Science of the Total Environment 529 (2015) 168–181

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Effects of climate change and agricultural adaptation on nutrient loading from Finnish catchments to the Baltic Sea

Inese Huttunen [a,*], Heikki Lehtonen [b], Markus Huttunen [a], Vanamo Piirainen [a], Marie Korppoo [a], Noora Veijalainen [a], Markku Viitasalo [a], Bertel Vehviläinen [a]

[a] *Finnish Environment Institute SYKE, P.O. Box 140, FIN-00251 Helsinki, Finland*
[b] *Natural Resources Institute Finland LUKE, Latokartanonkaari 9, FIN-00790 Helsinki, Finland*

HIGHLIGHTS

- Climate change is expected to increase winter runoff and slightly increase the annual runoff sum.
- Climate change is expected to affect crop growth, level of fertilization and production intensity.
- Combined climate and agricultural changes are expected to increase nitrogen and phosphorus loading to the Baltic Sea.
- Higher yields are needed for reducing nutrient balances, and more land should be allocated to water protection programs.

ARTICLE INFO

Article history:
Received 4 November 2014
Received in revised form 12 May 2015
Accepted 14 May 2015
Available online xxxx

Editor: Eddy Y. Zeng

Keywords:
Climate change
Nutrient loading
Baltic Sea
Agricultural scenarios
Water quality modeling
VEMALA

ABSTRACT

Climate change is expected to increase annual and especially winter runoff, shorten the snow cover period and therefore increase both nutrient leaching from agricultural areas and natural background leaching in the Baltic Sea catchment. We estimated the effects of climate change and possible future scenarios of agricultural changes on the phosphorus and nitrogen loading to the Baltic Sea from Finnish catchments. In the agricultural scenarios we assumed that the prices of agricultural products are among the primary drivers in the adaptation to climate change, as they affect the level of fertilization and the production intensity and volume and, hence, the modeled changes in gross nutrient loading from agricultural land. Optimal adaptation may increase production while supporting appropriate use of fertilization, resulting in low nutrient balance in the fields. However, a less optimal adaptation may result in higher nutrient balance and increased leaching. The changes in nutrient loading to the Baltic Sea were predicted by taking into account the agricultural scenarios in a nutrient loading model for Finnish catchments (VEMALA), which simulates runoff, nutrient processes, leaching and transport on land, in rivers and in lakes. We thus integrated the effects of climate change in the agricultural sector, nutrient loading in fields, natural background loading, hydrology and nutrient transport and retention processes.

1. Introduction

According to modeling results, future climatic conditions in northern Europe will be warmer and wetter, and temperature increase will be higher in northern than in southern Europe (IPCC, 2007, 2013). According to Ruosteenoja et al. (2010) the annual average temperature in Finland will increase by 2–6 °C by the end of the 21st century. In winter the increase will be 3–9 °C, in summer 1–5 °C. Furthermore, the annual precipitation has been predicted to increase by 12–22% (10–40% in winter, 0–20% in summer). This means a 30–45 days longer growing season by 2100. The temperature sum during the growing period is forecasted to increase from 1300 to 1900 degree days in southern Finland, from 1100 to 1600 degree days in central Finland and from 900 to 1200 degree days in the north. Since the summer precipitation may increase only slightly, increasing temperature stress and early summer droughts, which are considered as one of the main causes of low crop yields currently in Finland (Peltonen-Sainio et al., 2009), may become more common. On the other hand, climate change also implies increasing frequency of rainy days and heavy rainfall events. Decreased length of the thermal winter, reduced snow cover and number of frost days are also probable consequences of climate change (Peltonen-Sainio et al., 2009; Höglind et al., 2013).

1.1. Climate change impact on nutrient loading

Recent publications suggest that nutrient loading from land to water bodies, and hence to the Baltic Sea, will increase due to climate change

* Corresponding author.
E-mail address: Inese.Huttunen@ymparisto.fi (I. Huttunen).

http://dx.doi.org/10.1016/j.scitotenv.2015.05.055
0048-9697/

(Arheimer et al., 2012; Eriksson Hägg et al., 2014). The estimates vary, and depend on the type of models and methodologies used in the studies. Arheimer et al. (2012) concluded that the simulation of nutrient loads under future climate conditions indicates that the nitrogen inflow may be reduced, but the phosphorus inflow may be slightly increased to the marine basins. However, some climate projections indicate the opposite. Eriksson Hägg et al. (2014) concluded that in the catchments draining into the northern sub-basins of the Baltic Sea (Bothnian Bay, Bothnian Sea and Gulf of Finland), the potential impact of climate change on nutrient loads is higher than the changes caused by a lifestyle shift. In a small scale study of nitrogen leaching, Rankinen et al. (2013) concluded that adjusting the N balance at a parcel level was more important than the vegetation cover. In the future, adaptation at the crop level is potentially an efficient way to manage the nutrient loading risk.

