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Carbon benefits of wolfberry plantation on secondary saline land in Jingtai oasis, Gansu – A case study on application of the CBP model

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ABSTRACT

The largest global source of anthropogenic CO_2 emissions comes from the burning of fossil fuel and approximately 30% of total net emissions come from land use and land use change. Forestation and reforestation are regarded worldwide as effective options of sequestering carbon to mitigate climate change with relatively low costs compared with industrial greenhouse gas (GHG) emission reduction efforts. Cash trees with a steady augmentation in size are recognized as a multiple-beneficial solution to climate change in China. The reporting of C changes and GHG emissions for sustainable land management (SLM) practices such as afforestation is required for a variety of reasons, such as devising land management options and making policy. The Carbon Benefit Project (CBP) Simple Assessment Tool was employed to estimate changes in soil organic carbon (SOC) stocks and GHG emissions for wolfberry (*Lycium barbarum* L.) planting on secondary salinized land over a 10 year period (2004–2014) in the Jingtai oasis in Gansu with salinized barren land as baseline scenario. Results show that wolfberry plantation, an intensively managed ecosystem, served as a carbon sink with a large potential for climate change mitigation, a restorative practice for saline land and income stream generator for farmers in soil salinized regions in Gansu province. However, an increase in wolfberry production, driven by economic demands, would bring environmental pressures associated with the use of N fertilizer and irrigation. With an understanding of all of the components of an ecosystem and their interconnections using the Drivers-Pressures-State-Impact-Response (DPSIR) framework there comes a need for strategies to respond to them such as capacity building, judicious irrigation and institutional strengthening. Cost benefit analysis (CBA) suggests that wolfberry cultivation was economically profitable and socially beneficial and thus well-accepted locally in the context of carbon sequestration. This study has important implications for Gansu as it helps to understand the role cash trees can play in carbon emission reductions. Such information is necessary in devising management options for sustainable land management (SLM).

1. Introduction

Human activities have led to a rise in atmospheric concentration of CO_2 from 280 ppm in the pre-industrial era to nearly 400 ppm at present with a still increasing rate of about 2.2 ppm yr^{-1} (Lal, 2011), which can alter the earth's climate. The largest source of emissions comes from fossil fuel use while land use and land-use change make up 30% of total net emissions, hence sparking interest in the study of GHG emission reduction and sequestering CO_2 by sustainable land management (Milne et al., 2010a). Afforestation of marginal agricultural lands is considered an effective, immediate and low-cost strategy to reverse some of the degradation processes, sequester carbon and provide other ecosystem services (Niu and Duiker, 2006;

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Manrique et al., 2011; Zhang et al., 2005; Yang et al., 2009). Cash trees and agro-forestry are integral components of forestry while cash trees and shelterbelts for farmland occupy an important place in agro-ecosystems in China. China is a large cash tree producer globally with its total cash tree planting area reaching 11,000,000 ha in 2011 (Wang, 2011). Lin et al, (2005) estimated a total of 25,806,581 Mg C sequestered in orchards in China. With agricultural economic restructuring, China's cash tree area is still expanding. In terms of its storage capacity of fixed C and the size of planting area, cash trees have a large role to play in the C cycle of terrestrial ecosystems and climate change mitigation as well.

Wolfberry (*Lycium barbarum* L.), a salt tolerant and drought resistant shrub, is accepted as a restorative land use for salinized soil, and a profitable cash tree mainly cultivated in northwest China (Li, 2010). In recent years, area planted to wolfberry has increased in Gansu and its neighboring provinces. The shrub starts to bear fruits in the first year of planting. Most of the total biomass of 4, 7, and 11 year old wolfberry plants is vertically distributed in the 50–100 cm layer above ground and most of the fruit and leaf biomass of 11 year old plants in the 100–150 cm layer (Liu et al., 2012). The total biomass and carbon sequestration of wolfberry plantation in Ningxia Hui Autonomous Region, a neighbor of Gansu, are 1.05×10^5 t and 5.29×10^4 Mg respectively (Yang et al., 2012). Furthermore several recent studies looking for judicious cultivation, management technologies have revealed a mixed operation to combine wolfberry plantations with poultry raising, where chickens graze within the wolfberry plantation, shaping an ecological agricultural model (Zeng et al., 2013; He et al., 2011; Wu et al., 2001; Sheng and Su, 2011).

A number of models have been used to estimate biomass carbon, soil organic carbon (SOC) stocks, and carbon emissions including the Century Model (Parton et al., 1987), Roth C (Jenkinson et al., 1992) and DNDC (Li, 2002). Some empirical and allometric equations and computer models combined with national forest inventory data are also employed to estimate carbon sequestration and dynamics of forest ecosystems in China (Xu, 1995; Huang et al., 2012; Zhang and Xu, 2002).

