Carbon Farming Optimiser

Curracabark case study

NSW GOVERNMENT | Department of Primary Industries

Optimising the farm enterprise to deliver multiple benefits (Production, Carbon and improved resource condition)

"Curracabark" case study

Context

Enabling primary producers to participate in carbon markets may have multiple benefits, for farmers and to NSW. Carbon farming can provide additional farm income, greater farm enterprise resilience, create regional jobs and economic opportunities, and increase biodiversity delivering multiple co-benefits to regional NSW. Evaluating opportunities for farmers to participate in on-farm climate change abatement activities, maintain or increase production and improve the resource base is a major focus of the "Accessing Carbon Markets" project under the NSW DPI Climate Change Research Strategy. Here, we describe one component of the larger project which seeks to determine the feasibility of a Carbon Farming Optimisation (CFO) tool to determine the combination of potential activities a farm enterprise could undertake to achieve maximum economic returns and deliver multiple benefits (carbon sequestration, production and environmental).

Information is lacking that allows farmers to make well-informed decisions about the economic consequences entering carbon markets or identifying the potential for non-market abatement activities. These activities include on-farm emissions reduction or sequestration and have the potential to benefit the farm enterprise by improving landscape condition and increasing agricultural production. Understanding the economic and environmental trade-offs and synergies associated with a change in land management (*e.g.* changing grazing strategy) or land-use (*e.g.* reforesting grasslands) to incorporate carbon farming and access carbon markets as well as abatement activities not currently supported by the carbon markets is the focus of this case study.

This case study is one of three on-farm studies which aim to identify cost effective abatement opportunities with multiple benefits (production and environmental). Each study is undertaken in different landscapes/enterprises as a proof-of-concept for the development of an on-farm tool allowing farmers to optimise the farm enterprise for carbon, environment and production. Farmers will not only be able to optimise land management/use for abatement activities but understand where trade-offs between agricultural production, biodiversity and resource condition occur, helping to support the sustainable use of natural resources. Where environmental co-benefits are verified, additional value could be realised through markets that provide a financial incentive to provide environmental services (*e.g.* biodiversity), adding to returns from carbon trading.

The case study is structured into three sections: A description of the enterprise and farmer aspirations for land use change; examination of multiple environmental co-benefits indicators; and the implementation of the Carbon Farming Optimisation.

Enterprise description

"*Curracabark*" is an aggregation of approximately 5000 ha in the upper Hunter region of NSW, approximately 70 km west of Taree on the mid-north coast of NSW (Figure 1) with a summer dominant long term average annual rainfall of 961mm. The aggregation is used to produce stud Angus and Hereford cattle and also has a large commercial cattle herd. Curracabark is mostly cleared with shade trees and situated in a valley that divides two nature reserves. An area of the property had a solid fertiliser history with a very low PBI (indicating a historic use of phosphorous fertilisers). The property can be divided into three landscapes; low, medium and high productivity pastures. Low productivity pastures are very hilly and subject to regrowth of native vegetation. The carrying capacity of these areas was 2 DSE/ha. Moderate productivity pastures were less hilly with a carrying capacity of 6 DSE/ha. The carrying capacity of high productivity pastures were 9 DSE/ha. High productivity pastures were on better quality soils and more accessible so had a history of fertiliser applications. *"Curracabark"* has been undertaking activities to improve the economic and environmental performance of the enterprise. This has included moving from superphospate to increase soil P to BioAgPhos, undertaking revegetation and participating in producer projects to assess the economic and soil carbon benefits of improving pastures. For the case study, it was assumed that the enterprise was only for commercial cattle production. The aggregation has a separate block to the south of the main aggregation and this was not included in the case study.

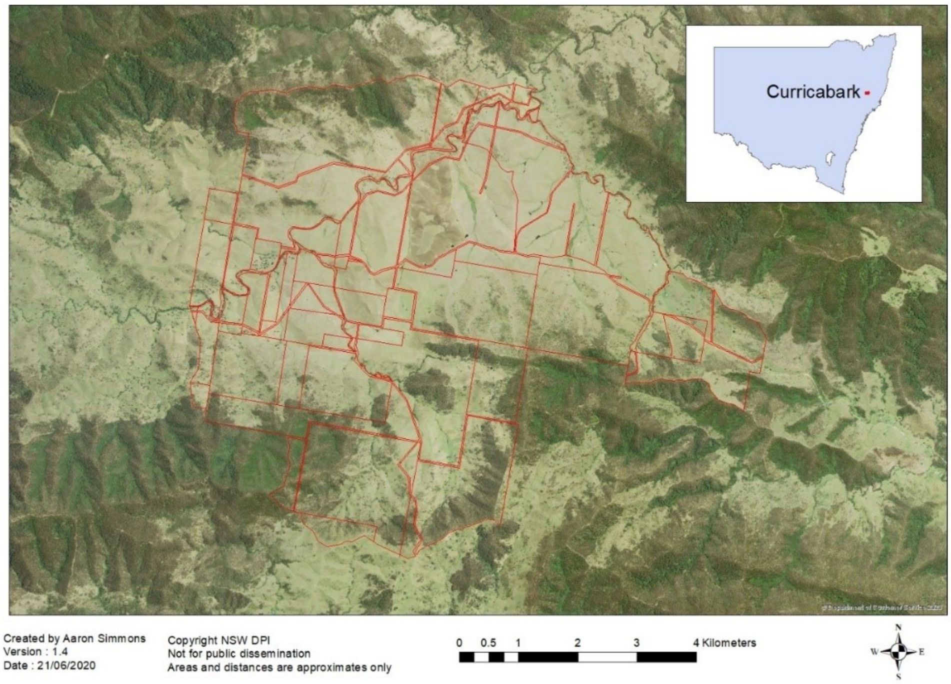


Figure 1. Approximate location of Curracabark within NSW and property boundaries. Internal lines are cadastral lots not paddock boundaries.

Landscape characteristics

The Curracabark property is characterised by land ranging from gently sloping to very steep (

Figure 2a) with an elevation ranging from 300 to 800m ASL (

Figure 2b). The steep and higher to mountainous areas are covered by woody and sparse woody vegetation (

Figure 2c).

