FORECASTING PRODUCTION EFFECTS OF IRRIGATED FABA BEAN (*VICIA FABA* VAR. *MINOR*) DEPENDING ON DROUGHT LEVELS

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Abstract
The aim of the article was to develop formulas, which can be used to model forecasts of production and economic effects of irrigated faba bean (*Vicia faba* var. *minor*), depending on drought severity level in a growing season. For the analysis we used data of ten-year (2005 – 2014) production effects of irrigated faba bean and indices calculated on the basis of meteorological data from the measuring point set in the vicinity of the experimental site in region of Bydgoszcz city, central Poland. Based on them, the most relevant relationships between irrigation productivity and chosen drought indices, calculated for a period of high water needs of the plant, were searched. Presented results have demonstrated that the non-irrigated faba bean yields depended significantly on drought severity level and showed very high variability in time. Irrigation contributed to a significant 49% increase in yields and their stability in the years. Due to this treatment, the coefficient of variation of the yield decreased from 55.1 to 19.6%. The production effects of irrigation depended significantly on moisture conditions over the period of high water needs of faba bean. In wet seasons, the increases in yields due to irrigation were insignificant and about three-fold lower, while in the dry periods – more than a half higher (57%) than the average increases. The results presented in the work are of great importance because they can be used to model forecasts of production, as well as to plan the development of irrigation systems in the given area.
Key words: drip irrigation, faba bean, yield, drought index, atmospheric precipitation, evapotranspiration.

Introduction

Faba bean is a leguminous plant whose seeds are widely used as a component for blends with other livestock feeds. An important feature of faba bean is a high protein content of 25 – 30%, the ability to bind atmospheric nitrogen in the process of symbiosis with Rhizobia. This plant has also a structure-creating effect by enriching the soil with organic matter and nutrients, and improving its physical and chemical properties (Podleśny, 2005). All this causes faba bean to be a desirable forecrop for cereals, especially for winter wheat *(Triticum aestivum)*, which is dominant in the structure of sowings. Despite these advantages, the area of cultivation of legumes in Poland, including faba bean, in the first decade of the 21st century was only about 100 thousand hectares (Podleśny, 2005) and only after receiving special subsidies under the EU Common Agricultural Policy it exceeded 400 thousand hectares in 2015 (Adamska *et al.*, 2016). The ecological importance of this plant, confirmed by many EU research programs (Święcicki, Chudy, & Żuk-Gołaszewska, 2007), indicates that this trend will be perpetuated.

The main disadvantage of all legumes, including faba bean representing the coastal climate plants, is lower yielding in dry growing seasons, when atmospheric precipitation totals are considerably reduced. In the transitional climate in central part of Poland, atmospheric droughts that turn into soil droughts, and in some cases even into hydrological ones, are frequent and irregular (*Łabędzki*, 2007). Their severity and range were observed in the last 30 years in the growing seasons of 1989, 1992, 2000, 2003, 2008 and 2015 (Żarski *et al.*, 2017). The occurrence of drought during increased water needs of faba bean, coinciding with the reproductive phase, contributes to the deterioration of yield, not only in terms of quantity, but also quality (Szukała *et al.*, 2007; Dudek, Żarski, & Kuśmierek-Tomaszewska, 2011; 2013; Di Paolo, Garofalo, & Rinaldi, 2015; Rokosz & Podsiadło, 2015).

An effective treatment, applied to prevent the negative effects of drought in plant production, is irrigation. The use of irrigation systems in Poland, despite the rapid development of the country, is still a future solution. However, this creates an alternative for theprogress in agricultural production in the future. Factors that accelerate the development of irrigation in agriculture, apart from providing higher and more stable, good quality yields, include the noticeable progress in modernity of farms and a raise of their competitiveness, as well as the forecasted climate change (Łabędzki, 2009; Rzekanowski, Żarski, & Rolbiecki, 2011).

The aim of the article was to develop formulas for a model determining production effects of irrigated faba bean, depending on a drought severity, based on meteorological indices representing moisture conditions.

