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Economic benefit of potassium use in potato-cereal crop rotation

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Abstract

Crop production is among others an economic activity, and farmers should have a profit from the fertilizers use. To test the profitable use of fertilizers in different climatic and soil conditions, a five years' experiment was set up in the Czech Republic (CZ), Poland (PL), and in Albania (AL) in a rotation scheme with potato, as the main crop, preceding winter wheat and winter barley. In all the experimental sites, potato was the crop that reacted better to K fertilization, showing the highest profit compared with the other crops. The benefit of the farmers using fertilizers in the potato-cereal rotation reached than 11.200 Euro ha^{-1} in Albania and 3000 and 4100 Euro ha^{-1} for The Czech Republic and Poland, respectively. The beneficial profitable effect of K fertilization was recorded also in the second year after its application, in turn increasing economic benefits in barley production. The highest benefit was achieved when the requirements of the main crop, i.e. potato was fully covered by application of three essential nutrients, i.e. N, P and K. The balanced application of the three nutrients, not only affected positively the yields, but also contributed to increase the farmers' incomes.

Key words: Balanced fertilization, Nitrogen and Potassium interaction, Central European Countries

1. Introduction

Crop nutrition is frequently inadequate as a result of the expansion of marginal lands use. The high yields can be achieved, provided increasing demands on soil nutrient reserves, and environment and economic concerns, when applying fertilizers [11]. In addition, recovery of nutrients applied in fertilizers by plants is low in many soils [4]. Estimates of overall efficiency of applied fertilizers have been about 50% or lower for N, less than 10% for P, and close to 40% for K [2]. In most cases, crop nutrients use efficiency, is reduced due to agronomic factors, where the non-balanced use of fertilizers plays an important role [10, 3]. The real yields in most countries are far lower than the potential ones [6]. Many scientists think that more research on improving efficiency from both inorganic and organic nutrient sources is needed to determine costs, benefits and optimal practices [13]. An economic analysis in the evaluation of fertilizers use efficiency is indispensable since the farmer's decision to adopt new technologies or practices is generally slow, and to a great extend is strongly influenced by input costs and prices of applied measures [Fischer et al. 2014].

According to EUROSTAT, in 2016, more than 11 million mt of N, 1.1 of P, and 2.4 of K were consumed in EU 27. If we compare these data with the uptake ratio between N:P:K that are 1:0.3:0.8 for cereals; 1:0.3:1.8 for potato and sugar beet, and 1:0.15:1.1 for forage plants [10], it becomes clear that N is not balanced with P and K. This dis-balanced fertilization could be one of the causes of low nutrient efficiency of applied fertilizers, resulting in paltry economic turnout [5].

In years 2010 to 2014, three field trials on nutrient recovery by plants grown in the potato-cereals cropping sequence were carried out on different locations in the Central Europe and with peculiar N, P and K treatments. The objective of the experiment was to have the identical trial layout/treatments on three

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distinctive soil and climate conditions, typical for Albania, The Czech Republic, and Poland. The whole benefit from the cultivated land is much more important for the farmers than the total amount of production. That's why we calculated the economic benefit of applied fertilizers. Since potassium can influence the crop yield also in the second year, these calculations are made not only for the first year, but for the two cycles of potato-cereal rotation.

The objective of this study was to evaluate the effect of N and P fertilization on total benefit not only in the main crop, but also in two cycles of the whole potato-cereals rotation.

2. Materials and Methods

The efficiency of different fertilizers rates was tested during five years in different climatic and soil conditions. The experiment was situated in three different sites, i.e. in: The Czech Republic(CZ), Poland (PL), Albania(AL), respectively: Fushë Krujë (AL), 41°29'N. 19°43'E; Lipa (CZ) 49°33′N. 15°32′E; Donatowo (PL) 52°05'N 16°52'E. The soil was a Vertic Cambisol (AL); a Cambisol (Lipa) (CZ), and an Albic Luvisol (PL).

