Policy reforms to promote efficient and sustainable water use in Swiss agriculture

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Abstract

The more sustainable use of scarce water resources is a policy goal in several countries. In this regard, current discussions on potential policy reforms in Switzerland revolve around the subsidization of water-saving irrigation technologies. Today, the share of drip irrigation systems is low, at 3%. In Switzerland, environmental laws specify levels of water flow that must not be undercut. Variable pricing of water, however, has not yet been used. This paper analyzes whether subsidies on water-saving irrigation techniques would be beneficial in this legislative setting, and shows that such subsidies may have crowding out effects because they could provide incentives to switch from non-irrigated crops (e.g. wheat) to the production of crops (e.g. potatoes) that require irrigation. This may result in even higher water withdrawal rates. Such an increased competition for water resources may also result in adverse conditions for farmers. By contrast, our analysis shows the implementation of water prices could lead to a sustainable increase in the share of water-saving technologies, to a shift from irrigated to non-irrigated crops, and therefore to a reduction of overall water use in agriculture. Thus, the introduction of water prices should have absolute priority if agricultural water policies are reformed in Switzerland.

Keywords: Agricultural water use; Crowding out effects; Drip irrigation; Subsidies; Switzerland; Water prices

Introduction and background

Water-saving irrigation technologies such as drip irrigation increase water use efficiency and can thus help to use scarce water resources more sustainably. Consequently, water-saving technologies can reduce problems of environmental degradation. Due to this fact, policy makers have an obvious incentive to increase the adoption of these technologies. In Europe, several countries introduced agri-environmental programs that aim to reduce the quantity of water used in agriculture (EC, 2005). These program schemes, for example, give incentives for the conversion of arable to grassland or for


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changes in crop types used (EC, 2005). In this paper, we specifically focus on the case of Switzerland, where current discussions of potential policy reforms with regard to agri-environmental programs comprise the subsidization of water-saving irrigation technologies as a measure to reduce the environmental impact from agricultural water use. More specifically, we analyze if this subsidization is necessarily beneficial for the environment and farmers. The goal of this paper is twofold. First, it should provide a basis for policy-related discussions regarding sustainable use of water in agriculture. To this end, we develop a theoretical argument that is the basis for numerical simulations which are then presented in the final part of the paper. Second, the hypotheses developed in this paper should be the basis for empirical analyses in situations where similar subsidies have actually been introduced.

Currently, only 5% of agricultural land in Switzerland is irrigated. Although its use is not widespread, irrigation (at least locally) harms the environment (e.g. fish populations) and agricultural water use is in competition with other potential water users (Mühlberger de Preux, 2008). The latter effects were especially observed during the drought and heat wave of 2003, where low levels of water flow and the (temporarily) widespread use of irrigation caused precarious situations in several water bodies (BUWAL et al., 2004). In Switzerland as a whole, the use of irrigation in agricultural production has shown an increasing trend over the last few years (Weber & Schild, 2007). Climate change will increase water needs for agricultural production, and may lead to the frequent occurrence of situations where water demand exceeds water supply from natural water bodies (Fuhrer, 2010). Problems of water (over-) use for irrigation are currently particularly observed in Western Switzerland. In this region, irrigation is particularly necessary for the production of special crops such as vegetables, as well as in potato production. Potato production is highly profitable compared to other agricultural activities if measured on a profit per hectare basis. However, its widespread applicability is limited because it requires rather high levels of water input. In particular, due to quality requirements (if potatoes are sold for consumption), rain-fed potato production is not possible in this region under the present rainfall regimes during the growing season, and irrigation is thus required (Mühlberger de Preux, 2008).

