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Economic and environmental assessment of irrigation water policies: A bioeconomic simulation study

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ABSTRACT

We present a bioeconomic modeling approach that links the biophysical crop growth model CropSyst to an economic decision model at field scale. The developed model is used in conjunction with a genetic algorithm to optimize management decisions in potato production in the Broye catchment (Switzerland) in the context of different irrigation policy scenarios. More specifically, we consider the effects of water bans, water quotas, and water prices on water consumption, profitability, and the financial risks of potato production. The use of a genetic algorithm enables the direct integration of the considered decision variables as management input factors in CropSyst. We employ the farmer's certainty equivalent, measured as the expected profit margin minus a risk premium, as the objective function. Using this methodological framework allows us to consider the potential impacts of policy measures on farmers' crop management decisions due to their effects on both expected income levels and income variability.

Our results show that the region's current water policy, which frequently prevents irrigation during hot and dry periods by banning water withdrawal, causes high levels of income risk for the farmer and increases the average water demand in potato production. In contrast, the implementation of an appropriate water quota could significantly decrease water consumption in potato production while allowing the farmer's certainty equivalent to remain at the same level as it is under the current irrigation water policy.

1. Introduction

Although agriculture in Switzerland is mostly rainfed, some regions of the country face climate conditions that require irrigation for crop production (Weber and Schild, 2007). One example of catchment, in which irrigation is intensively used for cultivation, is the Broye catchment, an important potato production region located in Western Switzerland (Fig. 1) (Robra and Mastrullo, 2011). For potatoes, irrigation is of particular importance to avoid yield losses under dry climate conditions in the summer months and also to meet the quality levels demanded by customers and the processing industry (Mühlberger de Preux, 2008). As the region's agricultural demand for irrigation has increased in recent years due to both changing climate conditions and the higher potato-quality demands of the processing industry, surface water bodies have repeatedly suffered from low water levels during the summer months in the Broye catchment. Such low water levels in the region's rivers, which are caused by water withdrawals for agricultural purposes, have also resulted in higher water temperatures (Mühlberger de Preux, 2008). The Broye river, for instance, has experienced water temperatures of up to 27 °C during the summer months in recent years, which is much higher than the optimal water temperature required by the river's typical fauna[1] (Mühlberger de Preux, 2008).

Currently, Swiss law addresses environmental problems resulting from agricultural water use by imposing water withdrawal bans if a river's flow rate falls below a critical threshold (BAFU, 2000). Water withdrawal bans in the canton of Vaud over the 1998–2011 period are presented in Fig. 2. In seven out of the last nine years, water withdrawal bans have been implemented in the canton of Vaud, mostly in late summer.

From the potato grower's perspective, withdrawal bans that occur during potato tuber initiation and ripening – when potato yields are most sensitive to water stress (Fabeiro et al., 2001) – are

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[1] For instance, the maximum growth rates of the brown trout, which is one of the most important fish in Swiss rivers, occur at 13.1–13.9 °C (Elliot and Hurley, 2001).

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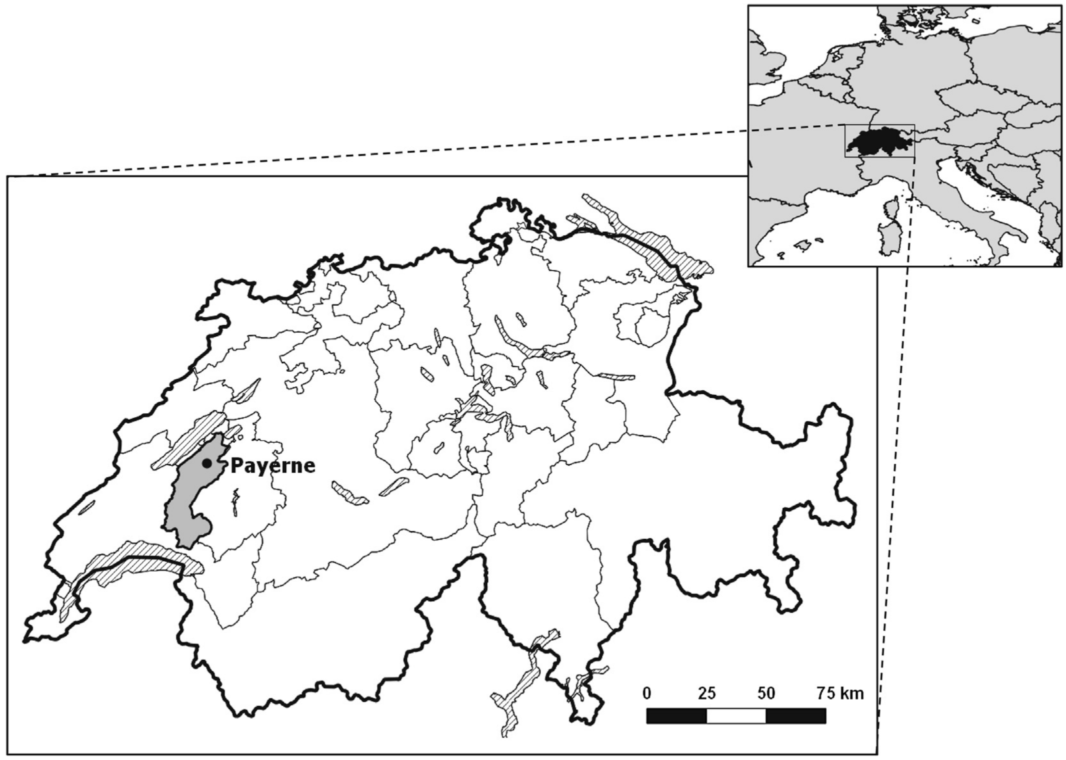