Materials and Methods

For the analysis we used meteorological data from the agrometeorological monitoring, gained from the measuring point owned by the Department of Land Reclamation and Agrometeorology (UTP University of Science and Technology in Bydgoszcz, Poland) and the yields of irrigated and non-irrigated faba bean. The

procedures used in the meteorological measurements were compliant with the World Meteorological Organization (Guide to Meteorological Instruments and Methods of Observation, 2014) measuring standards. The experimental site is located in Mochełek village, about 20 km away from Bydgoszcz city center, on the south-eastern edge of the Krajeńska Upland (53°13'N, 17°51'E, 98.5 m. a. s. l.); in the zone of the highest average precipitation deficit and high needs for supplementary irrigation in Poland in terms of the climate criterion (Łabędzki, 2007; Rzekanowski, Żarski, & Rolbiecki, 2011; Żarski *et al.*, 2017). The experiment was set up in Luvisol (LV) with a fine sandy loam texture (World reference base for soil resources 2014). In terms of compaction, it is a sandy soil on compact subsoil.

Data obtained from the long-term field experiment of sprinkler irrigated faba bean grown for seeds, carried out in 2005 – 2014 were used in the study. Considering the soil conditions of the experiment, irrigation was, typically for Poland's climate conditions, used in emergency, supplementing the seasonal precipitation deficit over the period of high water needs of the crop tested. The plants were optimally irrigated, ensuring the reserve of readily available water throughout the period of high water needs, which span the phases from the beginning of flowering BBCH 60 to the technical maturity of seeds 89 BBCH, in the soil layer with controlled moisture level, which means that water needs of plants during the growing season were fully covered (the soil moisture was maintained in the range of pF-value of 2.0 – 2.5). Faba bean was irrigated with a portable system with low-pressure Nelson type sprinklers, withthe unit capacity of 200 dm³ h⁻¹. The irrigation dates were determined based on information from continuous soil root layer moisture monitoring, by balancing the reserve of readily available water based on the weather parameters and direct soil moisture measurements using Fieldscout TDR 300 Soil Moisture Meter probe. The number of disposable irrigation doses and the total seasonal dose depended on the weather conditions, mainly on the amount and distribution of atmospheric precipitation. Detailed information on the factors, the pattern of experiment, and faba bean agrotechnics can be found in the works of Dudek *et al.* (2011, 2013).

In order to determine the most significant relationships between the production effects of irrigated faba bean in the subsequent years and selected indicators characterizing the moisture content during the period of high water needs of faba bean from 1 June to 31 July, a correlation and regression analysis was applied. The critical value of the correlation coefficient for a number of paired observations n=10 at the significance level p=0.05 is 0.6319. The following indicators were considered

for the analysis: absolute precipitation (P), relative precipitation index (RPI) (Bąk & Łabędzki, 2002), standardized precipitation index (SPI), described by Guttman (1999), as well as the ratio of precipitation to potential evapotranspiration (ET), calculated on the basis of the Grabarczyk's formula:

$$ET = 0.32 \left(d + \frac{1}{3}t \right) \qquad (1)$$

where d – mean vapor pressure deficit in hPa, t – mean air temperature in °C. According to the studies by Grabarczyk & Żarski (1992), the value of potential evapotranspiration calculated for grass according to the Grabarczyk's formula correlated stronger with real evapotranspiration compared to the ET values calculated on the basis of the Penman's equation. The season of 2010 was excluded from the regression analysis due to the extremely unevenly distributed rainfall. In June and July of 2010, the total rainfall was 125.5 mm, but as much as 100.2 mm fell only in the last week of July. As a result, the yield of non-sprinkled faba bean was much lower, and the effects of sprinkler irrigation were significantly higher than those determined by regression equations.

Results and Discussion

In respective years, taken for the analysis, weather conditions in the period of high water needs of faba bean (growth phases BBCH 61-89), varied a lot. The average rainfall total was 140.7 mm, changing from 46.0 mm in 2006 to as much as 249.4 mm in 2012. The RPI ranged from 38 to 203%, SPI from -1.66 to 1.87, and the level of coverage of evapotranspiration by precipitation – from 0.12 to 1.26. Three dry, three normal and four wet seasons were recorded. Therefore, in such rainfall conditions, irrigation was applied in emergency cases, which is typical for the climate of central Poland (Rzekanowski, Żarski, & Rolbiecki, 2011; Żarski *et al.*, 2017) (Table 1).

