Co-benefits of climate change mitigation from innovative agricultural water management: a case study of corn agroecosystem in eastern Canada

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With the increasing attention concerning the impacts of climate change in agriculture, Beneficial Water Management Practices (BWMPs) have been identified to decrease GHG emissions from the crop production process. Notably, the adoption of such practices simultaneously may also generate other benefits for the society (including producers), commonly called co-benefits. Understanding and evaluation of such co-benefits of BWMPs can be of high necessity for decision-makers to understand the overall gains in society's wellbeing by the adoption of such practices by individual producers. Although such associated benefits of the innovative water management system may not be the initial target of climate change mitigation, such knowledge would be linked to the development of efficient policy measures regarding climate change mitigation and adaptation. This study employed the conceptual framework of co-benefits in climate change mitigation to quantitatively evaluate such values from adopting BWMPs. The specific evaluation method consisted of financial analysis for assessing the private economic return as well as life cycle assessment (LCA) for measuring environmental benefits of the implementation of BWMPs compared with conventional free drainage system as the Base technology. Using farm-level financial and biophysical data of corn production from the study farm in St. Emmanuel, Quebec, the estimated NPVs of implementing BWMPs showed a 62.5% increase over the entire life of the innovative water management system, from $ 158.15/ha with Base technology to $ 256.99/ha with BWMPs. Then by calculating environmental impacts with their environmental prices, total environmental costs of Base technology and BWMPs were $ 465.21 and $ 336.48 per ha, respectively, which lead to summarized co-benefits value as $ 227.56/ha. In conclusion, the positive value of co-benefits demonstrated the auxiliary benefits of implementing innovative water management in association with climate change mitigation and the significance in adapting agricultural water management to climate change by adopting BWMPs. Additionally, it may offer a rationale for the role of policy incentives like green payments, in encouraging the adoption of BWMPs.

Introduction

Climate change has been posing a significant threat to global agricultural production and food security for widespread land degradation and water scarcity, which will broadly restrict the potentials for increased crop yields in the future (FAO, 2016). The agriculture sector in eastern Canada may be affected significantly by the impact of climate change. Lobell et al. (2008) projected that yields of major crops, like corn, wheat, and soybean, could decline modestly by mid-century but more steeply by 2100 under the reduced precipitation and limited water availability, thereby increasing the demand for agricultural irrigation. Nevertheless, the role of agriculture in climate change should be attached to great importance to understanding and maintaining its ecological function in reducing Greenhouse Gases(GHG) emissions and soil carbon sequestration through various agroecosystems (Derpsch, 2005; Pachauri and Reisinger, 2007).

Co-benefits of climate change mitigation were proposed in the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) as "benefits of policies that are implemented for various reasons at the same time, including climate change mitigation" (Pachauri and Reisinger, 2007). The incorporation of co-benefits has introduced a critical path to achieve the dual goals of reducing GHG emissions and pollutants with lower costs and thus significantly change the outcome of economic assessments of the GHG mitigation policy (Ürge-Vorsatz et al., 2014). Accordingly, it is essential to analyze and evaluate the co-benefits to obtain further motivations and incentives for potential adopters and policymakers aside from climate change mitigation benefits in implementing an innovative agricultural water management system in eastern Canada. Consequently, the objective of this study is to conduct a quantitative evaluation of the level of co-benefits from the implementation of innovative agricultural water management based on a case study for the corn agroecosystem in eastern Canada.

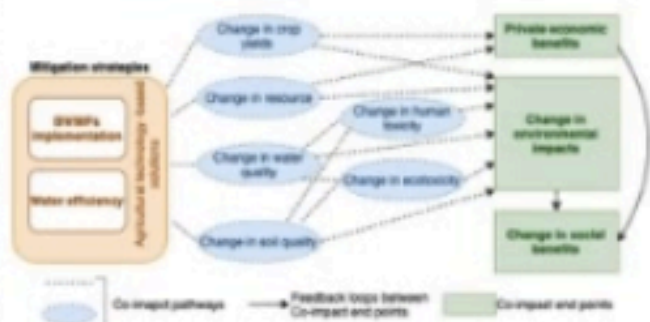

Fig.1 Conceptual framework of the co-benefits analysis of BWMPs implementation as mitigation strategies(Adapted from Ürge-Vorsatz et al. 2014)

Measuring Co-benefits of agricultural water management system

• Study site

The study farm in St. Emmanuel (Coteau-du-lac, Quebec) has a total area of 100 ha, and the study field consisted of 4.2 ha. Annual cropping production in this study farm is mainly corn (*Zea mays*), sporadically alternating with soybean and peas. The conventional tile drainage system was installed in the entire farm's study field as the Base technology. The system's tiles were placed approximately 1 m deep from the ground surface and spaced 15 m apart. Whereas, controlled tile drainage and subsurface irrigation as the BWMPs, which consisted of a water level control structure to adjust the water table in the growing season, working in half of the whole study field (Madramootoo et al., 1993). When the soil is saturated during rainfall, the water level can exceed the height of the stoplog and drain water into a ditch for the water reservoir during the dry period.