1.2. Climate change impact on crop growth

Crop growth is one of the key drivers in the development of agricultural production, land use and nutrient balances. Rötter et al. (2012) summarized the impacts of climate change on the most relevant agrometeorological indicators of crop yields. They concluded that a longer growing season and higher effective temperature sum are likely to increase the crop yield potential, whereas an increasing number of dry days and more frequent adverse weather events are factors that may significantly affect crop yield levels and increase their inter-annual variation. On the other hand, Peltonen-Sainio et al. (2009) concluded that an increase in yield potential requires crop cultivars capable of utilizing a longer growing period. Höglind et al. (2013) simulated grass yields in various locations of northern Europe under the A1B climate scenario. The yield increase due to climate change was estimated at +11% for grass production in southern Finland, while central Finland (Kuopio region) would reach approximately 20% increase in grass yields with the assumption of optimal overwintering conditions and current CO_2 level. Rötter et al. (2013) estimated yields of cereal crops in Finland for the 21st century under the SRES A2 climate scenario. The results indicated decreasing yields of current cultivars in the A2 and increasing yields in the B1 and A1B climate scenarios. Moreover, the yield potential of major crops under climate change decreases under A2, but might be sustained close to the current level even in the A2 climate scenario if new cultivars better tuned to a longer growing season are adopted.

1.3. Impact of agricultural change on crop growth

Crop yields are also likely to affect land use and nutrient balances, which in turn are among the key drivers of nutrient loading. Nutrient balance, i.e. the difference between the annual (N and P) fertilization level per ha and the amount of N and P nutrients per ha harvested, has been decreasing significantly in all regions of Finland since 1995. The average nitrogen balance per ha of farmland in Finland has decreased from 94 kg/ha in 1990 to 47 kg/ha in 2007–2013. The average phosphorus balance has decreased from 28.6 kg/ha in 1990 to 2.9 kg ha^{-1} in 2007–2013 (Salo et al., 2007; Salo and Lemola, 2014). Phosphorus balance has decreased considerably since 2000 because of specific limits imposed on phosphorus fertilization, on the basis of the soil P status of each field parcel, and, most probably, because of significantly increased prices of P fertilizers.

Few previous studies (Abler et al., 2002; Hattermann et al., 2007) have combined national and regional level agricultural scenarios with detailed nutrient modeling. In this paper, we estimate the effects of climate change and possible future scenarios of agricultural changes on the phosphorus (P) and nitrogen (N) loading to the Baltic Sea from Finnish catchments. Our objectives are: (1) to present a method to assess the effects of changes in climate and agricultural practices on nutrient loading by coupling two models: the economic agricultural sector model DREMFIA and the nutrient loading model VEMALA and (2) to show and discuss the simulated results of the TP and TN loading trends in the different sub-basins of the Baltic Sea under different climate and agricultural scenarios.

2. Methods and materials

2.1. Study area

Finnish catchments draining to the Baltic Sea cover 301,300 km^2. The Baltic Sea around the Finnish territory is divided into the following marine sub-basins (Fig. 1): Gulf of Finland (GF), Archipelago Sea (AS), Bothnian Sea (BS), and Bothnian Bay (BB). In our study we also considered the Vuoksi river catchment (VUO, Fig. 1), which contributes to the Gulf of Finland through the Neva River. The annual discharge to the Baltic Sea from Finnish catchments in 2006 was 2050 $m^3\ s^{-1}$, which represented 15% of the total riverine flow to the Baltic Sea (HELCOM, 2011). The annual riverine loading of total nitrogen (TN) and total phosphorus (TP) from Finnish catchments in 2006 was 79,000 TN t yr^{-1} and 3490 TP t yr^{-1}, which represented 12% of the total riverine TN and TP loading to the Baltic Sea.

2.2. Climate change scenario

Three climate scenarios were used in this study. All scenarios use the emission scenario A1B, in which greenhouse gas emissions are rather high in the first part of the century and start to decrease from 2050 (IPCC, 2000). This emission scenario produces intermediate greenhouse gas concentrations compared to other SRES scenarios by the end of the 21st century. The importance in the choice of the emission scenario increases by the end of the century, but until 2050 the differences between the greenhouse gas concentrations produced by different emission scenarios are small (IPCC, 2000).

One of the climate scenarios is the Mean A1B scenario, which is an average scenario calculated from 19 global climate models for Finland by the Finnish Meteorological Institute (Ruosteenoja et al., 2007). The other two scenarios are from Regional Climate Models (RCMs) obtained from the ENSEMBLES data base (van der Linden and Mitchell, 2009). The scenarios were HIRHAM-ARPEGE-A1B (referred to as the "dry" scenario since the precipitation increase is small) and RCA3-HadCM3-A1B (referred to as the "wet" scenario since the precipitation increase is large). These two scenarios were selected from a larger ensemble of RCM scenarios to represent the uncertainty associated with climate change. The greatest difference in the results was obtained with regard to changes in precipitation and therefore the RCM scenarios were selected from the high and low ends of the range of projected precipitation change.

The climate scenarios were calculated as monthly changes in average temperature (°C) and precipitation (%) for the periods 2010–39 and 2040–69 compared to the control period 1971–2000 (Ruosteenoja et al., 2007). The results were provided as a 2.5 degree grid for Finland and surrounding areas for the Mean A1B scenario and as a 0.25 degree grid for the RCM scenarios. The results from the four closest grids were used to calculate values for each sub-catchment of the hydrological model. Precipitation increase by 2040–69 compared to 1971–2000 was 11.5% in the Mean A1B scenario, 4.7% in the dry scenario and 16.2% in the wet scenario. Corresponding temperature increases were 3.2, 2.6 and 2.5 °C, respectively.

2.3. Agricultural scenarios

In addition to the climate change scenarios, we chose a baseline and three socio-economic scenarios of agricultural adaptations and change for 2014–2050. More details of the baseline scenario are given in Lehtonen (2013). Adaptation scenarios are described in full in Lehtonen (2015).