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Environmental consequences of adaptation to climate change in Swiss agriculture: An analysis at farm level

Danielle M. Tendall [a,b,1,*], Gérard Gaillard [a]

[a] Agroscope Reckenholz-Tänikon Research Station ART, Reckenholzstrasse 191, Zürich 8046, Switzerland
[b] Swiss Federal Institute of Technology Zürich ETHZ, Ecological Systems Design, Schafmattstr. 32, Zürich 8093, Switzerland

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ABSTRACT

Climate change is expected to affect agricultural production in the coming decades, to which agriculture must adapt in order to maintain productivity and profitability. The effect of such changes on environmental impacts must be assessed, if the environmental goals of agriculture are also to be achieved in the future. We therefore assess the environmental impacts of adaptation scenarios previously developed with a purely economic perspective, for two case study regions in Switzerland. We use life cycle assessment at the whole-farm level, which enables the consideration of multiple environmental impact indicators, allowing us to identify potential trade-offs. We assess a simulated mixed livestock and arable crop farm representative of average farms in the two case study regions. The simulated farm is economically optimized for a reference scenario (current situation) and four future scenarios combining a climate change scenario representing a "worst case" change signal, and various price and policy scenarios. Results show that environmental impacts tend to increase in the future climate. Farms tend to extensify production, leading to a decrease in eco-efficiency, even more so if a decrease in agricultural product prices is assumed: socio-economic conditions may have even more influence than climate change, suggesting that there is a high potential for policy-makers to influence and mitigate the effects of climate change on agricultural productivity and the associated environmental impacts. The impacts of irrigation water use on aquatic biodiversity are revealed to be an important trade-off with farm economic optimization in the future. It is therefore recommended that aquatic biodiversity impacts be considered in assessments of agricultural adaptation to climate change. Policies directly targeting restriction of water use do not resolve this trade-off, although they do reduce impacts on aquatic biodiversity. Broader and more integrative policies are therefore required to support agricultural adaptation to the future climate while mitigating environmental impacts. In addition, different regions are found to react in a different way, suggesting that differentiated policies may be required for specific regions.

1. Introduction

Climate change is expected to greatly affect agricultural practice in the next 50 years (IPCC, 2007, 2014): indeed, increasing temperatures, decreased summer precipitation and intensified extreme weather events (including drought) should cause changes in yields (Lobell and Field, 2007) and create water-related risks in some parts of the world (such as Europe, European Environment Agency (EEA), 2009; including Switzerland, Climate Change and Switzerland 2050, 2007; Fuhrer, 2012). It is expected that agriculture will be able to adapt – at least partially – to these new climatic conditions (Burton and Lim, 2005; Smit and Skinner, 2002), provided sufficient technology (Lobell and Field, 2007) and capital are available, and that management modifications are undertaken at the farm scale (decision unit of the farmer), at the regional scale (decision unit of local policy-makers) and at the national and international scales (decision scale of national policy-makers) (Burton and Lim, 2005; Howden et al., 2007; Klein et al., 2005). However from a sustainability perspective, it is important that these adaptation strategies not only ensure economic profitability and maintain productivity, but also avoid the deterioration of environmental conditions (Kirchmann and Thorvaldsson, 2000; Robertson and Swinton, 2005). Thus the trade-offs between the benefits and impacts of adaptation must be assessed.

In this context, the impacts of climate change on agricultural profitability, and possible agricultural adaptation behavior, have been studied for the case of Switzerland, producing agricultural adaptation scenarios at the farm scale, which maximize farm profit under the expected climate in the year 2050 (Fuhrer et al., 2013; Lehmann, 2013a). These scenarios can be seen as the spontaneous

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* Corresponding author. Tel.: +44 632 85 56.
E-mail address: danielle.tendall@usys.ethz.ch (D.M. Tendall).

[1] Present address: Swiss Federal Institute of Technology Zürich ETHZ, Sustainable agro-ecosystems, Tannenstrasse 1, Zürich 8092, Switzerland.

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adaptation farmers might implement if no other incentives exist, since adaptation is conducted from a purely economic perspective. Such scenarios are used to inform policy-makers of possible future outcomes (Webb and Stokes, 2012). However, the environmental impacts of these scenarios have not been assessed, although this is necessary (Robertson and Swinton, 2005) in order to identify trade-offs and support policy-making for impact mitigation while adapting agriculture to climate change (van Vuuren et al., 2011). The environmental impacts of agriculture in Switzerland under current conditions have been assessed in many studies focusing on the crop level (Mouron et al., 2006; Nemecek et al., 2011) and the animal production level (Alig et al., 2012), and one important study exists at the farm level (Hersener et al., 2011). However to our knowledge, none have addressed the environmental impacts of agriculture under future climatic conditions. In general worldwide, studies assessing in detail the environmental impacts of agricultural scenarios under future climate do not seem to be available yet, although some reports provide general indications of the type of impacts that can be expected (Climate Change and Switzerland 2050, 2007; European Environment Agency (EEA), 2009; IPCC, 2007, 2014). "Environmental impacts" is a broad term covering many different aspects. It is essential to consider as many relevant indicators of environmental impacts as possible, in order to ensure that potential trade-offs between different aspects are captured and burden shifting is avoided (Van Der Werf and Petit, 2002). Life cycle assessment (LCA) is a framework for assessment of the environmental impacts of a product, process or system, which considers the impacts of its entire "life cycle" (from resource extraction, through processing and consumption, to waste disposal). Multiple environmental indicators are addressed. LCA thus enables identification of burden shifting along the life cycle and of trade-offs between environmental indicators, and has been found to be an adequate framework for assessing whole-farm environmental impacts (Hersener et al., 2011; Thomassen and De Boer, 2005).

