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Global warming potential of intensive wheat production in the Yaqui Valley, Mexico: a resource for the design of localized mitigation strategies

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ABSTRACT

A reduction in greenhouse gas (GHG) emissions from productive activities can contribute to climate change mitigation by diminishing the future impacts on natural and socioeconomic systems. Nitrous oxide is one of the most important GHGs and agriculture represents its main anthropogenic source. Using a standardized life cycle assessment (LCA) methodology, this study aims to identify and quantify the GHG emissions associated with the different stages of wheat production using local information to develop localized climate change mitigation strategies in one of the most intensive agricultural areas in the world. A set of mitigation scenarios created based on inputs and information obtained directly from producer's associations and farmers were evaluated. These scenarios range from the traditional approaches to the more innovative strategies currently being applied. They are considered to maintain the same yields considering changes mainly in fertilization, tillage and machinery efficiency. We found that the main source of GHGs in wheat production in the Yaqui Valley is fertilizing, with an average of 83% of the life cycle emissions in all the production scenarios proposed. The second contributing activity is tillage, accounting for 13% of Global Warming Potential (GWP) in conventional systems and 1% with 'no tillage' strategies. Results show that the manufacture of fertilizers accounted for 42% of the fertilizing emissions and 35% of the total life cycle emissions of wheat. In addition, by using more efficient tractors that decreased diesel inputs, emissions from conventional tillage can be reduced by 33% and emissions from no tillage can be reduced by 24%. The application of the LCA methodology allowed providing a more detailed quantification of the GHG and environmental impacts of different wheat production processes. Compared to other studies, the mitigation strategies developed from this work have a better chance of being adopted by producers because there were developed based on the actual practices proposed by the farmers and consider existing approaches currently being promoted by producer's associations for cost reduction purposes. In this sense, the results of this LCA suggest that implementation of innovation strategies in fertilizing, tillage, and machinery efficiency can both reduce costs and mitigate GHG emissions in intensive wheat production systems all over the world.

1. Introduction

Anthropogenic greenhouse gases (GHGs) are considered to be the main contributor in the increase of radiative forcing (RF)[1] over the last century. The raised RF has led to a considerable uptake of energy by the earth's climate system, which is linked directly to the warming of the atmosphere and ocean, loss of ice and snow, rise of sea levels and the changes in the global water cycle (IPCC, 2013). Of the different GHGs in the atmosphere, carbon dioxide (CO_2) is the largest contributor accounting for approximately 76% of the total. However, other important GHGs are methane (CH_4) and nitrous oxide (N_2O) which account for 16 and 6.2% of the emissions respectively (IPCC, 2013). Combined together, these three GHGs account for about 98% of the total GHGs in the atmosphere. N_2O is

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[1] Radiative forcing is the change in energy flux caused by a driver and is calculated at the tropopause or at the top of the atmosphere in watts per square meter (W m^{-2}) (IPCC, 2013).

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considered a very important GHG because it has a lifetime of 121 years in the atmosphere and 264 times more global warming potential than CO_2 (IPCC, 2013). N_2O not only contributes to global warming, but also leads to the depletion of stratospheric ozone (Crutzen, 1970; Ravishankara et al., 2009; Rowland, 2006). Agriculture is the largest anthropogenic source of N_2O (Bouwman et al., 2002b; IPCC, 2013; Reay et al., 2012), with the application of nitrogen fertilizers being the main source of generation (Adom et al., 2012; Ahrens et al., 2008; Matson, 2012).

Despite the anthropogenic impacts associated to agriculture, this activity is a critical component of any nation's economic development and one of the keys to attain global food security. It is the major land use across the world with more than 1.5 billion hectares (around 12% of the world's land area) being harvested each year to fulfill the needs of the growing population (FAO, 2013). However, providing access to food at the global scale is a challenge because current food production rates are not keeping pace with ongoing population growth. This situation has led to a reduction in the private and public grain reserves (Godfray et al., 2010; Howden et al., 2007; Schmidhuber and Tubiello, 2007). Currently, cereals alone provide around 50% of world food calories and since the Green Revolution,[2] the world has witnessed a slow growth in their production (Fischer et al., 2014). Given that a 44% increase in the demand of cereals is projected from 2005 to 2050, in order to supply this demand, production will have to grow by 60% from 2010 to 2050 (Alexandratos and Bruinsma, 2012; Fischer et al., 2014). The increase in cereal production will likely come from an increase in both crop area and yields. However, a considerable expansion of agriculture areas worldwide is difficult given its current extension and these expansions will come with a significant risk of damage the remaining natural ecosystems. In that sense, future agricultural growth should rely more on higher productivity through increased yields rather than promoting the expansion of crop area (Fischer et al., 2014; Lobell et al., 2005).