The experimental design comprised potato, followed by winter wheat and winter barley (Table1). The fertilizer's treatment (Table 2) during the first year included control treatment (without fertilizers), two different nitrogen rates (75% and 100% of crop needs), and four potassium rates (0%, 50%, 100%, and 150% of the respective crop requirement). For the calculation of N fertilization, the mineral N in the soil available to plants was also taken into consideration. The second and third crop, i.e. wheat and barley did not receive fertilizer potassium. Fertilization of wheat with nitrogen was done as for potato 75% and 100% of the needs at the respective treatments, whereas barley received uniform nitrogen fertilization according to the crop needs. The experimental design was a randomized block with four replications, and the size of the plots was 50 m^2.

The crop yield was recorded in each of the treatments. Prices of the product, as well as prices of the fertilizers, were registered according to the official data of the respective countries. The evaluation of the economic benefit of the fertilizers use in the rotation scheme was calculated according to the following formula:

$E_{bf} = V_{pt} - V_{p0} - C_f - C_t$

where:

E_{bf} – Economical benefit of the fertilizers;

V_{pt} – Value of the product at each treatment;

V_{p0} – Value of the product at the zero treatment (without fertilization);

C_f – Cost of fertilization (cost of fertilizers + spreading);

Ct – Cost of transport of fertilizers and of higher amount of crop product in the different treatments compared with the control treatment.

The value of the product for each treatment was calculated by multiplication of the amount of the product with the respective price. The cost of fertilization was calculated by multiplication of the amount of the applied fertilizers with its price, and adding the costs of transport and fertilizer application in the field. The costs of transport and fertilizers application were calculated according the calculations done in Germany by "Kuratorium für Technik und Bauwesen in der Landwirtschaft [9]".

The obtained data were subjected to the analysis of variance [Statistica 10. StatSoft. Inc.. Tulsa. USA], and the differences between treatments were evaluated with Tukey's test. The simple regression was applied to define the optimal set of K relative rates for the maximum economic benefit.

3. Results and Discussions

From the data presented in Tables 3-5, we can see that there are substantial differences between the countries and between the crops in the E_{bf}. Compared with wheat and barley, potato presents the crop where the use of K shows the highest economic performance. It is already known that potato is not only a crop that requires high amounts of K, but also with a generally low efficiency in taking up K from the intra-layer K pool [1; 12]. The observed response is reflected not only at the yield of potato [8], but also at the E_{bf} of this crop. The highest E_{bf} in the potato in the first rotation in Lipa (CZ) and Fushe Kruje (AL) was achieved in the treatment with N 100% and K 100%, ranging from 1.040 to 8.000 Euro ha^{-1}, whereas in Donatowo (PL) the highest E_{bf} was achieved in the treatment N 100% and K 50%. The differences between the countries are due to the distinctive prices of the product and the fertilizers. In Albania, potato was cultivated under irrigation conditions that were not the case in Poland and Czech Republic.

In the first rotation cycle, wheat showed different results in the three locations. In Donatowo (PL) no real effect of the K fertilization on the E_{bf} could be detected, whereas in Fushe Kruje (AL) the treatments N75 K150 and N100 K150 and in Lipa (CZ) the treatments N75 K100, and N75 K150 showed a significant increase of the E_{bf} due to residual effect of higher K rate applied for potato. From the data, it is made clear that the most profitable treatments are those that in the first, year received the adequate amount of K. Barley, as the third crop in the rotation cycle, received N and P, but no K. The residual effect of K has significantly increased barley yield, in turn improving the E_{bf} of the N fertilizer.