Robra & Mastrullo (2011) conducted a survey of 115 irrigating farmers in the region of the Broye catchment in Western Switzerland. Respondents indicated that 40% of the irrigated surface and 47% of the water used were devoted to potato production, with 80% of the water used for irrigation taken from rivers or creeks, while water use from groundwater or lakes plays only a minor role (Robra & Mastrullo, 2011). Western Switzerland regularly faces water scarcity in mid-summer, i.e. water flows in rivers and creeks fall below the minimum tolerable levels from an environmental perspective (Mühlberger de Preux, 2008). In the Broye catchment, 89% of the surveyed farmers use sprinkler irrigation; drip irrigation is used only by 5% of the farmers (Robra & Mastrullo, 2011). In Switzerland as a whole, the share of drip irrigation systems is even lower at about 3% (Weber & Schild, 2007).

The water use efficiency (i.e. the ratio between water available to the plant and the total amount of water applied) is 75% for sprinkler irrigation systems and 90% for drip irrigation systems (FAO, 1989). Obviously, a switch from sprinkler to drip irrigation would relieve the environmental problem and, if all farmers switched from sprinkler to drip irrigation, about 15% less water would be required in potato production. Even though return flows (from water that is applied to the crop but not utilized by it) may return to the water body via surface runoff or deep percolation after specific time periods (see Ward & Pulido-Velazquez, 2008), the water-saving properties of drip irrigation have an important advantage: in summer months where water flow is lowest and the water needed for irrigation is greatest, the lower amount of water withdrawal from a river for irrigation leads, all other things being equal, to more stable water flows and thus to lower environmental impacts.
The main reason for the non-adoption of drip irrigation in Swiss agriculture is its lower profitability compared to sprinkler irrigation. Even though the water consumption and the electricity or diesel costs for pumping (due to the lower pressure required) are smaller, they do not outweigh the much higher fixed costs of a drip irrigation system. Spörri (2011) surveyed detailed information on the costs of different irrigation technology options from existing irrigation projects in Western Switzerland. The fixed costs (water extraction and transportation, hose reel, hoses, rainguns, etc.) for a sprinkler irrigation system are, on average, about 700 Swiss francs (CHF) ha\(^{-1}\) year\(^{-1}\). By contrast, a drip irrigation system, with fixed costs above 2,000 CHF ha\(^{-1}\) year\(^{-1}\), is much more expensive (Spörri, 2011). Variable costs for irrigation in Western Switzerland are comprised of only electricity or diesel costs for pumping; no variable water prices exist. On this basis, Lehmann et al. (2012) and Spörri (2011) point out large differences in per hectare profits between drip and sprinkler irrigation systems of more than 1,000 CHF ha\(^{-1}\) year\(^{-1}\). Thus, (slightly) smaller variable costs in drip irrigation systems cannot, currently, outweigh the much higher fixed costs because farmers are not charged for the extraction of water. (An empirical application for potato production in Western Switzerland, which includes more detailed descriptions of costs and benefits from specific irrigation systems, is presented in the final part of this paper.)

Current policy and proposed reforms

In Switzerland, agricultural water use is regulated at two different levels: the government sets the framework legislation that is particularly concerned to avoid environmental impacts from water withdrawal, while the cantons (i.e. federals states) are responsible for managing and coordinating water use for agricultural and other purposes. The management and coordination role of the cantons may be also delegated to the municipalities. Thus, the Swiss government sets environmental limits for water use, e.g. defined by a specific water flow that should not be undercut (see BAFU, 2000, for details). Note that these thresholds reflect maximum tolerable states, but environmental impacts may also occur before these thresholds are reached. The use of such regulatory policy elements to prevent catastrophic impacts from agricultural water use on the environment is a recommended way to influence water use from a governmental perspective (see Ward, 2007).

Cantons are responsible for awarding water use licenses to farmers and other water users. Thus, cantons have freedom to set prices for licenses (fixed costs) as well as water prices. The latter option, however, is seldom used in Switzerland. Cantons are also responsible for banning water use from particular water bodies if water flow falls below environmental thresholds. Farmers can receive subsidies for their irrigation projects, i.e. up to about 50% of the costs for infrastructure concerning water extraction and water transportation can be contributed by the government and the canton. Note that infrastructure beyond extraction and transportation of water (e.g. the sprinkler or drip irrigation application system) is not yet subject to subsidies. In this subsidization process, there are no explicit criteria regarding the technology used; however, overall economic and environmental sustainability of the irrigation project have to be proven by the applicant (BLW, 2009).