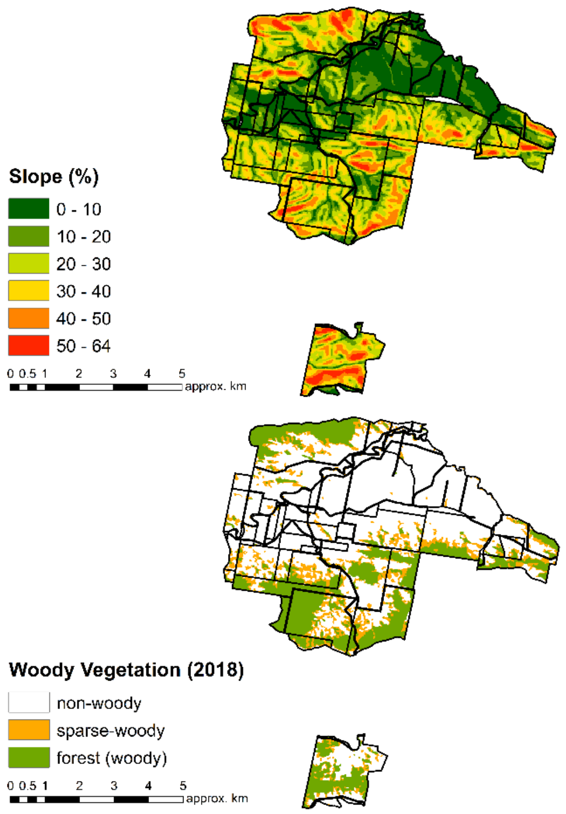


Figure 2 Curracabark boundaries showing a) slope (%), b) elevation, c) woody vegetation cover.

Available spatial data suggests that the majority of the property has soils with a clay content generally of 8 – 30 % for the top 5 cm of the soil and that some areas have a very heavy clay topsoil with a clay content of up to 46 % (Figure 3a) representing the diverse geology of the property. As would be expected the clay content of soils generally increases with depth (Figure 3b). The soil pH for most of the property in the 0-30cm layer is moderately acidic (Figure 4a) with pH increasing with increasing soil depth (Figure 4b).

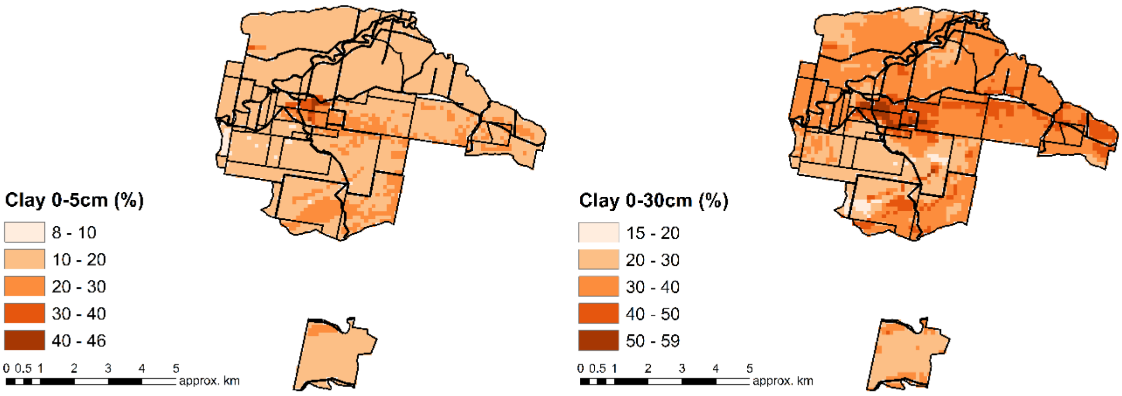


Figure 3 Curracabark boundaries showing % clay for a) 0-5cm and b) 0-30cm.

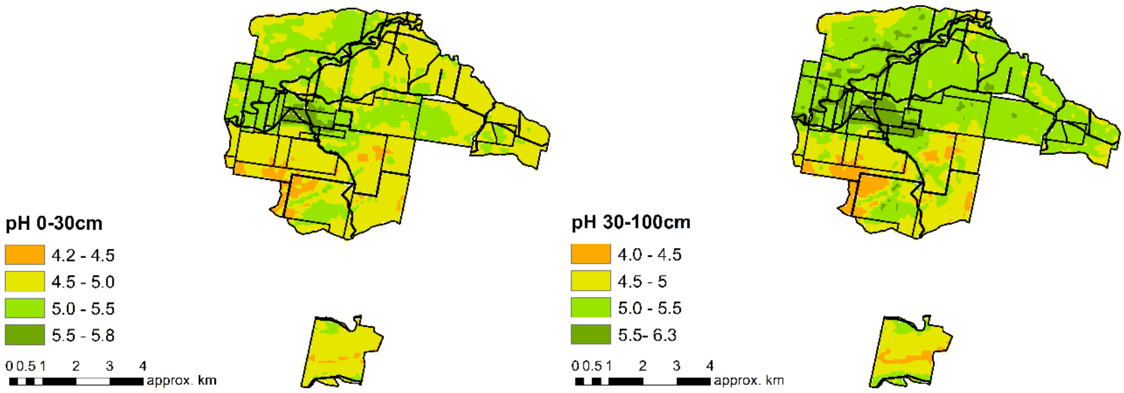


Figure 4 Curracabark boundaries showing soil pH for a) 0-30cm and b) 30-100cm.

Environmental indicators

Soil organic carbon

Soil organic carbon (SOC) is an important indicator of soil condition and increasing SOC stocks can sequester carbon from atmosphere providing climate change mitigation. Two datasets were available to assess SOC data for Curracabark (Figure 5a and Figure 5b). The range of SOC stocks for Curracabark differed for each dataset with the dataset developed by this project using multiple linear regression ranging from 50 – 113 t SOC/ha and the dataset developed using random forests ranging from 50 – 90 t SOC/ha.

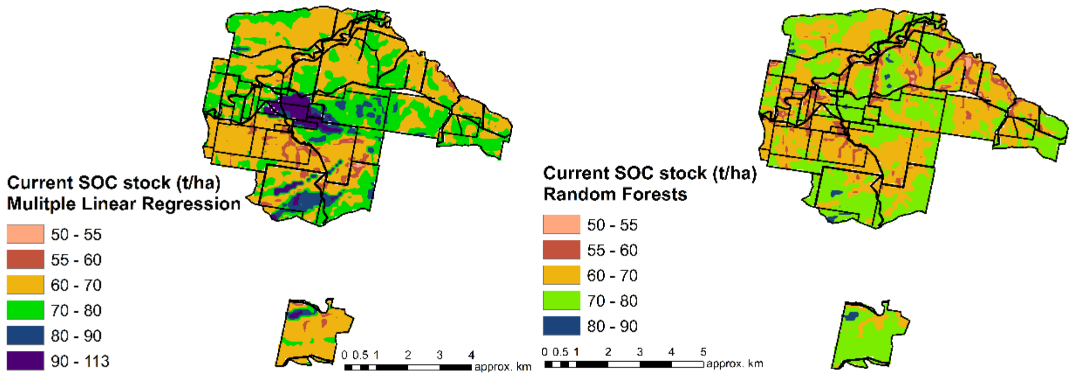


Figure 5 Current soil organic carbon stock modelled using different method a) multiple linear regression, b) random forests

Ground cover

Ground cover thresholds to reduce wind (50%) and water (70%) erosion have been well established[1] but total vegetation cover (woody and ground cover) has been proposed as a more effective indicator of exposure to wind erosion[1]. Over time, ground cover has been accepted as a proxy for the provision of ecosystem services such as soil conservation. The importance of retaining ground cover is embedded into natural resource planning for western NSW through catchment targets to retain 50% ground cover.

