating ACCUs only had moderate benefits on economic returns when compared to crop yield benefits.

A review of organic fertiliser found organic/manure-based products have an estimated 33 per cent lower Scope 3 carbon footprint than synthetic fertiliser, and local results are finding crop yield benefits. A high-level analysis of vegetation of non-cropped areas can offset cropping-based emissions, with each case study site either carbon neutral or a net carbon sink, although default native vegetation species used in the G-GAF model did not provide option for woodland density at the farm level.

Future research may include economic and sustainability analysis on the use of enhanced efficiency fertilisers in crop rotations to reduce emissions, alongside organic products such as manure pellets. Whole farm carbon footprint analysis and measuring biodiversity scores across various dryland regions where local vegetation species can be identified to improve the accuracy of sequestered carbon may be useful to build awareness of the value and stewardship of non-cropped areas. Conducting a review of emerging biodiversity score 'tools' available and their value in the marketplace is an emerging area of consumer and brand influence. Given the low relative carbon/water footprints of dryland cotton - owing to modest nitrogen use and on-farm vegetation, exploratory economic analysis on dryland cotton branding premiums in the marketplace has commercial potential. Consumer/brand market research, EU market access, accreditation design parameters, traceability frameworks in a prospective unique supply chain benefit cost study may also be valuable for dryland cotton growers.

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