In central Poland, the irrigation's role is to supplement precipitation deficit, unlike in the dry and semi-dry climate zones, where it is a basic and indispensable yield-forming practice. This treatment is applied mainly in the case of long periods without rain. In the temperate climate of Poland, there occur periods and even whole growing seasons when it is used very rarely or it is not applied at all. In our research, such a situation took place in 2007 (faba bean was irrigated only once) while in 2009, due to evenly distributed rainfall in June and July, application of irrigation was not necessary. National research aiming at the improving irrigation in central Poland cover primarily the aspects of its advisability in various crop cultivations by determining the production and economic efficiency and changes in the quality of yield (Rolbiecki *et al.*, 2000; Dudek *et al.*, 2011;

Table 1

**Moisture content indicators and the total irrigation rates over the period of high water needs
in faba bean from June to July**

Year	Drought level acc. to SPI	P mm	RPI %	SPI	ET mm	P/ET	D mm
2005	moderately dry	64.1	52	-1.11	290	0.22	140
2006	very dry	46.0	38	-1.66	372	0.12	110
2007	moderately wet	210.2	171	1.42	224	0.94	25
2008	mild dry	74.2	61	-0.85	277	0.27	200
2009	wet	175.4	143	0.97	186	0.94	0
2010	normal	125.5	102	0.20	268	0.47	180
2011	very wet	233.3	190	1.69	221	1.06	65
2012	very wet	249.4	203	1.87	198	1.26	65
2013	normal	128.3	105	0.24	223	0.58	120
2014	normal	100.3	82	-0.27	211	0.48	140
Average	normal	140.7	115	0.45	247	0.57	104

P – absolute precipitation, RPI – relative precipitation index, SPI – standardized precipitation index, P/ET –precipitation to potential evapotranspiration ratio, D – total irrigation rate.

2013; Żarski *et al.*, 2013; Rolbiecki *et al.*, 2015; Wszelaczyńska *et al.*, 2015), as well as optimizing irrigation doses in relation to the water needs of plants (Kuśmierek-Tomaszewska, Żarski, & Dudek, 2012). In climatic zones where irrigation plays the main role as a factor shaping the yield, the prospects and effects of partial coverage of plant's demand for water are examined, due to the need to save water. In reference to the species *Vicia faba* L., such research was conducted inter alia by Bryla, Banuelos, & Mitchell (2003), Di Paolo, Garofalo, & Rinaldi (2015), Ouji *et al*. (2017) and S. Sarkar, A. Sarkar, & Zaman (2017).

The results indicate that the yield of non-irrigated faba bean was, on average, in the research years 3.21 t ha^{-1} (Table 2). In respective years, the yields showed a very high variation – from 0.58 to 5.55 t ha^{-1}. The coefficient of variation (CV) for them accounted for 55.1%. The regression analysis (Figure 1) demonstrated that yielding depended significantly on moisture content over the period of high water needs in faba bean growth stages from 60 to 89 according to the BBCH spanning June – July. Of all the indicators analyzed, the strongest correlation with the seed yield in non-irrigated faba bean referred to the P/ET

Table 2

Seed yields and sprinkler irrigation effectiveness in faba bean depending on drought level

Year	SPI	Drought level acc. to SPI	Seed yield at 15% moisture content (t ha^{-1})		Seed yield increase under irrigation		
			O	W	t ha^{-1}	%	kg·mm^{-1}
2005	-1.11	moderately dry	2.05	4.23	2.18	106	15.6
2006	-1.66	very dry	1.44	3.52	2.08	144	18.9
2007	1.42	moderately wet	4.14	5.01	0.87	21	34.8
2008	-0.85	mild dry	0.58	3.70	3.12	538	15.6
2009	0.97	wet	5.26	5.38	0.12*	2	0.0
2010	0.20	normal	1.23	4.89	3.66	298	20.3
2011	1.69	very wet	3.44	3.84	0.40	12	6.2
2012	1.87	very wet	5.55	6.27	0.72	13	11.1
2013	0.24	normal	4.58	5.88	1.30	28	10.8
2014	-0.27	normal	3.83	5.10	1.27	33	9.1
Average	0.45	normal	3.21	4.78	1.57	49	15.0

