IRRIGATION AND DRAINAGE
Irrig. and Drain. **65**: 502–513 (2016)
Published online 5 April 2016 in Wiley Online Library (wileyonlinelibrary.com) **DOI**: 10.1002/ird.1983

PROFITABILITY ASSESSMENT OF POTATO PRODUCTION APPLYING DIFFERENT IRRIGATION METHODS†

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ABSTRACT

The present research was conducted during the dry and warm growing seasons of 2011, 2012 and 2013 at Guča, which is a well-known potato-growing region of Serbia. Potato was grown under both rainfed conditions and with irrigation, applying two methods: sprinkler and subsurface drip irrigation. The objective of the research was to conduct a comparative analysis and assess the profitability of potato production under rainfed conditions and with irrigation by these two methods. The main outcome of the research showed that higher yields and more profitable production are achievable with irrigation, compared to rainfed conditions. Subsurface drip irrigation was found to be more profitable than sprinkler irrigation. The results provided insight into the structure and distribution of income and expenses, the income and expense growth trend, the percentage profit growth in the case of sprinkler and subsurface drip irrigation, as well as potential income losses at the national level if the irrigation methods considered are not used. A detailed analysis of the production costs provided insight into the feasibility of optimizing potato-growing approaches for all three types of production. The higher profitability of irrigated potato production opens the question of the need to increase irrigation coverage in Serbia. Copyright © 2016 John Wiley & Sons, Ltd.

KEY WORDS: Potato; economic return; Serbia; sprinkler irrigation; subsurface drip irrigation

Received 5 March 2015; Revised 20 August 2015; Accepted 20 August 2015

RÉSUMÉ

La présente recherche a été menée au cours des saisons de croissance des périodes chaudes et sèches des années 2011, 2012 et 2013 à Guča, une région de la Serbie bien connue pour la culture de la pomme de terre. La pomme de terre a été cultivée sous conditions pluviales et irriguées. Deux techniques d'irrigation sont utilisées: par aspersion et par goutte-à-goutte enterré. L'objectif de cette étude était de réaliser une analyse comparative et d'évaluer la rentabilité de la production de la culture de la pomme de terre en condition pluviale et par les deux techniques d'irrigation. Les résultats principaux de cette étude ont montré qu'un rendement plus élevé et une production plus rentable sont réalisables en conditions irriguées par rapport aux conditions pluviales. L'irrigation au goutte à goutte enterrée a été trouvée être plus rentable que l'irrigation par aspersion. Les résultats ont fourni un aperçu de la structure et de la répartition des revenus et des dépenses, la tendance de la croissance des revenus et des dépenses, la croissance de la marge bénéficiaire dans l'irrigation par aspersion et l'irrigation au goutte à goutte enterrée, ainsi que les pertes de revenus potentiels au niveau national si les techniques d'irrigation choisies ne sont pas utilisées. Une analyse détaillée des coûts de production a donné un aperçu sur la faisabilité de la croissance de l'approche d'optimisation de la culture de la pomme de terre pour les trois types de production. La rentabilité plus élevée de la production de la pomme de terre irriguée ouvre la question de la nécessité d'accroître la couverture de l'irrigation en Serbie. Copyright © 2016 John Wiley & Sons, Ltd.

MOTS CLÉS: pomme de terre; rendement économique; Serbie; irrigation par aspersion; irrigation goutte à goutte enterré

INTRODUCTION

In Serbia, potato is the most widespread vegetable, taking up 35% of all farmland where vegetables are grown. However, the average tuber yield is relatively low, amounting to about $10\,t\,h^{-1}$ (Vlahović *et al.*, 2010), or some 43% lower than the

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European average. Given that Serbia's annual potato output is about 859 000 t, revenue streams from potato exports are small. Namely, the share of potato exports in all agricultural exports is only 0.18%.

There are several reasons for such ineffective potato production: low quality of planting material, lack of machinery (Jovanović *et al.*, 2012), poor agronomic practices and, primarily, production mostly under rainfed conditions (no irrigation). Irrigation systems cover only 12–15% of all potato farmland (Broćić and Stefanović, 2004). On the other hand, assessments of climate parameters show the need for irrigation; the best indicator is that there have been droughts in Serbia in July and August in 80% of all years on record (Dragović *et al.*, 2008). In the past two decades, the region that featured the highest rainfall in Serbia's lowlands exhibited arid and semi-arid conditions in July and August in three out of four years (Matović *et al.*, 2013b).

Because of its shallow root system, potato is sensitive to water stress (Opena and Porter, 1999; Thornton, 2003; Unlu *et al.*, 2006), and even a short period of drought is likely to substantially reduce tuber yield (Jovanović *et al.*, 2012). Experience gained to date shows that tuber yield increases considerably with irrigation (Milić *et al.*, 2010). Potatoes are most often irrigated by furrow, sprinkler and drip methods. Worldwide, drip irrigation is preferred because of higher yields and better tuber quality (Yuan *et al.*, 2003; Onder *et al.*, 2005; Kaur *et al.*, 2005) and because it uses less water than other methods. In context of scarcity, more water used for irrigation means less water for other areas of the economy (Sidibe *et al.*, 2012).