The pooled E_{bf} data for the first rotation clearly showed that the highest benefit for the farmers due to fertilizers use, was highly variable (Figures 1-3). In Poland, as results from the Figure 1, the optimum relative rate of applied N and K was 100% and 84%, respectively. This set of variables resulted in the E_{bf} of 1045 EUR/ha. Potato in the N75 treatment yielded the best provided K relative rate reached 91%. However, the E_{bf} was amounted to 756 Euro/ha, i.e. 28% lower compared to the optimal set of N and K. In Albania, the E_{bf} pattern, in general, confirmed the trend observed for Poland, but its value was several times higher (Figure 2). In this case, the limiting factor was the amount of applied N. The optimum K rate for both N treatments slightly exceeded 150% of really applied K fertilizer. The maximum E_{bf} for N100 amounted to 8415 EUR/ha. It was by 19% higher compared to N75. Completely different patterns of E_{bf} response to K rates were detected for The Czech Republic (Figure 3). In the treatment with N75, the E_{bf} trend showed a negative response to the increasing K rates. A reverse response was recorded in the N100 treatment. In this case, the E_{bf} followed the quadrate regression model. The optimum K rate of 97% resulted in the maximum E_{bf} of 1334 EUR/ha. Patterns presented for all three countries clearly indicate the necessity to optimize both crucial nutrients, i.e. N and K.

In the second rotation cycle, the E_{bf} response to the different fertilization treatments was much more variable between the studied localizations. The key reason was the lupine, following barley and preceding potato in the 2nd rotation cycle. It was sown only in Poland (Figure 1, Table 3). In this country, the E_{bf} was significantly higher compared to the 1st rotation cycle. As a rule, the recorded patterns of the E_{bf} were similar to those observed in the 1st rotation cycle. The maximum E_{bf} of 4076 EUR/ha was recorded for the N100 and K86. This value was almost 4-times higher with respect to the 1st cropping sequence. At the same time, it was by 63% higher as compared to the treatment N75 and K105. In Albania, the E_{bf} was significantly lower with respect to the 1st rotation cycle (Figure 2, Table 4). For the N75 treatment, it showed a negative trend with increasing K rates. There was not found any significant response to the tested K treatments (Table 4). In the Czech Republic, the maximum E_{bf} of 2105 EUR/ha was achieved in the N75, provided K rate was 110%. In the N100 treatment, the significant impact was recorded for two plots, i.e. N100 x K100, N100 x K150 (Figure 3, Table 5).

Considering the total set of data at the end of two rotation cycles, clearly the highest E_{bf} was a result of interactional effect of N x K, for the treatments with 100% of nutrient application with respect to potato requirements. The significant response of potato to both nutrients at this specific rate, obviously corroborate the opinion by Allisson et al. [2000). These authors stated that potato was highly sensitive to balanced application of both nutrients. It was recorded that the maximum E_{bf} for the farmers fluctuated from 3000 for Czech Republic, through 4100 for Poland to 11.200 Euro/ha for Albania.

The influence of N and K fertilization on the E_{bf} is stressed also if we evaluate the impact of the N x K interaction on the E_{bf} (Figure 4). As we can see the determination coefficient in all the three locations for the two N rates are, with one exception, was higher than 0.7. This value clearly confirms the increase of the economic benefit for the farmers due to the increasing of potassium rates up to 100% of the plant needs. In Poland, the maximum E_{bf} of 4078 EUR/ha was obtained in the N100 treatment with the optimum K rate of 86% of the recommended one. It was by 26% higher as compared to the N75 treatment with 98% of the recommended K rate. In Albania, the relative K rate was almost the same (160%), but the maximum E_{bf} of 11 210 EUR/ha was the attribute of the N100 treatment. It was by 17% higher as compared to the N75 treatment. In the Czech Republic, the maximum E_{bf} can be only achieved, provided the recommended N rate is applied. The maximum Ebf of 3001 EUR/ha was achieved provided the K rate of 117% of the recommended one. Also from the two factorial ANOVA analysis, it results a clear interaction between N x K rates with respect to farmers benefit in all three locations (Table 6-8). These results show that only with a balanced fertilization, farmers can achieve not only the higher yields, but also the highest profit from the grown crops.