Yet, China has made very limited efforts in quantifying carbon sequestration, distribution and dynamics of cash tree and shelter forest ecosystems (Huang et al., 2010). In addition, little is known about wolfberry ecosystems in this respect. Reliable tools and accurate estimates of carbon sequestration are needed in Gansu and throughout China to quantify carbon benefits from cash crop cultivation. This would help assess the role cash trees could play in GHG emission reductions, domestic carbon trading market development and devising management options that enhance carbon sink capacity and sustainability of cash tree ecosystems, thus contributing to climate change mitigation. This paper reports on the first example of application of the CBP tools (CBP, 2013) to perennial cropland in China. The main objectives of this paper are, to use the CBP tools, to look into (1) the effect of wolfberry planting on carbon emission and soil carbon stock changes in secondary saline land in the Jingtai oasis in northwest China; (2) identify the main drivers and barriers for adopting the practice as well as responses to the barriers using a Drivers-Pressures-State-Impact-Response (DPSIR) tool; and (3) give an insight into a cost-benefit analysis (CBA) from the point of view of farmers in the context of carbon sequestration.

2. Materials and methods

2.1. Study site

Jingtai County is located in the north of Gansu province (103°33′–104°43′E, 36°43′–37°28′N), a transitional zone between the loess plateau and the Tengger desert (Fig. 1). There is a west-east gradient within the territory and the average altitude is about 1,610 m. The terrain comprises hilly areas, alluvial plains, stony eroded hills and sandy land with a dry continental climate. The Jingtai irrigated (oasis) area lies mainly in the central part of the county with an average annual temperature of about 8.6 °C, a mean annual rainfall of 185 mm, of which 90% falls between April and September, an annual evaporation of 3,038 mm and a frost-free period of 159 days.

The Yellow River flows along Jingtai's eastern boundary from south to north. The main crops include wheat, corn, oil flax and water melon. Cash trees include wolfberry, Chinese date and pear. Soils in the region are predominantly desert Sierozem with soluble salts and the organic matter content in the top layer of the soil is about 1%. There are red sandstone and mudstone buried under some localities within and around the region, which are rich in salinity with poor water penetration (Dou et al., 2006). The Jingtai power water-lifting project from the Yellow River, one of largest power water-lifting projects in China, consists of a first stage project (completed in 1974) and a second stage (established in 1994). The first stage project mainly supports the Jingtai irrigated area. The Jingtai water-lifting project irrigated areas are composed of the central Jingtai, covered by the first stage project and the joint region of northwest Jingtai County, northeast Gulang County and Ayouqi County of Inner Mongolia, irrigated by the second stage project. The central Jingtai irrigated area is geologically made up of 3 semi-closed sub-basins with poor drainage. The groundwater quality is extremely poor with main chemical categories being $Cl-SO_4-Na$, $Cl-SO_4-Na-Mg$, $SO_4-Cl-Na$ and $SO_4-Cl-Na-Mg$ (Zhang et al., 1990). The salinity ranges from 1.2 to 8.9 g L^{-1} with a maximum of 357 g L^{-1}. Before the water lifting project the area was under rain-fed agriculture with a deep groundwater level about 18 m in its central part. The groundwater table is close to the ground surface in some localities at present. Furthermore the salinity of water lifted for irrigation is about 0.4–0.5 g L^{-1} (Dou et al., 2006). Now salt accumulation in the top soil layer is a severe problem due to rising groundwater level, strong evaporation, upward salt movement etc. As a result of salinization, a great amount of farmland has been abandoned, putting great pressure on society. As a bioremediation solution wolfberry, has proved a highly practical option, and has already shown advantages in not only utilizing salinized land but also bringing decent incomes to farmers.

2.2. The Carbon Benefits Project models

The Carbon Benefits Project (CBP), co-funded by Global Environment Facility (GEF), was aimed at developing a standardized suite of tools for SLM and NRM projects to measure, monitor, model and forecast C stock changes and greenhouse gas (GHG) emissions and emission reductions. The system, designed to be used at any scale, has four options:

(1) The simple assessment which follows an IPCC tier 1 approach and is based on stratification by broad climate region, land use/cover and soil class, requiring users to input land management information and using default IPCC factors. Tier 1 is a relatively simple carbon accounting approach that uses default equations, along with default reference carbon stocks and emission factors to estimate stocks and net fluxes of carbon from different land use systems in a given area over a given period and under a given management system (IPCC, 2006; Batjes, 2011). Soil carbon stocks were estimated to 30 cm depth.