This current policy does not explicitly support the use of drip irrigation. In order to overcome the mismatch between the desired state of drip irrigation adoption and the current situation, the Swiss government aims to introduce additional subsidy payment schemes for resource efficiency (BLW, 2011). In general, these payments should induce a more efficient use of natural resources such as soil and water. With regard to irrigation, these payments would be used to increase the efficacy of the irrigation infrastructure, i.e. to subsidize drip irrigation. In Swiss agricultural policy such direct environmental
payments (embedded in an agri-environmental program) are usually available to all farmers without restrictions (Finger & Lehmann, 2012). Thus, usually, no distinction with regard to farm or farmer characteristics is made in the subsidy distribution process. Along these general implementation processes of agri-environmental measures, a subsidy payment for drip irrigation would thus be available to all farmers. An important question during the recent policy elaboration process is whether such subsidies are a good solution to overcome environmental problems.

**Evaluation of recent policy proposals**

At first sight, subsidies supporting drip irrigation in particular seem to be a good instrument to reduce environmental impacts from agricultural water use. However, there might be substantial drawbacks of such policy reform (see below). It is important to note that the share of potato production in Western Switzerland is currently low, e.g. 6 and 3% of the arable land in the Fribourg and Vaud cantons, respectively (SBV, 2011). This is also the result of insufficient amounts of rainfall, and the costs necessary to install an irrigation system. Highly subsidized irrigation systems could give incentive to other farmers to start potato production.

The situation is schematically presented in Figure 1. The population of farmers (or the arable land) in a specific region is represented as a circle. On the x-axis, the decision ‘drip versus sprinkler irrigation’ is presented, while the y-axis depicts the decision of ‘growing potatoes versus other (non-irrigated) crops (e.g. wheat)’. The solid circle shows the current situation, where the majority of land is devoted to other crops (Field C), i.e. not to potatoes. Among the potato producers, sprinkler irrigation is mainly used (Field A) and only a small area is devoted to drip irrigation potato production (Field B). Two potential scenarios on the effects of a subsidy are visualized (note that the changes indicated in Figure 1 reflect strategic adaptation responses, i.e. they comprise a period of more than one growing season):

- The dashed circle shows the first scenario where a subsidy leads to a shift from sprinkler to drip irrigation among potato producers (a leftward shift on the horizontal axis); however, there is no shift in the vertical axis, which means that the proportion (by area) of potatoes and other crops remains

![Fig. 1. Potential effects of subsidies on land-use and irrigation technology choice.](https://iwaponline.com/wp-content/uploads/2012/05/01-900x675.png)
unaffected. This is actually the desired outcome: farmers mainly using drip instead of sprinkler irrigation but with no extension of the potato area and, thus, less water is consumed as a whole.

- The dotted circle shows the second scenario that is also represented by a sharp reduction of the sprinkler irrigation area and an increase of drip irrigation. However, this scenario implies an increase of the total potato production area at the expense of other (non-irrigated) crops. Thus, the subsidy has a crowding out effect on other, non-irrigated crops. In sum, even more water may be used under this scenario.

These different responses to subsidies may be the result of heterogeneous starting positions regarding the profitability of different crops (and irrigation techniques) across farmers. Two potential situations are shown in Figure 2:

- In Situation 1 (left panel of Figure 2), potato production with sprinkler irrigation is the most profitable alternative without any subsidies, i.e. in the current situation. If subsidies are paid for drip irrigation, sprinkler irrigation is replaced by drip irrigation as desired.

