

Economic assessment of the effectiveness of cultivation of edible, purple-flesh potato cv. Blue Congo

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Abstract. The article presents results of a field experiment involving Blue Congo, an edible potato cultivar with purple-flesh tubers, which is not very common on the Polish market but which may become an alternative to ordinary potatoes owing to its aesthetic and healthful properties. The experiment has proved that more intensive nitrogen fertilisation favours more efficient production and desirable economic output, with a dose of 120 kg N ha⁻¹ being an optimal one, at which the technological effectiveness index equals 20.41. Regarding potassium fertilization, it is not justifiable, neither for production nor for economic results, to exceed a dose of 120 kg K ha⁻¹. Any dose higher than that leads to severe deterioration of the effectiveness indicators. The economic parameters can be improved if market prices are higher, which seems possible when potato tubers are of other colours than the ordinary one.

Keywords: costs, profitability, potato, yield

INTRODUCTION

For years, potato cultivation in Poland has been struggling with various obstacles in the spheres connected with the potato market, production, organization and economics. Consequently, the total area covered by potato plantations has been decreasing steadily. No other European country has experienced difficulties in potato cultivation on a comparable scale (Plichta, 2017). Table 1 contains data such as potato production volume, total area of potato fields and yields of potatoes over years. Following a steady decrease in the acreage of potato fields in Poland, an increase was noted first in 2015 and subsequently in 2016, when 307 thousand ha were seeded with this crop. The spring of 2017 did not favour potato cultivation as the low temperatures, falling down to minus 5 or 6 °C, caused damage to

plantations of early cultivars. Moreover, the low demand, large quantities of potatoes in store and poor interest in potato export did not encourage farmers to undertake potato production. Gross warehousing sale prices for potatoes are 330–430 PLN t⁻¹. The average price of potatoes sold on vegetable markets at the end of April 2017, as reported by the Ministry of Agriculture and Rural Development in Poland, was 0.74 PLN kg⁻¹, compared to 0.95 PLN kg⁻¹ at the same time in 2016 (Agricultural Market, 2017).

With respect to potato yields, Polish agriculture is inferior to its western neighbours. The yield of potato tubers in Poland in 2015 was 21 t ha⁻¹ (Table 1), whereas in the same year in Germany the tuber yield reached 43.8 t ha⁻¹ (Landwirtschaft ..., 2016), thus being similar to the yield harvested in the Netherlands, where it was *ca* 43 t ha⁻¹ (Sutor et al., 2016). Such high yields are mostly secured by adequate technologies, replacement of seed potatoes, cultivation of high-yielding varieties and, above all, better quality of soil. The investigations carried out by the IHAR-PIB in

Table 1. Changes in acreage, yield and crop volume of potato in the years 1991–2016 in Poland.

Years	Production area [thous. ha]	Harvest [mln t]	Yield [t ha ⁻¹]
1991–1995	1694	27.34	16.1
1996–2000	1292	23.37	18.1
2001–2005	813	14.68	18.1
2006–2010	525	9.88	19.0
2011	406	9.36	23.0
2012	373	9.04	24.2
2013	346	7.29	21.0
2014	277	7.70	27.8
2015	292	6.15	21.0
2016	307	8.80	29.7

Source: Nowacki W., 2015; GUS (Yearbook 2016).

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Table 2. Potato use and potato production balance in Poland ('000 tons).

Specification	2010/2011	2011/2012	2012/2013	2013/2014	2014/2015	2015/2016	2016/2017 forecast
Harvested yields	8449	9362	9042	7290	7689	6314	9120
Import	258	138	94	206	134	164	100
Total amount available	8707	9500	9136	7496	7823	6478	9220
Consumption on farms:	4162	4699	4102	2921	3090	2020	3750
planting	1016	933	875	695	750	768	750
animal nutrition	1816	2436	1897	1026	1150	102	1860
table potatoes for in-house use	1330	1330	1330	1200	1190	1150	1140
Sales:	3836	3981	4284	3975	4133	4088	4470
consumption	2306	2345	2280	2100	2050	2000	2000
industrial supply [#]	1438	1611	1935	1834	2061	2072	2410
export	92	25	69	41	22	16	60
Damage and loss	709	820	750	600	600	370	1000

[#] potatoes used by industries, irrespective of the end.

