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EVALUATION OF ECONOMIC EFFICIENCY OF IRRIGATION IN CORN FOR GRAIN PRODUCTION IN 2005-2016

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Abstract

To evaluate the economic efficiency of irrigation in corn cultivated for grain, production effects were used, which were obtained from studies conducted by researcher team from the Department of Land Reclamation and Agrometeorology at the Experiment Station of the UTP University of Science and Technology in Bydgoszcz in 2005-2016. The research covered the effect of irrigation on yielding of the crop. Economic efficiency calculations were made using the direct surplus increase calculation method. In each variant irrigation enhanced production effects. It was not always economically justified, however. The irrigation costs (for drip and sprinkler irrigation systems) per hectare were decreasing with an increase in acreage. Applying drip irrigation was economically unjustified in moist years and on average in the multi-year period. In the years with dry and average precipitation conditions the direct surplus was positive, except for irrigation of 1 ha. As for the sprinkler-irrigation system, a lack of economic efficiency was reported in moist years, whereas in dry and average years as well as on average in the multi-year period, except for 1 hectare acreage, corn sprinkler-irrigation was economically justified.

Key words: drip irrigation, sprinkler irrigation, economic efficiency, corn for grain, drought categories

INTRODUCTION

The key yield-forming factor is water availability to plants during the vegetation period. A negative effect of dry spell periods can be minimized with irrigation, which is, however, an expensive practice (Prokopowicz and Lipiński 2008).

As for corn, a high grain yield variation in successive years is conditioned by water deficits, which lead to an uneven plant growth and development over the vegetation period. For that reason corn is a plant predisposed to cultivation with irrigation (Dudek *et al.* 2009). Irrigation efficiency of corn for grain in the Bydgoszcz facility with the use of sprinkler was analysed already in 1995 (Żarski *et al.* 2004), and with drip systems – starting from 2003 (Grzelak and Żarski 2009). Drip irrigation system is considered to be most precise and water-saving as water reaches directly the root system region, which helps avoiding evaporation losses from irrigated plant surface (Trawczyński 2013). According to Pierzgalski and Jeznach (1993), by applying drip irrigation 5-fold less energy is consumed than during sprinkler irrigation with long range sprinklers. As reported by Żarski *et al.* (2015), both methods lead to yield increases and stability.

Literature offers very few economic efficiency analysis reports for irrigation, which would indicate a purposefulness of introducing such practice as part of agricultural practices of growing a specific crop. Publications on fruits, e.g. cherry orchards (Brzozowski and Klimek 2010) or strawberries (Lipiński 2012), prevail, but economic evaluation was also performed for potatoes (Lipiński 2015). For corn such analysis was carried out by Kledzik *et al.* (2015). Żarski *et al.* (2001), on the other hand have proposed a thesis that irrigating that crop can be economically effective. Due to changing costs and prices of material, such calculations should be updated every few years.

The aim of this paper is to provide evaluation of economic effects of irrigation in corn for grain applying two systems: drip and sprinkler irrigation.

A research hypothesis assumes that introducing irrigation to corn cultivated for grain should bring positive economic effects. As seen from the research, only positive economic effects can be a stimulus for introducing it at a greater scale in agricultural practice.

MATERIAL AND METHODS

Production effects of irrigation of corn for grain were determined with the results of field experiments, performed in 2005-2016. The multi-year period was divided, according to the drought intensity scale of the period of corn intensified water requirements, into three categories: dry years, years with average precipitation and moist years. The experiments were performed in an experimental field of the Department of Land Reclamation and Agrometeorology of the University of Science and Technology, located at Mochełek in the vicinity of Bydgoszcz. The object of study included various corn hybrids: 'Cedro' (years 2005-08), 'ES Progress' (2009-11), 'KWS 5133 ECO' (2012-14) and 'Smolan' (2015-16). Besides irrigation, the factors differentiating the grain yield were varied nitrogen fertilization (2005-08) or nitrogen top-dressing application method (2009-16). The experiments were performed in Haplic Luvisol, representing IVa soil valuation class and very good rye soil suitability complex. In terms of the level of compactness, it is a light soil deposited on compact formation (sand on shallow-deposited sandy clay loam).

