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Original Research Article

Soil carbon sequestration, carbon markets, and conservation agriculture practices: A hypothetical examination in Mozambique

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ABSTRACT

Payments for Environmental Services (PES) are relatively novel mechanisms whereby the adoption of sustainable management practices by a stakeholder is rewarded by incentives linked to external markets. Adoption of PES for conservation agricultural practices (CAPS) by smallholder farmers may provide opportunities to increase household income or cover the technology costs of adoption if the carbon sequestration benefits of CAPS are quantifiable, adoption rates are accelerated and maintained, a mechanism exists whereby carbon sequestration services can be compensated, and carbon offset exchange markets are viable. This research suggests a methodology to examine a PES market for carbon offsets generated by the adoption of CAPS by farmers in Mozambique. Assuming a cumulative adoption of 60% over a 20-year period, revenue from PES market participation to CA adopters was two times higher than revenue earned when disadoption occurred midway through the simulation. Lower adoption targets are associated with higher per household returns when fertilizer rates typical to the region are increased. Establishing and maintaining a sustainable PES system in the study region would require significant investment in time and resources. The lack of on-the-ground institutions or local support for such a program would also challenge successful implementation. Finally, the programs where participant success depends on external markets, such as the hypothetical one suggested here, are subject to the ebb and flow of foreign demand for carbon offsets. Addressing these three broad constraints to a PES/CAPS program in the region would require grass-roots driven policy initiatives with buy-in at multiple social, economic, and political levels.

1. Introduction

The United Nation's Kyoto Protocol introduced a Clean Development Mechanism for signatory countries to trade carbon (C) emissions. Under the provisions, stakeholders emitting CO_2 above the agreed limit in developed countries can offset their emissions by paying environmental services (PES) provided by agents implementing activities that reduce or absorb C in developing countries (Breidenich, Magraw, Rowley, & Rubin, 1998; Ringius, 2002). In 2015, signatories of the United Nations Framework Convention on Climate Change (UNFCCC) adopted the Paris Agreement along with a more ambitious carbon emission reduction goal. At this time, there were at least 8000 registered PES projects in over 105 countries, with an issuance of 1.6 billon tons of certified carbon emission reductions (UNFCCC, 2016). This trading mechanism could provide smallholders in developing countries a way to improve rural livelihoods (Smith & Scherr, 2002) and potentially be an economic incentive for the adoption of agronomic practices that conserve soil and sequester C (Marland, McCarl, & Schneider, 2001).

Payments for environmental services systems use markets to promote natural resource and environmental conservation goals (Pagiola et al., 2007; Wunder, 2005). PES programs differ from conventional conservation projects because they institutionalize returns from indirect benefits through market mechanisms (Sikor, He, & Lestrelin, 2017). PES programs are voluntary, whereby users of an environmental good pay service providers for the service itself or for a land use that provides such service (DAI, 2008; Wunder, 2005). Payments received by service providers under a PES arrangement may act as a financial incentive to increase the production of an environmental service or to adopt sustainable farming practices (Engel, Pagiola, & Wunder, 2008). When ecosystem benefits justify a monetary value that outweighs the private opportunity cost of

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resource uses or practices that generate off-site social costs, then PES programs work (Robinson, Albers, Lokina, & Meshack, 2016). These programs could eventually contribute to the incomes of smallholders engaged in livelihoods with high income volatility such as agriculture, thereby potentially stabilizing or augmenting income streams (Landell-Mills & Porras, 2002). However, data requirements, community and political support, and ill-defined markets complicate and challenge the establishment and sustainability of PES programs. Coordination of a market between smallholders and carbon brokers is further complicated because of information asymmetries, transparency questions, and transaction costs. The complicating effects of these factors could be reduced with accurate methods to measure, report, and verify the carbon offsets generated from the implementation of best management practices (Turnhout et al., 2017).

The primary contribution of this research to the PES literature is methodological. This study is a 'proof of concept' exercise that introduces a modeling approach that could supplement PES programs that are just gaining traction, are currently implemented, or are in early planning stages. We introduce a 'time-to-target' (3T) model focusing on the adoption of Conservation Agriculture Practice Systems (CAPS) that demonstrably sequester soil carbon. As the name suggests, the 3T model determines the rate, trajectory, and time until an adoption plateau is obtained by a community of users. The 3T model is completely generalizable to other agronomic crops, forest, or water resources. This research focuses on the adoption of CAPS by smallholder maize and bean producers in Mozambique. Previous research on PES opportunities in Mozambique include Hegde and Bull (2011), Jindal, Kerr, and Carter (2012), and Palmer and Silber (2012) work on a PES agroforestry program in Mozambique's Nhambita region. Using simulation modeling and household survey information, these authors concluded that the PES program had a positive impact on income through revenues from C offsets sold in foreign exchange markets.