Source: Potato market. Current state and prospects. Market analyses. Listopad 2016: IERiGŻ-PIB, ARR, MRiRW, Warszawa, 43, 3.

Jadwisin into different potato cultivation systems implicate that the total yields of tubers obtained from the integrated method (31 t ha⁻¹) are about 20% higher than those harvested from the ecological system (25 t ha⁻¹) (Nowacki, 2012).

Another factor which matters in potato production is the intended use of potatoes. The structure of changes in potato consumption, that is the breakdown of the potato market (Table 2) shows decreasing sales for direct consumption but an increase in the supply of industries.

It is worth adding that consumption of unprocessed potato has been declining steadily since 1960. This tendency has paralleled the rising salaries and improved standard of living of the population in Poland.

At the moment, there are very dynamic changes in the consumption of food products in Poland. This is a consequence of changes in our lifestyle and nutrition. While it is true that potato cultivars with tubers of other than classical colour do not sell very well in Poland and their market share is almost negligible, the attitude of Polish people to culinary novelties is positive. The main barrier to buying innovative products is their perceived high price. Moreover, some consumers do not buy novel food because they prefer traditional and well-known products (Jasiulewicz, 2014). Nevertheless we can expect a rising share of such potato cultivars, as we can see an increasing market contribution of Jerusalem artichoke, sweet potatoes or garden asparagus, i.e. crops which were practically unseen in Polish shops a few years ago. The changing expectations of consumers seem to incline to organic and healthful (functional) food. In Poland, it is possible to observe an increasing consumer awareness regarding relationships between food, nutrition and health, which may encourage many food producers to launch products with special pro-health or functional properties as well as food with enhanced nutritional value. These trends on the Polish food market are

supported by the fact that health has the highest value for the vast majority of Polish people (Dąbrowska, 2013). The health-promoting compounds in classical colour potato tubers include phenolic acids, ascorbic acid, carotenoids, tocopherol, as well as selenium, while potato tubers with coloured flesh additionally contain anthocyanins, that is compounds with very high anti-oxidant potential (Brown et al., 2003; Jansen, Flamme, 2006). The latter cultivars are potential raw material for production of food with an enhanced content of bioactive compounds. Some authors claim that a diet rich in antioxidants can be associated with a lower risk of cardiovascular disease, some neoplasms and age-related macular degeneration (Cao et al., 1999). Nemš (2015) proved that potato cultivars producing dark colour tubers are richer in starch and sugars than cultivars which yield light-colour tubers, in addition to which the former have a 5-fold higher content of phenolic compounds and 6- to 7-fold higher antioxidant potential. Colour-flesh cultivars of potatoes are a valuable addition to our diet because the anthocyanins they contain reveal several positive pharmacological properties, for instance they lower the fragility of capillary vessels and improve the clarity of vision by enhancing the eye's blood supply (Hamouz et al., 2008; Jarienè et al., 2013).

The potato cultivar Blue Congo, also referred to as Blau Kongo or Blau Schweden, was reported to have been grown as a vegetable in Sweden. However, its origin is unknown. The cultivar yields oval-shaped and medium-size to large tubers, with flat eyes, dark-purple peel, purple flesh with distinctly visible, mottled, colour layers. This is a medium late cultivar which ripens in August. Boiled tubers are slightly sweet, hard and starchy (Naturwuchs Katalog 2016/2017). Compared to cultivars with light-colour peel, Blue Congo contains much vitamin C, but the reproducibility of yields is low compared to other cultivars (Sa-

wicka et al., 2009). Blue Congo is not a widespread variety in Poland, but may be successfully used for cooking and garnishing dishes owing to its unique colour. Its production does not differ from the cultivation of classical potato cultivars, thus the only determinant to its occurrence on the market is the demand.