- However, in other situations, such a subsidy can also have crowding out effects. In Situation 2 (right panel of Figure 2), other (non-irrigated) crops and not potatoes are the most profitable alternative in the current situation without any subsidies. If the level of subsidies is high enough, the non-irrigated crops are replaced by potatoes under drip irrigation. This assumption is in agreement with the study of Ward & Pulido-Velazquez (2008), who have reported a similar observation, i.e. that subsidies for drip irrigation systems even led to an increase of water use on a basin scale.

Situation 2 shows how subsidies for drip irrigation can lead to an increase of the area under potatoes and thus can lead in sum to higher water consumption. This is particularly relevant if we take into account that irrigation systems are not a short-term but, rather, a long-term investment because the amortization period ranges between 10 and 15 years (Finger et al., 2011; Spörri, 2011; Finger, 2012). Subsidies could thus have a so called lock-in effect, holding farmers in an irrigation intensive activity.

![Fig. 2. Potential effects of subsidies on the profitability of crops and technologies.](https://iwaponline.com/wp/article-pdf/14/5/887/406128/887.pdf)
In reality, Situations 1 and 2 are both present because we observe that some farmers currently use irrigated potato production, while others do not cultivate potatoes (and do not use irrigation). Whether a farmer is in either of these situations depends on natural conditions (e.g. soil quality, slopes) and the cost structure of their specific farm (e.g. for water extraction and transportation).

Subsidies for water-saving technologies could thus lead to counterintuitive increases of the total water use if the subsidy crowded out non-irrigated crops in favor of potato production. Taking the long service life of irrigation infrastructure into account, this would mean that water resources could be under even more pressure after the proposed policy reform if more irrigated potato production were to take place. From an environmental (in this case, water saving) perspective, the subsidization of drip irrigation could thus be problematic.

In addition to the drawback from an environmental perspective, we think that such subsidies could even give the wrong economic incentives to farmers. More specifically, irrigation bans due to low water flows in rivers have become a rather frequent phenomenon in Western Switzerland. Figure 3 shows the periods where water withdrawal has been prohibited in the canton of Vaud from 1998–2010. The horizontal axis in Figure 3 represents days, whilst the ‘yes’ or ‘no’ state of a water ban is shown on the vertical axis. Thus, the wider the span of an event indicated in Figure 3, the longer was the water ban. Note that in the period of a water ban, all water withdrawal from surface water bodies is prohibited. Figure 3 shows that in 6 of the last 8 years, water withdrawal was temporarily forbidden. Bans are announced if environmental thresholds of specific river water flow are undercut and are then lifted if water flow is above the threshold (see BAFU, 2000, for details). In spring 2011, another ban was issued (not shown in Figure 3). If water use is banned frequently, irrigation infrastructure will not pay off because these bans usually occur when water is actually needed most, i.e. in the hottest and driest years (Lehmann et al., 2012).

The effect of water bans on profitability is expected to become even more amplified due to climate change, which will increase the problem of water availability during the summer months and thus increase the frequency of bans (OCCC, 2007). Thus, policy makers have to take the expected effects of climate change into account when designing water-saving policies.
change on water availability in water bodies into account. Furthermore, increasing agricultural water use due to subsidization as described above may amplify the frequency of bans because environmental thresholds would be crossed earlier. Thus, subsidization may actually imply a higher frequency of water bans due to increased water use, which would ultimately reduce the profitability of the irrigation infrastructure. Thus, paradoxically, support of environmentally-friendly irrigation techniques could result in a situation where a government-subsidized irrigation project could not be used when it was needed most due to a government water use ban during the driest and hottest periods of the growing season.

Alternatively, (more) frequent bans of surface water use by farmers may lead to an increased use of groundwater, which usually reaches critical levels later than small surface water bodies do. If surface water supply is uncertain it has been observed that farmers switch more frequently to groundwater use for irrigation (Rogers et al., 2002; Garrido et al., 2006). The use of groundwater, however, is even more critical from an environmental and social perspective because groundwater withdrawal often exceeds its regeneration, leading to decreasing water tables, which finally impacts other water bodies and other water users (Garrido et al., 2006). Thus, taking water use bans as well as potential future developments into account, infrastructure investment due to subsidization can thus cause non-optimally used investments, income losses for farmers, waste tax money and induce more frequent groundwater withdrawal.

