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Carbon-neutral wool farming in south-eastern Australia

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Abstract. Ruminant livestock production generates higher levels of greenhouse gas emissions (GHGE) compared with other types of farming. Therefore, it is desirable to reduce or offset those emissions where possible. Although mitigation options exist that reduce ruminant GHGE through the use of feed management, flock structure or breeding management, these options only reduce the existing emissions by up to 30% whereas planting trees and subsequent carbon sequestration in trees and soil has the potential for livestock emissions to be offset in their entirety. Trees can introduce additional co-benefits that may increase production such as reduced salinity and therefore increased pasture production, shelter for animals or reduced erosion. Trees will also use more water and compete with pastures for water and light. Therefore, careful planning is required to locate trees where the co-benefits can be maximised instead of any negative trade-offs. This study analysed the carbon balance of a wool case study farm, Talaheni, in south-eastern Australia to determine if the farm was carbon neutral. The Australian National Greenhouse Gas Inventory was used to calculate GHGE and carbon stocks, with national emissions factors used where available, and otherwise figures from the IPCC methodology being used. Sources of GHGE were from livestock, energy and fuel, and carbon stocks were present in the trees and soil. The results showed that from when the farm was purchased in 1980–2012 the farm had sequestered 11 times more carbon dioxide equivalents (CO_2e) in trees and soil than was produced by livestock and energy. Between 1980 and 2012 a total of 31 100 t CO_2e were sequestered with 19 300 and 11 800 t CO_2e in trees and soil, respectively, whereas farm emissions totalled 2800 t CO_2e. There was a sufficient increase in soil carbon stocks alone to offset all GHGE at the study site. This study demonstrated that there are substantial gains to be made in soil carbon stocks where initial soils are eroded and degraded and there is the opportunity to increase soil carbon either through planting trees or introducing perennial pastures to store more carbon under pastures. Further research would be beneficial on the carbon-neutral potential of farms in more fertile, high-rainfall areas. These areas typically have higher stocking rates than the present study and would require higher levels of carbon stocks for the farm to be carbon neutral.

Additional keywords: climate, greenhouse gases, policy, resource management, sheep.

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Introduction

Agriculture contributes 10–12% of all global anthropogenic greenhouse gas emissions (GHGE) and is the main source of anthropogenic methane (CH_4) and nitrous oxide (N_2O) (Smith *et al*. 2007). Livestock production generates more GHGE than other types of farming (Garnett 2009). Therefore, it is desirable to reduce or offset those emissions wherever possible. The term ‘carbon neutral’ is used when any carbon dioxide equivalents (CO_2e) generated is balanced out by equivalent CO_2e sequestration or mitigation. Although mitigation options exist that reduce ruminant GHGE through the use of feed management, flock structure or breeding management, these options currently only reduce emissions by up to 30% (Gerber *et al*. 2013), whereas planting trees has the potential for livestock emissions to be offset in their entirety through C sequestration. Various global policy measures have recognised that agriculture has the potential to reduce or sequester CO_2e and have encouraged farmers to reduce GHGE through the use of C-offset schemes (Thomassin 2003; DCCEE 2012; Commonwealth of Australia 2014). However, developing policies that support sustainable agricultural production continues to be a challenge (Pretty *et al*. 2010).

Sustainable farming has become increasingly important to ensure farming areas remain productive and ideally increase their productivity into the future. Trees may provide important co-benefits besides C storage such as reduced salinity, increased pasture and crop production (Lin *et al*. 2013), windbreaks, shelterbelts for animals in winter to improve survival, reduced soil erosion and increased biodiversity (Brandle *et al*. 2004). Trees will also use more water and may compete with pastures for water and light. Therefore, careful planning is required to locate trees to maximise the co-benefits and minimise any potential negative trade-offs.

Salinity in Australia is a particularly important issue because salt is naturally present at high levels in many subsoils of Australian agricultural land (John *et al*. 2005). Dryland salinity in Australia occurred after native vegetation was cleared and more rainfall entered the groundwater, causing watertables to rise and salt to mobilise (Rengasamy 2002). Planting trees absorbs excess water, lowering the watertables and reducing salinity (John *et al*. 2005). In Switzerland, planting trees on fertile land reduced soil erosion and nitrate leaching by 78% and 46%, respectively, in addition to sequestering C and improving biodiversity (Kaeser *et al*. 2011). The trees were planted in strips as part of an agroforestry system and increased productivity per area by 30% compared with monoculture crops, however, overall profitability declined due to reduced land availability (Kaeser *et al*. 2011). The purpose of this study was to evaluate the C balance of a wool case study farm to determine if C stocks in soil and trees can offset the CH_4 and N_2O emissions from the wool production system under varying levels of annual rainfall.