With regard to the drip method, the effect of subsurface irrigation has recently become a focus of research. This method has major advantages in terms of efficient use of water resources (Camp, 2012; Lamm and Trooien, 2003), including reduced evaporation and water losses through deep percolation, as well as the elimination of surface runoff.

The objective of the present research was to assess the profitability of potato production under rainfed conditions and with sprinkler irrigation and subsurface drip irrigation, based on the commercial yields achieved on potato plots at Guča from 2011 to 2013, and the profits earned. The results provided insight into the structure and distribution of income and expenses, and the higher rate of income growth than the rate of increase in expenses, afforded by sprinkler irrigation and subsurface drip irrigation. The results also indicated the percentage profit growth in the case of sprinkler and subsurface drip irrigation, as well as the potential loss of revenue at the national level if the considered irrigation methods are not applied.

MATERIALS AND METHODS

The research was conducted in the Moravica region, near the town of Guča, 43º 46' 22″ N, 20º 13' 19″ E, on alluvial soil (pH = 6; humus about 2%), in the Bjelica River valley. Mid-season-ripening 'Laura', a potato variety with deep red skin and rich yellow flesh, was grown for three years: 2011, 2012 and 2013. This potato was produced under rainfed conditions and with irrigation, applying two methods: sprinkler and subsurface drip irrigation (SDI). The experimental field comprised three plots, 120 × 85 m (1 ha) for each of the treatments. The rows were spaced 70 cm apart, and the plants in a row 30 cm apart. Standard agronomic practices were followed. The crop was harvested mechanically. The marketable tuber yield (tuber diameter > 30 mm) from the entire plot was measured.

T-Tapes (TSX 506-20-500) were used for drip irrigation, placed in each row 2–3 cm below the ground surface. The laterals were installed at the time of earthing-up (one month after planting), using a specially designed machine. The space between the drippers of a lateral was 20 cm. The dripper flow rate was $5 l h^{-1}$ linear m^{-1}. Sprinkler irrigation was applied by means of NaanDanJain® 5035 sprinklers, with a flow rate of $1.5 m^3 h^{-1}$. The space between the sprinklers was 18 m, and the space between the mobile pipes was 14.7 m (every 21 rows). The precipitation rate was $5.8 mm h^{-1}$. Water was extracted from the Bjelica River, adjacent to the field, and pumped via a pipeline to the irrigated plots.

The potatoes were irrigated at the time of their highest water demand, near the end of the phenological stage that entails rapid green mass development and tuber formation, and at the time of maximum green mass and tuber growth. Irrigation was scheduled on the basis of water use for potato crop evapotranspiration (ET_c). ET_c was determined from the relation (Allen *et al.*, 1998): $ET_c = ET_0 \times k_c$. Potential evapotranspiration (ET_0), calculated applying the Hargreaves method (Hargreaves and Allen, 2003), was taken from the Hydrometeorological Service of Serbia on a daily basis. The crop coefficient (k_c) was taken from a publication of the Food and Agriculture Organization of the United Nations (FAO) (Allen *et al.*, 1998). Subsurface drip irrigation was undertaken after 20 mm and sprinkler irrigation after 45 mm of the water had been used up. The irrigation treatments fully compensated for the water uptake by the potato crops. Each rainfall event pushed back the time (day) of watering, depending on the amount of rain. The climate parameters (mean monthly air temperature, daily and monthly precipitation total, number of tropical days) as daily ET_0, were obtained from the Hydrometeorological Service of Serbia, for the weather station at Požega, which is representative of the study area.

Climate conditions

The climate at Guča is moderately continental and the average altitude is about 330 m. The warmest month is July, with an average (1981–2010) temperature of 20 °C (Figure 1), while the coldest month is February, with an average (1981–2010) temperature of -1.6 °C.

During the year, this region receives an average of 726 mm of rainfall, of which 423 mm in the growing season (April–September). The study years featured warmer (by 1.6 °C on average) and drier growing seasons (119 mm less precipitation), compared to long-term averages (Figure 1, Table I). The least rainfall from April to September (274 mm) was recorded in 2011, while in 2012, apart from a low precipitation total (287 mm), the air temperature was extremely high, as much as 2 °C higher than the long-term average (Table I). June, July and August were especially warm (Figure 1). That particular year recorded as many as 67 tropical days (Table I), or 131% more than the long-term average. As a result, high temperatures caused potential evapotranspiration at Guča to measure a record 889 mm (Table I), or 117 mm higher than the long-term average. The extremely warm and dry summer of 2012 decimated crop yields in most of Serbia.

Economic parameters

The economic assessment of potato production with irrigation was based on profit (Pérez-Pérez *et al*., 2010; Stikić *et al*., 2011, Kresović *et al*., 2014) and the profitability evaluated by means of a comparative analysis of profits generated under rainfed conditions and with irrigation (Kresović *et al*., 2014), applying the sprinkler and subsurface drip irrigation methods. Profit calculations required accounting of income and expenses, relative to the considered treatment, during the period 2011–2013.