We examined the use of two ground cover products, Sentinel fractional cover images and Landsat fractional cover images which primarily differ in their resolution and time period. For example, Landsat fractional cover images (the source data for groundcover estimates in products such as FarmMap4D and VegMachine) provides seasonal fractional ground cover at a 30m resolution at 3-monthly intervals based on the Landsat images. These seasonal images are available from 1988 onwards. The Sentinel fractional cover images were retrieved from Digital Earth Australia and are available from November 2017 to November 2019 with 2-3 images per month.

Ground cover "clumpiness"

Vegetation patch dynamics is a major factor influenced by grazing. Patches of vegetation control water flow through the landscape with increased vegetation retaining water[2] and concentrating nutrients[3] while reducing run-off and erosion. The spatial arrangement and temporal dynamics of cover has been linked to landscape condition[4]. The use of spatial variance analysis to characterise the 'clumpiness' of patches into a clumpiness index has been proposed by those authors to access changes in the spatial heterogeneity. The clumpiness indicator reflects landscape spatial heterogeneity and may provide more information as a co-benefit indicator than ground cover alone, because it indicates the relative size of the patch of bare ground with larger patches being potentially more susceptible to erosion. High levels of clumpiness indicate that there are relatively large patches of bare ground between clumps of vegetation. "Range" is used to indicate clumpiness with the range representing the distance at which the pattern of patches and vegetation in a landscape become homogenous. For example, a range of 100 m means that any two or more transects 100 m long that are placed across the area of interest will have similar proportions of bare ground to vegetation. This means that the greater the range, the greater the variability in the landscape (*i.e.* patches of bare ground are bigger).

Sentinel-2 factional cover images (10m resolution) were obtained from November 2017 to November 2019. Fractional cover consists of four bands; Band 1, bare ground, rock, disturbed, Band 2, photosynthetic vegetation, Band 3, non-photosynthetic vegetation and Band 4, model fitting error. Monthly mean bare ground (Band 1) was processed from 2-3 images per month. The mean bare ground was used in this study as the amount of bare ground relates to exposure to wind erosion.

Paddock comparisons

To assess the potential for clumpiness to be used as a co-benefit indicator, the clumpiness of a paddock that has not been pasture improved was compared to a paddock previously improved under a Hunter LLS incentive scheme (Figure 6). The percentage of bare ground was also compared between paddocks. Remote sensing has been used frequently to investigate landscape patterns. Here, we obtained Sentinel-2 factional cover images (10m resolution) from November 2017 to November 2019 for the two paddocks. Fractional cover consists of four bands; Band 1, bare ground, rock, disturbed, Band 2, photosynthetic vegetation, Band 3, non-photosynthetic vegetation and Band 4, model fitting error. Monthly mean bare ground (Band 1) was processed from 2-3 images per month for each of the paddocks. The range or the size of the bare ground between clumps was analysed using variogram modelling.

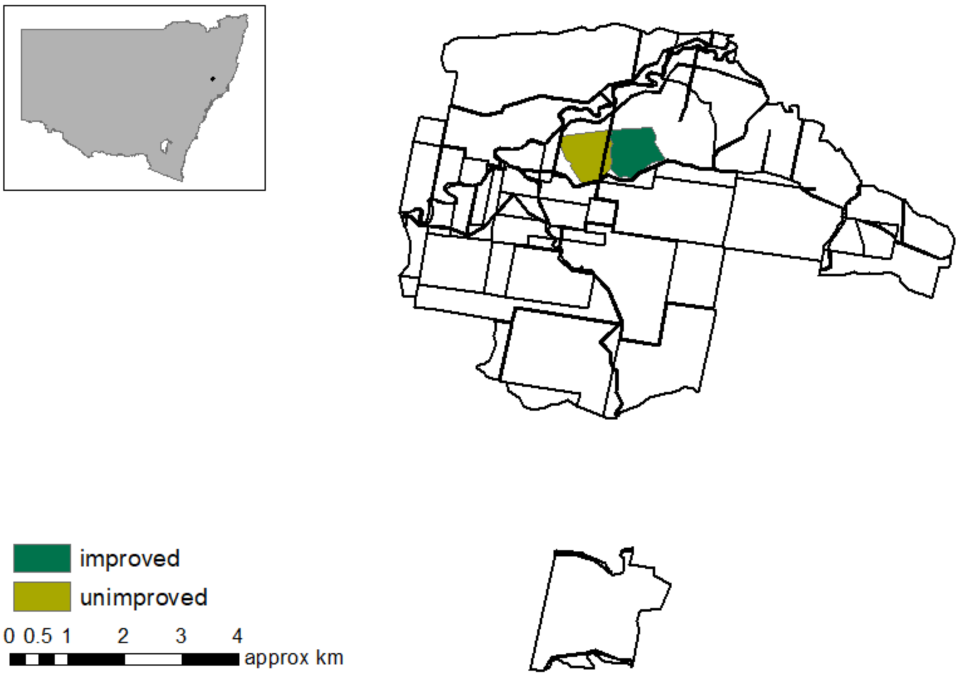


Figure 6. Location of paddocks within Curracabark boundaries that were used to assess whether clumpiness and bare ground differed between pasture improved and unimproved paddocks.