Methods

The case study farm, Talaheni

Talaheni is a small (250 ha) self-replacing sheep farming enterprise 35 km north of Canberra (34°57′S, 149°10′E) that specialises in ultrafine Merino wool but also has beef cattle and farm forestry (Ive and Ive 2007). Average rainfall (1912–2012) for the site is 625 mm. When Talaheni was purchased in 1980 the property, like many other farms in the region, had lost significant topsoil from erosion, encountered increases in dryland salinity and experienced reduced soil organic matter, which restricted pasture growth and plant survival (Rengasamy 2002).

The terrain of Talaheni is rolling to hilly with the flatter areas and mid-slopes most suited to grazing and the upper slopes and ridges containing the majority of trees, mainly Red Box (*Eucalyptus polyanthemos*) and Red Stringybark (*Eucalyptus macrohyncha*). To combat dryland salinity the ridges and upper slopes at Talaheni were revegetated to lower the watertable recharge and hence the watertable, reducing soil salinity in the flatter areas. Revegetation was achieved by intensively grazing selected high recharge areas and then removing the sheep to allow tree seeds to readily establish on the disturbed ground. Selective thinning of the revegetated areas was performed in 2004 to develop more vigorous and sustainable tree densities. In areas where trees numbers were too low to provide sufficient seed, seedlings were planted in row strips and woodlots with native species such as Red Box that produce quality timber. An estimated 200 000 trees were revegetated from seedlings on 86 ha, and ~20 000 seedlings were hand planted on 12 ha.

The dominant vegetation on the mid-slopes is the native perennial grass species Weeping Grass (*Microlaena stipoides*). The lower slopes and flats have deeper soils that retain more moisture than the slopes and are planted with phalaris (*Phalaris aquatica*).

Modelling sheep on the Talaheni site

The whole-farm, biophysical model GrassGro (Freer *et al*. 1997) was used to model livestock on the flats and mid-slopes of Talaheni, and this model has been validated elsewhere (Clark *et al*. 2000). GrassGro is a mechanistic model containing interacting modules for climate, soil dynamics, pasture growth and animal production. The model used 50 years of SILO data drill daily weather datasets (see http://www.longpaddock.qld.gov.au/silo/, verified 10 December 2015) for Talaheni, where the climate data is interpolated from point measurements performed by the Australian Bureau of Meteorology. The modelled pasture represented the major grass species at the site, being annual ryegrass (*Lolium rigidum*), microlaena (*Microlaena stipoides*), phalaris (*Phalaris aquatica*) and subterranean clover (*Trifolium subterraneum*). The model was run from January 1960 to December 2012, with the first 3 years being discarded to minimise the impact of initialisation parameters and reflect the management of the site. Although the study calculated the C balance over a period of 50 years we focussed on the period from 1980 when the farm was purchased and restored by the current owners. The annual stocking rate was static at 5.0 ewes/ha but the stocking rate in dry sheep equivalents (1 DSE = 8.8 MJ/day, the energy required to maintain a 50-kg non-lactating sheep) fluctuated over time and through the season depending on the available feed and animal liveweights each year. As the model did not allow the stocking rate in ewes/ha to change, recent stocking rates were chosen as a more conservative way of estimating animal dynamics to calculate GHGE and the C balance of the farm, despite the farm having lower stocking rates when it was purchased in 1980.