In summary, a subsidy for drip irrigation could result in situations where both farmers and the environment are worse-off (a lose-lose situation): in peak periods of water demand, irrigation might be banned frequently, which could result in welfare losses (profit reductions for farmers, wasted tax money) because the irrigation infrastructure cannot be used when needed most. In periods without irrigation bans, there could be even more water demand due to an increased adoption rate of potato production (with irrigation), leading to even higher pressure on water resources. Anticipatory policy making processes should thus consider other policies to reduce the environmental problems of agricultural water use.

**Alternative policy propositions**

We think that measures other than subsidies for drip irrigation systems could be more efficient, i.e. could induce welfare increases and reduce water use in the water bodies under pressure. One option to avoid the expansion of crops with high water needs at the expense of non-irrigated crops could be that the subsidy on drip irrigation is only made available to existing irrigation systems. This would mean that only those farmers switching from their existing sprinkler irrigation systems to drip irrigation would receive a subsidy. Such a policy would give no incentive for an expansion of the irrigated area and thus ensure that total water consumption decreases. However, such a measure would be politically difficult to implement due to the clear inequality across farmers as a whole. This is of particular relevance because equity is of highest importance in water management issues, and a fair allocation of resources (and access to technology as well as subsidies) is necessary for a policy change to sustain a political process (Ward, 2007). Agricultural policy in Switzerland and other countries is explicitly targeted to reduce inequalities between farmers (Finger & El Benni, 2011). Furthermore, such a policy would cause inefficient allocation of water and infrastructure resources over time, e.g. in the case of mergers and the closing down of farms, or if currently non-irrigating farms start irrigation. Along these lines, an efficient allocation of resources may be difficult.

In contrast to the above-presented measures, we think that water prices in particular are an effective instrument to induce drip irrigation adoption and a switch from irrigated to non-irrigated crops, thus reducing the overall amount of water used. We suggest that the non-existence of water prices is a crucial
determinant for the non-adoption of drip irrigation systems because farmers are given no incentive to save water. Drip irrigation systems have higher water use efficiency than sprinkler irrigation systems and consequently lower amounts of water have to be used to reach identical crop yields. This water-saving property can only give incentives to adopt drip irrigation if water prices exist (and are high enough). Figure 4 visualizes this effect.

As noted above, a certain amount of water is ‘saved’ if drip irrigation is used instead of sprinkler irrigation, without a reduction of crop yields. If the water price is zero, this water-saving property of drip irrigation has no monetary value for a farmer (except for reduced pumping costs). However, there is an increasing competitive advantage of drip irrigation over sprinkler irrigation if water prices increase, as shown in Figure 4. If the water price is high enough ($P^*$), the water-saving property of drip irrigation makes it more profitable than sprinkler irrigation. However, water prices would also make irrigation and thus potato production less attractive for some farmers. Thus, some farmers are expected to switch to drip irrigation, while others switch to crops that require no irrigation (see Figure 5). In total, the area under potatoes decreases, while the majority of the remaining area uses drip irrigation, which in sum reduces the amount of water used for irrigation. Moreover, the smaller area under irrigation is also beneficial from the perspective that accounts for irrigation bans because reduced agricultural water use may reduce the frequency with which these bans have to be applied. Thus, future income losses due to irrigation restrictions are avoided.

An overview of estimated elasticities of agricultural water demand to water prices was presented by Scheierling et al. (2006), showing that farmers indeed react to price incentives as assumed in our analysis. Furthermore, empirical evidence that water prices have a positive influence on the adoption probabilities of drip irrigation systems are, for example, provided by Alcon et al. (2011), who also provide an overview of related studies. However, this study also shows that water prices alone are not sufficient as a policy instrument. More specifically, education and information are crucial determinants of adoption and have to be explicitly addressed by policy makers to foster a sustainable use of water.