The purpose of this study has been to make an economic evaluation of different fertilization regimes applied in the cultivation of purple-flesh potato (Blue Congo) over two years of its cultivation. The experiment was located in north-eastern Poland, in the zone of warm moderate transient climate. The calculations were based on data collected during the experiment conducted at the Experimental Station of the University of Warmia and Mazury in Olsztyn.

MATERIAL AND METHODS

Seeds of the purple-blue potato cv. Blue Congo were purchased from the Finnish Seed Potato Centre Ltd. (Suomen Siemenperunakeskus, Finland). A field experiment was located at the Agricultural Experimental Station in Tomaszkowo (53°42'N, 20°26'E, Poland). Two main, one-factorial experiments were laid out as a Latin rectangle, and were performed in 3 replicates, where a single factor corresponded to different fertilization doses of particular elements, i.e. (I) nitrogen and (II) potassium.

In the first part of the experiment (I), nitrogen was applied as urea fertiliser (46%). The doses of nitrogen, 40 kg ha⁻¹ and 80 kg ha⁻¹, were applied to soil before potato planting. The dose of 120 kg N ha⁻¹ was split into 100 kg N ha⁻¹ before potato planting in the second decade of May 2015 and 20 kg N ha⁻¹ before the last earthing-up on 26 June 2015 (Table 3). In this part of the experiment, potassium and phosphorus were used before potato planting (2nd decade of May 2015) at doses of 120 kg K ha⁻¹ (potassium sulphate, 50%) and 80 kg P ha⁻¹ (triple superphosphate, 46%).

In the second part of the experiment (II), potassium was applied as potassium sulphate (50%) at doses of 120 kg K ha⁻¹, 150 kg K ha⁻¹ and 180 kg K ha⁻¹. The whole doses were supplied to the soil prior to potato planting in the second decade of May 2015 (Table 3). In this part of the experiment, nitrogen and phosphorus were spread over soil before potato planting (2nd decade of May 2015) at doses of 80 kg N ha⁻¹ (urea 46%) and 80 kg P ha⁻¹.

The doses of the fertilizers corresponded to the needs of the cv. Blue Congo, and were applied separately because

the N-K abundance in the agricultural ecosystem had already been recognized (Johnston et al., 2009).

Tubers (class CA material) were planted at 40-cm intervals, in rows spaced at 62.5 cm, hence the plant density was 40,000 plants per hectare.

For the purchased potato seeds, the supplier provided the information about recommended nitrogen doses and the concentration of nitrogen in soil. Each experimental plot was 10.80 m² (2.25 m × 4.80 m) large, and the area designated for harvest was 5.85 m². The whole experiment covered 2.6 acres. Field experiments were carried out in the second decade of May 2015, and the potatoes were collected in the last ten days of September 2015.

The experiment was established on Haplic Luvisol originating from boulder clay (IUSS 2006). Composite soil samples were taken from each plot, from a depth of 20 cm, to determine the chemical properties of soil. On the experimental sites, soil pH approximated 4.96 and the soil nutrient levels 242 mg kg⁻¹ P (the Egner-Riehm method), 180 mg kg⁻¹ K (the Egner-Riehm method), 34 mg kg⁻¹ Mg (AAS) (Houba et al., 1995).

The plant cultivation treatments included double hilling and several sprays. The following plant protection chemicals were used to:

Herbicides:

- Afaon Dyspersyjny 450 SC (*linuron*) – 2 dm³ ha⁻¹.
- Sencor Liquid 600 SC (*metribuzin*) – 0.5 dm³ ha⁻¹,
- Agil 100 EC (*propaquizafop*) – 1.5 dm³ ha⁻¹.