The IPCC methodology (IPCC 2006), as described in the Australian National Inventory (DIICCSRTE 2013) was used to calculate on-farm GHGE. The sources of GHGE modelled were enteric CH_4 from livestock and CH_4 from manure; N_2O from soil cultivation, dung and urinary depositions, as well as indirect N_2O as a result of N losses via leaching, runoff and ammonia volatilisation; and CO_2 emissions from diesel, petrol and electricity use. Pre-farm emissions from the production of farm inputs were included from the production of supplementary feed barley at 0.30 t CO_2e/t grain (Christie *et al*. 2011) and the production of SuperPhosphate fertiliser at the rate of 0.23 t CO_2e/t SuperPhosphate. Farm emissions were converted to t CO_2e/farm and emissions intensity (t CO_2e/t clean fleece weight), using the global warming equivalent for each gas (DIICCSRTE 2013). As sheep farms produce both wool and meat, a percentage of emissions were allocated to each product. Mass allocation was used where emissions are assigned according to the percentage by weight of sold product (Casey and Holden 2005). Emissions from livestock, energy, fuel and the production of supplementary feed and fertiliser were then subtracted from the C sequestered in trees and soil to obtain the C balance of the farm.

Modelling tree and soil C sequestration

The FullCAM model, version 3.55 (Richards and Evans 2004), was used to calculate C stocks in trees and soil at Talaheni on an annual basis. The FullCAM model was designed as Australia's tier 3 National Carbon Accounting System and is a point-based model relevant to Australian conditions, used spatially as part of Australia's National Carbon Accounting System. The areas (ha) of trees planted or revegetated from seed at Talaheni were estimated by determining the tree borders on LandSat and Google maps, then transferring the bordered images into a Geographic Information System (see Table 1) and finally entered into the FullCAM model. The majority of the 250-ha site was cleared between 1860 and 1880, therefore in FullCAM the year 1870 was chosen to clear the majority of trees on the slopes, and smaller pockets of land were cleared in the 1970s (Table 1). On the farm 100 ha of near-treeless land was dedicated to grazing, an additional 115 ha had trees (although livestock were excluded from only 30 ha), 30 ha was retained as virgin forest and 5 ha of land was dedicated to laneways, roads and buildings. The FullCAM model was run from the time that trees were cleared in 1870 forward to the year 2070.

Soil C measurements at Talaheni were used in combination with modelling to determine the amount of soil C under the pastures. FullCAM could not reflect the overgrazing that most likely caused the soil degradation that existed in 1980 and therefore this combined approach was chosen to more accurately represent the site. Nutrient Advantage (Nutrient Advantage Laboratory, Melbourne, Vic., Australia) soil tests showed soil C levels from the pasture areas of Talaheni of 0.8% (30 cm depth) in 1980, and 1.4% (30 cm depth) in 2011. Initially the same rate of soil C sequestration was used under pasture as was calculated in FullCAM for the slopes, as the land clearing activities of the flats and slopes were similar. The soil C levels were then gradually reduced from the 1.0% (30 cm depth) reported from FullCAM in 1950 to 0.8% in 1980 to be consistent with the measured data. Soil C was then gradually increased from 1982 and stabilised at 1.4% in 2011 again to match the measured data.

Data were not analysed statistically, but long-term average outputs were compared for the past 50 years (1963–2012) and since the purchase of the farm (1980–2012). Additionally, two individual contrasting years were examined that represented a dry year (2006) and a year of high rainfall (2012), based on annual rainfall and farmer knowledge. Low- and high-rainfall years were chosen to compare differences in GHGE as a result of the varying pasture production and animal intake.

Table 1. Events modelled in FullCAM to calculate tree and soil carbon sequestration
sph, stems per ha

Farm area	Year	Area (ha)	Tree stocking rate (sph)
Uncleared forest	1870	30.0	<500
Cleared forest	1975	5.3	0
Cleared forest	1978	11.6	0
Revegetated	1982	82.9	>1500
Planted trees	1984	0.7	<500
Planted trees	1985	0.6	<500
Planted trees	1987	0.6	<500
Planted trees	1988	0.5	<500
Planted trees	1989	3.7	>1500
Planted trees	1994	0.5	<500
Planted trees	1998	1.0	<500
Planted trees	2000	0.5	<500
Planted trees	2002	1.0	<500
Revegetated then thinned	2004	3.5	>1500
Planted trees	2005	1.8	<500
Planted trees	2010	0.3	<500
Planted trees	2011	0.5	<500
Total area of tree plantings	–	145.0	–

Results

The modelling estimated that 19 300 t CO_2e and 11 800 t CO_2e were sequestered in trees and soils, respectively, between 1980 and 2012 (Fig. 1), with a positive C balance of 28 300 t CO_2e once GHGE were subtracted. The annual average sequestration rate from 1980 to 2012 in trees was 4.0 t CO_2e/ha and 2.5 t CO_2e/ha in soils. Cumulative emissions from 1980 were offset completely from the year 1984 onwards (Fig. 1). From 1980 to 2012, 61% of the C sequestration occurred in trees with the remaining sequestration occurring in soils.

