PV Water Pumping for Carbon Sequestration in Dry Land Agriculture

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Abstract

This paper is inspired by theory related to the water-food-energy-climate nexus and suggests a novel model, suited for analysing carbon sequestration in dry land agriculture using irrigation. The model is applied specifically to photovoltaic water pumping (PVWP) systems for irrigation of grasslands in China. We argue against the narrow approaches to analysing the water issue often found in literature and propose that carbon sequestration, energy security, food security together with local moisture recycling patterns should be included within the system boundary in order to make analyses of dry land agricultural activities more relevant and accurate.

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Nomenclature

 ET Evapotranspiration
 PVWP Photovoltaic water pumping

1. Introduction

During the latter part of the 20\textsuperscript{th} century, drought and arid areas increased substantially on a global scale [1]. Agricultural drought is mainly caused by deficit in soil moisture usually inflicted by anomalies in the precipitation pattern [2]. Drought in irrigation fed agriculture can be caused by reduced groundwater reservoir levels but in general the possibility of adapting to drought is much higher than in rainfed agriculture [3], hence supplementary irrigation decreases the vulnerability to weather anomalies. Aridity is projected to increase in large areas of the world [1]. At the same time food demand in the world is projected to be 70\% higher in 2050 compared to today [4] imposing a tremendous challenge to intensify agriculture all around the world. It has been suggested that a nexus approach to the issues of water, energy, and food security in respect to climate change is needed to tackle the multiple challenges simultaneously [5].

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This paper is inspired by theory related to the water-food-energy-climate nexus and suggests a novel model, suited for analysing carbon sequestration in dry land agriculture using irrigation. The model is applied specifically to PVWP systems for irrigation of grasslands in China. PVWP irrigation can be a feasible way to increase farmers’ yields and income [6], restore degraded grasslands and sequester carbon in the soil [7], but irrigation in water limited areas always face constrains.

2. A model to analyse carbon sequestration in dry land agriculture

The dual task of feeding humanity and curbing climate change calls for a balanced use of water for carbon sequestration [8]. However, carbon sequestration in agriculture could improve productivity and can therefore both increase food production and sequester carbon. In addition to productivity, changes in evapotranspiration (ET) and moisture recycling should be considerations when assessing water use for carbon sequestration [9, 10]. There is a need for different perspectives when it comes to water issues, since some water constraints are local and some operate on much larger scales. The model developed here with two complementary system boundaries is illustrated in Fig. 1. Table 1 describes all the components in the model more thoroughly and connects the components with assessments and benefits/concerns.

![Fig. 1. (a) A model with two complementary system boundaries considering water availability, carbon sequestration and sustainable development on project scale (brown boundary) and water, food and energy security on a suitable, larger, nexus scale (blue boundary). (b) The project scale (brown boundary) enlarged.](image)

<table>
<thead>
<tr>
<th>Component</th>
<th>Proposed assessment</th>
<th>Benefit/concern</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy security</td>
<td>The robustness, maintenance and suitability of the energy needed to sustain the carbon sink.</td>
<td>Electricity is used to pump water and irrigate, thus energy security is essential for the project.</td>
</tr>
<tr>
<td>Blue water availability</td>
<td>A water resource assessment should guarantee the water availability and environmental flows in the project area (see study [11] for details).</td>
<td>Water availability is essential for sustainable production, drought resilience and carbon sequestration.</td>
</tr>
<tr>
<td>Climate change mitigation benefit</td>
<td>A project methodology with baseline scenario calculates the climate change mitigation benefit including soil carbon sequestration and reductions of CO2 emissions (See study [7] for details). Sustainable development benefit and climate change adaptation might also be analysed.</td>
<td>The projects could both mitigate and adapt to climate change, by introducing carbon sequestration methods and renewable energy into the agriculture system. Sustainable development benefits could be a co-benefit of carbon sequestration.</td>
</tr>
<tr>
<td>Food security</td>
<td>Decreased vulnerability of food production systems due to the project is assessed.</td>
<td>Water is used to produce food and sequester carbon, enhancing food security.</td>
</tr>
<tr>
<td>Moisture recycling</td>
<td>Moisture recycling ratio is assessed. Baseline for moisture recycling should be the same as for the climate change mitigation benefit for consistency.</td>
<td>Moisture recycling from terrestrial evaporation directly affects the precipitation and increases the irrigation need in other locations.</td>
</tr>
</tbody>
</table>

The project system boundary (brown) is important in order to manage the local water resources. With insufficient water resources, the project cannot sustain agricultural production and will inevitably fail. The nexus system boundary (blue) is important in order to see the project as a part of a larger picture with...
impacts on food and energy security. The impact on ET is included here because land-use change in vegetation can have a huge impact on rainfall for a region and this can be considered as important for food security as the project itself; although the benefits are spread out on a larger area. Any estimation of the value of rainfall tends to grossly underestimate the benefits for the ecosystem. We assume that the rainfall can be replaced with pumps and irrigation which is a conservative estimate since the ecosystem service that rain has goes far beyond the value of crop growth.