On-farm optimisation

Carbon farming opportunities

Curracabark consists of the floor and sides of a valley that separates two areas of native vegetation. An opportunity exists to increase overall resource condition by planting shelterbelts to provide landscape connectivity. An opportunity also exists to increase areas of native vegetation by allowing low productivity pastures to revegetate by removing livestock increasing biodiversity and sequestering atmospheric C. Landholders have the potential to earn income from credits provided under the Human Induced Regeneration (HIR) methodology of the Emissions Reduction Fund. The final potential change is improving high productivity native pastures with improved species. Pasture improvement will increase the carrying capacity of high productivity pastures and would normally increase soil organic carbon but in this instance this was assumed not to occur (see below for more detail). It was assumed that pasture improvement increased production in by 20% based on data supplied by the landholder. The property was mapped identifying the different areas where change could be implemented and the potential area of each change and the length of fencing required (were applicable) calculated using ArcGIS.

Data sources and assumptions for carbon farming optimiser

Data

Enterprise data, described in sections below was used in the CFO and given in appendix A.

Available operating and capital costs

Capital costs associated with the changes were for fencing and costs were estimated by the landholder. Capital costs for tree seedlings required for shelterbelt establishment were provided by the LLS. Available operating and capital was constrained to $300 000 per annum.

Stocking rate and pasture availability

Stocking rate on a per ha basis was provided by the landholder for each pasture type. Pasture availability was estimated based on livestock requirements with the provided stocking rate. It was assumed that one 450 kg cow required 126 MJ ME day^{-1}. Low productivity pastures are very hilly so it was assumed that the daily energy requirement in those areas was 10% greater than for medium and high productivity pastures to account for the additional energy consumed walking in these paddocks.

Gross margins

Gross margins for cattle breeding were developed from the estimated returns and variable costs for each enterprise. The purchase and sale price of the livestock were estimated by the landholder as were the daily liveweight gains, distance to saleyards.

Commissions, industry levies, transport costs and saleyard fees, where relevant, represented current industry values.

The cost of animal health products were taken from NSW DPI livestock gross margins [5].

GHG emissions and sequestration

Greenhouse gas emissions associated with the production of cattle were calculated using the sheep and beef greenhouse accounting framework [6]. All default emissions factors were used for calculations. The enterprise has a spring and autumn calving but for simplicity it was assumed that one calving occurred in Spring. GHG emissions included were enteric methane and N_2O from manure and urine deposition, consistent with the Australian GHG inventory report.

Sequestration of carbon via regeneration of native vegetation was modelled using FullCAM. Default values for vegetation and soil for the co-ordinates of the low production area were used and the model run for 100 years. The growth rate used in the carbon farming optimiser was a linear estimation for growth rates over 25 years.

Soil organic carbon

Figures for SOC provided by the landholder showed that SOC on Curracabark were already relatively high for their soil type/climate combination (*i.e.* > 4%). These high values are likely due to the high historical use superphosphate. It was therefore assumed that changing management did not increase SOC. Nevertheless, we assessed the ability of the SOC stock maps and estimated changes developed by this project against the SOC stocks estimated via monitoring on the property.

Labour

Labour was constrained to 6 500 hours per annum as an approximation of three full-time workers being available. Labour hire was not assumed to be available.

Additional indicators

Additional indicators of co-benefits were assessed for inclusion in the optimisation modelling with the intention of including income from credits associated with providing co-benefits (*e.g.* biodiversity credits).

Results

Soil organic carbon

Soil organic carbon (SOC) values obtained from the landholder for the pasture improved paddock were in % so were converted to SOC stocks assuming a bulk density of 1.3 and a gravel content of 30%. This estimated gave an estimate of SOC stocks of 110 t SOC ha^{-1} to 30 cm. SOC values predicted by the spatial layers developed as part of this project (Figure 5) estimate that SOC for the improved paddock were between 60 – 80 t SOC ha-1 so underestimates the SOC stocks for this paddock. It should be noted that the SOC stocks for this paddock are likely to be higher due to historic use of superphosphate that has resulted in high fertility and therefore relatively high SOC and that management information such as this his information was not available for the development of the spatial layers.

Clumpiness

It was hypothesised that the improved paddock would have smaller patches and overall lower percentages of bare ground, due to producing more biomass. However, Table 1 (below) suggests no trend in the range of clumpiness, as derived from variograms, between the pasture improved and unimproved paddocks. These results suggest that pasture improvement may not provide a co-benefit of reducing bare ground and creating a more homogenous landscape (*i.e.* smaller patches of bare ground). Fractional cover data from Landsat imagery confirmed suggests that improving pastures reduced the % bare ground relative to the unimproved pasture (Figure 7a). Landsat imagery suggested that the proportion of biomass that was photosynthetic was similar in the improved and unimproved paddocks and that improvement in 2016 had no noticeable increase in photosynthetic biomass (Figure 7b). Annual peaks of photosynthetic vegetation appear to coincide with summer rainfall events (Figure 7c).

Table 1. Average range of clumpiness (m) and mean bare ground (%) for pasture unimproved and improved paddocks on a monthly basis over a two-year period. Note that the maximum detectable range is 500 m. Data based on Sentinel-2 fractional cover images at 10m resolution.

Date	unimproved	improved	unimproved	improved
	Range (m)	Range (m)	BG (%)	BG (%)
Nov-2017	500	500	13	18
Dec-2017	136	146	19	20
Jan-2018	500	500	8	9
Feb-2018	500	225	16	12
Mar-2018	132	172	38	35
Apr-2018	500	145	16	19
May-2018	190	500	9	16
Jun-2018	500	180	23	24
Jul-2018	500	500	15	16
Aug-2018	273	500	26	25
Sep-2018	273	500	26	25
Oct-2018	500	227	16	20
Nov-2018	500	500	11	16
Dec-2018	500	358	10	17
Jan-2019	500	500	28	27
Feb-2019	500	500	38	27
Mar-2019	500	258	15	18
Apr-2019	190	87	26	28
May-2019	500	368	34	22
Jun-2019	214	500	16	17
Jul-2019	146	500	19	18
Aug-2019	273	500	26	25
Sep-2019	500	500	22	23
Oct-2019	500	500	25	26
Nov-2019	500	500	22	23