Table 1. Rotational scheme of the experiment

Year	2010	2011	2012	2013	2014
Field	potato	Winter wheat	Winter barely	potato	Winter wheat

Table 2. Soil properties and absolute nutrient application rates employed during a three-year potato experiment in Central-East European countries

Country	Year	Soil pH	Soil available nutrient[1]			Nutrient application rate	
			P	K	N_{min}	N	K
			mg/kg soil		kg/ha	kg/ha	
Albania (AL)	2010	6.8	43[L]	146[S2]	18	120,160[3]	0, 150, 300[4], 450
	2011	7.4	77[S]	185[G]	23	118,158	
	2013	6.9	69[S]	161[S]	34	120,160	
Czech Republic (CZ)	2010	6.1	33[L]	183[G]	93	58,77	0, 75, 150[4], 225
	2011	5.5	63[S]	252[G]	30	105,140	
	2013	6.1	33[L]	183[G]	93	122,163	
Poland (PL)	2010	6.2	75[S]	90[L]	36	120,160	0, 66, 132[4], 199
	2011	6.9	85[G]	154[S]	36	120,160	
	2013	5.0	77[L]	133[S]	60	120,160	

[1]Mehlich 3 procedure;
[2]classes of available soil P and K content: L – low; S – suitable; G - good; H – high;
[3,4]equel to 100% of the recommended rate.

Table 3. Economic benefit of fertilizer use in Donatowo (PL) Potato Rotation (EUR ha^{-1})

Treatments	Potato	Wheat	Barley	I. Rotation	Potato	Wheat	II. Rotation	Total
N75 K0	-542 (A)	67 (B)	304.0 (DE)	**-171 (A)**	1576 (A)	146 (AB)	**1722 (A)**	**1551 (A)**
N75 K50	431 (D)	141 (D)	306 (E)	**878 (E)**	1673 (A)	136 (A)	**1809 (A)**	**2687 (B)**
N75 K100	119 (B)	66 (B)	270 (D)	**455 (B)**	2746 (C)	152 (B)	**2898 (C)**	**3353 (CD)**
N75 K150	130 (B)	74 (B)	307(DE)	**511 (BC)**	1986 (AB)	177 (C)	**2163 (A)**	**2674 (B)**
N100 K0	-367 (A)	161 (D)	247 (B)	**41 (A)**	1772 (A)	178 (C)	**1950 (A)**	**1991 (A)**
N100 K50	920 (E)	11 (A)	219 (A)	**1150(EF)**	2053 (B)	247 (D)	**2300 (B)**	**3450 (D)**
N100 K100	405 (D)	100 (C)	278 (C)	**783 (D)**	3260 (C)	226 (D)	**3486 (D)**	**4269 (E)**
N100 K150	247 (C)	78 (BC)	249 (B)	**574 (C)**	2055 (B)	172 (C)	**2227 (AB)**	**2801 (BC)**

[A]Different letters show significant statistical differences among the treatments.

Table 4. Economic benefit of fertilizer use in Fushe Kruje (AL) Potato Rotation (EUR ha^{-1}).

Treatments	Potato	Wheat	Barley	I. Rotation	Potato	Wheat	II. Rotation	Total
N75 K0	-147 (A)	196 (C)	166 (A)	**215 (A)**	2030 (C)	613(AB)	**2643 (A)**	**2859 (A)**
N75 K50	3886 (C)	210 (C)	229 (B)	**4325 (C)**	1753 (B)	701(CD)	**2454 (A)**	**6779 (C)**
N75 K100	5160 (D)	310 (D)	222 (B)	**5692 (D)**	1736 (AB)	750 (D)	**2486 (A)**	**8178 (D)**
N75 K150	6539 (E)	475 (F)	208 (B)	**7222 (E)**	1538 (A)	913 (E)	**2451 (A)**	**9673 (E)**
N100 K0	741 (B)	-130 (A)	160 (A)	**771 (B)**	2183 (C)	617 (B)	**2800 (A)**	**3571 (B)**
N100 K50	2927 (C)	124 (B)	192 (B)	**3243 (C)**	2106 (C)	569 (A)	**2675 (A)**	**5918 (C)**
N100 K100	7938 (F)	376 (E)	171(AB)	**8485 (F)**	2487 (D)	665 (C)	**3152 (B)**	**11637(F)**
N100 K150	7339(EF)	445 (F)	192 (B)	**7976 (EF)**	1951 (BC)	763 (D)	**2714 (A)**	**10690 (E)**

[A]Different letters show significant statistical differences among the treatments.

