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Tagasaste (*Cytisus proliferus* Link.) reforestation as an option for carbon mitigation in dryland farming systems

R. Wochesländer[a], R.J. Harper[a,*], S.R. Sochacki[a], P.R. Ward[b], C. Revell[c]

[a] School of Veterinary and Life Sciences, Murdoch University, 90 South Street, Murdoch, WA, 6150, Australia
[b] CSIRO, Agriculture Flagship, Private Bag 5, Wembley, WA, 6913, Australia
[c] Department of Agriculture and Food WA, 3 Baron-Hay Court, South Perth, WA, 6151, Australia

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ABSTRACT

The Agriculture, Forestry and Other Land Use Sector (AFOLU) plays a major role in national and international strategies to manage increasing global greenhouse gas emissions. This study investigated the option of increasing carbon storage in biomass and poorly productive soils in dryland agricultural systems, while avoiding competition with food production, using tagasaste (*Cytisus proliferus* Link.), a woody N-fixing perennial species. Perennial plants often have deeper and more extensive root systems than annual plants, and therefore may increase soil organic carbon (SOC) stocks deeper than the IPCC standard sampling depth of 0.3m. Above- and below-ground biomass carbon and SOC to a depth of 2 m were measured on a 22-yr-old replicated field experiment in Western Australia (mean annual rainfall, 498 mm yr^{-1}) comparing unmanaged plantations of tagasaste with conventional annual crop and pasture rotations. Carbon sequestration was 2.5 Mg C ha^{-1} yr^{-1} over the 22-yr lifespan for the tagasaste treatments, with a change of 0.9 Mg C ha^{-1} yr^{-1} in SOC and 1.6 Mg C ha^{-1} yr^{-1} in biomass. Tagasaste plots contained significantly larger SOC stocks compared with control plots for soil to 0.9 m, however beyond this depth, treatment differences were not significant. It is recommended that soil sampling be extended to depths of 1 m under such perennial systems with no benefit from sampling to depths deeper than this. In contrast to its current use as a fodder supplement for livestock, this study clearly demonstrates the potential of tagasaste for carbon mitigation within dryland farming systems, especially on soils marginal for conventional agriculture.

1. Introduction

Currently, the Agriculture, Forestry and Other Land Use (AFOLU) sector accounts for almost a quarter (10–12 Pg CO_2–e yr^{-1}) of global anthropogenic GHG emissions mainly from deforestation and agricultural emissions from livestock, soil and nutrient management (Smith et al., 2014). Considering the accumulation of anthropogenic CO_2 emissions since the beginning of the Industrial Era it has been estimated that 180 ± 80 Pg C were emitted to the atmosphere between 1750 and 2011 due to land use change, including deforestation, afforestation and reforestation (Ciais et al., 2013). These large historic losses and the associated potential to return to pre-deforestation conditions are the reasons many researchers believe there is great potential for agricultural systems to sequester large amounts of atmospheric CO_2 relative to current levels. Mitigation can occur through several pathways such as increasing carbon stocks in biomass and soils through revegetation, afforestation or reforestation (Canadell and Raupach, 2008), by substituting fossil fuel use through the use of bioenergy (Chum et al., 2011) or by reducing agricultural emissions from ruminant livestock and soils (Smith et al., 2014). Similarly, Lal (2004), estimated that adoption of improved agricultural management practices would enable the world's agricultural soils to potentially sequester 0.4–0.8 Pg C per year.

Although there can be positive benefits of mitigation (Bustamante et al., 2014), a major issue with mitigation on agricultural land is the competition with food (Smith et al., 2014) and water (Jackson et al., 2005). Agroforestry – the integration of agriculture and forestry – is one option to increase carbon and increase the sustainability of land use (Watson et al., 2000). Because of its potential to mitigate climate change and its links to agriculture and forestry, agroforestry is gaining particular attention in developing countries (Anderson and Zerriffi, 2012).

Reforestation of agricultural land has been proposed as a way to combat land degradation problems like salinity, wind erosion, water balance issues, and biodiversity reduction (Harper et al.,

* Corresponding author.
E-mail address: R.Harper@murdoch.edu.au (R.J. Harper).

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2012b; Lal 2009; Lorenz and Lal 2014). Increasing desertification has affected profitability and livelihoods across agricultural lands globally (Reed and Stringer, 2015) and creating carbon sinks through reforestation with deep-rooted perennial systems and selling the carbon in carbon markets may represent an option for more profitable land uses (Harper et al., 2007) and repair or stabilize degraded land (Lorenz and Lal, 2014).

Carbon mitigation could be achieved by sequestering additional carbon in biomass and soils, or producing biomass for bioenergy production. One option for increasing carbon mitigation with perennials, while avoiding land competition issues, is to use abandoned or marginal farmland (Sochacki et al., 2012). Perennials have extensive root systems, which can grow deep into the soil and thereby increase deep soil organic carbon (SOC) inputs (Lorenz and Lal 2014; Nair et al., 2010). Sequestration rates vary depending on factors such as species, plant age, climate, soil composition, and topography (Polglase et al., 2013). Yet, there are few studies on carbon storage in perennial species suitable for the low-rainfall areas of Australia and other similar Mediterranean environments.

Compared to many northern hemisphere soils, Australian soils are often severely constrained for agricultural production by the lack of nutrients, accumulation of salt, and poor water retention (Chen et al., 2009). In addition, a drying climate may further limit the carbon sequestration potential of Australian soils. However, Sanderman et al. (2010) identified several possible ways to maintain or increase organic carbon in Australian agricultural soils. Some could be achieved by management changes within existing cropping/livestock systems, while others require more radical shifts to different systems such as conversion from cropping to permanent pasture, or other perennial-based systems.