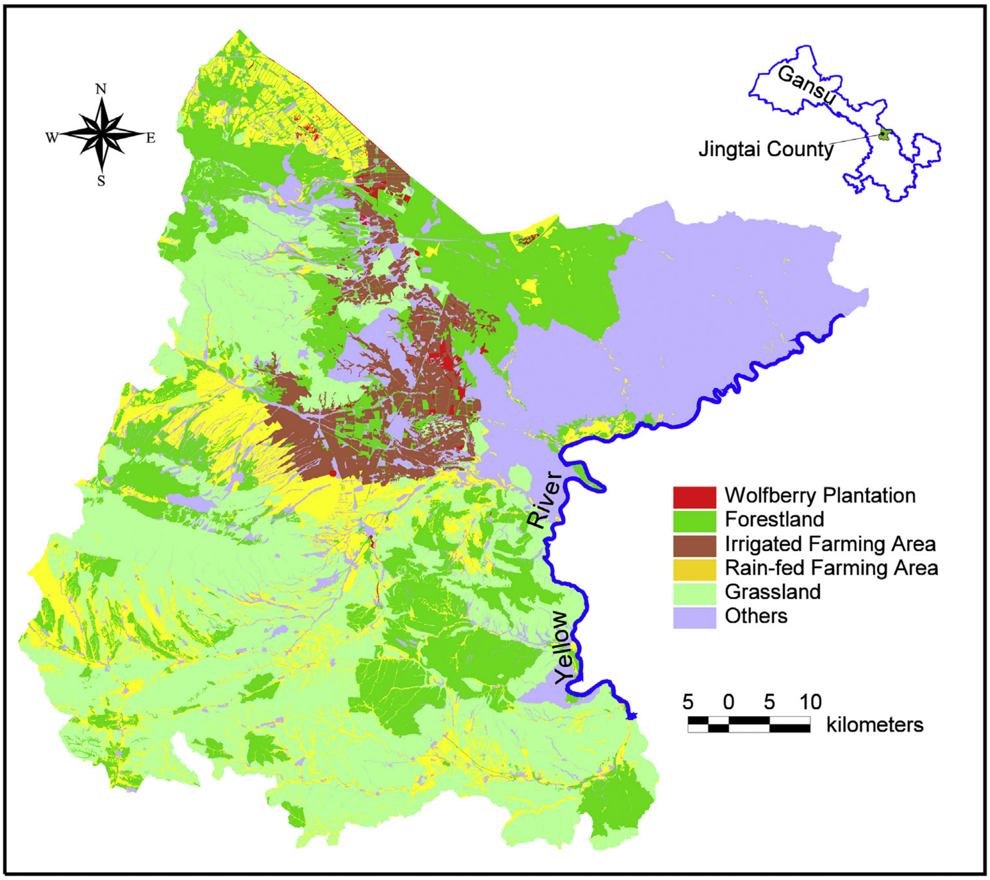

Fig. 1. Distribution of land use in Jingtai County, Gansu (2012). Data source: Gansu Integrated Ecosystem Management (IEM) Information Center, Gansu Forestry Survey and Planning Academy.

(2) The detailed assessment which also is supported by the IPCC method, allows use of project-specific information and emission factors.
(3) The dynamic modeling, based on the GEFSOC modeling system, which is a version of the Century model linked to a GIS.
(4) The socioeconomic tool is composed of the Driver-Impact-Response (DPSIR) analysis and the cost-benefit analysis (CBA).

A systemic DPSIR framework encompasses Divers, Pressures, States, Impacts and Response.

The Simple Assessment requires 5 categories of data: geographical location, area, crop type, land system and land management for a baseline, initial land use and a project scenario.

By employing the Simple Assessment toolkit, this case study was to look into C stock changes and greenhouse gas (GHG) emissions and projected emission reductions in severely salinized land after planting of wolfberry in the Jingtai oasis in central Gansu. The simple assessment process involves initial land use state, baseline and project scenarios, comparing the baseline and project scenarios to estimate the incremental carbon benefit, which is served as a basis for devising SLM options and policy decision making.

The initial land use was waste land, severely salinized with thin halophyte vegetation, used by local farmers as pasture. .

The baseline scenario was the continuation of the initial land use without any farming activity, taken as barren land and used as poor quality desert grassland.

The project scenario was bioremediation of saline land through wolfberry planting over a 10 year period of time from 2004 to 2014.

2.3. Data acquisition

Data on locations and areas of land use types, derived from the second grade survey of forest resources of Gansu (finished in 2011), were obtained from Gansu IEM Information Center, Gansu Forestry Inventory and Planning Academy (Gansu Forestry Inventory and Planning Academy, 2012).

Data for DPSIR and cost benefit analysis were acquired through baseline household investigation with random sampling in 2010. About 30% households of the village, totally 34 households, were surveyed with questionnaires.