In the context of the present study of adaptation strategies of Swiss agriculture to climate change, an important issue consists of an increased use of water for irrigation (Fuhrer, 2012). This may however be in competition with other water requirements, such as for human consumption (drinking water, cooling water, industrial processing, fisheries, hydropower, and leisure) as well as for aquatic ecosystems. Competition in use of water can result in potential impacts on aquatic biodiversity in particular (Malmqvist and Rundle, 2002). 71% of agricultural irrigation water is sourced from surface water (The United Nations World Water Development Report 3: Water in a Changing World, 2009) (75% in Europe, European Environment Agency (EEA), 2009; and up to 95% in certain regions of Switzerland, Robra and Mastrullo, 2011). Therefore the impacts of river water consumption in particular, including the impacts on river ecosystems themselves, should not be neglected when assessing the environmental impacts of agricultural adaptation strategies (Rack et al., 2013; Richter et al., 2003) – an issue which is unfortunately often neglected in LCA studies.

Thus the objectives of this paper are to analyze the environmental impacts of farm adaptation to climate change in 2050 for the case of Switzerland using LCA, including application of a recent approach to assess potential impacts on aquatic biodiversity. This includes a detailed analysis of global warming potential and potential aquatic biodiversity loss, as well as the correlations and trade-offs that may occur between environmental indicators, and with economic objectives. We also investigate the compatibility between economic farm adaptation to climate change, and mitigation of climate change. We furthermore discuss the potential of different policy approaches to address environmental impacts, with a focus on a policy targeting water use restriction through setting a price on water.

2. Methods

2.1. Life cycle assessment

One existing operational methodology for farm LCA, including inventory and impact assessment tools as well as a database is SALCA (Nemecek et al., 2010), specifically developed for Switzerland. Further environmental impact assessment approaches developed for farms and directly applicable to Switzerland include REPRO (Küstermann et al., 2010), RISE (Häni et al., 2003), INDIGO (Bockstaller et al., 1997) and the approach of Eckert et al. (2000), however these either do not consider the entire farm life cycle, or are less complete in terms of impact pathways considered (Van Der Werf et al., 2007). According to a comparative study of impact assessment approaches for agricultural systems (Bockstaller et al., 2009), SALCA had a high to highest performance in scientific soundness. We thus chose to use the SALCA methodology.

2.1.1. Life cycle inventory

The system boundary considered for the farm LCA was "cradle to gate", i.e. from raw material extraction (cradle) to output of the farm (gate of the farm). This includes all inputs to the farm and their own life cycle impacts, as well as on-farm processes and direct emissions (such as field operations, pesticide, nutrient and greenhouse gas emissions etc.). The following input groups were considered, based on the SALCA methodology for farm LCA (Nemecek et al., 2010, 2011):

- Infrastructure and machinery (e.g. stables, storage buildings, tractors, irrigation infrastructure).
- Energy carriers (e.g. diesel, electricity).
- Mineral fertilizers (mineral nitrogen, phosphate, potassium etc.).
- Pesticides.
- Seeds.
- Water for irrigation (assumed to be river water) and animals (assumed to be tap water).
- Animals for herd replenishment.
- Fodder (e.g. concentrated feeds, as well as silo maize and hay in case of insufficient on-farm production).

On-farm processes included field operations, grain and hay drying, storage, milking (in case of dairy cows); manure and slurry were applied only if sufficient on-farm quantities were available and sufficient demand for application was present (i.e. first fertilization of arable crops, fertilization of grasslands). Processes occurring after the farm production system were not considered (e.g. transport of products, processing, retailing), since no change in these processes was simulated in the scenarios.

The inventory of all inputs and emissions was established for each farm adaptation scenario (described in Section 2.3), reflecting the changes in the variables and outcomes of these scenarios. The outcomes of the farm optimization model (Lehmann, 2013a) (described below) in each scenario provided the following inventory flows as required in SALCA: crop land allocation, yields, nitrogen fertilizer application (quantity and dates), total irrigation water use, sowing dates, harvest dates, and soil parameters. For inventory flows which were not provided by the farm optimization model, consistent assumptions were made based on inventories of representative model farms of the same type (previously developed for Switzerland; Hersener et al., 2011), for farm infrastructure, seeds, energy use, pesticide application, fertilizer contents and brands; based on reference norms for Swiss agriculture (Flisch et al., 2009) for phosphorous, potassium, calcium and magnesium fertilizer application; and based on a study on irrigation efficiency (Spoerri, 2011) for irrigation infrastructure. Direct farm emissions (methane, nitrous oxide, ammonia, and nitrogen oxides emissions to air; heavy metal, phosphorous and phosphate emissions to surface water by runoff and erosion; heavy metal and phosphate emissions to groundwater by