Economic efficiency of irrigation was defined as the product of production effects recorded as a result of field experiments and the average corn grain evaluation result in respective years. Average grain purchasing prices were estimated applying 2005-2016 data provided by the Central Statistical Office (GUS). For each irrigation system, an increase in direct surplus was calculated (Grabarczyk 1987):

$$\Delta D=\Delta P-(Kd+\Delta Kr)$$

where:
ΔD – increase in direct surplus (PLN·ha^{-1}),
ΔP – additional production value received by introducing irrigation (PLN·ha^{-1}),
Kd – total irrigation costs (PLN·ha^{-1}),
ΔKr – direct costs related to receiving additional production (PLN·ha^{-1}).

Sprinkler and drip irrigation systems were compared, assuming five irrigated acreage variants each: 1, 5, 10, 30 and 50 hectares. The total irrigation costs are made up of investment costs and operating costs. The investment costs evaluation for a drip irrigation system was performed with the information provided by company Łukomet (Jankowiak and Rzekanowski 2006, Łuszczyk 2009). To evaluate the sprinkler system costs, Bauer Group Polska (http://www.bauerpolska.pl) data were used (evaluation performed in November 2016). For the calculation the following assumptions were made: 6.67% depreciation rate (15-year period of use), 5% capital percentage rate, and the costs of repairs and consumables of 2% of investment costs. The distance between driplines was defined as 150 cm, and their replacement was expected once every three years (included in investment costs). The irrigation systems designed involved the use of electric pumps, which are eco-friendly, more economical and cheaper than the diesel ones. Electricity costs for the sprinkler system were entered according to the website data (http://www.cenapradu.strefa.pl/) for PLN 0.55 per 1kWh (according to tariff G11). As for drip irrigation, Moser (1980) and Łuszczyk (1999, 2009) reports the energy costs being 80% lower than the sprinkler irrigation method and such proportion was included in the calculations. For comparison, it was assumed that water comes from the surface source located in a close vicinity of the plantation and it does not require additional treatment; labor costs were also disregarded. A yield increase results in an increase in direct costs related to production, the so-called agricultural costs, established at 30% of the margin recorded.

RESULTS

As seen from the data provided in Tables 1 and 2, total investment costs are increasing with acreage, irrespective of the plant irrigation system analyzed. Unit investment costs per hectare for drip irrigation were 1.6-fold decreasing with an increase in acreage from 1 to 50 hectares, and for 50 hectares the costs increased slightly, as compared with the acreage of 30 hectares. An identical relationship was observed for sprinkler irrigation; the unit costs were decreasing 3.9-fold with an increase in acreage. An increase in investment costs was more definite for increasing the irrigated acreage from 30 to 50 ha – by 620.00 PLN$\cdot$ha^{-1}. The biggest part of annual costs related to the use of irrigation system was depreciation, irrespective of the system. The electricity cost depended on the irrigation rate which, in turn, depended on the drought level of the period of intensified water requirements.

Table 1. Drip irrigation costs in corn cultivated for grain

Drip irrigation costs in corn for grain						
Irrigated area (ha)		1	5	10	30	50
Total investment cost (PLN)		21 220	74 730	140 260	400 835	671 050
Investment cost (PLN·ha^{-1})		21 220	14 946	14 026	13 361	13 421
Annual costs (PLN·ha^{-1})						
Amortization 6,65% (PLN·ha^{-1})		1 415	996	935	891	895
Interest rates of capital 5% (PLN·ha^{-1})		1 061	747	701	668	671
The costs of repairs and materials (PLN·ha^{-1})		424	299	281	267	268
Energy costs (PLN·ha^{-1})	Dry years (2005,06,08,15)	92	92	92	92	92
	Average years (2009,10,13,14)	61	61	61	61	61
	Wet years (2007,11,12,16)	18	18	18	18	18
	On average in the years 2005-2016	57	57	57	57	57
Total costs (PLN·ha^{-1})	Dry years (2005,06,08,15)	2 992	2 134	2 009	1 918	1 926
	Average years (2009,10,13,14)	2 961	2 103	1 978	1 887	1 895
	Wet years (2007,11,12,16)	2 918	2 060	1 935	1 844	1 852
	On average in the years 2005-2016	2 957	2 099	1 974	1 883	1 891