There are obviously also other possible options to reduce water use, for example the rationing of water, quota systems for water withdrawal and the compulsory use of drip irrigation systems (e.g.}

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**Figure 4.** Effects of water price on the profitability of sprinkler and drip irrigation.
Molle et al., 2008). However, a policy goal of ‘efficient water use’ should be targeted to a situation where farmers’ marginal benefits of water use are equal to its marginal costs (taking private, social and environmental costs into account). A water price that reflects all these costs remains the most efficient tool to reach this goal. However, numerical analyses of the economic and environmental consequences of all possible options should be addressed in future research.

**Case study: profitability of different irrigation systems in the Broye catchment**

In order to quantitatively compare the financial profitability of sprinkler and drip irrigation systems, as well as to show the influence of both water prices and subsidies for drip irrigation systems, we have employed a simulation case study for potato production in the Broye catchment, located in Western Switzerland (see Lehmann et al., 2012, for an overview). In this region, strong water use conflicts exist between agriculture and other users (e.g. fishery), as well as with environmental goals (Mühlberger de Preux, 2008).

To simulate yields from irrigated potato production under current climatic and soil conditions, we have used CropSyst, the process-base crop growth model (Stöckle et al., 2003). This model was calibrated for the study region by Klein et al. (2011), based on farm-level observations of potato yields in the period 1981–2009. Note that soil- and plant-specific characteristics of the region are taken into account in the CropSyst simulations (see Lehmann et al., 2012). CropSyst requires daily weather data as well as information on crop management as input for simulations.

In order to represent current climatic conditions, we used the stochastic weather generator LARS-WG (Semenov & Barrow, 1997; Semenov et al., 1998) which was calibrated on observed weather data for the Payerne climate station (located in the Broye catchment). This weather generator was used to simulate 50 sets of daily weather data representing current climatic conditions in this region and which were input for CropSyst simulations. Crop management (e.g. fertilization, sowing) followed the standard recommendations for potato production in Switzerland (e.g. AGRIDEA & FiBL, 2010).

We made a distinction between sprinkler and drip irrigation, assuming that they had an irrigation efficiency of 75 and 90%, respectively (following FAO, 1989). Table 1 summarizes the revenues and costs.
Based on the information shown in Table 1, we computed the potato production profit margin for each of the 50 weather years, assuming different water prices ranging from 0 to 15 CHF m$^{-3}$ (Table 1). The profit margin is defined as follows:

\[ \pi = \rho + \text{DP} - c_{\text{fix}} - c_{\text{var}} - c_{\text{irrig,fix}} - c_{\text{irrig, var}} \]  

where \( \pi \) is the profit margin (CHF ha$^{-1}$), \( \rho \) is the revenue (CHF ha$^{-1}$) and DP represents governmental direct payments (CHF ha$^{-1}$); \( c_{\text{fix}} \) stands for the fixed costs (CHF ha$^{-1}$), \( c_{\text{var}} \) for the variable costs, \( c_{\text{irrig,fix}} \) for the fixed costs of the irrigation system (CHF ha$^{-1}$) and \( c_{\text{irrig, var}} \) for the variable irrigation costs (CHF ha$^{-1}$).