Table I. Main climate parameters: precipitation (*P*), mean air temperature (*T*), number of tropical days, potential evaporation (ET_0), by growing season (April–September) at Guča

Year	*P* (Apr–Sep) (mm)	*T* (Apr–Sep) (°C)	Number of tropical days	ET_0 (mm)
2011	274	17.9	51	821
2012	287	18.4	67	889
2013	350	17.6	37	814
2011–2013	304	18.0	52	841
1981–2010	423	16.4	29	772

The profit reflected the net economic gain equal to the difference between income and production costs (Younis *et al*., 1991; Kendall *et al*., 2007; El-Waheda and Ali, 2013; Kresović *et al*., 2014):

$$NP = PY\ PP - Tc \qquad (1)$$

where NP is net profit (€), PY is potato yield (kg), PP is potato price (€ kg^{-1}) and Tc – total costs (€).

The income earned from potato production and the associated production costs were calculated and shown for rainfed conditions, sprinkler irrigation and SDI. Income was the product of the marketable tuber yield and prevailing market prices (Kendall *et al*., 2007; El-Waheda and Ali, 2013; Kresović *et al*., 2014; Weligamage *et al*., 2014) (Table II).

The costs were the product of the amounts and unit costs of production inputs. Expenses were divided into two groups: fixed expenses and variable expenses. Fixed expenses included those that remained constant regardless of treatment (rainfed conditions, sprinkler irrigation and subsurface drip irrigation). They included the purchase price of planting material, crop protection, fertilizers, loading of fertilizers and planting material, ploughing, disk harrowing, transportation of seed potatoes and fertilizers, filling of

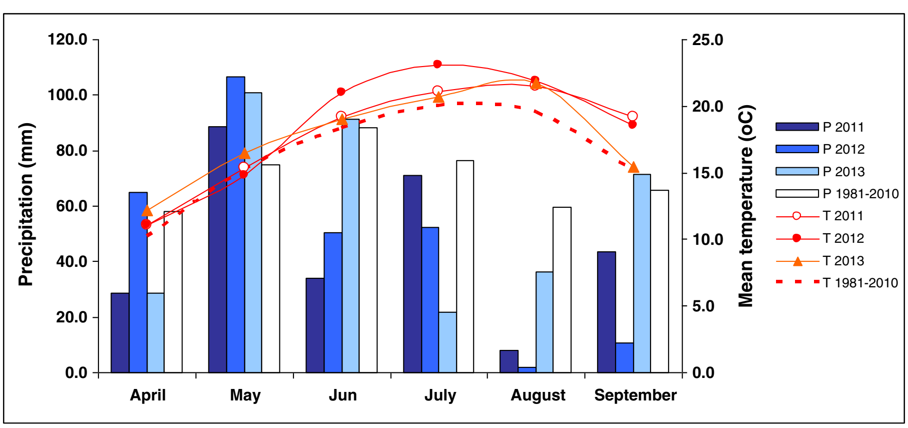

Figure 1. Mean monthly air temperatures (*T*) and monthly precipitation totals (*P*) (2011–2013) at Guča, relative to long-term (1981–2010) averages

Table II. Income parameters

Year	Tuber yield (kg ha^{-1}) Rainfed condition	Irrigation method Sprinkler	SDI	Unit price (€ kg^{-1})
2011	25 100	35 200	52 000	0.24
2012	11 200	29 100	38 200	0.22
2013	22 000	34 000	47 900	0.25

Source: Farmer's internal records and the National Statistical Office of Serbia.

cyclone spreaders, spreading of fertilizers and pesticides, mechanical planting and harvesting (Table III).

Fixed expenses also included depreciation of the irrigation system, where applicable. Annual depreciation for sprinkler irrigation was €285 and for subsurface drip irrigation €796. Depreciation in the case of sprinkler irrigation was related to pipes, pumps and ancillaries, and the annual rate was 10%. In the case of subsurface drip irrigation, depreciation included T-Tapes, whose annual depreciation rate was 100%, as well as the cost of other equipment whose lifespan was five years and whose depreciation was linear.

Variable expenses included irrigation costs, which were not incurred under rainfed conditions, and costs that varied as a function of yield or nature of the irrigation method. In the case of sprinkler irrigation, costs arose from water, fuel, lubricants and related labour. Subsurface drip irrigation costs included water, energy and related labour. Irrigation water costs included a mandatory water usage fee (regulated by the government based on the Serbian Water Law), depending on the amount of water used. Costs that varied as a function of yield or the nature of the irrigation method included labour, PVC bags and transportation from field to storage facility. Labour costs were incurred for earthing-up, harvesting, loading and unloading. Earthing-up costs depended on the nature of the irrigation method, while the costs of harvesting, loading, unloading, PVC bags and transportation from field to storage facility depended on the yield (Table IV).

The income and expenses for the three different treatments were calculated using the above parameters. Income-related data were obtained from the farmer's internal records and the National Statistical Office. The information needed to calculate expenses was taken from the farmer's internal records.