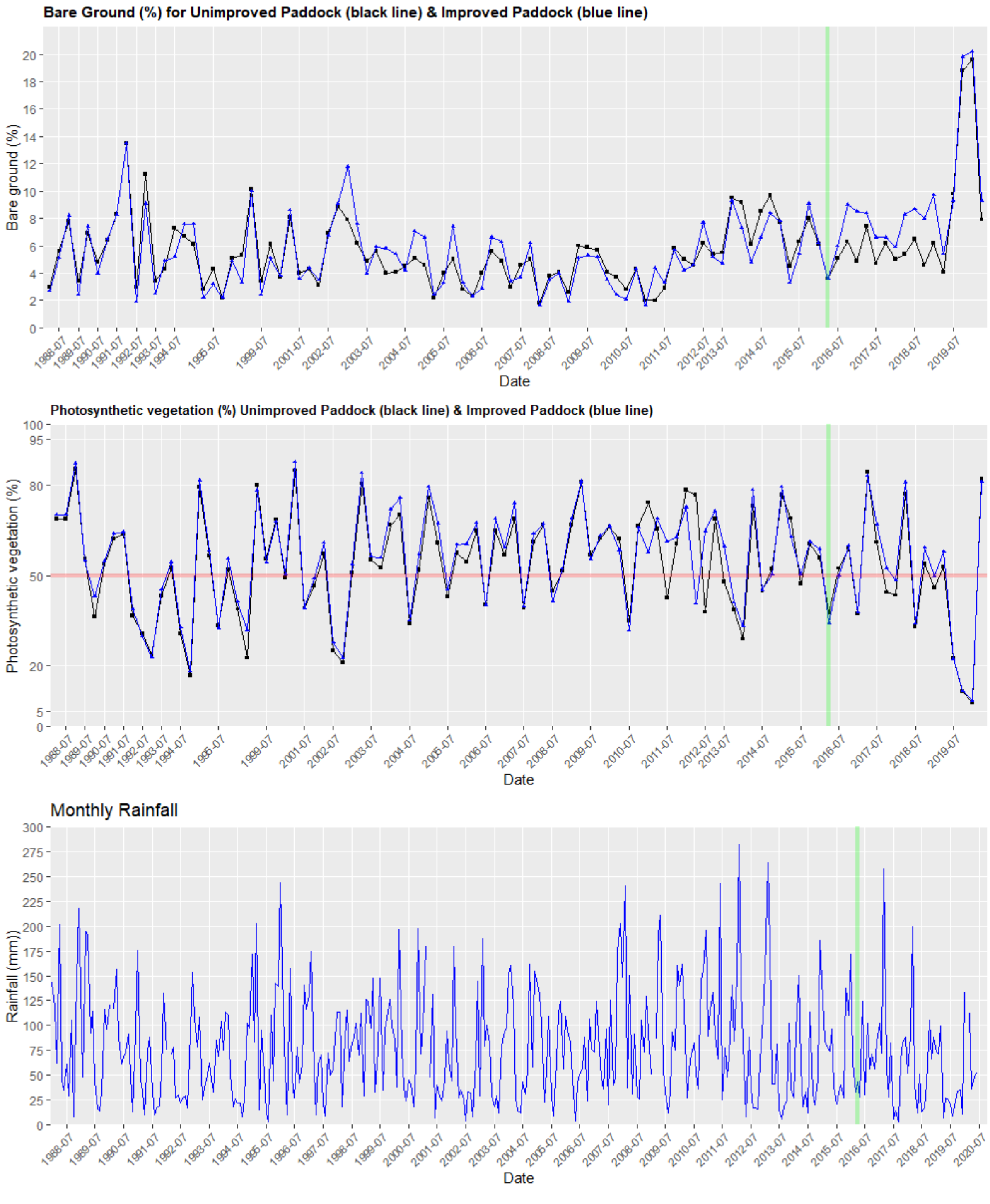
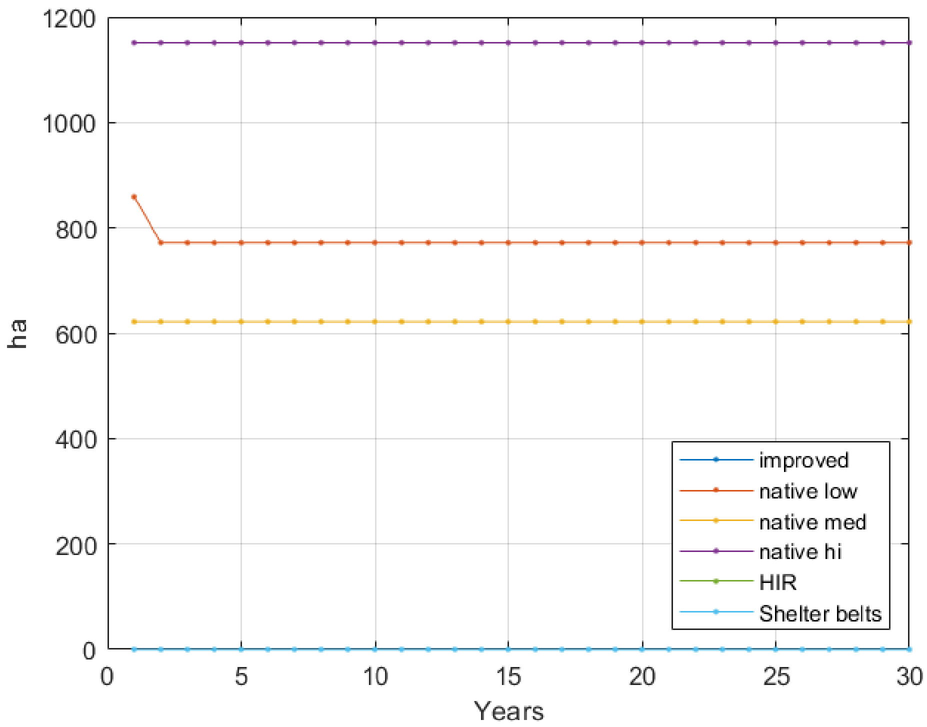


Figure 7 For unimproved and improved pasture paddocks between 1988 and 2020 a) % bare ground b) % photosynthetic vegetation and c) monthly rainfall. Vertical green line indicates when pasture improvement occurred.

Carbon Farming Optimisation

The baseline run used the livestock production figures provided by the producer for the three production zones and assumed that no additional income was sourced from the sale of SOC sequestered (*i.e.* a C price of \$0). The CFO optimisation suggested that without a C price the economics of converting low productivity pastures to forests via regeneration and improving high productivity native pastures did not maximise returns for the enterprise (Figure 8).

Figure 8 For years 0 – 30 of the CFO simulation the area of each potential landuse on Curracabark with a C price of \$0.



When a C price of \$15 t C^{-1} was assumed, results from the CFO suggest that returns in the enterprise can be maximised by quickly converting low productivity pastures to HIR and improving approximately 800 ha of the high productivity native pastures (Figure 9). The low productivity pastures are first converted to HIR after which time the income received from the HIR and the reduction in costs associated with managing low productivity native pastures is directed to improving high productivity native pastures. At a price of \$15 t C^{-1} shelterbelts are not included when optimising the enterprise for profit however this may change once the CFO has the capacity to include biodiversity credits. A C price of \$15 t C^{-1} also increases the NPV of the enterprise over the 30 year period by approximately \$1.43M and a C price of \$30 increases that further relative to no C price by approximately \$3.65M (**Figure 9Figure 9** For years 0 – 30 of the CFO simulation the area of each potential landuse on Curracabark with a C price of \$15.