We used two different scenarios for the fixed costs of irrigation systems. First, average fixed costs for irrigation systems that have been observed in existing irrigation projects in the case study region were used (following Spörri, 2011). However, this estimate is biased because such a dataset contains irrigation projects that have been realized at low costs. For instance, these farms may be located next to a water body, leading to low cost levels for installing water extraction and transportation systems. In contrast, many farms do not have an irrigation system – potentially due to the high costs for installing such a
The latter group may contain farms located far away from a water body and thus with high costs to install water extraction and transportation systems. The two scenarios employed here (see Table 1 for details) reflect the two possible situations described in Figure 2. Figure 6 shows mean values of the profit margin as a function of water prices derived from the 50 simulation years for both sprinkler and drip irrigation systems. Note that Figure 6 represents the situation of farms currently implementing irrigated potato production (i.e. Situation 1 in Figure 2). For drip irrigation, three options are assumed: in the first (solid black line), no subsidies for the drip irrigation system are paid (reflecting the current situation); in the second (dashed black line) and third (dotted black line) situations, 50 and 100%, respectively, of the drip irrigation application system is subsidized. The dark grey solid line represents the profitability of the sprinkler irrigation system. Note that in all cases (i.e. including for sprinkler irrigation), a 52% subsidy on the water extraction and transportation infrastructure is assumed (Table 1).

The horizontal line in Figure 6 represents the profit margin for wheat (following AGRIDEA & FiBL, 2010), which is the most abundant crop in Swiss agriculture and thus was chosen as the reference category here. It is produced without irrigation, and thus its profitability does not depend on the water price.

Figure 6 shows that if the water price is small, irrigated potato production is the most profitable activity. Furthermore, it shows that sprinkler irrigation is more profitable than drip irrigation if the water price is low. More specifically, a water price of about 10 CHF m\(^{-3}\) (point A in Figure 6) is required before non-subsidized drip irrigation (black solid line) becomes more profitable than sprinkler irrigation (dark grey solid line). At this point, the lower water consumption required due to the higher water efficiency of the drip irrigation system (i.e. the lower variable irrigation costs) outweighs its much higher fixed costs compared to those of a sprinkler irrigation system. However, at a water price of
10 CHF m\(^{-3}\), irrigated potatoes are not profitable anymore (farmers would even make a substantial loss), and farmers would likely grow wheat, the alternative presented here, (solid light grey horizontal line) which does not require irrigation. This switch from irrigated potato to non-irrigated wheat production would already be profitable if the water price was larger than 3 CHF m\(^{-3}\) (at the intersection of the dark grey and horizontal light grey line in Figure 6). Figure 6 also shows that the availability of an alternative that leads to similar high profit margins (e.g. wheat) reduces the potential negative impact of water prices on farmers’ profits.

Subsidies for drip irrigation systems lead to a vertical upward shift of the profit margin line (dotted and dashed with solid black line in Figure 6). Consequently, drip irrigation becomes more profitable than sprinkler irrigation at a lower water price (of about 3.5 CHF m\(^{-3}\)) (see point B in Figure 6) if 50% of the fixed costs for the drip irrigation system are subsidized. Assuming that the subsidy covers the entire fixed costs for drip irrigation systems, drip irrigation would always be more profitable than sprinkler irrigation systems.

Figure 7 is similar to Figure 6, but represents the situation of farms that currently do not employ irrigated potato production but produce other, non-irrigated crops such as wheat (i.e. Situation 2 in Figure 2). In contrast to the case presented in Figure 6, we have assumed that the fixed costs for water extraction and transportation are substantially higher, e.g. because the farm is located far away from the water catchment (see Table 1). Figure 7 shows that under current conditions (i.e. no water price, no specific subsidies for drip irrigation systems), wheat is the most profitable alternative and thus no irrigation is used. If water prices increase, this obviously does not affect this choice because no water is used in wheat production. However, Figure 7 shows that if drip irrigation was to be heavily subsidized (dotted black line), potato production would become more profitable. This situation

Fig. 7. Profitability of drip and sprinkler irrigation systems vs water price. Scenario 2: high fixed costs for water extraction and transport.
represents the crowding out effect that was discussed in the previous sections. In the displayed situation, however, a small water price (of about 0.5 CHF m\(^{-3}\)) would be sufficient to make wheat production more profitable again.