The profitability of potato production with sprinkler and subsurface drip irrigation was determined as the difference between income growth as a result of yield increase, and expenses incurred on account of the irrigation method applied. Apart from calculating the absolute profit, an accurate assessment of the profitability of potato production with sprinkler and subsurface drip irrigation required a detailed analysis of the structure and distribution of income and expenses, variable and fixed expenses, percentage increase in income and expenses depending on treatment, and finally the percentage profit growth in the case of sprinkler irrigation and subsurface drip irrigation.

Table III. Summary of fixed expenses, 2011–2013

Description	Quantity	Unit cost (€)
Seed potatoes, first reproduction (kg)	3000	0.35
Overall potato protection per ha	1	567.45
Fertilizer 8 : 16 : 24 + MgO (kg)	1200	0.27
KAN fertilizer (kg)	300	0.30
Loading of fertilizers and seed potatoes (h)	2	0.88
Plowing in both directions (h ha^{-1})	6	13.26
Tillage/disk harrowing (h ha^{-1})	6	13.26
Transportation of seeds and fertilizers (h ha^{-1})	4	8.84
Filling of cyclone spreaders (h)	3	0.88
Fertilizer spreading (h ha^{-1})	2	8.84
Mechanical planting (h ha^{-1}) + 3 workers	6	13.26
Application of all pesticides (h ha^{-1})	12	8.84
Mechanical harvesting (ha)	10	13.26

Source: Farmer's internal records.

RESULTS AND DISCUSSION

Tuber yield under rainfed conditions

Weather conditions tend to cause fluctuating and unpredictable agricultural yields in Serbia (Bošnjak, 2004; Dragović *et al.*, 2008; Dragović, 2012; Matović *et al.*, 2013a). As a result, the potato yields generated from the experimental

Table IV. Summary of variable expenses, 2011–2013

Irrigation costs	Sprinkler irrigation Frequency	Unit cost (€)	SDI Frequency	Unit cost (€)
2011	3	142	7	44.19
2012	5		11	
2013	4		8	
Costs as a function of yield or nature of irrigation method	Rainfed	Quantity Sprinkler	SDI	Unit cost (€)
Earthing-up (h ha^{-1})[a]	5	5	15	8.84
Manual harvesting (h)	250	400	550	1.33
Loading and unloading of potatoes (h)	45	55	65	0.88
PVC bags, 50 × 80	800	1300	1300	0.08
Transportation from field to storage facility	25	40	40	0.88

[a]Earthing-up costs in the case of subsurface drip irrigation include installation of T-Tapes.
Source: Farmer's internal records.

plots at Guča in the three growing seasons varied to a large extent (from 11.2 to 25.1 t ha^{-1}) (Table V). The lowest yield was recorded in the extremely warm and dry growing season of 2012. Given that the year 2012 registered as many as 67 tropical days, with $T_{max} > 30\,°C$ (Table I), it is believed, according to Timlin *et al*. (2006), that the high temperature stress slowed down photosynthesis, accelerated respiration and decelerated the transport of carbohydrates from the leaves to the tubers, and resulted in reduced tuber growth. This is consistent with Patel and Rajput (2007), who claim that potatoes prefer relatively colder regions (temperatures from 15 to 25 °C) and that tuber growth is severely reduced when air temperatures are above 30 °C (Food and Agriculture Organization of the United Nations, FAO, 2009). The variation in rainfed yields at Guča is a result of different temperature and rainfall regimes, where rainfall distribution relative to the potato's water demand was an important consideration (Matović *et al*., 2013a).

Tuber yield under irrigation conditions

Many researchers have found that increase in tuber yield depends on water availability (Yuan *et al*., 2003; Thornton, 2003; Kiziologlu *et al*., 2006) and that irrigation is of crucial importance for tuber growth and ultimate yield (Kashyap and Panda, 2003; Kang *et al*., 2004; Onder *et al*., 2005; Kaur *et al*., 2005; Shahnazari *et al*., 2007). Accordingly, irrigation resulted in a considerable increase in potato yields at Guča, compared to rainfed conditions. Subsurface drip irrigation recorded the greater increase; an average of nine irrigation treatments resulted in a tuber yield of 46 t ha^{-1}, or 155% greater than in the case of rainfed conditions. Sprinkler irrigation was applied four times on average and the resulting yield was 33 t ha^{-1}, or 85% more than under rainfed conditions (Table V). The greatest increase in irrigated yield, compared to rainfed (241% in the case of subsurface drip irrigation and 160% with sprinkler irrigation), was achieved in the extremely warm and dry growing season of 2012. This was consistent with Maksimović *et al*. (2004), who claim that rainy years, with a favourable rainfall distribution, reduce the effectiveness of irrigation since rainfed production is also able to achieve relatively high yields.

A comparison of the effectiveness of subsurface drip irrigation and sprinkler irrigation showed that in all three years subsurface drip irrigation was more efficient and resulted in a 40% greater tuber yield, on average, compared to sprinkler irrigation. This result supports Garb and Friedlander (2014) in their claim that subsurface drip irrigation is one of the most prospective options for increasing irrigation efficiency.

ECONOMIC EVALUATION

As expected, sprinkler and subsurface drip irrigation resulted in a higher income that depended solely on yield. Compared to rainfed conditions, sprinkler and subsurface drip irrigation boosted income during the study period, on average, by 85 and 155%, respectively. Compared to sprinkler irrigation, during the study period the average increase in income resulting from subsurface drip irrigation was 40% (Table VI).