3. Results and discussion

3.1. Carbon benefits

The arable land area of Jingtai County is about 68,609 ha, of which 22,230 ha, located in the Jingtai basin, are irrigated. Over 10% of the irrigated area is suffering from secondary salinization and some are heavily affected. Based on years of plant species introduction experiments for secondary saline land improvement, wolfberry has been well accepted locally for both salinization control and income generation. The total area under wolfberry has reached about 3866 ha, and is still expanding in not only Jingtai County but also in its surrounding regions. It has contributed significantly to restoration and utilization of salinized lands in arid and semi-arid regions in Gansu.

Afforestation of degraded/marginal agricultural lands has large potential for sequestration of carbon in soils (Akala and Lal, 2001). Establishing tree crop plantations with appropriate tree species can enhance soil fertility and sequester C in soil and biomass. Results from the CBP tool simulations show that over a 10-year period of time, wolfberry planting on saline land revealed quite a positive effect on soil carbon sequestration and a reduction in carbon emissions (Table 1). Under the baseline scenario, the barren saline land was sequestering carbon at a rate of 4.1 Mg CO_2e yr^{-1} ha^{-1}, while under the project scenario wolfberry plantation was predicted to sequester more carbon at a rate of 12.9 Mg CO_2e yr^{-1} ha^{-1}, including 6.2 Mg CO_2e yr^{-1} ha^{-1} in soil and 7.3 Mg CO_2e yr^{-1} ha^{-1} in biomass. Usually nitrogen fertilizer use leads to N_2O emissions, in the case of wolfberry planting scenario in Jingtai, nitrogen fertilizers were used, which gave rise to N_2O emissions at a rate of 0.56 Mg CO_2e yr^{-1} ha^{-1}. Both baseline and project scenarios were in the state of emission reduction. The incremental carbon benefits in total greenhouse gas emissions were −8.81 Mg CO_2e yr^{-1} ha^{-1} (corresponding with −2.4 Mg C ha^{-1} yr^{-1}) ("−"means emission reduction). As a result, wolfberry plantation on saline land in the Jingtai oasis serves as a carbon sink according to the CBP tools.

Ten years of simulated land management scenario show that wolfberry planting on the secondary salinized land led to significant C sequestration. Ma et al. (2014) reported a total measured C sequestration rate of 11.53 Mg C ha^{-1} yr^{-1} (including 10.8 Mg C ha^{-1} yr^{-1} in soil and 0.73 Mg C ha^{-1} yr^{-1} in biomass) with a net C sequestration of 3.98 Mg C ha^{-1} yr^{-1} to 1 m depth in an 11-year wolfberry plantation. The estimates from our results are different from those observed by Ma et al. (2014), possibly because of differences in the estimation depth, duration of the studies and the means from which the estimates were taken.

Soil is the main carbon storage of wolfberry ecosystems, accounting for over 90% of the total carbon stocks of the ecosystem (Ma et al., 2014). Different soil management options significantly affect the C fluxes of cash tree ecosystems. Compared with conventional management, conservation practices in tree crop ecosystems, such as the addition of manure, growing grass, mulching, minimum tillage and zero-tillage can reduce carbon emissions by reducing emissions from biomass burning, biomass decomposition, the decomposition of soil organic matter, while sequestering C through practices that increase biomass production and promote the build up of soil organic matter, moreover, improving soil structure, fertility and biodiversity (Milne et al., 2010b; D'Haene et al., 2009). Continuous inputs of C to agro-ecosystems through the use of fertilizers/manures, irrigation etc. would result in the accumulation of organic C in the soils, which could have big potential for C sequestration (Lal, 2002). Like other agro-ecosystems, wolfberry plantations are managed through fertilizing, irrigation, covering, zero-tillage etc. to not only achieve fruit production but also to sequester considerable quantities of atmospheric CO_2 in the system, thus offsetting C emissions from other sectors of the economy (Li et al., 2010; Wu et al., 2012). In Gansu's 12th 5 year master plan for forestry development, cash trees is listed as one of key components while according to the Gansu's 12th 5 year plan for cash tree development (Gansu Forestry Department, 2011), the area under wolfberry plantation will reach 16,667 ha by 2012, which could potentially sequester 215,004 Mg CO_2e yr^{-1} from the atmosphere based on calculations from the Simple Assessment Tool. Investigations show that wolfberry plantation has seen a 40% increase in the last 3 years in Gansu as well as a steady growing trend in its neighboring provinces following agricultural restructuring strategies, as a consequence presenting large potential in GHG emission reductions.

