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Improved water use efficiency with new irrigation systems and strategies in potatoes – A case study from Serbia

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Abstract
In this paper it is analysed if a tax on water may give farmers an incentive to shift to more water efficient irrigation systems and strategies. Two irrigation systems and three strategies for irrigation in potatoes are investigated. It is found that by changing from the present system and strategy it will be possible to save water significantly. With increased taxes on water it may also be possible to give incentives for the farmers to change to new systems and strategies. However the results also indicate that the water taxes should be very high. Therefore a tax on water quantity would not necessarily be a relevant solution from a farm management point of view.

Keywords: Irrigation system; Irrigation strategy; Water tax; Serbia

Introduction

As population increases and development calls for increased allocations of groundwater and surface water for the domestic, agriculture and industrial sectors, the pressure on water resources intensifies. The increasing stress on freshwater resources brought about by ever rising demand is of serious concern (FAO, 2008). Despite the increase in water use by sectors other than agriculture, irrigation continues to be the main water user on a global scale.

Irrigated agriculture occupies 18% of total arable land in the World and produces more than 33% of its agricultural production (Johansson et al., 2001). With increasing demand for food there is an increasing pressure for water to be used more efficiently in the agricultural sector.

Technology improvements such as more efficient irrigation systems and reduced pipe leakage are contributing to increased efficiency in amount of irrigated water applied, and reduced environmental pressures, but there is scope for much improvement. For example, only about one-third of the water withdrawn for irrigation purposes actually reaches the crop (OECD, 2006) and irrigation efficiency is highly dependent on the irrigation system (Smajstrla et al., 1991). Among three widely used systems: furrow, sprinkler and drip irrigation, furrow is the least efficient while drip is considered the most efficient. Although drip irrigation has increased 28-fold since the mid-1970s it is still employed in less than 1% of the world’s irrigated areas, primarily in OECD countries (OECD, 2006). According to OECD (2006) another problem is that production and input subsidies continue to misalign farmer’s incentives and overuse and pollution of water across many OECD countries. Market price support provides incentives to intensify agricultural production, while support for irrigation infrastructure (construction and depreciation costs), operation and maintenance costs (including institutional costs) together with support to lower water supply charges, discourages the more efficient use of water resources.

There are several ways to encourage farmers to use water more efficiently. In Johansson et al. (2001) various mechanisms to improve water efficiency is investigated. Among these are volumetric pricing, non- volumetric pricing, quotas and water markets. To use these mechanisms information about the value and use of irrigation water is necessary (Johansson et al., 2001).

The water use efficiency is very much related to the irrigation techniques and water management strategies used by the farmers. In this article we will focus on sprinkler and drip irrigation techniques in combination with full irrigation and some deficit irrigation strategies investigated and improved. Applied deficit irrigation strategies included partial root drying (PRD) and deficit irrigation (DI).

The objective of this paper is to investigate economical effects of different irrigation strategies that can lead to a more efficient irrigation system in saving water resources for agriculture. The study is based on data from field experiments in Serbia. Focus here is on drip and sprinkler irrigation since sprinkler is the primary used system in Serbia while drip irrigation is a water saving alternative.

Sprinkler irrigation

The purpose of sprinkler irrigation is to distribute water in a uniform coverage over an irrigated area. Water is distributed through a pipe system and is finally sprayed into the air through sprinklers so that it breaks up into small water drops which fall to the ground (FAO, 2008). The equipment for sprinkler irrigation is listed below (see figure 1):

- Pump
- Pipes from the well to the laterals (mainlines)
- Filters
- Laterals
- Sprinklers
- Electrical system
- Computer system

