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Socially optimal drainage system and agricultural biodiversity: A case study for Finnish landscape

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ABSTRACT

This paper examines the socially optimal drainage choice (surface/subsurface) for agricultural crop cultivation in a landscape with different land qualities (fertilities) when private profits and nutrient runoff damages are taken into account. We also study the measurable social costs to increase biodiversity by surface drainage when the locations of the surface-drained areas in a landscape affect the provided biodiversity. We develop a general theoretical model and apply it to empirical data from Finnish agriculture. We find that for low land qualities the measurable social returns are higher to surface drainage than to subsurface drainage, and that the profitability of subsurface drainage increases along with land quality. The measurable social costs to increase biodiversity by surface drainage under low land qualities are negative. For higher land qualities, these costs depend on the land quality and on the biodiversity impacts. Biodiversity conservation plans for agricultural landscapes should focus on supporting surface drainage systems in areas where the measurable social costs to increase biodiversity are negative or lowest.

1. Introduction

An imperative to incorporate conservation of biodiversity into production landscapes has been discussed in scientific and political arenas (Kleijn et al., 2011; Perfecto and Vandermeer, 2010; Wossink et al., 1999; Krebs et al., 1999). One reason to secure the level of diversity of organisms capable of adapting to production landscapes pertains to the functional diversity present in the systems and contributing to the key functions supporting production (Tscharntke et al., 2012, Swinton et al., 2007). The second reason lies in the amenity and cultural values assigned to species inhabiting production landscapes, especially in the regions with few remaining natural ecosystems (Swinton et al., 2007). Finally, the more wildlife friendly the production landscape is, the more it can permit and facilitate the movements of organisms between patches of other ecosystems. Conservation of biodiversity and functioning of the agricultural landscapes, as outlined above, generally depends on the preservation or recreation of typical physical characters and features of any given landscape.

Agricultural surface drainage systems have an important role in the agricultural biodiversity conservation (Herzon and Helenius, 2008). An agricultural drainage system at field level refers to a network of artificial drains intended to prevent a field from waterlogging, thus aiming at improvement of soil for cultivation purposes. Effective drainage is important especially in the rainfed cultivation areas, such as in the Nordic Countries. Field drainage systems are divided into surface and subsurface drainage systems. A surface drainage system typically consists of open drainage ditches, a collection ditch and an outlet, whereas in a subsurface drainage system, open ditches are replaced with subsurface pipes.

Agricultural modernization has led to increased subsurface drainage, partly at the expense of fields with surface drainage systems, and thereby increasing the homogenization of agricultural landscapes (Hietala-Koivu et al., 2004; Ihse, 1995; Agger and Brandt, 1988). Most of the new drainage systems are subsurface drainages, but during the recent decades the replacement of surface drainage ditches with subsurface pipes has also been large-scale. In 2007 in Finland 58% of all cultivated field area was drained by subsurface drainage systems, whereas the equivalent proportion in 1944 was only around 5% (Ruuska and Helenius, 1996; Salaojayhdistys ry, 2008). In Europe, the current rate of surface-drained fields of the total of drained area varies from 0%

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(for example, Sweden and Denmark) to over third (Finland, Poland and The Netherlands) (Herzon and Helenius, 2008).

In fields drained by surface drainage systems, parallel ditches run every 10–50 m, resulting in 5–25% loss in effective, cultivated field area (Herzon and Helenius, 2008; Haataja and Peltola, 2001). Despite the fact that, as an investment, subsurface drainage systems are expensive, farmers favor installing them. By doing so, they improve the efficiency of field work and increase the cultivated field area, which may lead to private profit maximization. Agricultural investment subsidies also increase the private profitability of subsurface drainage installments; such is the case in Finland (Haataja and Peltola, 2001; Salaojakeskus ry, 2006).

Installment of subsurface drainage systems has also been socially justified by environmental reasons; it is claimed that agricultural crop production will lead to lower nutrient runoff damages, particularly by decreasing erosion, when a subsurface drainage system is used instead of a surface one (Haataja and Peltola, 2001). However, there is no specific scientific evidence to prove this claim. What is known is that subsurface drainage may lead to decreased phosphorus loss and increased nitrogen loss, when compared with *surface drainage* runoff, and especially with *surface runoff* (Turtola and Paajanen, 1995; Ohio State University, 1998). Regardless of the drainage system, nutrient runoff varies greatly depending on soil type and field slope, as well as on the other characteristics of the agricultural field and drainage system.

Open ditch ecosystems considerably contribute to agro-biodiversity since they offer a habitat or an important part of a habitat for many plant and animal species (review in Herzon and Helenius, 2008). Numerous positive correlations between the presence or the amount of open ditches, and species diversity or abundance in agricultural surroundings have been found for plant species in, for example, Estonia (Aavik and Liira, 2009; 2010), Netherlands (Manhoudt et al., 2005) and Belgium (Deckers et al., 2004), and for bird species in, for example, Finland (Piha et al., 2003; Vepsäläinen et al., 2010), Estonia (Marja et al., 2013), Sweden (Berg and Pärt, 1994), UK (Arnold, 1983) and Canada (Nocera et al., 2007).