Note that the situations displayed and numbers presented in this section may not be generally applicable for potato production in the Broye catchment or Switzerland at large: each farm (or even each field) faces site-specific environmental characteristics as well as different cost structures, especially with regard to the costs for irrigation infrastructure. Thus, neither policy measure will result in corner solutions (e.g. no potatoes produced, or all farmers switching to drip irrigation), but will rather lead to a change in the percentage of farmers using specific crops and irrigation techniques, as indicated in the (theoretically derived) Figures 1 and 5.

Furthermore, the welfare effects of any policy measure (whether a subsidy or water price) remain uncertain. This is due to the fact that both measures create economically inefficient situations. A subsidy on drip irrigation will lead to a situation where farmers install such a system even though their profits from it are smaller than the full costs of the system itself. A water price, in contrast, may have the welfare reducing effects of a tax, i.e. the revenue from water prices is smaller than the losses incurred by the farmers. However, the crucial aspect in any welfare assessment of water policy is the value of a more sustainable water use in monetary terms. To fill this gap in the case of Western Switzerland, different valuation methods may be applied for specific stakeholders (e.g. Buchli et al., 2003).

Conclusion and policy recommendations

Our analysis shows that granting subsidies for drip irrigation systems, in the absence of water prices, is not the optimal method for dealing with the problem of (temporal) water scarcities that have negative environmental effects. It may even lead to an increase in the total amount of water used and may constitute an economic trap for farmers. Thus, subsidies for drip irrigation systems may not necessarily save water at the basin scale (Ward & Pulido-Velazquez, 2008).

In contrast, water prices would lead to an increase in the adoption rate of drip irrigation and thus contribute to reduction in the total amount of water used. Moreover, our numerical analysis for irrigated potato production in Western Switzerland showed that higher water prices could also lead to a shift to non-irrigated crops such as wheat. Thus, only those producers for whom the benefits from water use for irrigation are higher than the increasing costs due to water prices would continue to irrigate. Water prices should give farmers important signals on the private, social and environmental costs of water use. To this end, a water price is usually assumed to be optimal if it contains a full-cost recovery including environmental externalities (Rogers et al., 2002). The optimality of the use of water prices compared to any governmental solution without any price for water use is in line with almost all of the literature (e.g. Rogers et al., 2002; Ward, 2007; Zilberman et al., 2008). This means that the introduction of water prices should have absolute priority for reducing environmental loads from agricultural water use and increasing overall agricultural water use efficiency. However, such an introduction has to be accompanied by education and information on water-saving cropping and irrigation systems.

The current policy regulation in Switzerland regarding the definition of environmental limits for water use that should not be undercut is a highly effective way of preventing the catastrophic impacts of agricultural water use on the environment. Thus, this policy element should be maintained and the use of water prices introduced in addition to it.
A major drawback of water pricing compared to subsidies is that agricultural policy makers and farmers can have problems accepting it as a measure (Bartolini et al., 2010), and the introduction of a water price can therefore be ‘politically dangerous’ (Ward, 2007) and generate significant political opposition (Johansson et al., 2002). However, this may particularly be the case if the basic human needs or incomes of stakeholders involved are at high risk (Ward, 2007). In contrast to farmers in arid or semi-arid regions, farmers in Switzerland would not suffer large income reductions due to increasing water prices, because rain-fed production of other crops is always possible (Figures 6 and 7). This should facilitate the policy process for the introduction of water prices. Following Johansson et al. (2002), the implementation of water pricing often requires appropriate institutions and is not free of costs. In the current setting in Switzerland, where cantons already license water use and charge (non-variable) fees, water pricing could be managed by the existing cantonal bodies. The introduction of water prices will imply particular costs, for instance, to measure physical water use as well as for the monitoring and control of measurement systems. In line with the full-cost recovery pricing recommended in the literature (Garrido, 2002; Rogers et al., 2002), these costs should be completely borne by farmers. Note that several ways exist to actually price water (see e.g. Johansson et al., 2002, for an overview), which also affects the implementation costs and should be considered during any policy implementation process.

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