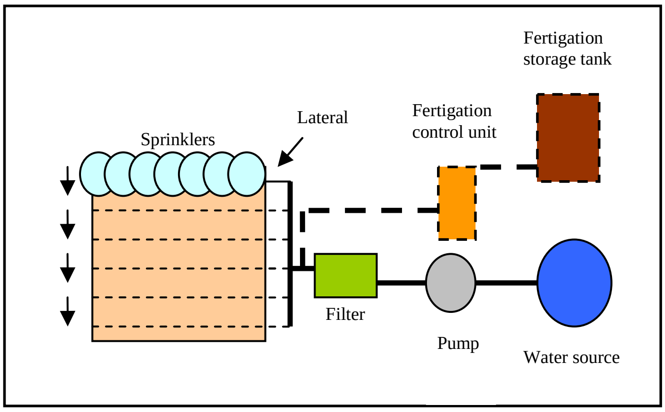

Figure 1: Sprinkler irrigation

In figure 1 a sprinkler system is illustrated. A pump is bringing the water from the source and provides adequate pressure for delivery to the pipe system. Before entering the system the water can be filtered for particles that otherwise could block the sprinklers. Finally, the water enters the field through the laterals and sprinklers. The lateral and sprinklers can either be a permanent installation in the field during the growing season or it can be removable. A permanent system will cover the whole field while a removable one is located in one position until the irrigation is complete in that area. The pump is then switched off and the lateral is disconnected from the mainline and moved to the next location. It is gradually moved around the field until the whole field is irrigated. A common problem with the movable sprinkler irrigation is the large labour force needed to move the laterals and sprinklers around the field. A fertigation system can be connected to the system.

Drip irrigation

With drip irrigation, water is conveyed under pressure through a pipe system to the fields, where it drips slowly onto the soil through drip lines which are located close to the plants (FAO, 2008). The system consists mainly of the following items (see figure 2):

- Pump
- Pipes from the well to the drip lines
- Filters
- Drip lines
- Electrical system
- Computer system
- (Fertigation device can be a part of the system)

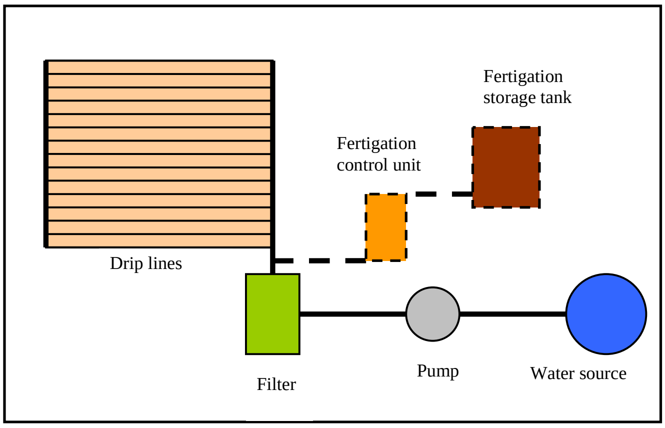

Figure 2: Drip irrigation

In figure 2, the drip irrigation system is illustrated. The pump brings water from the water source (river or well) and provide the right pressure into the pipe system. Before entering the drip lines the water is typically filtered since small particles can block the emitters in the drip line. As in sprinkler irrigation a fertigation device can be connected to the system. For annual crops e.g. potatoes the lines are either laid out when the crops are sown or afterwards and the lines are retrieved before or during harvest. In perennial crops like fruit trees, olives and vines the drip lines are typical permanent installed.

From a technical point of view, micro sprinklers have higher irrigation intensity and run off, it needs a higher pressure (head) and are more susceptible to evaporation compared to subsurface drippers. It means that subsurface drippers have a higher water and energy use efficiency than micro sprinklers. From an economic point of view, in most cases, subsurface drippers are more costly than sprinkler systems.

New irrigation techniques and strategies

Drought is one of the most common environmental stresses that may limit agricultural production worldwide. Many vegetables, including potato, have high water requirements and supplemental irrigation is necessary for successful production (Fabeiro et al., 2001). However, in many countries as a consequence of global climate changes and environmental pollution, water use for agriculture is reduced (FAO, 2002). Therefore, the challenge is to produce "more crops per drops"(Passioura, 2006).