In the study period, all three treatments were characterized by a dominant share of fixed expenses in overall expenses. The average share in the case of rainfed conditions, sprinkler and subsurface drip irrigation was 84, 67 and 70%, respectively (Table VII). The average share of variable expenses was much lower and in the same three cases amounted to 16, 33 and 30%, respectively (Table VII).

During the study period, average fixed expenses of potato production under rainfed conditions and with sprinkler irrigation were largely made up of the costs of seed potatoes, overall potato protection, and fertilizers. In the case of rainfed conditions, the averages were 40.9, 22.1 and 12.6%, respectively, and in the case of sprinkler irrigation 36.8, 19.9 and 11.4%, respectively. With SDI, average fixed expenses were largely made up of the costs of seed potatoes, depreciation and overall potato protection. The average share of these costs in the fixed expenses with subsurface drip irrigation during the study period was 31.2, 23.7 and 16.9%, respectively (Table VIII).

Table V. Precipitation (*P*) at planting/harvesting stage, potato water demand (potato potential evapotranspiration ET_c), irrigation frequency, tuber yield and increase in tuber yield depending on irrigation method at Guča, 2011–2013

Year	*P* (planting/ harvesting) (mm)	ET_c (mm)	Irrigation frequency		Tuber yield (t ha^{-1})			Increase in tuber yield under irrigation (%)	
			SDI	Sprinkler	Rainfed	SDI	Sprinkler	SDI	Sprinkler
2011	213	658	7	3	25.1	52.0	35.2	107	40
2012	167	731	11	5	11.2	38.2	29.1	241	160
2013	251	667	8	4	22.0	47.9	34.0	118	55
Average	210	685	9	4	19.4	46.0	32.8	155	85

Table VI. Income and income growth trend by type of treatment, 2011–2013

Treatment	Income (€ ha^{-1})			Average
	2011	2012	2013	
Rainfed	6 020	2 460	5 500	4 660
Sprinkler irrigation	8 450	6 400	8 500	7 780
Subsurface drip irrigation	12 500	8 400	12 000	11 000
Income growth trend depending on treatment (%)				
Sprinkler irrigation vs rainfed conditions	40	160	55	85
Subsurface drip irrigation vs rainfed conditions	107	241	118	155
Subsurface drip irrigation vs sprinkler irrigation	48	31	41	40

Source: Calculation based on farmer's internal records and information obtained from the National Statistical Office.

Table VII. Expenses (€ ha^{-1}) and average share (%) in total expenses, 2011–2013

Expenses	Treatment								
	2011			2012			2013		
	Rainfed	Sprinkler	SDI	Rainfed	Sprinkler	SDI	Rainfed	Sprinkler	SDI
Fixed	2 570	2 850	3 360	2 570	2 850	3 360	2 570	2 850	3 360
Variable	500	1 190	1 370	500	1 470	1 550	500	1 330	1 410
Total	3 070	4 040	4 730	3 070	4 320	4 910	3 070	4 180	4 770
Share of fixed expenses, 2011–2013 averages (%)									
	Rainfed			Sprinkler			SDI		
Fixed	84			67			70		
Variable	16			33			30		
Total	100			100			100		

Source: Calculation based on farmer's internal records.

Table VIII. Fixed expenses (€ ha^{-1}) and average share (%), 2011–2013

Expense	Treatment 2011–2013					
	Rainfed	Sprinkler	SDI	Rainfed	Sprinkler	SDI
	(€ ha^{-1})			(%)		
Seed potatoes, first reproduction	1 050	1 050	1 050	40.9	36.8	31.2
Overall potato protection	567	567	567	22.1	19.9	16.9
Fertilizer 8 : 16 : 24 + MgO (kg)	324	324	324	12.6	11.4	9.6
KAN fertilizer	90	90	90	3.5	3.2	2.7
Loading of fertilizers and seed potatoes	2	2	2	0.1	0.1	0.1
Plowing in both directions	80	80	80	3.1	2.8	2.4
Tillage/disk harrowing	80	80	80	3.1	2.8	2.4
Transportation of seed potatoes and fertilizers	35	35	35	1.4	1.2	1.1
Filling of cyclone spreaders	3	3	3	0.1	0.1	0.1
Spreading of fertilizers	18	18	18	0.7	0.6	0.5
Mechanical planting	80	80	80	3.1	2.8	2.4
Application of pesticides	106	106	106	4.1	3.7	3.2
Mechanical harvesting	133	133	133	5.2	4.7	3.9
Depreciation	0	285	795	0.0	10.0	23.7
Total fixed expenses	2 570	2 850	3 360	100	100	100

Source: Calculation based on farmer's internal records.