A key challenge to implementing agricultural GHG mitigation strategies is having reliable, cost efficient tools to quantify, monitor, and verify the performance of mitigation practices. Interest in the use of plantation forests to sequester atmospheric CO_2 has increased in China recently because it can be more cost effective than industrial emission reductions. There have been several studies on forestry C sequestration using various methods such as simulations based on climatic, soil, topography and population, and national forest inventory data, the F-CARBON model etc. (Kang et al., 1996; Zhang and Xu, 2003). However there are large discrepancies in forest carbon flux estimation due to insufficient basic research in forest C cycling resulting in uncertainties, and the limitations of current models (Li, 2002). The CBP simple assessment uses a Tier 1 IPCC approach, employing default emission and stock change factors. In addition it uses global framework of SOC stocks to 30 cm depth under native vegetation, taking into account default classes for climate and mineral soils. The estimates of SOC stocks represent globally averaged values under native vegetation that may differ from country/region specific values (Batjes, 2011). Revision or replacement of default values for climate and soil classes with country/project specific values will be necessary to reduce uncertainty in SOC stock changes (Li, 2002; Fu et al., 2011). Further, combining a national/regional-scale set of measurement data with a model-based estimation framework would provide the basis for a reliable and cost effective system to quantify carbon sequestration performance (Paustian et al., 2009). In use of the simple assessment tool of the CBP system, data relating to management activities are required. In the case of wolfberry plantations, additions of fertilizers/manures, pruning etc. were considered. The CBP simple assessment provides an accessible straightforward means of estimating the carbon benefits of land management practices (CBP, 2013). Estimates of uncertainty are included with the results. Uncertainty could be reduced in the future by altering emission and stock change factors as they become available.

Carbon in the fruit of the tree is not included in carbon sequestration estimation in the CBP modeling. According to laboratory analysis, fruit carbon accounts for 39.4% of the dry fruit biomass in the case of the Jingtai wolfberry. Fruits are one of the

Table 1
Estimates of CO_2 sequestration based on a 10 year projection by the CBP simple assessment tool for baseline scenario (salinized barren land), project scenario (wolfberry planting), and carbon benefits in the Jingtai oasis.

Source category	Baseline scenario	Project scenario	Incremental difference (carbon benefits)	
	MCE[a] yr^{-1} ha^{-1}	MCE yr^{-1} ha^{-1}	MCE yr^{-1} ha^{-1}	Uncertainty (%)
Total soil nitrous oxide	0.00[b]	0.56	0.56	102
Total biomass carbon stocks	0.00	−7.33	−7.33	10
Total soil carbon stocks	−4.13[c]	−6.17	−2.04	35
Total greenhouse gas emissions	−4.13	−12.94	−8.81	26

[a] MCE: Mg CO_2 e.
[b] "+": emissions.
[c] "−": uptake.

primary exports from the ecosystem. The total export of carbon, nitrogen, phosphors, potash, and sulfur from fruits are 1259.1 kg ha^{-1} yr^{-1} with carbon accounting for 92.3% (Ma et al., 2013). Therefore fruit carbon is a significant component of carbon cycling of the wolfberry plantation ecosystem and should be brought into the simulation to increase the reliability of carbon changes in the ecosystem.

The use of the CBP simple assessment tool, a standardized C benefits protocol (Milne et al., 2010b), in the wolfberry plantation ecosystem has made a substantial step towards building a quantification system for the role of cash tree and shelterbelt trees as C sinks in China. This could facilitate C trading in forestry and agricultural sectors in the future, especially if the CBP Detailed Assessment was used in a way that met the stipulations of a specific C certification scheme.

3.2. Analysis of the social and economic drivers affecting carbon sequestration using the DPSIR analysis

This case demonstrates the application of the DPSIR framework to help decision-making in wolfberry planting in the Jingtai oasis in the context of carbon emission reduction. Due to special geological and topographic features as well as inappropriate irrigation, the Jingtai oasis is severely affected by soil salinization. Wolfberry was introduced in the 1990s as an alternative option for salinized land improvement and a cash tree species as well. After pilot trials, demonstration, extension, and active adoption, the area under wolfberry has been steadily growing and it is doing well in not only poverty reduction but restoring the degraded soil, and developed into a promising industry. The plantation has been expanding fast beyond Jingtai County in Gansu province and developed into a pillar of the rural economy. This study suggests it can be carbon friendly and financially attractive based on results from the CBP tools. However, in recent years, some problems have become apparent in its management, for instance, insufficient technical support, limited access to credits, shortage of new varieties, extravagant irrigation, etc., which affects the cash tree's economic yields and ecological functioning. Wolfberry plantation management involves natural systems (soil, plant, water and so on) and social systems (rural community, policy, market etc.). A holistic approach is needed to understand the interconnections within and between the natural and societal elements of the ecosystem to support both policy makers and farmers in their decision making.

In the context of wolfberry cultivation in Jingtai County, the DPSIR framework encompasses *Drivers*, which are the key demands by farmers and creates *Pressures*, and identifies *State Changes* of the system and *Impacts*, then requires *Responses* by society (Fig. 2). *Drivers and Pressures* are mainly associated with wolfberry's cultivation and management. The over-arching driving forces refer to the need of farmers for income and more land under cultivation. Local farmers are aware of how important wolfberry is in lifting them out of poverty and they try to improve their techniques through training and study. In the last decade, the price of wolfberries has been generally stable with the income from wolfberry accounting for 38% of the total county revenue from cash trees (Lu, 2012). *Pressures* include perennial woody crop planting and associated irrigation and N fertilizer application.