To overcome the drought problems efficiently, an innovative sustainable irrigation technique called Partial Root Drying (PRD) was proposed. PRD is an irrigation technique where half of the root zone is irrigated while the other half is allowed to dry out. The treatment is then reversed, allowing the previously well-watered side of the root system to dry down while fully irrigating the previously dry side.

Comparing to other irrigation methods (especially regulated deficit irrigation), implementation of the PRD technique is simple and requires only the adaptation of irrigation systems (furrow irrigation or subsurface drip lines) in a such way to allow alternate wetting and drying of part of the root zone. The PRD results for different plant species (including potato) demonstrated the benefit of these methods in terms of improved water-use efficiency - in some cases almost a doubling was achieved (Loveys et al., 2000; Davies et al., 2000; Zegbe-Domínguez et al., 2003).

In presented study a number of new irrigation technologies and strategies are investigated and improved. Instead of full irrigation (FI) according to the water balance for the cropping system new irrigation strategies like DI, regulated deficit, and PRD strategies, as well as new precision irrigation techniques, like subsurface drip irrigation, are investigated.

Crop production and irrigation in Serbia

The total surface area of Serbia is 88,400 km^2. Agricultural land covers 57,340 km^2 of which 48,670 km^2 are arable land. Farmland comprises of 70% of the total surface area of Serbia. The plains offer favourable conditions for mechanized field crop farming and vegetable production. Rolling hills and foothills support fruit and wine production and livestock breeding. And the hills and mountains are attractive for developing sheep and cattle production and forestry (Serbian Government, 2008). The distribution of agricultural area and production among crops in Serbia is presented in table 1.

Table 1: Agricultural production in Serbia in 2006 and 2007

	--- 2006 ---			--- 2007 ---		
	Area	Yield	Total production	Area	Yield	Total production
Crop	ha	t/ha	1000 t	ha	t/ha	1000 t
Maize	1,169,976	5.1	6017	1,201,832	3.2	3,905
Wheat	539,813	3.5	1875	559,257	3.3	1864
Sunflower	186,431	2.1	385	154,793	1.9	295
Plums and sloes	164,000	3.4	556	200,000	3.4	681
Soybeans	156,680	2.7	430	146,988	2.1	304
Barley	93,520	29	276	93,844	2.8	259
Potatoes	84,434	11.0	930	81,379	9.1	743
Sugar beet	71,581	44.5	3189	79,016	40.6	3,206
Grapes	62,151	5.8	359	63,000	5.6	353
Oat	42,530	2.0	84	39,724	1.9	77

Source: FAOSTAT (2009)

Traditional family-owned small farms and private estates prevail, with the average commercial farm occupying 500-700 ha. Family farms consist of small plots and are based on subsistence production, being turned over to commercial use to a smaller degree than European farms (Serbian Government, 2008). Serbia's irrigation system covers 180,000 ha although only 30,000 ha of cultivated land are irrigated. For this reason, the potential for increased production of sugar beet, potatoes, sunflower, soy, vegetables and forage are not fully exploited (Serbian Government, 2008).

Serbian experiments and results
As a part of the SAFIR project, FI, DI and PRD strategies using subsurface drip irrigation has been tested in open filed trials at a location 10 km from Belgrade. The project is ongoing, but results from 2007 and 2008 indicate significant differences in amount of irrigated water applied and yields (table 2).

