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Agro-Ecological, Marketing Assessment for Siderate in Potato Cultivation

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ABSTRACT

Under current conditions, ecological component is becoming increasingly important. Restoration of potential soil fertility by their saturation with organic matter of intermediate crop siderates is the basis for growing environmentally friendly and high-quality products. Development and adaptation of effective agricultural technologies for growing potatoes in order to obtain organic products is an important scientific area today. One of the tasks of our research was to identify the payback of organic farming elements at current prices, in particular material resources directed on obtaining maximum and quality of potato harvest in the process of its growing. The results of farming and economic efficiency of using intermediate cultivation crops on green manure while growing potato are given. As a result of the conducted research was revealed positive influence of intermediate crops of sideral crops on economic efficiency of potato growing. Application of post-harvest *Raphanus sativum* siderate provided the highest yield of potato tubers – 30.9 t·ha⁻¹ and starch yield – 4.08 t·ha⁻¹. In the case of post-harvest *Raphanus sativum* siderate when growing potato, the highest net profit was obtained – 1369 €·ha⁻¹ and an additional profit of 460 €·ha⁻¹. Application of post-harvest *Raphanus sativum* siderate provided the lowest cost of potato growing – 36.35 €·t⁻¹, and the highest profitability level of its cultivation – 121.7%, with a payback of additional costs – 0.43 €·t⁻¹.

Keywords: fertilizers, green manure, yield, economic regulation of nature use, phytomass, potato, economic efficiency.

INTRODUCTION

Global agriculture requires the implementation of agrotechnical measures aimed at preserving and improving soil fertility indicators when growing potatoes. Restoration of soil fertility makes it possible to obtain high and stable yields of potatoes at relatively low production costs. This ensures the competitiveness and strong economic attractiveness of organic agricultural technologies [Woźniak, 2019; Sumbul et al., 2020; Mishchenko et al., 2022a; Mischenko et al., 2024]. In the conditions of Ukraine, fertility of black soils suffers from lack of

organic fertilizers and excessive tillage of the soil. To ensure favourable conditions for growing potatoes on soils with lost optimal fertility parameters, farmers are forced to invest significant financial resources in application of mineral fertilizers, growth stimulants, pesticides and additional soil loosening. As a result, the product loses its quality indices, and its economic recoupage and, accordingly, sale price become quite high [Murtić et al., 2021; Tonkha et al., 2021; Tsyuk et al., 2022; Karbivska et al., 2023]. Therefore, adaptation of organic farming elements to soil and climatic conditions of Ukraine is an actual scientific direction nowadays.

Ukrainian farms mainly use potato growing technologies which require application of mineral fertilizers, chemical products for plant protection, which cause a risk of soil contamination, cultivated products and the environment. Intensive technologies with insufficient application of organic fertilizers lead not only to excessive chemical stress [Kolisnyk et al., 2024; Hryhoriv et al., 2024]. But also in adverse weather conditions require additional agricultural measures which reduce economic attractiveness of the production as a whole [Seaman, 2016; Bondarchuk et al., 2018; Karbivska et al., 2020; Mishchenko et al., 2022a].

Under current conditions, ecological component is becoming increasingly important. Restoration of potential soil fertility by their saturation with organic matter of intermediate crop siderates, which is the basis for growing environmentally friendly and high-quality products, provides high economic efficiency of potatoes [Butenko et al., 2022; Radchenko et al., 2024], thanks to balancing nutrient regime of crops, improvement of agrophysical properties [Mooleki et al., 2016; Yakupoglu et al., 2021], its phytosanitary state [Isselstein and Kayser, 2014; Woźniak, 2019] and water [Düll et al., 2014; Flaig et al., 2015] and microbiological regimes [Mishchenko et al., 2022b; Möller et al., 2022].

Potatoes are quite demanding to growing conditions, and to obtain high and quality yields they require uncompacted soils with good aeration, free of weeds, sufficiently provided with moisture and nutrients. High economic profitability provision of potato cultivation is quite possible with application of the cheapest agricultural measure for replenishment of organic matter in the soil – intermediate crops on siderate [Mishchenko et al., 2022b; Kovalenko et al., 2024a]. Therefore, development and adaptation of effective agricultural technologies for growing potatoes in order to obtain organic products is an important scientific area today [Caldiz et al., 2016; Lü et al., 2019; Argenti et al., 2021; Kovalenko et al., 2024b].

One of the tasks of our research was to identify the payback of organic farming elements at current prices, in particular material resources directed on obtaining maximum and quality of potato harvest in the process of its growing.

MATERIAL AND METHODS

Determination of farming and economic efficiency of potato cultivation when using

intermediate post-harvest siderate crops was carried out in the conditions of the left-bank Forest-Steppe in the research field of Sumy NAU during 2019–2021 years. The study was conducted in a field experiment according to the scheme:

1. Control (without application of organic fertilizers to potatoes);
2. Application of *Raphanus sativum* post-harvest siderate;
3. Application of *Phacelia tanacetifolia* post-harvest siderate;
4. Application of *Fagopyrum sagittatum* post-harvest siderate;
5. Application of manure – 25 t·ha⁻¹.