The majority of on-farm GHGE (74%) at Talaheni were produced in the form of enteric CH_4 from livestock (Table 2). The second highest source of emissions was from indirect and direct N_2O emissions, followed by pre-farm emissions for the production of supplementary feed and fertiliser. Carbon dioxide emissions from energy and fuel were the lowest source of emissions on the farm. Livestock production produced more than three times the amount of emissions in a wet year (138 t CO_2e) compared with a dry year (41 t CO_2e), despite pre-farm emissions being higher in dry years. Pre-farm emissions were driven mainly by supplementary feed, and pre-farm emissions were 11 times higher in the dry year of 2006 than the wet year in 2012 (Table 2). Total emissions increased by a greater percentage (337%) than wool (8%) and consequently emissions intensity increased in a wet year.

In this study soils sequestered a higher total amount of C than trees over 200 years, but soil C stocks did not increase as much as in trees, where the C stocks declined with land clearing but increased rapidly as the re-established trees grew (Fig. 2). The soil C levels were influenced by the tree activity and steadily declined after land clearing in 1870 and then increased again after 86 ha of land was revegetated commencing in 1982. Since 1980 C sequestration in trees was greatest in the years following planting as the trees grew larger and sequestered more C before C sequestration stabilised around 2010 (Fig. 2).

Discussion

The average C sequestration rate in trees (4.0 t CO_2e/ha) was similar to Paul *et al*. (2013) who estimated that environmental

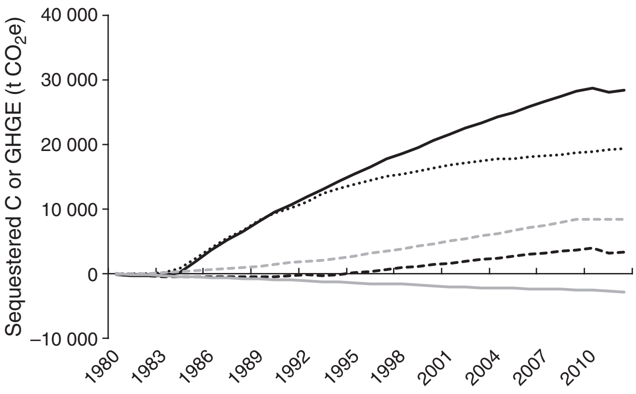

Fig. 1. Cumulative carbon balance from 1980 to 2012 (——) including farm emissions (on-farm methane, nitrous oxide, carbon dioxide and pre-farm emissions) (——), tree carbon sequestration (⋯⋯) and soil carbon sequestration under pastures (- - -) and on the slopes (- - -).

Table 2. Annual estimates of farm greenhouse gas emissions and long-term average carbon sequestration (2000–2012, 1980–2012 and 1963–2012) including selected years (2006, 2012) representing low- and high-rainfall (rf), respectively, in ascending order by annual rainfall

CO_2e, carbon dioxide equivalents; CFW, clean fleece weight; CW, carcass weight; DSE, dry sheep equivalents

Outputs (t CO_2e/farm)	Unit	2006 (low rf)	2000–2012	1980–2012	1963–2012	2012 (high rf)
Rainfall	mm/annum	326	577	616	617	723
Stocking rate	ewes/ha	5.0	5.0	5.0	5.0	5.0
Stocking rate	DSE/ha	7.2	8.1	8.3	8.4	9.7
Wool produced	kg CFW	1510	1391	1435	1463	1627
Meat produced	kg CW	4481	5137	5198	5303	6595
Carbon dioxide – energy	t CO_2	3	3	3	3	3
Methane – enteric	t CO_2e	22	63	67	68	103
Methane – manure	t CO_2e	0.00	0.01	0.01	0.01	0.02
Nitrous oxide – indirect	t CO_2e	3	11	12	12	18
Nitrous oxide – dung, urine	t CO_2e	2	8	9	9	13
Pre-farm emissions	t CO_2e	11	6	5	4	1
Total emissions	t CO_2e	41	91	95	96	138
Allocation percentage	% to wool	25	21	22	22	20
Emissions intensity	t CO_2e/t CFW	6.8	13.8	14.3	14.3	16.8
Carbon sequestration – trees	t CO_2e	160	227	610	325	209
Carbon sequestration – soil	t CO_2e	653	450	385	292	348
Net carbon balance trees only	t CO_2e	130	143	520	233	72
Net carbon balance trees and soil	t CO_2e	782	593	905	526	419