Our analysis focuses on the adoption of CAPS in Angonia, Tsangano, and Barue Districts, Mozambique, and a hypothetical opportunity to sell carbon offsets from the use of C-sequestering agronomic practices to a carbon exchange market. The study simulates 20 years of C sequestration for Mozambique farmers participating in a hypothetical Payment for Environmental Service-Conservation Agriculture Practices (PES-CAPS) program. We hypothesize that while the community of adopters may benefit from a PES exchange market, late adopters could experience negative returns when carbon prices remain stagnant or downward-trend and if the project horizon is limited to 20 years.

2. Conservation tillage and soil carbon

Conservation tillage, crop rotation and crop residue management are agronomic practices that potentially decrease greenhouse gas (GHG) emissions from agriculture (Dumanski, Peiretti, Benites, McGarry, & Pieri, 2006; Reicosky, Kemper, Langdale, Douglas, & Rasmussen, 1995). We define the combination of these practices as Conservation Agriculture Practice Systems (CAPS). CAPS were introduced to Mozambique in 1996. Extension efforts promoting CAPS in the study area began in 2006, led by the government of Mozambique, international technical assistance, and non-government organizations. Not ploughing soil decreases microbial action and soil organic matter oxidation which in turn decreases CO_2 emissions (Logan, Lal, & Dick, 1991). Crop residues on untilled soil surfaces also moderate organic matter decomposition due to reduced soil-residue contact and lower soil temperature (Reicosky et al., 1999). Rotating crops generally accelerates crop residue recycling into soil thereby increasing soil organic carbon (SOC) content and CO_2 sequestration (Hutchinson, Campbell, & Desjardins, 2007). Sequestration rates attributable to CAPS depend on edaphic and climatic conditions and what combinations of CAPS are practiced. Bayer, Martin-Neto, Mielniczuk, Pavinato, and Dieckow (2006) found that untilled tropical and subtropical soils stored more C than similar tilled soils. Campos et al. (2011) concluded that the combination of no-till and crop rotation achieved relatively higher C sequestration levels. Naab et al. (2008) found that combining no-till and crop residue retention resulted in higher C stocks. Estimates of C sequestration by no-till and mulching systems demonstrate that sequestration rates vary widely; from 50 to 150 kg C ha^{-1} yr^{-1} in dry zones, to 1000–1500 kg C ha^{-1} yr^{-1} in humid climate (Lal, 2004, 2011). Soil C stocks are dependent upon C inputs and C decomposition losses making C sequestration challenging in low yield systems common in tropical smallholder systems (Govaerts et al., 2009). Powlson et al. (2014) suggests that while no-till promotes soil health, the overall impacts on GHG and climate change may be overstated. The Denitrification-Decomposition (DNDC) model is used to determine C sequestration potential from soils and growing conditions characterizing the study area of this research. Stringer et al. (2012) provide an excellent argument for why models such as this are needed to address C sequestration potential on a temporal basis. Our 3T model is linked to the DNDC model to simulate potential reductions in soil C emissions in return for payments over an adoption horizon.

3. Materials and methods

3.1. Overview of simulation model and outputs

Three core elements of the 'time-to-target' model include: 1) identifying a price series for an external carbon market ('Module 1'); 2) estimating CAPS adoption curves in terms of farmer adoption and the area managed under CAPS ('Module 2'); and 3) determining the rate of soil carbon accumulation over time associated with CAPS and conventional agronomic practices characteristic of the region's farming systems ('Module 3'). For Module 1, carbon market data is from the European Energy Commission (Fig. 1). Data for Module 2 is from a household survey conducted in 2012. Data for Module 3 is also from the household survey, which is supplemented with meteorological and local soil composition data. The components of each module are discussed in sequel.

Primary outputs are 1) estimates of returns to the community of adopters in the survey region participating in the PES-CAPS program ('Output 1'), and 2) soil organic carbon accumulation on the aggregated area cultivated (measured as tons ha^{-1} yr^{-1}) ('Output 2'). For Output 1, soil organic carbon accumulation trends and annual carbon market prices are combined at point E (Fig. 2) to determine annual returns to CAPS adopters participating in a PES carbon market. Details of each module and their linkages follow.

3.2. Module 1: Carbon exchange markets

Carbon market prices are required to calculate the hypothetical payments received by CAPS adopters sequestering carbon over a 20-year period. Carbon prices from 2012 to 2020 were obtained from the European Energy Exchange stock market (European Energy Exchange, 2013). The prices for the remaining 12 years of the simulation 2020–2032) were forecasted as random Brownian walks with the mean and standard deviation of the observed series parametrizing the series (2013–2020 mean = US\$ 5.23 t^{-1}, standard deviation = 0.60, Fig. 1). Status-Quo, Optimistic, and Pessimistic price trends were generated by assuming a 1-standard deviation difference between the high and low trends and the status quo price series.