The intrinsic cost of sprinkler irrigation and SDI had the highest percentage share of variable expenses in the extremely dry year 2012 (Table IX), when the irrigation frequency was the highest (Table V). In that year irrigation costs accounted for 48.1% (sprinkler irrigation) and 31.4% (SDI) of variable expenses. Compared to 2012, in 2011 and 2013 this share was lower by 12.3 and 5.5%, respectively. In the case of subsurface drip irrigation, the share of irrigation costs in variable expenses in 2012, compared to 2011 and 2013, was 8.8 and 6.4% higher, respectively. The average share of irrigation costs in variable expenses during the study period was 42.2% in the case of sprinkler irrigation and 26.3% in the case of SDI.

Of the expenses that varied as a function of yield or nature of irrigation method, during the study period, irrespective of the type of treatment, potato harvesting had the largest average share. Under rainfed conditions, the share of these costs was 66.2%, and in the case of sprinkler and subsurface drip irrigation 40.3 and 50.8%, respectively. The cost of procuring PVC bags had a much smaller average share: 12.7% (rainfed conditions), 7.9% (sprinkler irrigation) and 7.2% (subsurface drip irrigation). The share of earthing-up costs in the overall variable expenses during the study period was 8.8% (rainfed conditions), 3.3% (sprinkler irrigation) and 9.2% (subsurface drip irrigation). The average cost of potato loading and unloading had the greatest contribution to overall expenses under rainfed conditions (7.9%), compared to sprinkler irrigation (3.7%) and subsurface drip irrigation (4.0%). The cost of transportation from the field to the storage facility had the smallest average share in variable expenses, for all three treatments: rainfed conditions 4.4%, sprinkler irrigation 2.7% and subsurface irrigation 2.5%.

The results of the present research showed that the share of variable expenses in total expenses was considerably lower than that of fixed expenses, irrespective of treatment (rainfed, sprinkler and subsurface drip irrigation). The low average share of variable expenses in the total expenses of potato production (Table VII) was largely a result of low water and energy costs (Stikić *et al.*, 2011), as well as of labour costs associated with irrigation (Kresović *et al.*, 2014). The cost of irrigation water in Serbia is relatively low (regulated by the government), such that farmers are not motivated to save water and, according to Ørum *et al.* (2010), they will continue to be unmotivated until there is a shortage of high-quality irrigation water or until water becomes more expensive. Compared to developed West European countries, the cost of electricity in Serbia is lower by a factor of about three (Kresović *et al.*, 2014); for example, in Spain it is about €0.12 kWh^{-1} (Perez-Perez *et al.*, 2010), in Portugal €0.13 kWh^{-1} (Rodrigues et al., 2013), and in Serbia €0.04 kWh^{-1} on average (Kresović *et al.*, 2014). The average hourly wage in Serbia is lower than in Hungary or Poland by a factor of nine (Kresović *et al.*, 2014). The ratio is roughly the same relative to Spain, where the hourly wage is €6.57 h^{-1} (Domínguez *et al.*, 2012). Compared to developed West European countries, the hourly wage in Serbia is much lower. For example, in France, Germany and Belgium the average hourly wage is about €36 h^{-1}, while in Serbia it is lower by a factor of even as much as 50 (Kresović *et al.*, 2014).

In general, production is profitable if expenses amount to less than 100% of income. In the study period, expenses were less than 100% in all cases, except under rainfed conditions in 2012. Rainfed production in 2012 resulted in

Table IX. Variable expenses (€ ha^{-1}) and share in total variable expenses (%), 2011–2013

Expense (€ ha^{-1})	2011			2012			2013		
	Rainfed	Sprinkler	SDI	Rainfed	Sprinkler	SDI	Rainfed	Sprinkler	SDI
Irrigation	0	426	309	0	709	486	0	567	354
Earthing-up	44	44	133	44	44	133	44	44	133
Manual harvesting	332	532	731	332	532	731	332	532	731
Loading and unloading	40	48	57	40	48	57	40	48	57
PVC bags	64	104	104	64	104	104	64	104	104
Transportation from field	22	35	35	22	35	35	22	35	35
Total variable expenses	500	1 190	1 370	500	1 470	1 550	500	1 330	1 410
% share	Rainfed	Sprinkler	SDI	Rainfed	Sprinkler	SDI	Rainfed	Sprinkler	SDI
Irrigation	0.0	35.8	22.6	0.0	48.1	31.4	0.0	42.6	25.0
Earthing-up	8.8	3.7	9.7	8.8	3.0	8.6	8.8	3.3	9.4
Manual harvesting	66.2	44.7	53.4	66.2	36.1	47.3	66.2	40.0	51.7
Loading and unloading	7.9	4.1	4.1	7.9	3.3	3.7	7.9	3.7	4.1
PVC bags	12.7	8.7	7.6	12.7	7.1	6.7	12.7	7.8	7.3
Transportation from field	4.4	3.0	2.6	4.4	2.4	2.3	4.4	2.6	2.5
Total variable expenses	100	100	100	100	100	100	100	100	100

Source: Calculation based on farmer's internal records.

a very low yield and an income which was 24% lower than expenses (Table X).

The 2011–2013 profitability assessment of irrigated potato production also addressed to what extent income growth was higher than that of the fixed and variable expenses attributable to irrigation (Table XI).