Table 5. Economic benefit of fertilizer use in Lipa (CZ) Potato Rotation (EUR ha^{-1})

Treatments	Potato	Wheat	Barley	I. Rotation	Potato	Wheat	II. Rotation	Total
N75 K0	656 (F)	294 (B)	200 (B)	**1150 (E)**	1043 (A)	269	**1311 (A)**	**2461 (B)**
N75 K50	541 (E)	290 (B)	250 (D)	**1081 (F)**	1579 (B)	254	**1833 (B)**	**2914 (D)**
N75 K100	53 (B)	340 (C)	192 (B)	**585 (B)**	1854 (C)	287	**2141 (C)**	**2726 (C)**
N75 K150	96 (C)	355 (C)	165(AB)	**616 (C)**	1710 (BC)	288	**1998 (C)**	**2614 (BC)**
N100 K0	-205 (A)	280 (B)	189(AB)	**264 (A)**	1426 (B)	272	**1697 (AB)**	**1961(A)**
N100 K50	451 (D)	194 (A)	228 (C)	**873 (D)**	1159 (A)	209	**1368 (B)**	**2241(B)**
N100 K100	1040 (G)	293 (B)	191 (B)	**1524 (G)**	1590 (B)	247	**1836 (C)**	**3360 (E)**
N100 K150	506 (E)	281 (B)	148 (A)	**935 (D)**	1580 (B)	273	**1853 (C)**	**2788(C)**

[A]Different letters show significant statistical differences among the treatments.

Table 6. Results of two factorial ANOVA on total E_{bf} Donatowo (PL)

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
K	16012276	3	5337425	86.27355	5.39E-13	3.008787
N	2192877	1	2192877	35.44541	3.82E-06	4.259677
Interaction	559338.4	3	186446.1	3.013695	0.049756	3.008787
Within	1484791	24	61866.3			
Total	20249282	31				

Table 7. Results of Two factorial ANOVA on total E_{bf} Fushe Kruje (AL)

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
K	2.62E+08	3	87297112	175.3096	1.88E-16	3.008787
N	9407608	1	9407608	18.89231	0.000219	4.259677
Interaction	19247189	3	6415730	12.88404	3.23E-05	3.008787
Within	11951031	24	497959.6			
Total	3.02E+08	31				

Table 8. Results of Two factorial ANOVA on total E_{bf} in Lipa (CZ)

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
K	2833199	3	944399.7	36.0124	4.78E-09	3.008787
N	67018.76	1	67018.76	2.555598	0.122988	4.259677
Interaction	2205558	3	735186.2	28.03454	5.15E-08	3.008787
Within	629383.1	24	26224.29			
Total	5735159	31				