2.1. Application of the model to PVWP systems for irrigation of grasslands in China

The model is applied to a PVWP system for increased grass production aimed at halting desertification in China (geographical coordinates: 100°14'E, 34°29'N). PV provides good features from an energy security point of view. Increasing energy tariffs can strike the irrigation fed agriculture hard and this sector is very sensitive to grid electricity prices [12]. PV systems guarantee a constant electricity price during its long lifetime and very low maintenance compared with diesel pumping systems [13]. The water resource assessment already conducted shows that water is available for irrigation of grassland and that environmental flow requirements can be guaranteed [11]. The climate change mitigation benefit is around 148 Mg CO₂ ha⁻¹, including both soil carbon sequestration and grid electricity substitution over a project time of 20 years [7]. The baseline is ‘restoration of severely degraded grassland’ (see [7] for details). Soil organic carbon increases water holding capacity, infiltration and soil porosity, and is a good proxy for soil productivity [14]. Investigating the literature on moisture recycling [e.g. 9] lets us assess the importance of vegetation in the project location on rainfall downwind. The moisture recycling ratio is at least 50% in Qinghai province. Given the same baseline as for the climate change mitigation benefit, reduction in ET has been estimated using the work of Kleidon et al. [15]. Using field data from Gao et al. [11] we estimated the lost ET to be equivalent to about 856 m³ ha⁻¹ year⁻¹, due to an increase in runoff. This volume of water would have fallen as rain and sustained biomass production and other ecological functions elsewhere. To compensate for the loss of rainfall, additional irrigation will be required downwind. Lifting 428 m³ of water 20 m with 50% hydraulic and electrical efficiency would require about 47 kWh year⁻¹ from a pump feeding an irrigation system. The benefits are summarized in table 2.

<table>
<thead>
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<th>Benefit</th>
</tr>
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<tbody>
<tr>
<td>Energy security</td>
<td>Solar radiation and plant water demand match well [16]; Renewable energy source; Fuel independent; Predictable price; Low maintenance.</td>
</tr>
<tr>
<td>Blue water availability (normal/wet/dry year)</td>
<td>2862/3295/2255 m³ per ha and year of water is pumped for irrigation and this can meet the water demand on a monthly basis, with sustained environmental river flows [11].</td>
</tr>
<tr>
<td>Climate change mitigation benefit</td>
<td>148 Mg CO₂ ha⁻¹ [7]</td>
</tr>
<tr>
<td>Food security</td>
<td>Drought adaptation: increased soil organic matter; Resilience to precipitation variability.</td>
</tr>
<tr>
<td>Moisture recycling</td>
<td>50% [9]; 428 m³ ha⁻¹ year⁻¹; 47 kWh pumping power ha⁻¹ year⁻¹</td>
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3. Conclusions

We have developed a model for assessing irrigation in dry land agriculture. It includes five interlinked components; (1) Energy security; (2) Water availability; (3) Climate change mitigation (4) Food security; and (5) Moisture recycling. The model also includes two complementary system boundaries the project boundary (component 2 and 3) and the nexus boundary (components 1, 4 and 5).

When applying the model to a PVWP irrigation system in China, we can draw some conclusions: (1) Energy security linked to the PVWP system is much higher than with a grid connected or a diesel pump system due to the fuel independency, the predictable price of electricity and low maintenance costs; (2) The blue water available is enough to sustain grass growth and satisfy environmental flow requirements; (3) The climate change mitigation benefit is about 148 Mg CO₂ ha⁻¹ after 20 years of
operation; (4) The system provides promising features for food security given the match between solar irradiance and plant water demand. The water resources are sufficient to sustain growth even in dry years and the increased energy need in dry years will be balanced by the increase in solar radiation [16]; (5) The geographical location of the studied system is important in terms of moisture recycling. 50% of the moisture that is evaporated will fall as precipitation on land downwind and this means that degradation and ultimately desertification in the area will lead to reduced precipitation downwind. We estimate that the reduction in ET from 1 ha degraded grassland in the case area is equal to a reduction in precipitation of 428 m³ year⁻¹, and if this has to be replaced with increased irrigation this would require about 47 kWh of pumping power per year per degraded ha land.

We have provided arguments and insight into how food security and energy security can be used in addition to water considerations when analysing carbon sequestration in dry land agriculture. Using solar power for irrigation of grassland, with the aim to prevent devastating effects of droughts, could both adapt dry land agriculture to climate change and mitigate the global effects of climate change by sequestering carbon. Using a PVWP system therefore seems like an appropriate way to increase social-ecological resilience, satisfying the need for agriculture intensification and reduction of vulnerability to droughts and climate change. Adaptation to climate change can be improved two times by using a PVWP system to irrigate grasslands due to the fact that vulnerability is decreased and exacerbation of drought is prevented. Although complex, the issue of moisture feedback effects is directly linked to precipitation in China [9] and desertification in West China will reduce precipitation in the important rain fed agriculture in North-East China [17]. With these insights we have tried to broaden the scientific debate on soil carbon sequestration in North and North-West China to include the triple goal of water, energy and food security.

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References
Biography
Alexander Olsson, M.Sc in Chemical Engineering, is currently pursuing a Ph.D in the topic of PV irrigation of grasslands and farmland in China at Royal Institute of Technology – KTH, in Stockholm, Sweden.