• Economic analysis

The data for conducting financial analysis regarding the adoption of BWMPs contain three primary categories: (1) Investment costs for implementing the water management system; (2) Revenues based on crop yield and price; and (3) Operating costs involving inputs and fixed costs.

• Environmental impacts analysis

The environmental impacts of BWMP in this study were estimated using a Life Cycle Assessment (LCA) framework for both technologies -- BWMPs and the Base technology. The objective was to compare and evaluate the co-benefits of these technologies.

In Life Cycle Inventory, input and output flows of product systems are created and measured in functional units. Input flows contain the materials, resources, and cultivation practices of corn production. The output flows mainly include emissions to soil, water, air from fertilizers, nutrients, and pesticides during the growing season, aside from the emissions generated from inputs flows. The final results of the LCI are reported by 1-tonne corn grain with a moisture content of 15 % at the storage.

Results and discussions

• Results

Table 1 illustrates a summarized co-benefits per hectare of BWMPs in comparison with Base technology for a continuous corn production system during the system's life span in eastern Canada. The change of net present values of investing in BWMPs compared with Base technology was $98.84/ha in Canadian dollars in 2019. This value calculating with the environmental benefits $128.72/ha resulted in a total co-benefits value of $227.56/ha. Although a producer will not internalize the environmental benefits as private economic returns, policymakers must be aware of these co-benefits and consider them in developing policies for the adoption of the BWMPs.

Table 1: Summarized co-benefits of BWMPs compared with Base technology for a continues corn production system in eastern Canada ($/ha)

Indicator	Base technology	BWMPs	Change in value
Economic benefits to producer (NPV)	158.15	256.99	98.84
Environmental categories:			
Eutrophication potential	152.64	71.05	-81.59
Acidification potential	127.12	87.14	-39.97
Freshwater aquatic ecotoxicity	20.87	20.07	-0.81
Human toxicity	7.47	7.18	-0.29
Terrestrial ecotoxicity	139.02	133.65	-5.37
Resources	18.10	17.40	-0.70
Total environmental costs	465.21	336.48	-128.72
Total Co-benefits			227.56

• Discussions

Since co-benefits of measures to mitigate GHGs are composed of economic benefits as well as environmental benefits, the connections between these two sections can be vital to the value of co-benefits. On the one hand, the farm-level economic analysis indicated that BWMPs was a more desirable alternative when compared to the Base technology. On the other hand, environmental benefits as public net benefits were found higher than private net benefits from farm-level. In this context, although there are variations and uncertainty in the key factors associated with the investment in the innovative water management practice, the controlled drainage with subsurface irrigation system proposed in the purpose of GHG emissions mitigation in the agricultural production show desirable co-benefits to raise the attention of decision-makers and thereby to encourage the adoption of BWMPs as a climate change adaptation strategy.

Conclusions

This study employed the value of co-benefits associated with the adoption of BWMPs (controlled tile drainage and sub-irrigation) by the producer for corn production in Quebec. In particular, two methods of valuation were used here: One, financial analysis from producer's perspective to measure the private economic value of the BWMP, and Life Cycle Assessment (LCA) which was used to measure the environmental benefits of the implementation of BWMPs compared with a conventional free drainage system. The total co-benefits of the BWMPs can be calculated as a sum of the change in net present value plus the reduction in environmental costs from retrofitting conventional free tile drainage to BWMPs, which was estimated at $ 227.56/ha.

The existence of co-benefits, particularly those resulting from reduced adverse environmental impacts, makes a case for the provision of incentives. In conclusion, aside from GHG emissions mitigation, innovative water management also generate extra values through the evaluation of co-benefits. Under the projection of climate change, which poses a threat to crop production in eastern Canada, adapting agricultural water management to climate change by adopting BWMPs is of increasing necessity.

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