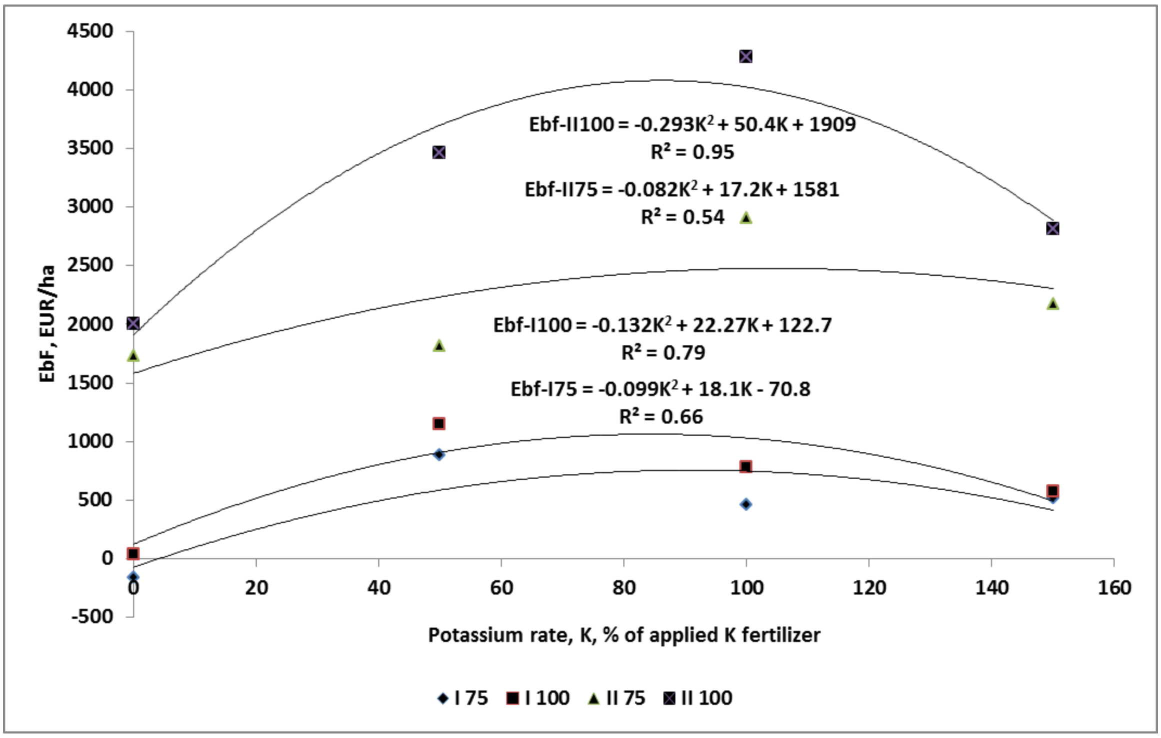

Figure 1. The E_{bf} for the I and II rotation cycles as a result of K fertilizer application – Donatowo (PL).
Legend: I, II – 1th and the 2nd rotation cycle; 75, 100 – relative rates of applied N fertilizer.