Fungicides:

- Ridomil Gold MZ 68 WG (*metalaxyl-M + mancozeb*) – 2 kg ha⁻¹,
- Acrobat MZ 69 WG (*dimetomorf + mancozeb*) – 2 kg ha⁻¹,
- Tanos 50 WG 0.7 (*cymoxanil + famoxat*) – 2 kg ha⁻¹.

Insecticides:

- Apacz 50 WG (*chlotianidin*) – 40 g ha⁻¹,
- Calypso 480 SC (*tiachlopid*) – 0.08 dm³ ha⁻¹.

All calculations adhered to the Polish agricultural bookkeeping methodology (Goraj, 2000), including the classical division into direct and indirect costs, which enabled us to calculate basic categories of costs and revenue according to the following scheme (Augustyńska-Grzymek et al., 2009):

- direct costs;
- indirect costs;
- total costs;
- unit production costs.

The unit costs of tractors and machinery as well as the costs of conducting individual agrotechnical treatments were calculated according to the methods used at the Institute for Building, Mechanization and Electrification of Agriculture in Poland (Muzalewski, 2007). The calculations of agricultural machinery costs included the costs of using machines owned by the Experimental Station in Bałcyn. The analysis of economic effectiveness was based on the logs of treatments and type of implements used in these

Table 3. Fertilization doses of nitrogen and potassium applied under potato cv. Blue Congo.

Variant	Doses [kg ha ⁻¹]			
Experiment I Nitrogen	0	40	80	120
Experiment II Potassium	0	120	150	180

treatments, as well as determined inputs of labour, power and inputs of materials. The hourly wage was estimated according to the remunerations paid at the Experimental Station.

RESULTS AND DISCUSSION

Compared to other crops, potato is a very expensive plant to grow. This explains why potato is becoming less competitive than other plants as a fodder plant, energy crop, or even as the basic source of starch (Chotkowski, 2009). Increasingly often, agricultural practice incorporates specialist technologies, rooted in different management systems (Nowacki, 2010). Labour done with tractors and machines plays an important role in potato cultivation, having a large share in total costs. In the field experiment reported herein, a traditional cultivation system was implemented. Among all the cultivation treatments performed, and specified in table 4, tuber harvesting incurred the highest cost, i.e. 1230 PLN ha⁻¹. The transport of potato tubers associated with potato combine harvesting was also a significant contributor to total expenses, as it cost nearly 770 PLN ha⁻¹. Another treatment which generates high costs and differs significantly from treatments done on other crops is tuber planting. In our study, it cost over 180 PLN ha⁻¹. The remaining costs do not diverge much from analogous costs in the cultivation of other agricultural crops.

In addition to the workload of tractors and machines, the intensity of a technology applied to grow potatoes is

another essential determinant of the economic output, as the level of yields depends on numerous factors, of which the major ones are the genetically conditioned yielding potential of a cultivar, climatic conditions during the plant growing season (distribution of precipitations), soil conditions and, last but not least, agronomic practice. The NPK fertilization level, intensity of protection against diseases and pests, correctness of the performance of crop cultivation and protection treatments affect the harvested tuber yields and yield quality (Nowacki, 2012). The level of yields produced by cv. Blue Congo is not much different from yields of other edible potato varieties. It is similar to yields of organic potatoes, where on average 24 t ha⁻¹ of tubers are harvested. These are not very high yields compared to ones obtained from intensively cultivated fields, where 50 t ha⁻¹ of tubers can be harvested (Nowacki, 2012).

The total worth of potato production depends on both the yields and the price earned. In our calculations, the average price of potato was 740 PLN per tonne. However, potatoes with purple-blue tubers can earn higher prices when the market for this product develops. As for the value of the production tested (Table 5), it was the highest under the nitrogen fertilization with 120 kg N ha⁻¹, where it reached 25 469 PLN ha⁻¹, being by 8362 PLN higher than in the control variant. Generally, each increment in the nitrogen dose resulted in an evident rise in production value. There was no similar relation for potassium. The highest production value was obtained in the first fertilization variant 120 kg K ha⁻¹, which fully satisfies the nutritional demand

Table 4. Breakdown of the costs of labour done with tractors and machines in the analysed technologies of the cv. Blue Congo potato cultivation.