Fig. 1. The Broye catchment: The lower plot on the left-hand side shows the geographic location of the Broye catchment in Switzerland (gray area). The hatched areas indicate the major lakes in Switzerland. The national boundary and the cantonal boundaries are represented by the thick and thin black lines, respectively. The upper plot on the right-hand side shows the geographic situation of Switzerland (black area) in Central Europe.

of particular concern because they can have significant negative consequences for yield levels and quality, thus affecting profitability. Therefore, the ability of policy makers to impose water withdrawal bans during dry periods constitutes an institutional risk to farmers because such legislation leads to uncertainty concerning the profitability of investments in irrigation systems.

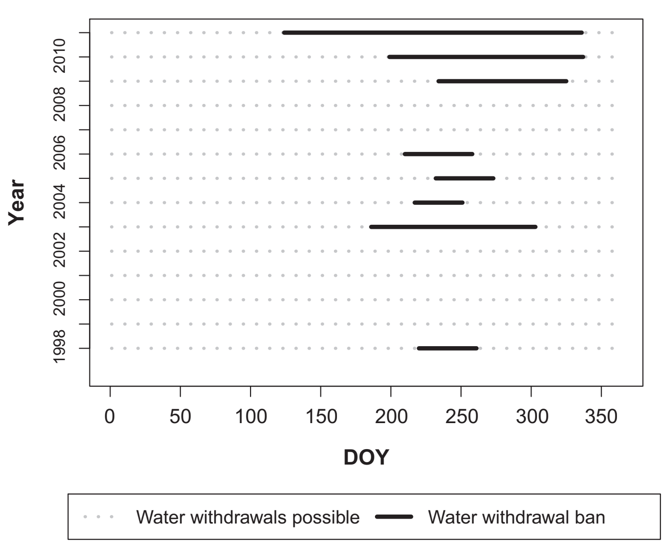

Fig. 2. The frequency and duration of water withdrawal bans for rivers in the canton of Vaud over the 1998-2011 period. Each black line represents a water withdrawal ban for a specific period (see horizontal axis, DOY = day of the year) in a specific year (see vertical axis). The wider the span of an event indicated, the longer the withdrawal ban.

In the next decades, water scarcity is expected to occur even more frequently due to a further expected rise in temperature (OcCC, 2007), which is likely to increase irrigation requirements in the Broye catchment (Fuhrer and Jasper, 2009; Lehmann and Finger, 2013). To minimize the ecological damage occurring as a result of agricultural water withdrawals in the Broye catchment, alternative water policies are required.

The effects of crop management decisions, such as nitrogen fertilization and irrigation, on crop yield levels are typically analyzed using process-based models such as CropSyst (see, e.g., Lehmann et al., 2013; Stöckle et al., 2003; Torriani et al., 2007 for overviews and applications). Because these models generally do not consider the economic incentives affecting decisions made by the farmer, crop growth models are often combined with economic models. In particular, in situations where complex economic and biophysical processes interact and managers and policy makers are required to ensure long-term sustainability, bioeconomic simulation models can be very helpful decision-making tools (Wise et al., 2007). deVoil et al. (2006) show that economic optimization models that implement the biophysical components of agro-ecosystems are well-suited to exploring sustainability issues in cropping systems. By using an evolutionary multi-objective algorithm and the crop growth model APSIM, they maximize the gross margin of a cropping system and minimize the risk of erosion and income loss. An integrated simulation model, which couples a whole-farm model and a nitrogen discharge function, is also used by Ramilan et al. (2011) to predict the responses of local producers to alternative nitrogen pollution policies. Semaan et al. (2007) combine the agronomic simulation model EPIC with an economic decision model at the farm scale to test the effects of three agricultural policies on a farmer's revenue and nitrate leaching. Furthermore, Finger et al.