Table 2: Amount of irrigated water applied and yields in drip irrigation strategies

Year	------------- 2007 -------------			------------- 2008 -------------		
Irrigation strategy	FI	DI	PRD	FI	DI	PRD
Amount of irrigated water applied (m^3/ha)	1970	1250	1300	2770	1630	1410
Yield (t/ha)	45.73	40.14	36.74	55.4	47.88	49.24
IWUE (kg/ha/m^3)	23.21	32.11	28.26	20.00	29.37	34.92

Comparison between investigated years showed that yield in drip irrigation strategy in 2008 seasons was about 20% higher than in 2007 season (Table 2). It is well known that potatoes are very sensitive to soil moisture stress (Onder et al., 2005) and, thus, the increased number of irrigation in 2008 had positive effect on yield. Comparing to FI the PRD and DI treatments had a reducing effect on yield in both investigated years, similarly to the results of Liu et al. (2006).

The PRD and DI treatments in both years (especially in 2008) resulted in highly significant increases in Irrigation Water Use Efficiency (IWUE). Compared with FI, the PRD and DI treatments saved significant amount of water to irrigation, leading to increase of IWUE. Similar data were obtained by other authors (Liu et al., 2006; Shahnazari et al., 2007).

In Serbia irrigated potatoes are typically grown in small plots on small, family farms. The typical farm and field size for these growers are 5 ha and 1 ha respectively. In practice micro sprinklers and full irrigation systems are according to the water balance the typical state of the art (reference irrigation techniques) strategies.

For the time being, full irrigation using micro sprinklers are the most profitable strategies and techniques, but a higher demand for water and quality of potatoes may be in favour of deficit and PRD strategies and subsurface drip irrigation.

Potato prices vary significantly from within years and from year to year. On average in 2008 the potato price for the farmer was 0.23 € per kilogram corresponding to 20 Serbian Dinar (CSD).

Sprinkler irrigation has not been a part of the Serbian SAFIR trials. However, to compare drip irrigation with sprinkler irrigation, amount of irrigated water applied and yields for sprinklers has been calculated (see table 3). It is assumed, that yields remain the same, whereas the amount of irrigated water applied is increased due to run off and higher evaporation. The amount of irrigated water applied is calculated by using general water use efficiency figures (Smajstrla et al., 1991). PRD is not an option with sprinklers.

Table 3: Average yield and calculated amount of irrigated water applied for potatoes 2007-2008

Irrigation system	-------------- Drip --------------			------- Sprinkler -------	
Irrigation strategy	FI	DI	PRD	FI	DI
Average efficiency (Smajstra et al., 1991)	85	85	85	70	70
Amount of irrigated water applied (m^3/ha)	2370	1440	1355	2878	1749
Yield (t/ha)	50.57	40.14	36.74	50.57	40.14
IWUE (kg/ha/m^3)	21.34	27.88	27.11	17.57	22.95

Irrigation costs

As part of the SAFIR program, economic data has been collected for drip and sprinkler irrigation in potatoes. The costs of the equipment are presented in table 4.

Table 4: Irrigation system costs

		- Conventional drip -		------ PRD drip ------		-------- Sprinkler --------	
Equipment	Unit	Costs	Depreciation time (years)	Costs	Depreciation time (years)	Costs	Depreciation time (years)
Well	€	800	10	800	10	800	10
Filters	€	100	3	100	3	100	3
Pump	€	1000	5	1000	5	1000	5
Electrical system	€	500	5	500	5	500	5
Computer programs	€	150	5	150	5	150	5
Pipes from well to field (200m)	€	400	5	400	5	800	5
Drip lines	€	3714	3	7429	3		
Sprinklers	€					750	5
Total costs 1 ha	€/ha/year	1761		3000		753	
5 ha	€/ha/year	1343		2581		271	

The costs is calculated by dividing the cost of each equipment part with the depreciation time (years) and the irrigated area (ha) and finally the costs are summed. In this case study the costs are investigated for one and five ha corresponding to the typical farm and field size for family farms. Since the PRD strategy uses a double set of drip lines compared to conventional drip irrigation, equipment costs are also calculated for the PRD strategy. The filter used in the calculation is a disc filter. Disc filters can be used whenever organic material, sand or sediments are present in the water source.