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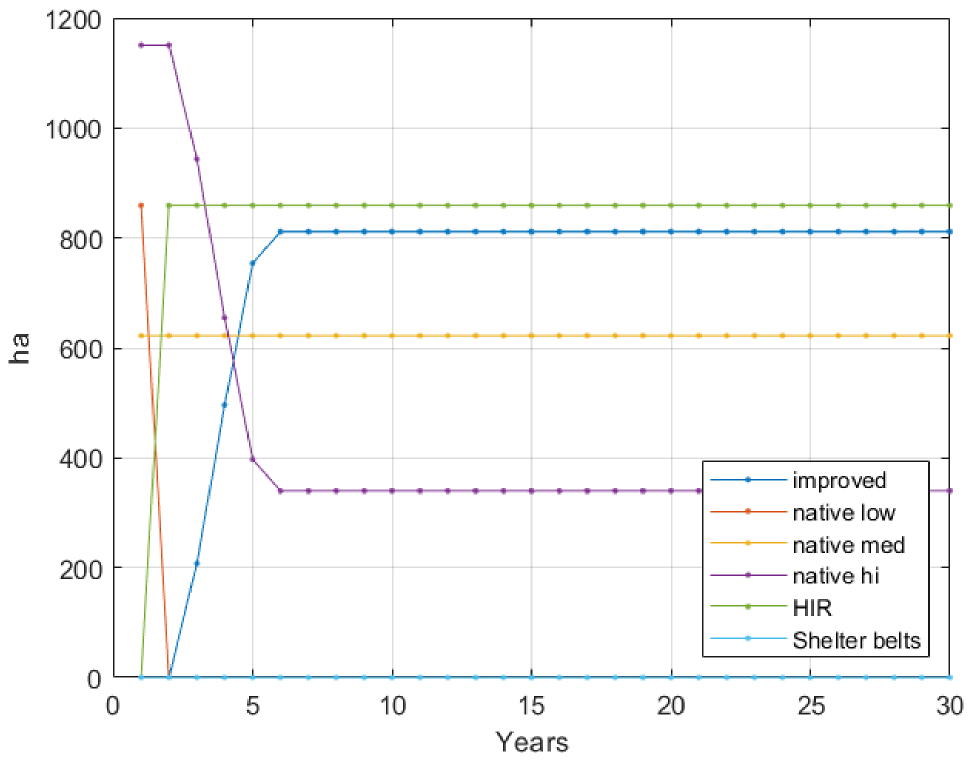

Figure 9 For years 0 – 30 of the CFO simulation the area of each potential landuse on Curracabark with a C price of $15.

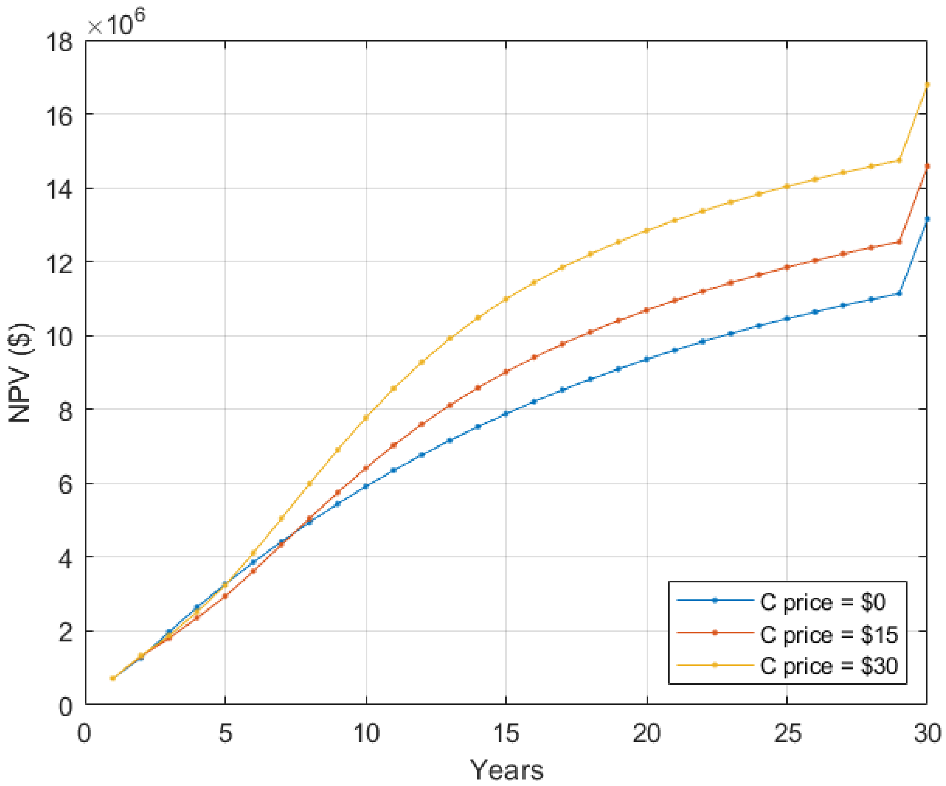

Figure 10 NPV over 30 years for Curracabark with a C price of $0, $15 or $30.

Operating and capital requirements are a key constraint in the CFO and the baseline run constrained this to $300 000 per annum. When the annual operating and capital is constrained to $200 000, the same trends as shown in Figure 9 occur (*i.e.* low productivity pastures are regenerated for C credits and high productivity pastures are improved) however the rate at which they are occur are slower than when operating and capital are constrained to $300 000.