During the study period, irrigated potato production, compared to rainfed, was consistently more profitable. In the case of sprinkler irrigation, relative to rainfed conditions, income growth due to yield increase was greater than the increase in total expenses by 64%, and greater than the increase in variable expenses by 73%, on average. Where

Table X. Percentage of income used to cover different types of expenditures under rainfed conditions and with sprinkler irrigation and subsurface drip irrigation (SDI), 2011–2013

	Treatment								
	2011			2012			2013		
Item	Rainfed	Sprinkler	SDI	Rainfed	Sprinkler	SDI	Rainfed	Sprinkler	SDI
Fixed expenses	43	33	27	104	43	40	47	32	28
Variable expenses	8	14	11	20	23	18	9	16	12
Total expenses	51	47	38	124	66	58	56	48	40
Income	100	100	100	100	100	100	100	100	100
Profit	49	53	62	-24	34	42	44	52	60

Source: Calculation based on farmer's internal records.

Table XI. Economic viability assessment of potato production from 2011 to 2013 based on analysis of revenue growth (%) relative to total expenses and variable expenses incurred by different irrigation methods

Description (€ ha^{-1})	2011	2012	2013	Average
Income, rainfed conditions	6 020	2 460	5 500	4 660
Income, sprinkler irrigation	8 450	6 400	8 500	7 780
Income, subsurface drip irrigation	12 500	8 400	12 000	11 000
Expenses, rainfed conditions	3 070	3 070	3 070	3 070
Expenses, sprinkler irrigation	4 040	4 320	4 180	4 180
Expenses, subsurface drip irrigation	4 730	4 910	4 770	4 800
Variable expenses, rainfed conditions	500	500	500	500
Variable expenses, sprinkler irrigation	1 190	1 470	1 330	1 330
Variable expenses, subsurface drip irrigation	1 370	1 550	1 410	1 440
Sprinkler irrigation vs rainfed conditions				
Difference in income	2 430	3 940	3 000	3 120
Difference in expenses	970	1 250	1 100	1 100
Difference in variable expenses	690	970	830	830
Income growth (%) relative to increase in expenses	60	68	63	64
Income growth (%) relative to increase in variable expenses	72	75	72	73
Subsurface drip irrigation vs rainfed conditions				
Difference in income	6 480	5 940	6 500	6 300
Difference in expenses	1 660	1 840	1 700	1 730
Difference in variable expenses	870	1 050	910	943
Income growth (%) relative to increase in expenses	74	69	74	72
Income growth (%) relative to increase in variable expenses	87	82	86	85
Subsurface drip irrigation vs sprinkler irrigation				
Difference in income	4 050	2 000	3 500	3 180
Difference in expenses	690	590	590	623
Difference in variable expenses	180	80	80	113
Income growth (%) relative to increase in expenses	83	71	83	79
Income growth (%) relative to increase in variable expenses	95	96	98	96

Source: Calculation based on farmer's internal records.

subsurface drip irrigation was applied, relative to rainfed conditions, there was a significant income growth but this growth was tempered by a large increase in variable expenses. In this case, income growth due to yield increase was greater than the growth of total expenses, by 72%, on average, and greater than that of variable expenses by 85%, on average. During the study period, potato production with subsurface drip irrigation was more profitable than with sprinkler irrigation; as a result of yield increase, the average income growth was 79% higher than the increase in expenses, and 96% higher than the increase in variable expenses.

The greatest difference in profits between the various treatments was noted in the extremely dry year 2012, when rainfed production recorded a loss (Table XII).

In 2011, compared to sprinkler and subsurface drip irrigation, the profit earned from rainfed production was lower by 49 and 162%, respectively, and in 2013 by 78 and 196%, respectively. During the same period, potato production with subsurface drip irrigation was 70% higher on average (Table XII), than with sprinkler irrigation. In terms of the study years, the profit generated with subsurface drip irrigation, compared to sprinkler irrigation, was 76% higher in 2011, 68% higher in 2012 and 67% higher in 2013.

In the past three years in Serbia, the average annual income from rainfed potato production was €2.340 ha^{-1} (Table XIII). Based on the assumption corroborated by the results of this research (Table VI), that sprinkler and subsurface drip irrigation of potatoes would result in an income growth of 85 and 155%, respectively, and that the increase in income as a result of subsurface drip irrigation, compared to sprinkler irrigation, would be 40%, the conclusion is that in the past three years Serbia sustained an average annual loss of (Table XIII):

- €1990 ha^{-1} under rainfed conditions, vs sprinkler irrigation;
- €3630 ha^{-1} under rainfed conditions, vs subsurface drip irrigation;
- €930 ha^{-1} with sprinkler irrigation, vs subsurface drip irrigation.

Given that in the past three years the average area of potato farmland in Serbia was 76 500 ha and that only some 12–15% of that farmland was irrigated (Broćić and Stefanović, 2004), the following potato production losses were incurred at the national level in that period:

- €131 million under rainfed conditions, compared to sprinkler irrigation;
- €240 million under rainfed conditions, compared to subsurface drip irrigation; and
- €62 million with sprinkler irrigation, compared to subsurface drip irrigation.