The data in table 4 shows clearly that there is a significant difference in the cost of equipment between sprinkler and drip irrigation. This difference is primary caused by the costs of the drip lines, which in this example is about 1238 €/ha/year, whereas the cost of establishing a sprinkler system is 150 €/ha/year. In particular, the equipment for PRD becomes fairly expensive because the system requires two sets of drip lines. From table 5 it is also evident that the system involves some investment costs for equipment. Though there is a significant difference whether the system is used for one or five ha.

Cost of input to the systems is presented in table 5. Since the irrigation strategies uses different amounts of water, electricity, labour etc. a calculations are made for each strategy.

Table 5: Input costs

Irrigation system		------------------ Drip	------------------		-------- Sprinkler	--------
Irrigation strategy		FI	DI	PRD	FI	DI
Labour operating, maintaining and establishing	h/ha/year	18	18	32	33	33
Cost of labour	€/hour	1.50	1.50	1.50	1.50	1.50
Total labour costs	€/ha/year	27.00	27.00	48.00	49.50	49.50
Amount of irrigated water applied	m3/ha	2370	1440	1355	2878	1749
Total water costs	€/ha	0.00	0.00	0.00	0.00	0.00
Energy use	kWh/m3	0.30	0.30	0.30	0.23	0.23
Total energy use	kWh/ha/year	711.00	432.00	406.50	661.91	402.17
Energy costs	€/kWh	0.12	0.12	0.12	0.12	0.12
Total energy costs	€/ha/year	85.32	51.84	48.78	79.43	48.26
Total input costs	€/ha/year	112.32	78.84	96.78	128.93	97.76

Regarding inputs to the two systems the sprinkler system are both more work demanding and uses significantly more water. The sprinkler system uses about 50 €/ha/year on labour whereas the drip irrigation system only uses 27 €/ha/year. In both systems the work load is primary used for setting up the systems and retrieving the sprinklers or drip lines again before harvest. The main difference in input use between the two systems is in amount of irrigated water applied. It is varying between 1355 m^3/year to 2877 m^3/year where the PRD strategy use less water amounts while the FI strategy in sprinkler uses the most. However this does only influence the total cost through the energy costs since water for irrigation is free of tax.

In table 6, the total costs of equipment and strategies are shown for the various systems.

Table 6: Total irrigation costs

Irrigation system	--------------------- Drip	---------------------		------------ Sprinkler	------------
Irrigation strategy	FI	DI	PRD	FI	DI

1 ha	1873 €/ha	1840 €/ha	3096 €/ha	882 €/ha	851 €/ha
5 ha	1455 €/ha	1421 €/ha	2678 €/ha	400 €/ha	368 €/ha

The data in table 6 show that drip irrigation, regardless of strategy, has a higher total costs than sprinkler irrigation. With the present water, energy and labour costs the current sprinkler irrigation system will be the economic optimal and preferred system by farmers.

A tax on water quantity might give incentives for the farmer to change to more water efficient systems or strategies (Johansson et al., 2001). In Serbia however, farmers who cultivate small land areas and who have established their own wells do not usually pay for water, while farmers with larger farm businesses are paying a symbolic extra costs of approximately 8 €/ha/month for irrigation water. In figure 3, is illustrated how water taxes and levies may affect the extra costs for an area with 1 ha of potatoes. The extra costs is calculated with an initial set up of the present system (e.i. sprinkler with FI) and compared with the extra costs of the other systems (e.i sprinkler with DI and drip irrigation with FI, DI and PRD). For all systems there is an increased water tax along the X-axes.