Source: own data and elaboration

Table 2. Sprinkler irrigation costs in corn cultivated for grain

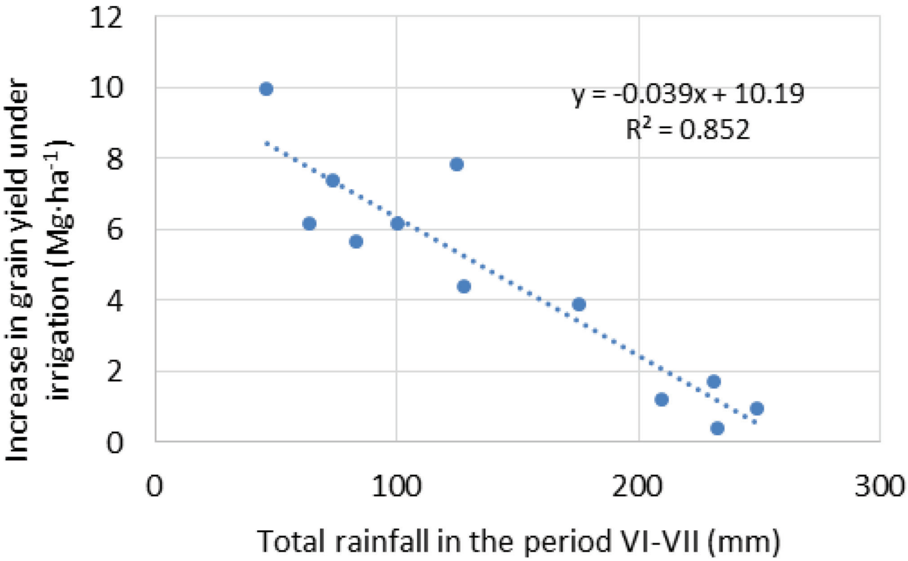
Sprinkler irrigation costs in corn for grain						
Irrigated area (ha)		1	5	10	30	50
Total investment cost (PLN)		21 000	33 000	61 000	144 000	271 000
Investment cost (PLN·ha^{-1})		21 000	6 600	6 100	4 800	5 420
Annual costs (PLN·ha^{-1})						
Amortization 6,65% (PLN·ha^{-1})		1 400	440	407	320	361
Interest rates of capital 5% (PLN·ha^{-1})		1 050	330	305	240	271
The costs of repairs and materials (PLN·ha^{-1})		420	132	122	96	108
Energy costs (PLN·ha^{-1})	Dry years (2005,06,08,15)	458	458	458	458	92
	Average years (2009,10,13,14)	306	306	306	306	61
	Wet years (2007,11,12,16)	92	92	92	92	18
	On average in the years 2005-2016	284	284	284	284	284
Total costs (PLN·ha^{-1})	Dry years (2005,06,08,15)	3 328	1 360	1 292	1 114	1 198
	Average years (2009,10,13,14)	3 176	1 208	1 140	962	1 046
	Wet years (2007,11,12,16)	2 962	994	926	748	832
	On average in the years 2005-2016	3 154	1 186	1 118	940	1 024

Source: own data and elaboration

PRODUCTION EFFICIENCY OF IRRIGATION

Production effects in a form of increases in corn grain yields due to irrigation depended significantly, linearly and were negatively correlated to the total precipitation from 1 June to 31 July (Fig. 1).

Due to a high coefficient of correlation (r = – 0.92), the interval was considered to be the period of intensified water requirements of corn. A significant precipitation – yield increase correlation also justified grouping the results depending on the drought level of that period. In a 12-year period of experiments, four dry periods (2005, 2006, 2008 and 2015), four average (2009, 2010, 2013 and 2014) and four moist (2007, 2011, 2012 and 2016) periods occurred. The mean total precipitation in those periods was 66.9, 132.4 and 231.2 mm, respectively, and relative precipitation index (RPI) – 53%, 105% and 183% (Table 3). In the years of dry periods of intensified water requirements, the corn grain yield increases due to irrigation were more than 30% higher than recorded in the average years and almost 7-fold higher than in moist years. Considering the means of all the 12 research years, irrigation was increasing the grain yield by 4.63 Mg·ha^{-1}, which accounted for a 51% increase.



Source: own data and elaboration

Figure 1. Dependence of production effects of corn irrigation on the total precipitation from 1 June to 31 July

Table 3. Production effects of corn irrigation depending on the drought categories of the period of intensified plant water requirements O – without irrigation, W – with irrigation, * RPI for the 1986-2015 period

Drought categories in the period VI-VII	Total rainfall (mm)	RPI* (%)	Dose of water (mm)	Grain yield ($Mg \cdot ha^{-1}$) 15% moisture		Increase in grain yield under irrigation		
				O	W	$Mg \cdot ha^{-1}$	%	$kg \cdot mm^{-1}$
Dry 2005,06,08,15	66.9	53	177	3.90	11.18	7.28	187	41.1
Average 2009,10,13,14	132.4	105	119	9.98	15.52	5.54	56	46.6
Wet 2007,11,12,16	231.2	183	36	13.43	14.48	1.05	8	29.2
On average in the years 2005-2016	143.5	114	111	9.10	13.73	4.63	51	41.7

Source: own data and elaboration, * – RPI – Relative Precipitation Index

ECONOMIC EFFICIENCY OF IRRIGATION

Irrigation enhanced the production effects in each of the periods analyzed. However, the purposefulness of introducing such practice to the agricultural practices is determined by the economic effectiveness defined by an increase in direct surplus .