Tagasaste (*Cytisus proliferus* Link.), or tree lucerne, is a hardy evergreen shrub originating from the Canary Islands (Snook, 1982). Its edible foliage provides supplementary fodder for ruminants (Townsend and Radcliffe, 1990). Tagasaste grows well on deep sandy soils, but is intolerant of salt and waterlogging conditions (Wiley and Davey, 2000). Its root system can extend deep into the soil (up to 10 m) (Snook, 1982), where it can access deeper water sources unavailable to annual plants (Lefroy et al., 2001).

Despite its potential value in grazing systems and also its adaptation to infertile soils in semi-arid climates, the carbon mitigation potential of tagasaste has not been examined in the formal literature, despite promising unpublished studies (Wiley and Davey, 2000). In this paper we examine the changes in biomass accumulation, and quantity and distribution of SOC following a shift in land use from an annual to a perennial-based tagasaste system in a long-term (22 year) replicated experiment (Lefroy et al., 2001). Many previous studies have investigated changes in SOC to only 0.3 m soil depth, as this is the Intergovernmental Panel on Climate Change (Aalde et al., 2006) default. A few studies have reported soil carbon stores to much greater depths (Harper and Tibbett, 2013; Jobbágy and Jackson, 2000). Given the reports of tagasaste roots occurring to depths of several metres (Lefroy et al., 2001) we also examined SOC accumulation to a depth of 2 m. Our results will assist in establishing the potential of this species for carbon mitigation, its potential environmental co-benefits and make conclusions as to whether it is cost-effective to include deep soil sampling in carbon projects.

2. Materials and methods

2.1. Site layout

The study site was located north-west of Moora, a town-site located 177 km north of Perth in the Wheatbelt region of Western Australia (WA) (Fig. 1). This study involved revisiting an experimental site in 2014, which was established in 1992 by Lefroy et al. (2001) to compare the water use and productivity of tagasaste and cereal crops. The soil is classified under the Australian Soil Classification (Isbell, 1996) as a yellow-orthic Tenosol (yellow deep sand). The site has a Mediterranean climate with mean annual rainfall and pan evaporation measured by the Australian Bureau of Meteorology at Moora (12 km distant), over the 22 year period of 498 and 2190 mm yr^{-1}, respectively.

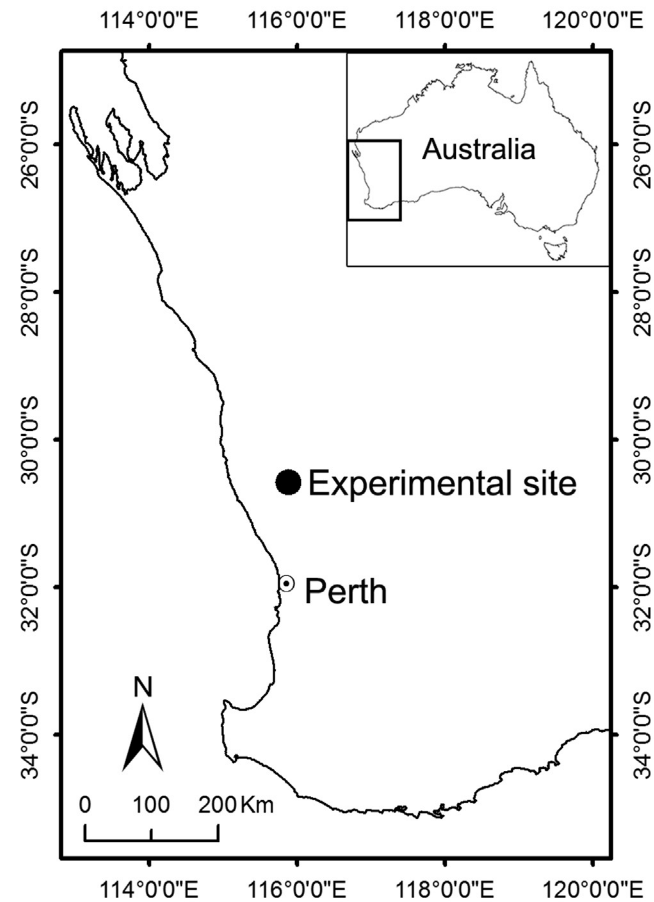

Fig. 1. Location of the study site (30°34′36.34″S; 115°52′23.55″E) near Moora, Western Australia.

The site contained two different types of tagasaste plantings (blocks and alleys) and agricultural controls in plots 50 m by 160 m in size (Fig. 2). The topography of the site was level and no differences in soil profile characteristics were observed. Tagasaste blocks consisted of tree rows 6 m apart and 0.7 m tree spacing within rows to give an effective density of 2300 trees ha^{-1}. Tagasaste alleys contained single tree rows 30 m apart with 0.7 m tree spacing within rows (550 trees ha^{-1}). Trees were left to grow without external interference (other than grazing by sheep) for a period of at least 15 years. Since 2005, the farmland surrounding the tagasaste plantations, and the agricultural control plots, have been under a rotation of wheat, lupins, and annual pasture (grasses and herbs) which is grazed by sheep. The inter-rows are also based on annual pastures but were excluded from any cropping. Grazing by sheep occurred after crop harvest, or during periods of pasture in the surrounding area.

2.2. Soil sampling

A mechanised coring apparatus developed by Sochacki et al. (2007) was used for sampling. Soil cores were sampled with a nominal diameter of 115 mm in the following nine depth intervals (in m):