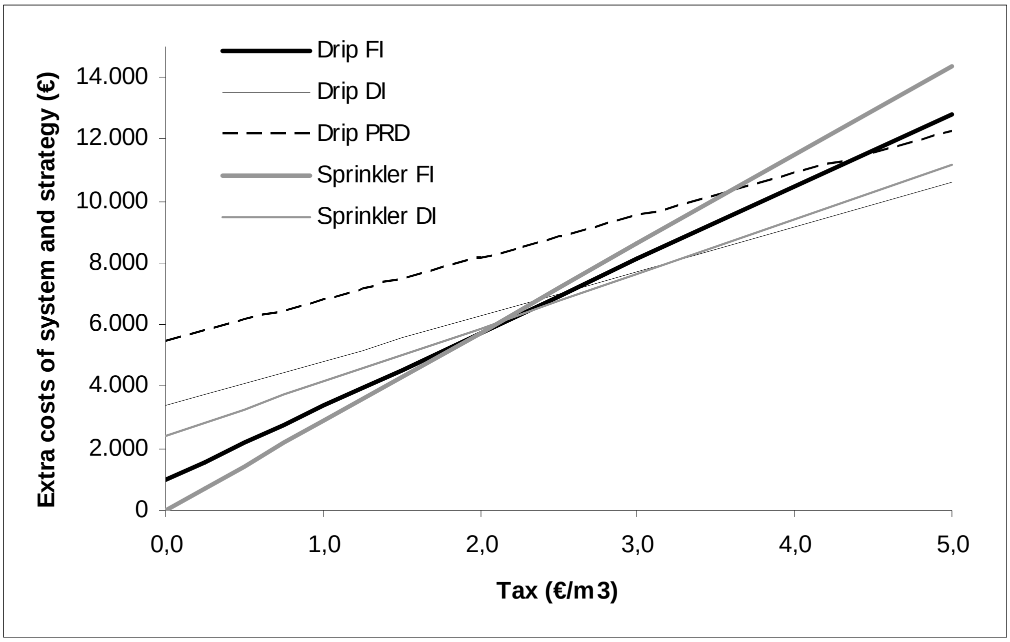

Figure 3: The extra costs of a water tax on production costs

The results as indicated in figure 3 shows that the size of the water tax will have an effect on which irrigation system and strategy that is the most economic optimal. To give an incentive for the farmers to change to a less water demanding strategy or system the tax should be approximately 2 €/m^3. At this point the FI strategy in drip irrigation will be the most profitable.

A further increase in the water tax to about 2.5 €/m^3 will give an incentive to use a DI strategy in sprinkler irrigation and with a further increase to 3.2 €/m^3 the solution will change to DI in drip irrigation. At last the tax should be 25 €/m^3 before the PRD strategy is chosen. The water savings related to the given taxes are shown in table 7.

Table 7: Water savings with a tax system

Water saving potential	Amount of irrigated water applied of system and strategy	Tax that gives incentives to change system	Water saving compared to present system m^3
Sprinkler FULL (Status quo)	2878	-	-
Drip FULL	2370	2.0 €/m^3	508
DI-Sprinkler	1749	2.5 €/m^3	1129
DI-Drip	1440	3.2 €/m^3	1438
PRD-Drip	1355	25.0 €/m^3	1523

The taxes presented in table 7 are very high. Therefore it is doubtful whether the increased tax will lead to a change in system or strategy. Whit this tax it seems more possible that the farmer will stop irrigating potatoes or shift his cultivation to a less water demanding crop.

Conclusion

With other strategies and system for irrigation it will be possible to save water compared to the present situation. Experimental results from Serbian field trials for both seasons confirmed that with deficit irrigation strategies it is possible to increase IWUE and save water for irrigation. This could be especially important for countries facing with drought and limited water resources for agricultural production as the current situation in Serbia.

With increased taxes on water it will be possible to give incentives for the farmers to change to these system and strategy and thereby save water. However the water taxes are very high and will probably lead the farmer to choose another crop or just stop irrigating his fields. Therefore a tax on water quantity would not necessarily be a relevant solution from a farm management point of view.

Since sprinkler irrigation not has been investigated in field trials further research will be needed to confirm the results for amount of irrigated water applied and yields. Furthermore field trials involving quality of the crops will be needed to investigate the effect of the strategies on the value of the yield.

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