Table 4. Economic efficiency of irrigation in corn for grain in dry periods

Irrigated area (ha)	Increase in grain yield under irrigation ($Mg \cdot ha^{-1}$)	Surplus value achieved by irrigation ($PLN \cdot ha^{-1}$)	Irrigation costs ($PLN \cdot ha^{-1}$)		Increase in direct costs ($PLN \cdot ha^{-1}$)	Increase in direct surplus ($PLN \cdot ha^{-1}$)	
			Drip	Sprinkler		Drip	Sprinkler
1			2 992	3 328		-581	-917
5			2 134	1 360		277	1 051
10	7.28	3 444	2 009	1 292	1 033	402	1 119
30			1 918	1 114		493	1 297
50			1 926	1 198		485	1 213

Source: own data and elaboration

Table 5. Economic efficiency of irrigation of corn for grain in average periods

Irrigated area (ha)	Increase in grain yield under irrigation ($Mg \cdot ha^{-1}$)	Surplus value achieved by irrigation ($PLN \cdot ha^{-1}$)	Irrigation costs ($PLN \cdot ha^{-1}$)		Increase in direct costs ($PLN \cdot ha^{-1}$)	Increase in direct surplus ($PLN \cdot ha^{-1}$)	
			Drip	Sprinkler		Drip	Sprinkler
1			2 961	3 176		-787	-1 002
5			2 103	1 208		71	966
10	5.54	3 106	1 978	1 140	932	196	1 034
30			1 887	962		287	1 212
50			1 895	1 046		279	1 128

Source: own data and elaboration

In the years with dry periods of intensified water requirements the application of drip and sprinkler irrigation for the 5, 10, 30 and 50 ha acreage was economically effective. Direct surplus ranged from 277 to 1297 $PLN \cdot ha^{-1}$ depending on the system and the acreage. Corn sprinkler irrigation of the acreage of 30 ha was most cost-effective. As for the irrigation of 1 ha both with drip irrigation system and the sprinkler, direct surplus was negative.

In average years in terms of precipitation conditions in the periods of corn intensified water requirements (2009, 2010, 2013 and 2014), the situation was the same as in dry years. The irrigation of 1 hectare plantation was not economically effective. Drip irrigation generated a positive direct surplus in the range from 71 $PLN \cdot ha^{-1}$ for 5 hectares to 279 $PLN \cdot ha^{-1}$ for the acreage of 50 hectares, whereas sprinkler irrigation generated much higher positive economic effects, ranging from 966 to 1128 $PLN \cdot ha^{-1}$ (Table 5).

Table 6. Economic efficiency of the irrigation of corn for grain in moist periods

Irrigated area (ha)	Increase in grain yield under irrigation ($Mg \cdot ha^{-1}$)	Surplus value achieved by irrigation ($PLN \cdot ha^{-1}$)	Irrigation costs ($PLN \cdot ha^{-1}$)		Increase in direct costs ($PLN \cdot ha^{-1}$)	Increase in direct surplus ($PLN \cdot ha^{-1}$)	
			Drip	Sprinkler		Drip	Sprinkler
1			2 918	2 962		-2 434	-2 478
5			2 060	994		-1 576	-510
10	1.05	691	1 935	926	207	-1 451	-442
30			1 844	748		-1 360	-264
50			1 852	832		-1 368	-348

Source: own data and elaboration

Table 7. Economic efficiency of irrigation of corn for grain in 2005-2016

Irrigated area (ha)	Increase in grain yield under irrigation ($Mg \cdot ha^{-1}$)	Surplus value achieved by irrigation ($PLN \cdot ha^{-1}$)	Irrigation costs ($PLN \cdot ha^{-1}$)		Increase in direct costs ($PLN \cdot ha^{-1}$)	Increase in direct surplus ($PLN \cdot ha^{-1}$)	
			Drip	Sprinkler		Drip	Sprinkler
1			2 957	3 154		-1 100	-1 297
5			2 099	1 186		-242	671
10	4.63	2 653	1 974	1 118	796	-117	739
30			1 883	940		-26	917
50			1 891	1 024		-34	833

Source: own data and elaboration

In moist years in terms of corn intensified water requirements (2007, 2011, 2012 and 2016), irrigation was not economically justified, irrespective of the system applied and the plantation acreage. The costs exceeded the value of production additionally generated thanks to irrigation. It was noted that the higher the acreage, the lower the losses. Much higher losses were generated by drip irrigation system, as compared with sprinkler irrigation (Table 6).