No.	Type of treatment	Unit cost of tractor labour [PLN ha ⁻¹]	Unit cost of machine labour [PLN ha ⁻¹]	Unit cost of tractor and machine labour [PLN ha ⁻¹]	Number of working hours	Value [PLN ha ⁻¹]
1	Skimming	83.76	7.75	91.51	0.5	45.76
2	Harrowing	50.55	3.43	53.98	0.3	16.19
3	Winter ploughing	146.70	39.51	186.21	0.8	148.97
4	Soil cultivation	73.76	7.73	81.49	0.4	32.60
5	Harrowing	50.55	3.43	53.98	0.3	16.19
6	Fertilization	83.86	41.44	125.3	0.2	25.06
7	Planting of tubers	50.55	10.43	60.98	3.0	182.94
8	Harrowing	50.55	3.43	53.98	0.3	16.19
9	Hilling	50.55	6.66	57.21	0.5	28.61
10	Fertilization	50.55	41.44	91.99	0.2	18.40
11	Sprays x 5	50.55	18.10	68.65	0.8	54.92
12	Hilling	50.55	6.66	57.21	0.5	28.61
13	Harvest	83.76	142.12	225.88	5.0	1129.40
14	Transport tractor + 2 carts	146.70	45.52	192.22	4.0	768.88
15	In total				16.8	2512.72

Table 5. Production costs of potato cv. Blue Congo [PLN ha⁻¹].

Fertilization variant	N				K			
	0.0	40.0	80.0	100+20	0.0	120.0	150.0	180.0
Production worth	17107.00	19327.00	22287.00	25469.00	17477.00	19697.00	18365.00	19697.00
Yield [t ha ⁻¹]	21.80	24.80	28.80	33.10	22.30	25.30	23.50	25.30
Yield worth	16132.00	18352.00	21312.00	24494.00	16502.00	18722.00	17390.00	18722.00
Direct subsidies	975.00							
Direct costs in total	4836.47	4973.06	5109.65	5246.24	4285.97	5109.65	5315.57	5525.49
Seeding material	2350.00							
Mineral fertilizers:	1357.00	1493.59	1630.18	1766.77	806.50	1630.18	1836.10	2046.02
Urea	0.00	136.59	273.18	409.77	273.18	273.18	273.18	273.18
Triple superphosphate (46%)	533.32							
Potassium sulphate (50%)	823.68	823.68	823.68	823.68	0.00	823.68	1029.60	1239.52
Plant protection:	1129.47							
Afalon Dyspersyjny 450 SC	129.00							
Ridomil Gold MZ 68 WG	135.60							
Sencor Liquid 600SC	76.50							
Apacz 50 WG	52.00							
Calypso 480 SC	52.24							
Agil 100 EC	147.27							
Acrobat MZ 69 WG	11.86							
Tanos 50 WG 0,7	525.00							
Indirect costs in total	3252.60	3252.60	3252.60	3284.45	3252.60	3252.60	3252.60	3252.60
Work of tractors and machines	2512.71	2512.71	2512.71	2537.86	2512.71	2512.71	2512.71	2512.71
Work input	319.20	319.20	319.20	323.00	319.20	319.20	319.20	319.20
Agricultural tax	125.00	125.00	125.00	125.00	125.00	125.00	125.00	125.00
Other indirect costs (+10%)	295.69	295.69	295.69	298.59	295.69	295.69	295.69	295.69
Costs in total	8089.07	8225.66	8362.25	8530.69	7538.57	8362.25	8568.17	8778.09

Table 6. Indicators of economic efficiency in the production of the potato cultivar Blue Congo.