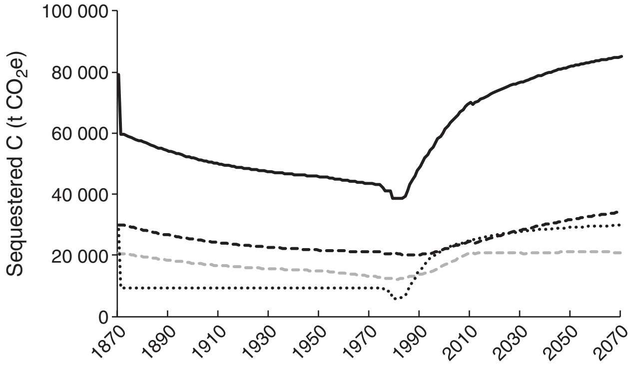

Fig. 2. Estimation of total carbon stocks (——), carbon stocks in soils on the slopes (- - -) and under pasture (- - -), and carbon stocks in trees (······) at Talaheni following land clearing in 1870, regeneration from 1982 and projected to 2070 using current conditions.

block plantings in Victoria sequestered ~5 t CO_2e/ha in a 600–700-mm annual rainfall area. Paul *et al.* (2013) found that planting in belts of 3–4 rows increased the volume, and subsequently C sequestration by 20–29% compared with block planting, due to the trees having reduced competition for light, water and nutrients. Maraseni and Cockfield (2015) used the FullCAM model to estimate that mixed environmental plantings at 18 different sites in southern Queensland would sequester on average 2.8–12.5 t CO_2e (average 7.7 t CO_2e/ha). The greater C sequestered at these sites than Talaheni was due to higher annual rainfall levels of 682–955 mm per annum.

Soil C sequestration on the slopes followed the tree activities, decreasing after tree clearing and sequestering more C in the soil after plantings due to more roots being available to break down into the soil. The soil under pastures on the lower slopes and flats was more degraded (0.8% soil organic C) than the soil modelled on the slopes (0.9% soil organic C) in 1980. The loss of soil organic C due to land clearing is consistent with a study by Fanning (1994) who suggested that overstocking in the late 19th century by sheep graziers in New South Wales caused the degradation of land. The reduced groundcover resulted in greater runoff and erosion on the slopes, whereas the valley floors were stripped and degraded due to higher stocking densities (Fanning 1994). Conant and Paustian (2002) have linked overgrazing to loss of plant productivity and soil organic matter and thus reduced soil C.

The GHGE from livestock was predominantly driven by stocking rate (DSE/ha) (Table 2), with more emissions produced in years of higher rainfall due to greater availability of pasture, leading to better animal health, reduced mortality (especially in lambs) and higher animal intake of pasture. Emissions intensity was twice as high during years of high rainfall than in drought years because greater rainfall increased pasture availability and animal intake, creating higher liveweight gain and greater associated GHGE. Yet during these years, wool production did not increase enough to compensate for the additional emissions (Table 2). This increase in emissions intensity with better seasons is the opposite of when the final product is directly linked to feed intake, such as meat or milk production (Browne *et al.* 2011, 2015) and meat production can be seen to increase with rainfall (Table 2). When the final product is meat or milk, increased production from good quality feed in years of high rainfall usually produces a greater amount of product relative to emissions and emissions intensity subsequently improves.