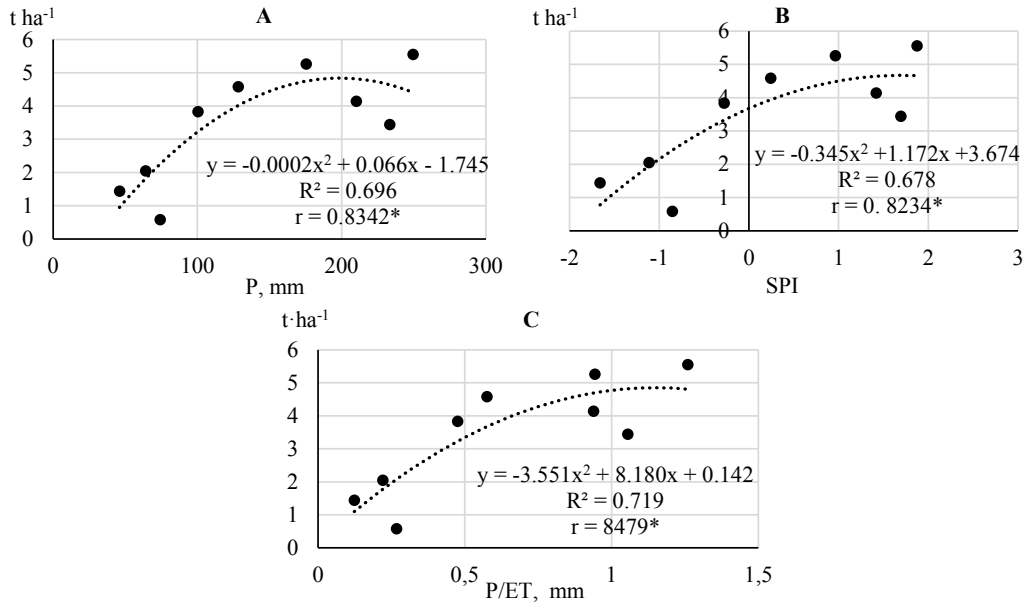O – non-irrigated plants, W – irrigated plants; *– the difference insignificant at the level of p=0.05.

Figure 1. Relationship between the seed yield of faba bean grown without irrigation and moisture
conditions over the period of high water needs: A – precipitation, B – standardized precipitation index SPI,
C – precipitation to evapotranspiration ratio.

ratio (Figure 1); however the other indicators, i.e. absolute precipitation and SPI determined the yield to a comparable statistical significance. The polynomial regression equations (Figure 1) show that the optimal precipitation for faba bean in the period from June to July was 190 – 210 mm, and the P/ET ratio – 1.10–1.20.

Seed yields of irrigated plants were on average 4.78 t ha⁻¹, ranging in respective years from 3.52 to 6.27 t ha⁻¹ (Table 2). Irrigation enhanced the yield stability since the coefficient of variation of the seed yield in irrigated faba bean accounted for 19.6%.