Fertilization variant	N				K			
	0.0	40.0	80.0	100+20	0.0	120.0	150.0	180.0
Indirect margin [PLN·ha ⁻¹]	12270.53	14353.94	17177.35	20222.76	13191.03	14587.35	13049.43	14171.51
Agricultural income [PLN·ha ⁻¹]	9017.9	11101.3	13924.7	16938.3	9938.4	11334.7	9796.8	10918.9
Indirect margin rate [%]	71.7	74.3	77.1	79.4	75.5	74.1	71.1	71.9
Agricultural income rate [%]	52.7	57.4	62.5	66.5	56.9	57.5	53.3	55.4
Costs per unit [zł t ⁻¹]	371.1	331.7	290.4	257.7	338.1	330.5	364.6	347.0
Profitability index	2.1	2.3	2.7	3.0	2.3	2.4	2.1	2.2

of potato. Fertilization was the factor that differentiated the technologies, and therefore the level of direct costs was differentiated by the costs of the purchase of nitrogen and potassium fertilizers. The highest direct costs were generated by the variant 120 kg N ha⁻¹, where they stood at 5 246 PLN ha⁻¹. The indirect costs for all variants were the same except for the fertilization variant with 120 kg N ha⁻¹, where an extra cost was incurred by the splitting of the nitrogen dose.

Table 6 presents basic indicators that serve to make an economic assessment of production. Noteworthy is the profitability index value at the nitrogen fertilization level of 120 kg N ha⁻¹ (3.0). It indicates the best ratio of production value to costs. The agricultural income in this variant was higher by 7920 PLN ha⁻¹ than in the economically least efficient control variant. Compared to many other crops, this is a very high value that can be obtained at a rather

Table 7. Cost-effectiveness of the production of the potato cultivar Blue Congo.

Fertilization variant	N				K			
	0.0	40.0	80.0	100+20	0.0	120.0	150.0	180.0
Tuber yield market value [PLN ha ⁻¹]	16132.00	18352.00	21312.00	24494.00	16502.00	18722.00	17390.00	18722.00
Increase in the value of tuber yield [#] [PLN ha ⁻¹]	–	2220	5180	8362	–	2220	888	2220
Nitrogen and potassium fertilization costs [#] [PLN ha ⁻¹]	0.00	136.59	273.18	409.77	0.00	823.68	1029.60	1239.52
Cost-effectiveness of input production (increase in market value of yield/increase in production costs)	–	16.25	18.96	20.41	–	2.70	0.86	1.79

[#] relative to system 0.00 N ha⁻¹ and 0.00 K ha⁻¹

moderate yield. Thus, the cultivar Blue Congo can become an interesting and profitable alternative to classical potato cultivars.

Agricultural producers, as well as others, while making decisions about production crops and applied technologies will be curious about the efficiency of particular components of each technology. As for nitrogen fertilization, the highest efficiency of more intensive production technology was achieved in the variant of 120 kg N ha⁻¹, where each zloty invested in nitrogen fertilizer generated an increment in yield value of 20.41 PLN ha⁻¹. Regarding potassium fertilization, the efficiency of potassium fertilizer was the highest at a dose of 120 kg K ha⁻¹, although the value of the index was not as impressive as the one for nitrogen fertilization, as it equalled just 2.70.

CONCLUSIONS

1. The Blue Congo potato responds very well to increased nitrogen fertilization, and the nitrogen dose of 120 kg N ha⁻¹ resulted in the best production and economic results.

2. The study showed that a potassium fertilization dose above 120 kg K ha⁻¹ deteriorates the gain from technology intensification and calculated values of the economic indicators selected for the research.

3. The Blue Congo potato achieved the yield level that is characteristic for organic farming, but when nitrogen fertilization was increased, the average yield of this potato cultivar was approximately the same as an average yield of classical potato cultivars in the integrated agricultural system.

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