Driven by decent financial benefits, some farmers have begun setting aside some of their cropland for wolfberry in addition to utilizing salinized waste land. Local governments encourage wolfberry industry with some incentives in its poverty reduction initiatives. It has promoted development of local rural cooperatives and professional associations on wolfberry. Furthermore several primary processors for wolfberry fruits have come into being. As a result, wolfberry planting-related industries have been mobilized.

Irrigation is necessary in arid regions for two reasons; the improvement of biomass production and the leaching of salts. Irrigation water is being lifted from the Yellow River through a large engineering project. The total installed capacity of the project is about $24.87*10^4$ kW and the electricity consumption for lifting 1 m^3 of water ranges between 1.4 kwh to 2.0 kwh (Peng, 2011; Hu, 2007). Water lifting by power is C-intensive and the energy use depends on the water table depth or the lift. Carbon emissions by irrigation are approximately 125–285 kg CE ha^{-1} yr^{-1} in general (West and Marland, 2002). Border irrigation and furrow irrigation are commonly employed while plastic film mulching, considered a multi-use practice, is used as an auxiliary effort in the early years of planting to retain moisture and avoid salt accumulation on the soil surface. The current irrigation norm is about 9450 m^3 ha^{-1} yr^{-1}, which is considered to be higher than the water requirements of the plant (Zhang, 2009). The current water price in the irrigated region is low comprising only 51% of its cost price (Peng, 2011). The current pricing of irrigation water is policy based instead of market regulated and also a result of the planned economy. The pricing mechanism has led to extravagant use of water resources, not only wasting water but also increasing the hidden C costs of inputs.

Similar to irrigation, fertilizers are applied in the intensively managed system, which enhances biomass production as well as increases the amount of above and below ground biomass returned to the soil. The fertilizers used consist of chemicals and manure. Manure is applied mainly in autumn as base fertilizer, while chemical fertilizers are used as top dressing and foliar application during growing seasons. Some growers operating large wolfberry plantations purchase sheep and chicken manure while others, managing small orchards, just use their own domestic animal manure after composting. The rate of fertilizer application increases slightly with tree age and some growers apply manures every other year with a view to controlling production costs; the optimum application rate of manure is 7.64 kg per plant while that of fertilizer nitrogen is 0.29 kg per plant in Jingtai area (He et al., 2011). The use of N fertilizers can result in N_2O and CO_2 emissions and N fertilizers have hidden C costs of 0.86 kg C/kg N (Lal, 2004; IPCC, 1996; Vergé et al., 2007). It is widely recognized that judicious use of fertilizers with high use efficiency, integrated nutrient management, recycling nutrient through manuring and so forth are efficient means of C sequestration and hidden C costs reduction (Matson et al., 2000).

The CBP tool suggests that wolfberry planting on saline land is a sink of atmospheric CO_2 in the Jingtai oasis. However the analysis considers on farm agricultural and land based emissions only, and the Simple Assessment draws on default data as a first approximation. Moreover, wolfberry production has brought impacts to the societal system, for example, stimulating local farmers' initiatives on gaining cultivation techniques to improve their capacity and living standards, boosting professional associations, cooperatives and farmers field schools (FFS), diversifying income sources, creating seasonal job opportunities etc.

Societal *responses* refer to management issues. Wolfberry planting plays an increasingly important role in the rural economy. Although some supporting policies and incentives, such as subsidies to planting on a planting area basis, and to seedlings, even providing free-seedlings, have been put in place, the policy regimes for cash tree planting are not perfect (Lu, 2012). In addition, some other options need to be integrated with current efforts, thereby making the industry more sustainable financially and efficient in the context of carbon sequestration: improving existing drainage systems, providing growers with easier access to rural credit services to ensure sufficient inputs; institutionalizing training with participatory methods to make farmers fully involved; reinforcing technical extension support; reforming the existing water pricing