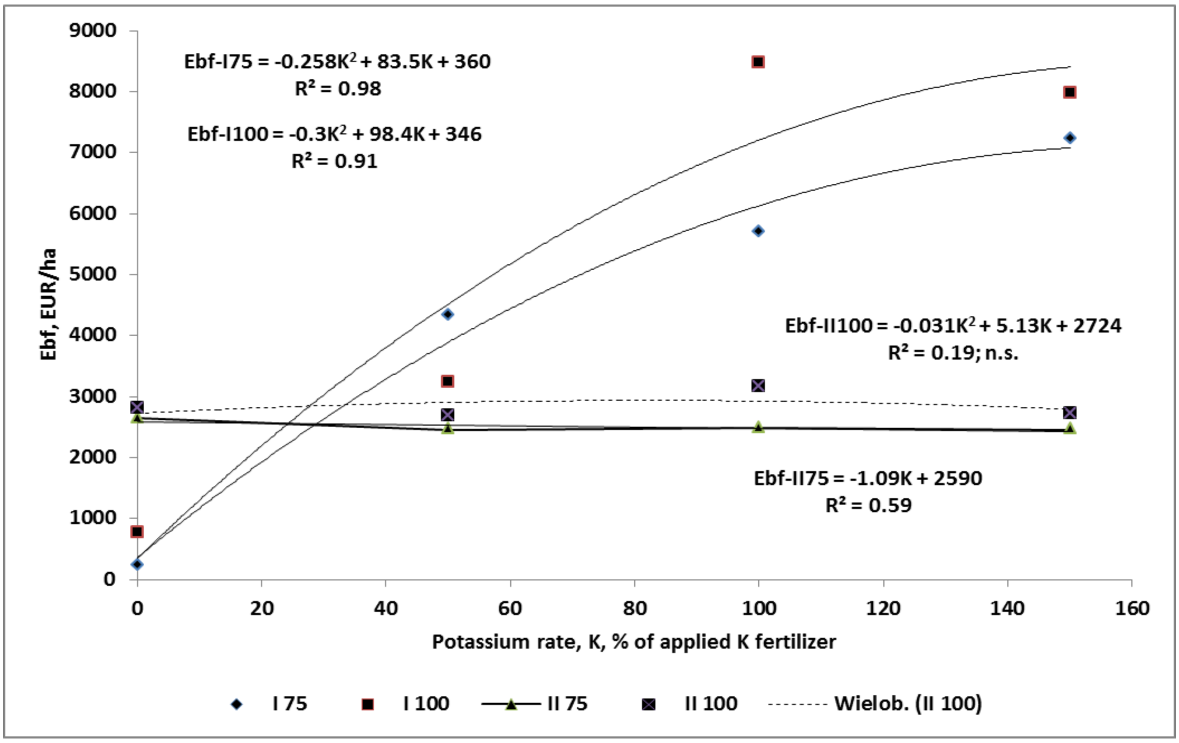

Figure 2. The Ebf for the I and II rotation cycles as a result of K fertilizer application – Fushe Kruje (AL). Legend: I, II – 1th and the 2nd rotation cycle; 75, 100 – relative rates of applied N fertilizer.

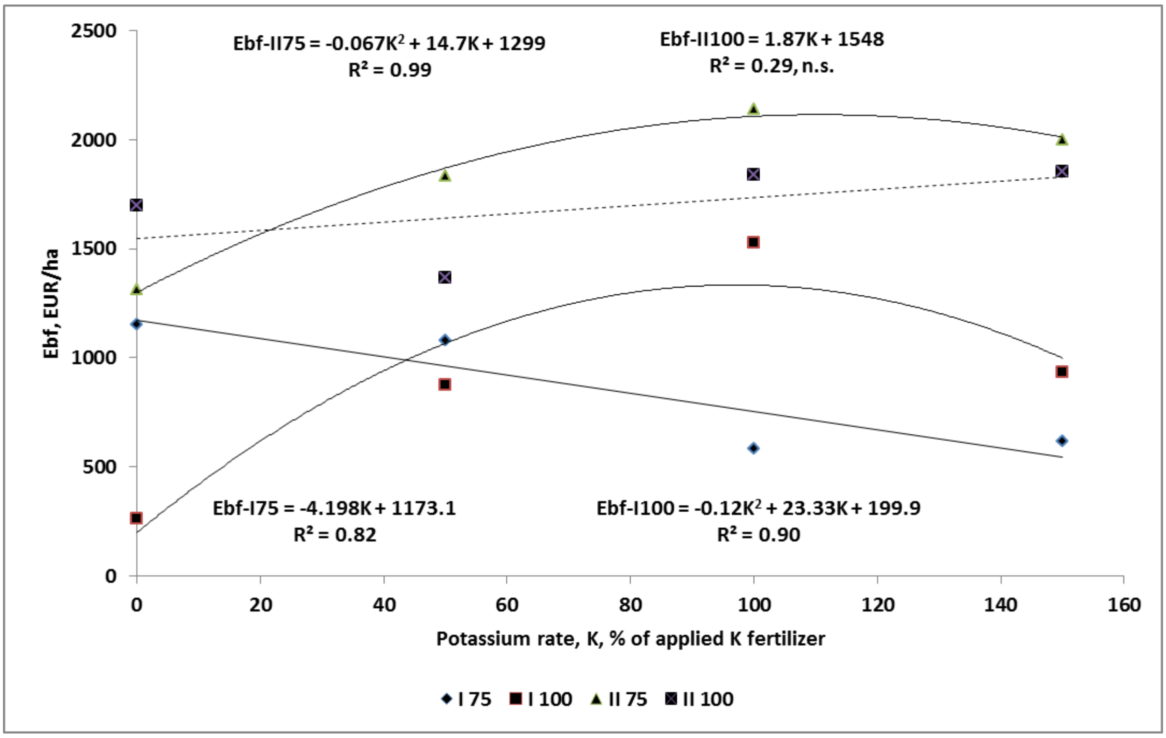

Figure 3. The Ebf for the I and II rotation cycles as a result of potassium fertilizer application – Lipa (CZ) Legend: I, II – 1th and the 2nd rotation cycle; 75, 100 – relative rates of applied N fertilizer.