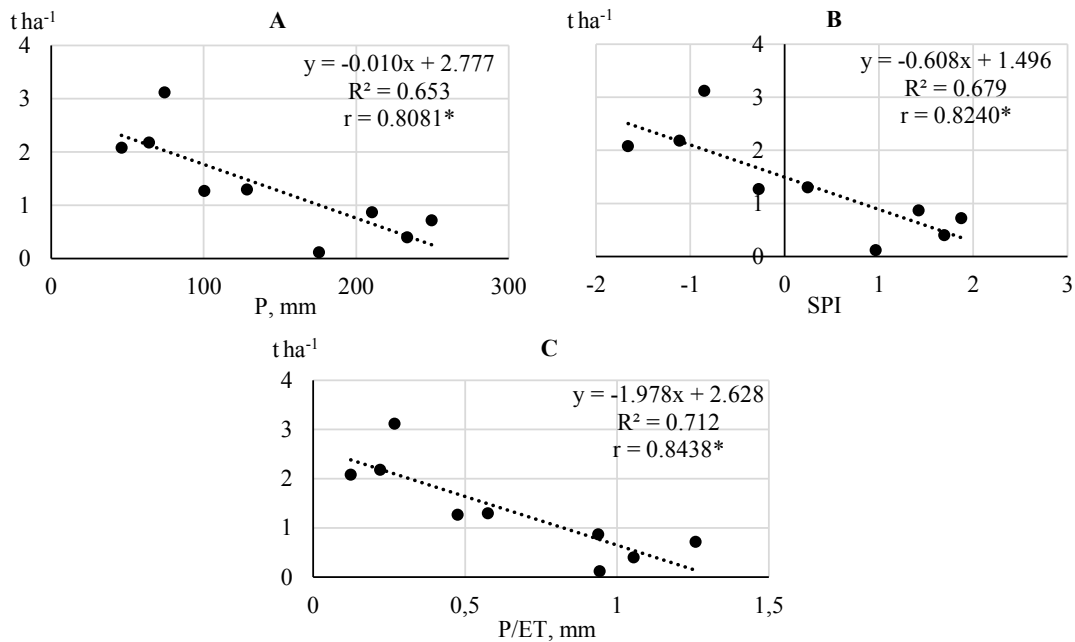Irrigation ensured the adequate plant growth and development, as well as intensified physiological

Figure 2. Linear relationship between faba bean seed yield increases due to irrigation and moisture
conditions over the period of high water needs: A – precipitation, B – standardized precipitation index SPI,
C – precipitation to evapotranspiration ratio.

processes. As the result, the average multiannual production effect of irrigated faba bean was 1.57 t·ha⁻¹, which accounted for a 49% increase in seed yield. One mm of water used for irrigation caused an average increase in seed yield at the level of 15.0 kg·mm⁻¹·ha⁻¹. In particular growing seasons, the irrigation production effects depended significantly and linearly on indices representing moisture conditions during the periods of high water needs of faba bean (Figure 2). The best indicator of those effects was absolute precipitation (R^2=0.712). The regression equation shows that increases in yields due to sprinkler irrigation are insignificant only when precipitation in June through July exceeds 250 mm and the P/ET ratio exceeds the value of 1.20.

The average production effects of faba bean irrigation presented in this work point to a great potential of increasing the production of faba bean in central Poland, provided that the water factor is optimized. Therefore, it can be concluded on the basis of the obtained results that the application of irrigation in the production of faba bean is a justified treatment. However, in agricultural practice, making that treatment common will depend to a great extent on the economic conditions, which have an impact on seed prices (Adamska *et al.*, 2016), as well as on infrastructural conditions – mainly the availability of water sources for irrigation purpose (Rzekanowski, Żarski, & Rolbiecki, 2011; Żarski *et al.*, 2013).

Conclusions

Presented results, based on the data from multiannual field experiment with sprinkler irrigation in faba bean grown in central Poland have demonstrated that the non-irrigated faba bean yields depended significantly on indicators characterizing moisture conditions. The results demonstrated a very high temporal variation. Irrigation contributed to a significant 49% increase in yields and their stability over the years. Due to that treatment, the CV of the yield decreased from 55.1 to 19.6%. The production effects of irrigation depended significantly on moisture conditions over the period of high water needs of faba bean, spanning the growth stages from flowering to full reap (BBCH 60-89) that occur in the period June – July. In wet seasons, the increases in seed yields due to irrigation were insignificant and about three-fold lower, while in the dry periods – more than a half higher (57%) than the average increases. The results presented in the work are of great importance because the formulas can be used to model forecasts of production and its economic effects, as well as to plan the development of irrigation systems in a given area.

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