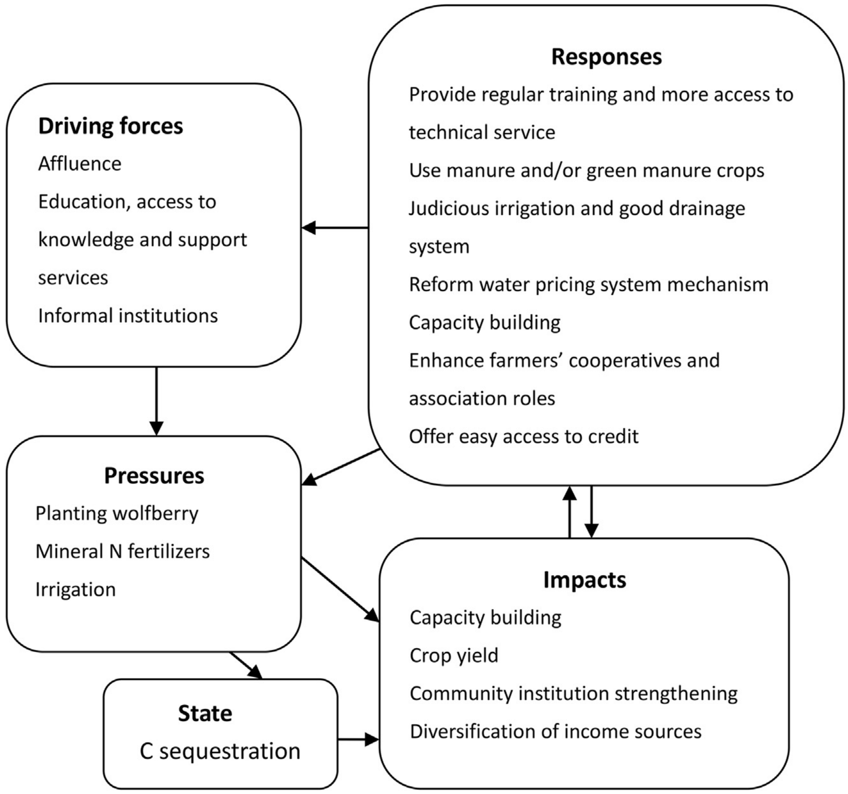

Fig. 2. The DPSIR framework for the management of the wolfberry plantation ecosystem.

mechanism and improving irrigation practices, using mulching or cover crops, strengthening the role of the professional associations and cooperatives, improving production-marketing mechanism and upgrading local processing capacity.

3.3. *Cost benefit analysis*

In the context of carbon benefits, the main objectives of conducting a cost-benefit analysis (CBA) are; to give an insight into the economic rationale for adopting or not adopting certain land management practices from the perspective of a land user, to help identify the tradeoffs that occur as a result of SLM interventions that impact carbon benefits, and to compare the financial effects and benefits of different sustainable land management (SLM) practices that lead to greenhouse gas.

(GHG) emission reductions and influence land users decision making. Results from the CBP simple assessment show that wolfberry planting in the Jingtai region is a C friendly land management practice, creating a positive carbon budget. Inputs for wolfberry planting are comprised of expenditure on initial establishment such as land preparation, seedlings, plastic film mulching etc. and recurrent management, including fertilizers, pesticides, irrigation, labor for pruning and fruit harvesting. According to household baseline surveys, seedlings accounted for 25.7% of total costs, the highest, followed by fertilizers for 20.5% and irrigation for 17.7% for the first year (Table 2). Of the costs for the fifth year, the full bearing period, fruit harvest comprised 49.2% of the total, the largest, followed by fertilizers (20.1%), irrigation (11.3%), and pruning (10.9%). The total costs for the 8th year were \$12,341 ha^{-1}, the highest, while that for the second year was \$6223 ha^{-1}, the lowest (Table 3). The yield started declining from the 8th year on, but the grower continued to increase manure input, thus making the investment the highest, in a bid to get a continued high production. The initial labor requirement was 415 person-days ha^{-1} in the first year; 395.2 person-days ha^{-1} for the second year (the lowest) and 915.9 person-days ha^{-1} (the peak demand) for the 8th year. Both of the total benefits and total net benefits presented the same trend: fast growth in first five years with the peak values being \$20,069 ha^{-1} and \$7,952 ha^{-1} respectively occurring in the 5th year, followed by a three year stable period, then a decline from the 8th year on. In contrast, the discounted net benefits showed a rapid growth in the first five years then starting declining from the 6th year on. The returns to labor (RL) for the first year were − US\$ 10.8 person-day^{-1} ha^{-1} and reached the peak of US\$9.5 person-day^{-1} ha^{-1} at year five then were decreasing slightly with a 10 year average of US\$ 5.2 person-day^{-1} ha^{-1}. Under the project scenario, with a 6% discount rate, the estimated net present value (NPV) is US\$ 31,310 ha^{-1}, the internal rate of return (IRR) is 65%; and the investment recovery period is 3.4 years. Wolfberry planting is not only economically attractive but makes use of saline land and sequesters carbon, hence presenting a win–win situation from the economic point of view in the context of carbon sequestration.