In terms of economic efficiency, considering the most important average-value approach for 2005-2016, drip irrigation did not bring a positive value of direct surplus . It was observed that the higher the corn plantation acreage, the lower the losses; for 30 and 50 hectares the values were close to zero. However, applying sprinkler irrigation for 1 hectare acreage, losses of 1297 PLN·ha^{-1} were recorded. As for the other 4 acreage variants, the value of the additional production exceeded the costs. The highest profit was reported for the variant of 30 hectares and it was 917 PLN·ha^{-1} (Table 7).

DISCUSSION

The results of the effect of irrigation on the yielding of corn for grain show that it is possible to generate considerable production effects, irrespective of the variant. However, a desired yield increase is not always accompanied by the economic efficiency of irrigation, which is clear from the results of the calculations.

In the years 2005-2016, the average grain yield increase due to irrigation was 4.63 Mg·ha^{-1}. Depending on the drought level of the period of intensified water requirements, the increases fluctuated from 1.05 for moist periods, through 5.54 in average years, to as much as 7.28 Mg·ha^{-1} in dry years. The results confirm a positive effect of irrigation on corn yielding and correspond to the results reported by Dudek *et al.* (2009) and Żarski *et al.* (2013).

Considering the drip irrigation system, high production effects translated into economic effects in dry and average years, when positive values were reported (except for the acreage of 1 hectare – a negative margin). The highest increase was 493 PLN·ha^{-1} for the acreage of 30 hectares in dry periods. However, for the multi-year period and moist years, irrespective of the plantation acreage analyzed, the application of drip irrigation did not generate a positive direct surplus . The highest losses were noted for 1-hectare plantation. Interestingly, the higher was the acreage, the lower the losses. The best result (-26 PLN·ha^{-1}) was reported for the multi-year mean for the acreage of 30 hectares but it is still a negative result. The recorded negative results coincide with those reported by Kledzik *et al.* (2015) for the years 2006-2012. They confirm that the drawback of drip irrigation systems are high investment inputs, related with the purchase of driplines and their replacement (Nowacki 2006).

Applying sprinkler irrigation results in a considerably higher level of an increase in direct surplus than in the case of drip irrigation systems. For dry and average periods as well as multi-year mean, except for the acreage of 1 hectare (a negative value of direct surplus), positive values were recorded, with the highest value for 30 hectare acreage. Sprinkler irrigation in moist periods was totally economically non-effective, with losses from – 2.478 PLN·ha^{-1} for 1 hectare acreage to – 348 PLN·ha^{-1} for 50 hectare acreage.

As seen from the results, irrigation generated positive production effects and enhanced the yield quality and stability. However, not in all the cases did it translate into economic efficiency, which could determine the purposefulness of a specific agrotechnical practice in corn for grain production. Nonetheless, one should remember that there are other factors to be considered when evaluating the irrigation cost-effectiveness, namely: price market situation, the level of agrotechnical practices of the farm or its soil conditions.

CONCLUSIONS

With the production effects received and direct surplus calculations based on those effects, the following conclusions can be made:

1. Introducing irrigation to agrotechnical practices of corn for grain production resulted in an increase in yield. It also affected the stability of yielding in years.
2. Irrigation costs (for the two systems) per hectare were decreasing with an increase in plantation acreage. Much higher costs concerned the drip irrigation system, as compared with sprinkler irrigation. Depreciation in both cases accounted for the greatest part of annual costs.
3. Direct surplus increase calculations for drip irrigation system show that, despite high production effects, the application of drip irrigation was economically non-effective in moist years and for multi-year mean, irrespective of the plantation acreage. Losses were decreasing with an increase in acreage. Introducing drip irrigation to agrotechnical practices of corn in dry and average periods generated a positive margin, except for 1 hectare acreage.
4. The economic analysis for the sprinkler irrigation system showed no economic justification for introducing such practice to agrotechnical practices in corn for grain production in moist periods, while for dry and average years and for multi-year mean, except for 1 hectare acreage, the direct surplus value was positive.

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