The Emissions Reduction Fund is a scheme run by the Australian government that allows farmers to claim C offsets for reducing emissions or sequestering C. The Emissions Reduction Fund requires projects from 30 June 2015 to pass the ‘newness requirement’, which means the project must not have been started before being registered with the Clean Energy Regulator if C offsets are to be claimed (CER 2015*b*). Therefore, the average annual 905 t CO_2e sequestered in trees and soils since the farm was purchased in 1980 (Table 2) cannot be claimed as a C offset, but Talaheni can make the claim of being C neutral and producing C-neutral wool and meat. Talaheni has also experienced economic benefits as a result of planting and revegetating over 200 000 native trees, due to the reduction in salinity and subsequent improvement in pastoral production. As the majority of trees were established on the upper slopes and ridges, which were less suitable for grazing than the lower areas, there was no significant loss of grazing land. Therefore, despite extra land being utilised for trees, productivity has improved. Although not captured in this study, Ive and Ive (2007) have observed a steady increase in the stocking rate at Talaheni of 0.15 DSE/ha.year on average since 1983 and also cattle standardised weaning weight has increased by 1 kg/year as pasture management and pasture availability have improved. The stocking rate (ewes/ha) remained the same in the GrassGro modelling that was used in this study, therefore GHGE would have been slightly overestimated in the earlier years when the farm could not support as high a stocking rate as in recent years.

For future projects, the Emissions Reduction Fund provides an incentive to store C on cleared farmland and the price of C is determined through a reverse auction tender, which has recently seen a C price of \$12.25 (CER 2015*a*). Harper *et al*. (2007) estimated that C sequestration is unlikely to be profitable with a C price below AUD \$15/t CO_2e, whereas estimates are higher at \$18 to \$40/t CO_2e in other studies (Paul *et al*. 2013; Polglase *et al*. 2013). Evans *et al*. (2015) estimated that for natural regeneration and environmental plantings to be viable a C price of \$66/t CO_2e and \$109/t CO_2e was required, respectively, with environmental plantings having higher up-front costs of purchasing and planting trees. Although some studies (Crossman *et al*. 2011) suggest that the economic returns of environmental plantings in selected areas could exceed the profitability of agriculture, this profitability is dependent on the C price and the costs of auditing, monitoring and reporting C stocks, which can incur substantial costs. Carbon stocks must be permanent for GHGE to be offset, but the amount of C sequestered in trees plateaus after ~20 years as trees reach maturity (Fig. 2), which would affect ongoing C sequestration rates. Additionally, when current land is permanently converted to trees to claim C offset income, farmers forego the opportunity of changing land use in the future and may reduce the grazing area, depending on where the trees are planted. Reeson *et al*. (2015) found that although C forestry can be more profitable than existing land uses, the uncertainty of future C prices and future commodity prices is likely to result in less adoption of C forestry than static modelling scenarios would suggest and further incentives may be required for revegetation to be attractive to landholders for environmental services (Maraseni and Cockfield 2015).

Agroforestry, where trees are planted without a subsequent change in land use (Schoeneberger 2009), may be more economically viable than afforestation. Carbon can be sequestered in substantial quantities by planting trees in small areas of land such as laneways, areas that are less accessible for farming, or marginal land with the majority of land remaining in agricultural production (Schoeneberger 2009). Thus, as was demonstrated at Talaheni, trees may be planted with a level of permanence, providing co-benefits such as windbreaks, biodiversity or shelter, without adversely impacting livestock production.

Conclusion

This study analysed the C balance of the wool farm Talaheni in south-eastern Australia, which had an average (1980–2012) stocking rate of 8.3 DSE/ha. Since the farm was purchased in 1980 with restoration beginning in 1982, 11 times more CO_2e/year has been sequestered in trees and soil than has been produced by livestock, energy and fuel use. Thus, any wool and meat produced at Talaheni is C neutral. However, the stocking rate in this study, although high for the region, was relatively modest compared with intensive sheep systems in higher-rainfall areas and farms that have higher stocking rates may not achieve the same C positive outcome due to the additional C sequestration required to offset GHGE from more sheep.

The tree planting activities and soil C improvements at Talaheni demonstrate that there are substantial gains to be made in soil C sequestration where initial soils are eroded and degraded and there is the opportunity to increase soil C either through planting trees or introducing perennial pastures to store more C under pastures. Further research would be beneficial on the C-neutral potential of farms in more fertile, high-rainfall areas that commonly have higher stocking rates than the current study region.

Including agroforestry activities on farms can provide important co-benefits such as sheltering animals, increasing biodiversity, reducing erosion or reducing salinity. As described at Talaheni, these co-benefits may assist to make farms more productive and sustainable for farming into the future.

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