China's abolished agricultural taxes in 2006 and provides subsidies as incentives for crop planting. Both external benefits are made internal to motivate farmers to increase agricultural production. In addition, local forestry extension stations provide free training, market information and technical consultation. The current irrigation norm of wolfberry ranges from 9450 m^3 ha^{-1} yr^{-1} to 12,600 m^3 ha^{-1} yr^{-1}, which is considered to be too high. Irrigation quotas of 4725 m^3 ha^{-1} yr^{-1} with plastic film covering and 6270 m^3 ha^{-1} yr^{-1} with straw mulching are advised for wolfberry planting in arid Yellow River irrigated areas (Zhang, 2009; Zeng et al., 2013). Therefore, adopting judicious irrigation with mulching would raise water use efficiency and reduce irrigation costs, which may make wolfberry planting more profitable and carbon friendly. Furthermore, the wolfberry planting industry brings about

Table 2
Wolfberry plantation costs in the Jingtai region.

	Year 1				Year 5			
	Cost $ ha^{-1}	Labor days ha^{-1}	Labor cost $ ha^{-1}	Total $ ha^{-1}	Cost $ ha^{-1}	Labor days ha^{-1}	Labor cost $ ha^{-1}	Total $ ha^{-1}
Seedling	1746.53	30.00	331.17	2077.70	0.00	0.00	0.00	0.00
Plastic mulch	122.86	15.00	165.59	288.45	0.00	0.00	0.00	0.00
Manure	59.14	45.00	496.76	555.89	236.39	60.00	662.34	898.73
Fertilizer	435.25	60.00	662.34	1097.59	870.50	60.00	662.34	1532.84
Pesticide	528.45	45.90	506.69	1035.14	528.45	45.90	506.69	1035.14
Machine	189.24	0.00	0.00	189.24	0.00	0.00	0.00	0.00
Irrigation	402.45	93.15	1028.36	1430.81	536.50	75.00	827.93	1364.42
Pruning	0.00	30.00	331.17	331.17	0.00	120.00	1324.68	1324.68
Fruit harvest		67.50	1064.48	1064.48	0.00	540.00	5961.06	5961.06
Total				8070.47				12116.88

Table 3
Costs and benefits of wolfberry planting in the Jingtai oasis.

Baseline year	1	2	3	4	5	6	7	8	9	10
Establishment costs (US\$ha^{-1})	−2365	0	0	0	0	0	0	0	0	0
Maintenance/recurrent activities (US\$ha^{-1})	−5704	−6223	−8734	−11,253	−12,117	−12,117	−12,312	−12,341	−11,916	−11,703
Total costs (US\$ha^{-1})	−8069	−6223	−8734	−11,253	−12,117	−12,117	−12,312	−12,341	−11,916	−11,703
Total benefits (US$/ha)	3584	5734	10,751	17,919	20,069	20,069	20,069	20,069	18,635	17,919
Net benefits (US\$ha^{-1})	−4486	−489	2017	6666	7952	7952	7757	7728	6720	6216
Returns to labor (US\$ha^{-1})	−10.8	−1.2	3.3	8	8.8	8.8	8.5	8.4	7.7	7.2
Discounted net benefits (US\$ha^{-1})	−4232	−435	1693	5280	5942	5606	5159	4848	3977	3471
Net present value (US\$ha^{-1})	31,310									
Internal rate of return (%)	65%									

some external benefits to society such as creating seasonal job opportunities, especially for women within and around the region during harvest time, motivating local farmers to learn about different technologies concerning cash tree cultivation and management, strengthened degree of agriculture organization, information dissemination through the internet and so on. If the current policy and market conditions remain, wolfberry planting will continue to boost local socioeconomic and ecological well-being.

4. Conclusions

Cash trees are considered an integral part of forest ecosystems in China and play an important role in the carbon cycle of global terrestrial ecosystems. Compared with herbaceous ecosystems, cash trees have a higher carbon sequestration rate.

With proper management, wolfberry planting in the Jingtai oasis can accrue carbon benefits and is a well accepted crop due to not only its good performance on saline land utilization, but also its profitability.

The application of the CBP tools to the case of wolfberry plantations in the Jingtai oasis demonstrates a substantial step in efforts to quantify carbon changes in the ecosystem through cash tree planting. Results have important implications for the assessment of the role cash trees or plantations can play in carbon emission offsets to develop and adopt best sustainable land management practices and promote inclusion of agriculture offsets in China's GHGs emission reduction policies.

Robust capabilities are needed to accurately quantify the carbon benefits associated with different land management options. The application of the CBP tools in the Jingtai oasis is part of the capability development for measuring, monitoring, and forecasting C stock changes and greenhouse gas emissions in China. However a coordinated direct field measurement network, which provides observational data to reduce uncertainties in soil carbon estimates, integrated within a model-based system is needed to form a framework at the regional level for reliable and cost-efficient quantification and verification systems to bring forestry and agriculture into emerging domestic carbon trading markets in China.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.jenvman.2015.04.020

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