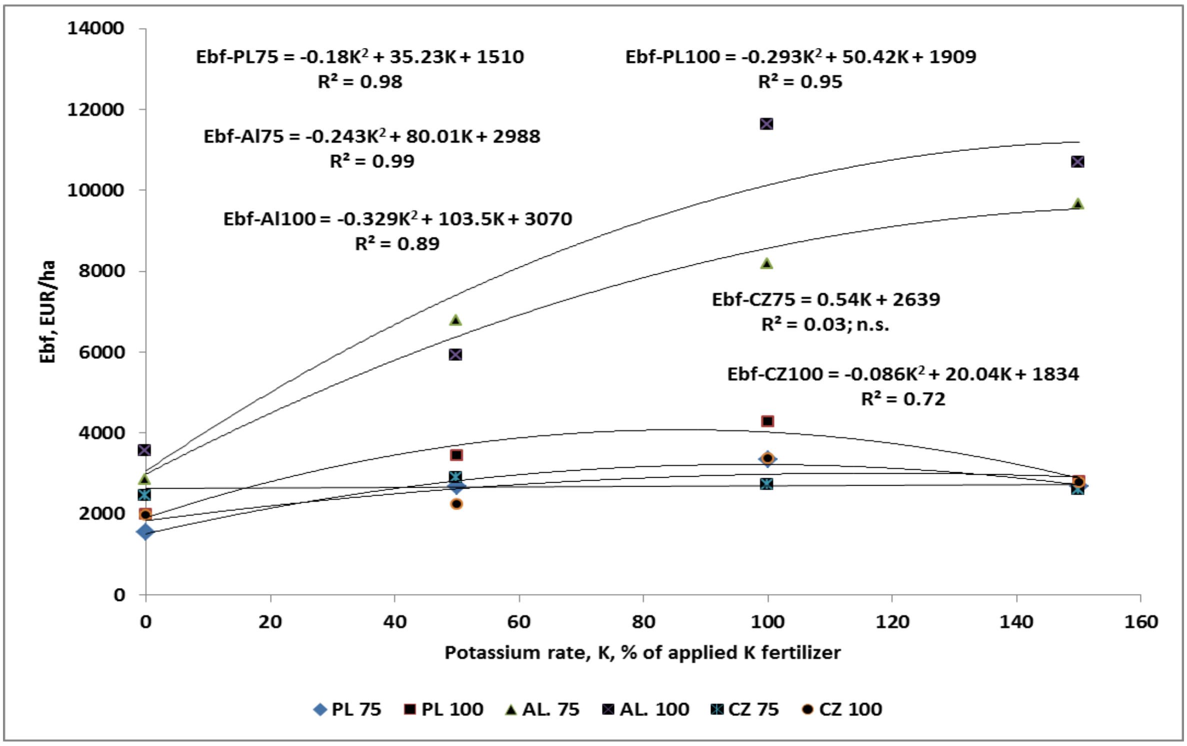

Figure 4. Trends in total Ebf for studied countries after two cycles of potato-cereal rotation

4. Conclusions

The present study confirms the importance of a proper fertilizers use not only in the crop yield but also in the farmers benefit. In three different soil and climatic conditions as well as economical frameworks, the highest benefit rates were achieved under a balanced fertilization. The N and K interaction with respect to farmers benefit in all three locations stress once more the need of an adequate use of these two nutrient elements.

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