Potential losses due to the absence of different types of irrigation, at the national level, were estimated assuming that there was a water source near the potato farm, from which irrigation water could be procured (Table XIII). The calculation did not include the cost of the infrastructure needed to 'bring the water closer to the user'. The construction and/or reconstruction of drainage and/or irrigation ditches, micro-reservoirs, pumping stations and ancillary facilities, which would support irrigated agriculture, is a matter of the country's strategic policy, to ensure the advancement of agriculture and the national economy as a whole. In that case, primary agricultural production would need to be restructured, agricultural machinery updated and new agribusiness capacities built (Petković, 2003).

Table XII. Profit (€ ha^{-1}) and growth (%) depending on irrigation method, 2011–2013

	Treatment								
	2011			2012			2013		
Item (€ ha^{-1})	Rainfed	Sprinkler	SDI	Rainfed	Sprinkler	SDI	Rainfed	Sprinkler	SDI
Income	6 020	8 450	12 500	2 460	6 400	8 400	5 500	8 500	12 000
Expenses	3 070	4 040	4 730	3 070	4 320	4 910	3 070	4 180	4 770
Fixed expenses	2 570	2 850	3 360	2 570	2 850	3 360	2 570	2 850	3 360
Variable expenses	500	1190	1 370	500	1 470	1 550	500	1 330	1 410
Profit	2 950	4 410	7 750	-610	2 080	3 490	2 430	4 320	7 210
Profit growth (%)									
Sprinkler vs rainfed		49			–			78	
SDI vs rainfed		162			–			196	
SDI vs sprinkler		76			68			67	

Source: Authors' calculation based on farmer's internal records.

Table XIII. Average loss of income on a national scale due to absence of irrigation (2011–2013), assuming availability of a nearby water source

Year	Potato farmland area (ha)	Price (€ kg^{-1})	Potato yield ($kg\,ha^{-1}$)	Income (€)
2011	78 000	0.24	11 400	2 730
2012	75 000	0.22	7 660	1 690
2013	76 500	0.25	10 400	2 600
Average income				2 340
Income growth of 85%				4 320
Income growth of 155%				5 970
Income growth of 40%				3 270
Loss of income under rainfed conditions relative to sprinkler irrigation				1 990
Loss of income under rainfed conditions relative to SDI				3 630
Loss of income with sprinkler irrigation relative to SDI				930
Average potato farmland area (ha)				76 500
Average potato farmland area (ha) less irrigated area (13.5%)[a]				66 170
Average loss at national level due to lack of sprinkler, relative to rainfed				131 000 000
Average loss at national level due to lack of SDI, relative to rainfed				240 000 000
Average loss at national level with sprinkler irrigation, relative to SDI				61 800 000

[a]13.5% is the average irrigation coverage (12–15%) of potato farmland in Serbia.
Source: Calculation based on farmer's internal records and information obtained from the National Statistical Office.

The more profitable irrigated production, due to greater yields, opens the question of the larger share of potato in Serbia's overall crop production and exports. This share increase would be 6% on average (Vukelić and Djuričin, 2012). In the past several years, Serbia's average income from potato exports has been €1.3 million (Broćić and Stefanović, 2004). The revenue stream from potato exports is considered low, given that the share in overall exports, agricultural exports and food exports has been only 0.01, 0.18 and 0.08% respectively.

Consistent use of existing irrigation systems and investment in new ones would increase yields and sales revenues, and consequently improve the farmers' bottom lines. Their likelihood of bankruptcy would be minimized or even eliminated, and the prospects of agricultural sector development improved (Djuričin and Bodroža, 2013).

CONCLUSION

This research focused on the growing seasons of 2011, 2012 and 2013, which were drier and warmer than the long-term averages. A comparative analysis of yields and profits was conducted for rainfed conditions and different irrigation methods. The results showed that potato production was more profitable with sprinkler and subsurface drip irrigation, than under rainfed conditions. The higher profitability of irrigated potato production was a result of a greater increase in yield due to irrigation than the associated increase in overall production costs. A detailed temporal and comparative assessment of all fixed and variable expenses incurred in potato production under rainfed and irrigated conditions provided insight into the extent of these expenses and the time of, and reason for, their variation. This shed light on the potential for optimization of potato production.

The results also indicate that greater yields and a higher profitability of potato production are achievable with subsurface drip irrigation than with sprinkler irrigation. The profits earned in the former case were about 70% higher. The highest profitability of irrigation was recorded in the driest and warmest year (2012), when rainfed potato production was not profitable as the yield was very low and the income lower than the expenses. Given rather pessimistic climate change predictions for south-east Europe, there are concerns that such an adverse outcome of rainfed potato production in the region might become increasingly frequent.

The higher profitability achievable with irrigation opens the question of the feasibility of rehabilitating existing irrigation systems and building new irrigation schemes in Serbia. Irrigated agriculture in Serbia would increase exports and improve the development prospects of Serbia's agricultural sector.

ACKNOWLEDGEMENTS

This paper is part of research project No. 31005 (A Modern Biotechnological Approach to Resolving Drought Issues of Serbia's Agriculture) and project No. 37005 (Assessment of Climate Change Impact on Serbia's Water Resources), both financed by the Ministry of Education and Science of the Republic of Serbia.

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