The agriculture, forestry and other land use sector (AFOLU), as determined by the IPCC, contribute a quarter of the global GHG emissions, with agriculture generating an estimated global average of 5.0–5.8 Gt CO_2 eq yr^{-1} (IPCC, 2014b). Reaching their maximum potential yield is the main goal of most farming systems in the world and is the reason for the existence of several agricultural research centers, such as the International Maize and Wheat Improvement Center (CIMMYT). A more intensive agricultural production system can relieve pressure on land expansion, however, it will require higher inputs (FAO, 2013). Intensification of agricultural activities requires increasing the use of fertilizers, machinery, pesticides, water and transportation in order to achieve higher yields. Implementing this type of systems may improve yields, but there are severe environmental and public health costs associated with these practices (Gregory et al., 2002; Tilman et al., 2002). Unsustainable intensive agricultural systems can result in environmental impacts such as soil erosion and impacts on soil properties (Wright and Hons, 2005), depletion of water resources (Ward and Pulido-Velazquez, 2008), impact on water quality (i.e. eutrophication, acidification, contamination by heavy metals and agrochemicals) (Ahrens et al., 2008; Vitousek et al., 2009), contribution to climate change through GHG emissions (Bouwman et al., 2002a; Burney et al., 2010) as well as impacts on human health associated with application of pesticides (Mostafalou and Abdollahi, 2013; Weisenburger, 1993), heavy metals (Meza-Montenegro et al., 2013), nitrate and nitrite contamination (Jamaludin et al., 2013) and tropospheric ozone formation (Shindell et al., 2012). In order to reach a sustainable intensification, innovation strategies should be implemented to both improve the system's efficiency and to reduce its environmental and public health impacts (FAO, 2013; Godfray et al., 2010; Matson, 2012; Tscharntke et al., 2012).

A first step in developing innovation strategies is to quantify the GHGs and environmental impacts associated with agricultural practices throughout the world and particularly in areas where intensive production is taking place. Some regions have a greater contribution to agriculture, such as the state of Sonora located in northwest Mexico. According to Mexico's National GHG Inventory from 1990 to 2010, agriculture accounted for 12.3% (92.18 Million tons (Mt) CO_2 eq) of the country's GHG emissions (CICC, 2012). In Sonora, this percentage climbs to 17.5% (3.7 Mt CO_2 eq) highlighting the relevance of agriculture in this region (Chacón Anaya et al., 2010). Sonora is the main wheat producer in Mexico. With approximately 305,000 irrigated hectares, the state of Sonora alone produces more than 2 million tons, 62.2% of the country's total (INEGI, 2014b). However, due to the wide scope of the existing GHG inventories, the share of emissions this intensive wheat production contributes to the state's inventory is unknown and therefore the design of mitigation strategies is restricted to a generalized regional scale. Using a standardized Life Cycle Assessment (LCA) methodology, this study aims to identify and quantify the GHG emissions associated with different stages of wheat production using local information to develop localized climate change mitigation strategies in one of the most intensive agricultural areas in the world.

LCAs are commonly used to assess environmental impacts of a product or process throughout the stages of its life (Guinée, 2002). By developing a LCA, all of the emissions and impacts of the analyzed process can be both identified and quantified for each activity or stage. LCAs have been widely used for GHG emissions in farming systems to assess the global warming potential (GWP) in different production stages or activities (Adom et al., 2012; Biswas et al., 2008; Brentrup et al., 2004a; Fallahpour et al., 2012; Meisterling et al., 2009; Schmidt, 2008). Several authors have applied the LCA methodology to estimate emissions for wheat production in different environments. Most studies have focused on either fertilization strategies (Brentrup et al., 2004b; Charles et al., 2006; Fallahpour et al., 2012; Goglio et al., 2014, 2012) or soil preparation practices (Sørensen et al., 2014; Zaher et al., 2013). Until very recently, LCAs have started to be applied using approaches for analyzing wheat production management scenarios that combine changes in tillage and fertilization strategies. For example, Wang et al. (2015) analyzed a winter wheat–summer maize rotation in the North China Plains to identify the best management practices for that region. This study considered different fertilizing, tillage, and irrigation scenarios, but did not analyze the interactions between these components. Their results indicate that the main contribution of emissions came from irrigation, attributed to the high amount of electricity required for pumping water. Another recent study conducted by Alhajj Ali et al. (2015) analyzed experimental wheat production in a wheat–faba bean rotation cycle in Italy with the goal of optimizing the environmental performance of wheat production. The LCA on wheat production conducted by these authors considered different tillage systems combined with different fertilization rates. Although both of these recent studies provide relevant information, the results do not apply to many other regions of the world because of the variable climate and environmental conditions in which wheat is produced. For example, the study conducted in North China evaluated the production of wheat irrigated primarily with groundwater in comparison with other regions that rely mostly of surface water.

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[2] The Green Revolution refers to the period of dramatic increase in wheat and rice production in Asia in the 1960s with the introduction of high-yielding semi-dwarf varieties of these crops and the use of nitrogen fertilizers, irrigation and pesticides (Fischer et al., 2014; Matson, 2012).