In landscapes dedicated primarily to agricultural production, the integration of both ecological and socio-economic impacts is critical (Polasky et al., 2008; Mouysset et al., 2011). The first objective of this paper is to examine the socially optimal drainage choice (surface/subsurface) for agricultural crop cultivation in a landscape with different land qualities (fertilities) when private profits and nutrient runoff damages are taken into account in the measurable social welfare. The second objective is to study the measurable social costs (the difference in the measurable social welfare between the drainage systems) to increase biodiversity in a landscape by surface drainage when the locations of the surface-drained areas affect the provided biodiversity.

We do not include biodiversity benefits in the measurable social welfare because there is no appropriate valuation function or price for biodiversity in a Finnish agricultural landscape. Our approach is thus to study what are the measurable social costs to increase an externality (biodiversity) which monetary value cannot be properly defined. A social planner can use these social costs, which are defined for each area of the landscape, to decide where surface drainage should be promoted to increase biodiversity socially cost-efficiently. From now on we refer to *measurable social welfare* and *measurable social costs* as just *social welfare* and *social costs*.

In order to study and compare the social profitability of surface and subsurface drainage systems as well as the social costs to increase biodiversity, we build a general theoretical model which we apply to empirical characteristics of Finnish agriculture. The theoretical model is developed in Section 2 and applied to empirical data in Section 3. Section 4 presents the results and the final conclusions are made in Section 5.

2. Theoretical framework: a model for an agricultural landscape

2.1. Social returns to surface and subsurface drainage in a landscape

We postulate a generalized hypothetical landscape composed of an $n \times n = n^2$ grid of square-shaped areas of a certain size, which each consists of cultivated farmland. We assume that these farmland areas are rainfed and therefore it is more profitable to cultivate them under surface or subsurface drainage than without any drainage system. The unique landscape locations $i = 1, \ldots, n^2$ define the positions of the areas in the landscape. The locations determine the land quality for each area, which affects the crop yield and thereby also the nutrient runoff. It is further assumed that the biodiversity impacts of the surface drained areas depend on their locations in the landscape. We first define the maximum social returns (social welfare) of crop cultivation for both drainage systems in the different locations of the landscape when the crop choice and the fertilizer application are optimized. The social returns include private profits to the farmer and the nutrient runoff damages resulting from the fertilizer application. We then compare the difference in the maximum social welfare between the drainage systems in each location, and use these welfare differences to assess the social costs to increase agricultural biodiversity by using surface drainage systems instead of subsurface drainage systems. However, these social costs apply only if cultivated crop and fertilizer application are set to maximize the social welfare given the drainage system of the area. This means that if surface drainage is promoted on areas with the lowest social costs to increase biodiversity, then the policies for crop choice and fertilizer application should be set accordingly on each area of the landscape. Otherwise the selection of areas where surface drainage is promoted to support biodiversity may not be socially cost-efficient. In this paper we do not study the policy instruments in more detail.

In order to study the profitability of crop cultivation we define a crop production functions for each crop in each area of the landscape. The land quality differs between the areas, but it is assumed that the land quality inside one area i is homogeneous. Thus the crop production functions can be defined as $f_{i,j_i}(N_i)$ where N_i denotes the fertilizer use in the area. The subscript j_i describes the cultivated crop in the area, which can be chosen from a set of studied crops $\{1, \ldots, K\}$. The derivatives of the production functions are $\frac{d f_{i,j_i}}{dN_i} > 0$, $\frac{d^2 f_{i,j_i}}{dN_i^2} < 0$. Let p_{j_i} denote the price of the crop and c_{j_i} the fertilizer price. In the case of surface drainage, the costs and revenues that depend on the cultivated field area are multiplied by an *area factor* $(1 - \overline{m})$ where $\overline{m}$ is the share of field area occupied by surface drainage ditches, also called drainage intensity. The area factor decreases the revenues and costs that depend on the cultivated field area compared to subsurface drainage. To facilitate the comparison of surface and subsurface drainage systems, we assume that the drainage intensity $\overline{m}$ is exogenous and results in same drainage efficiency as subsurface drainage. Therefore the crop production functions are the same for both drainage systems. The term M^{sur} denotes the costs related to cultivation practices and ϕ^{sur} the investment and maintenance costs for surface drained area. The economic problem of the farmer under surface drainage is to choose the optimal crop j_i and the optimal amount of fertilizer application N_i to maximize the private profits on each area: $\max_{N_i, j_i} (\pi^{sur}_{i,j_i}(N_i) = [p_{j_i} f_{i,j_i}(N_i) - c_{j_i} N_i - M^{sur}](1 - \overline{m}) - \phi^{sur})$. To