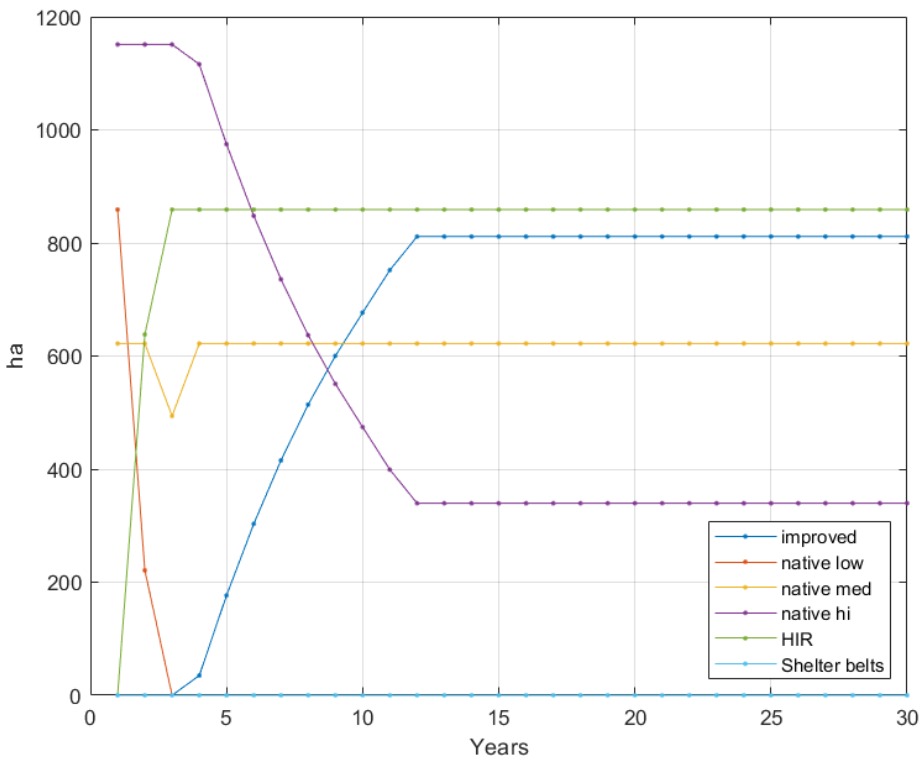

Figure 11 For years 0 – 30 of the CFO simulation the area of each potential landuse on Curracabark with a C price of $15 and operating and capital is reduced to $200 000 per annum.

Of interest is the C price at which participating in a carbon trading scheme by regenerating low productivity pastures becomes more profitable than running cattle. Running the CFO with a C price of $0 and $1.50 shows that regenerating a relatively small area (~90 ha) of low productivity pasture is profitable even at a C price as low as $1.50 t C^{-1} (Figure 12).

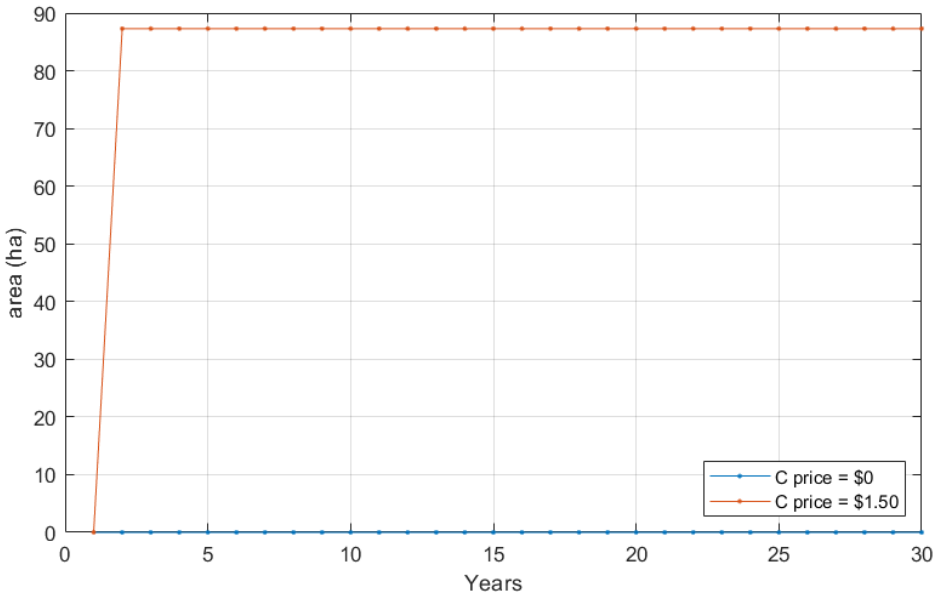

Figure 12 For years 0 – 30 of the CFO simulation, the area dedicated to human-induced regeneration with a C price of $0 or $1.50.

The amount of labour available also effects the results of the CFO. Results from a $15 C price (Figure 9) assumed that three people were available to work in the enterprise full time. When the labour available was lowered to two people available full-time, the results suggested that it was most profitable to regenerate areas of low productivity pasture and that areas in production of medium and high productivity pasture should be alternated (Figure 13). Alternating between high and medium productivity pastures suggests that labour is a constraint for the enterprise or alternatively that estimates of time requirements for animal husbandry and pasture maintenance are overestimated.

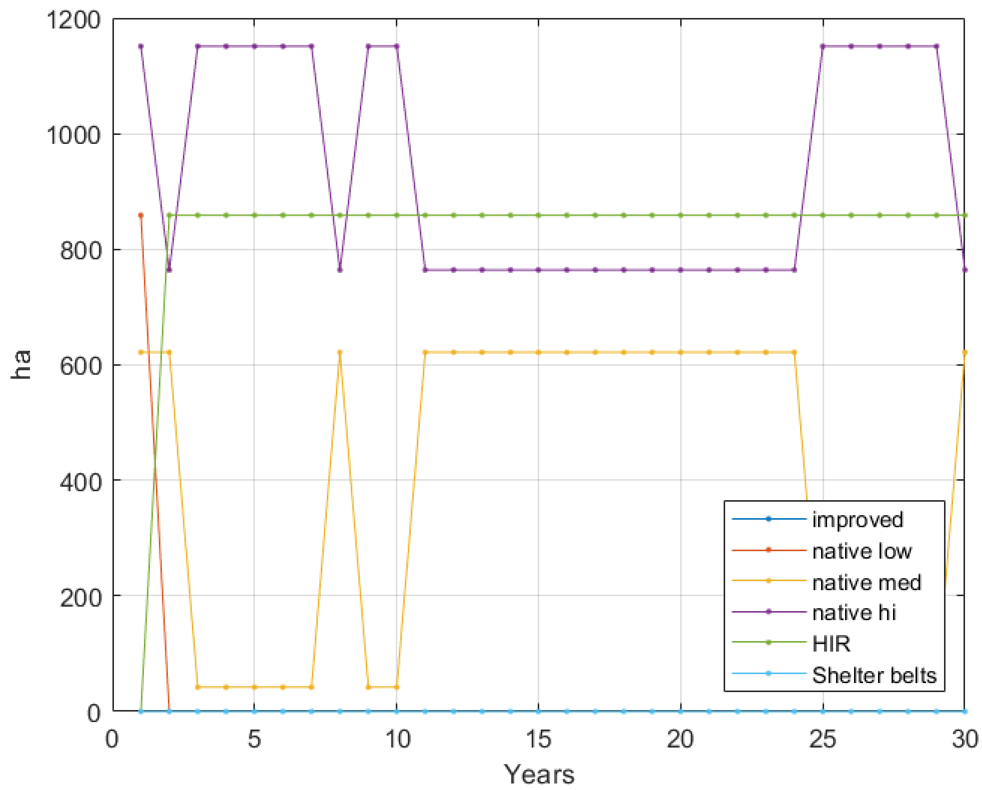

Figure 13 For years 0 – 30 of the CFO simulation the area of each potential landuse on Curracabark with a C price of $15 and the labour available is reduced to two people.

Conclusions

Optimisations from the CFO for Curracabark demonstrate that, using the input data provided by the producer, participating in an ERF methodology that incentivised regeneration of native vegetation on low productivity grazing land would increase the profitability of the enterprise at a relatively low C price of $1.50 (Figure 12). Any increase in C price would result in a more profitable enterprise (Figure 10**Figure 9** For years 0 – 30 of the CFO simulation the area of each potential landuse on Curracabark with a C price of $15.

) however this would occur due to the increase in income from C credits, not from optimising the system differently. Operating and capital to implement the changes is a key constraint with a reduction in the available operating and capital slowing the rate at which low productivity pasture is regenerated and high productivity pasture is improved.

The absence of any well-defined trend in clumpiness and bare ground between improved and unimproved pasture suggests that even if improving pastures provides benefits associated with clumpiness and a reduction in bare ground, this may not be able to be readily assessed using satellite imagery. Future iterations of the CFO will have the capacity to include a value to assess how adding income from any co-benefits affect the optimisation of Curracabark to maximise income. Including this in the CFO may result in shelterbelts being introduced as, in the case of Curracabark, shelterbelts can provide significant co-benefits by providing corridors for wildlife to move between two nature reserves. There is also evidence that shelterbelts can have benefits for stock in terms of protection from cold and heat.

Although SOC sequestration was not a key component of this case study there was on ground data to compare to the SOC spatial data generated by the project. Comparison suggest that the SOC maps developed as part of this project may not provide a good indication of current SOC levels. However, a key limitation of the spatial layers is that their development did not incorporate activities known to increase SOC in pasture systems (*i.e.* fertility) and this may account for the observed discrepancy. For pastures that do not have a history of fertiliser use the spatial layers may be closer to observed values.

References

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4 Scarth, P. & Trevithick, R. Management effects on ground cover “clumpiness”: Scaling from filed to Sentinel-2 cover estimates. *Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci* **42**, 183-188 (2018).

5 NSW DPI. Livestock gross margins. (https://www.dpi.nsw.gov.au/agriculture/budgets/livestock, 2020).

6 A Greenhouse Accounting Framework for Beef and Sheep properties based on the Australian National Greenhouse Gas Inventory methodology. Beta version revised 2020 by Integrity Ag and Environment for MLA (http://piccc.org.au/Tools, 2020).

Appendix A

Additional information used in optimisation model

Agent commission	5	%
Saleyard fees	12	$/head
Levy	2	$/head
distance to sales	440	km
$/km transport	5.5	
head/load	60	
transport cost per head	40.3333333	$/head

Gross margin for organic breeder

BEEF CATTLE BREEDING GROSS MARGIN and activity details			
Date			
Description:	Cattle breeding with progeny grown and sold over hooks to org processor		
Enterprise Unit:	400	Cows	

Pasture:	ha
improved	0
native	9200

INCOME:	hd	S/hd	Total value
Steer weaners	180	1,400	252,000
Heifers	82	1,120	91,840
CFA Bull	2	2,000	4,000
CFA Cows	90	1,350	121,500
Other culls	0	-	-
Total income			469,340

VARIABLE COSTS:	hd	$/hd	Total value
Replacement bull	2	5000	10,000
Cartage to Property	2	200	400
Livestock and vet costs*	760	20	15,200
Agents commision			23,467
Livestock selling cost (cartage, levies and selling fees)	354	54.3333333	19,234
	ha	$/ha	Total value
Fodder crops	0	0	-
Hay & Grain or silage	0	0	-
Drought feeding costs.	0	0	-
Total Variable costs			68,301
GROSS MARGIN			**401,039**

per hd annum	501.30
	550

Other variables		Unit
CO_2 emissions	2.46	t/hd
Labour required	7.34	hr/hd

Livestock reconciliation		unit
PTIC rate	90	%
Replacement heifers kept	98	hd
Calving (%)	100	%
Calves weaned	400	hd
Cow / heifer mortality	2	%
Year cows retained	8	years

Gross margin for agistment

BEEF CATTLE TRADING GROSS MARGIN and activity details			
Date			
Description:	Agistment		
Enterprise Unit:	710	hd	
	12	months	
Over time period			
Pasture:	0		
improved	9200		
native			
	hd/LSU	S/hd/week	Total value
INCOME:	710	5	184,600
Animals			

GROSS MARGIN		per hd	260.00

Other variables		Unit
CO_2 emissions	1.18	t/hd
Labour required	4.48325359	hr/hd

Gross margin for growing cattle out

BEEF CATTLE TRADING GROSS MARGIN and activity details			
Date			
Description:	Growing out steers 240kg - 460kg in 12 months		
Enterprise Unit:	710	hd	
Purchase weight	220	kg/hd	
Target weight	400	kg/hd	
Over time period	8.5	months	assumes 0.7 kg gain day LW
Pasture:	ha		
improved	0		
native	9200		

INCOME:	hd	$/hd	Total value	
Steers	710	1,400	994,000	$3.50

VARIABLE COSTS:	hd	$/hd	Total value	
Steer Purchase	710	$880.00	624,800	$4.00
Cartage to Property	710	40.3333333	28,637	
Livestock and vet costs*	710	10	7,100	
Livestock selling cost	710	124	88,277	
	ha	$/ha	Total value	
Fodder crops (12 ha)	0	0	-	
Hay & Grain or silage	0	0	-	
Drought feeding costs.	0	0	-	
Total Variable costs			748,813	
GROSS MARGIN			346,146	

per hd annum	487.53

Other variables		Unit
CO2 emissions	1.18	t/hd
Labour required	4.13521127	hr/hd