The area of the accounting plot is 60 m². The method of placing variants in repetition is systematic. Repetition of the experiment – three times. The soil of experimental field is typical deep low-humus medium loam black. The humus content in the soil layer 0–30 cm was 3.9 ± 0.3, and in the layer 40–100 cm – 2.02 ± 1.0%. Reaction of soil solution in the arable layer is close to neutral: pH of aqueous extract is 6.7, hydrolytic acidity – 1.47 mg eq./100 g. of soil, the sum of absorbed bases – 24.4 mg·eq./100 g of soil, degree of saturation with bases – 94.3%.

The soil is characterized by low level of hydrolyzed nitrogen supply – 101 mg·kg⁻¹ (according to Cornfield), high content of moveable compounds P₂O₅ and K₂O – respectively 135 and 117 mg·kg⁻¹ of soil (according to Chirikov) [Horodniy et al., 2005].

Structure coefficient of arable layer was 2.38, the content of waterproof units with a size of 3–5 mm – 42.8%. The density of composition and solid phase in the arable layer of soil was 1.20 and 2.46 g/cm³, and in the meter layer – 1.24 and 2.52 g/cm³, respectively. Total porosity in 0–30 cm layer was 51.16%, in the meter layer it decreased to 50.94%. The lowest moisture content was 28.27% in the arable layer, and in the layer 0–100 cm – 27.13%.

Postharvest siderates were sown in the first decade of August, and plowing of their mass – at the end of the third decade of October. The technology of growing potatoes variety Slovianka was generally accepted for the soil and climatic zone.

For specific determination of economic efficiency was used a system of calculated indices indicating profitability or unprofitability of cultivation technology in specific soil and climatic conditions [Pivovar, 2013; Karbivska et al., 2022].

RESULTS AND DISCUSSION

Post-harvest *Raphanus sativum* siderate, on average in the years of research, provided the highest potato yield – 30.9 t·ha⁻¹ and the highest yield increase – 6.1 t·ha⁻¹, compared to the control without siderate, where the yield was 24.8 t·ha⁻¹ (Fig. 1).

Post-harvest *Raphanus sativum* siderate under potatoes had an advantage over traditional fertilizers. It provided a significant difference in the yield of tubers: 1.2 t·ha⁻¹ more than with manure application and 1.7 t·ha⁻¹ more than with mineral fertilizers.

Application of post-harvest phacelia siderate was significantly inferior to *Raphanus sativum* in terms of potato yield – by 1.6 t·ha⁻¹, and prevailed the control without siderates by 4.5 t·ha⁻¹. Here,

the yield was at the level of plowing traditional fertilizers. Green fertilizer of buckwheat provided the lowest increase in potato yield compared to the control – 0.9 t·ha⁻¹, and was significantly inferior to other fertilizers in terms of yield – by 14–20%. Fertilizer background had 26.5% share of influence on the formation of potato yield. Phytomass of postharvest siderates of *Raphanus sativum*, *Phacelia tanacetifolia* and *Fagopyrum sagittatum* was closely correlated with potato yield (Fig. 2).

The share of weather condition influence in vegetation period on the formation of potato yield was – 70.1% (Fig. 1). The yield of testing crops was significantly influenced by air temperature and precipitation amount (Fig. 3).

Correlations between potato yield and average daily temperature and precipitation amount

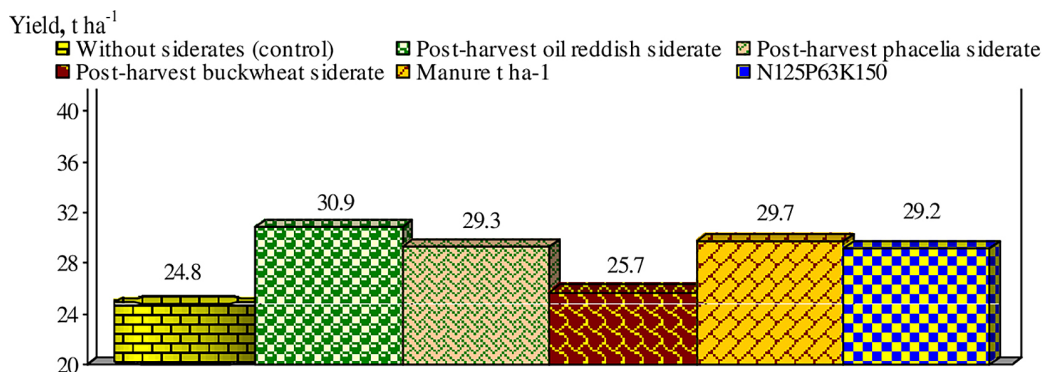


Figure 1. Potato yield under different fertilizer backgrounds, t·ha⁻¹

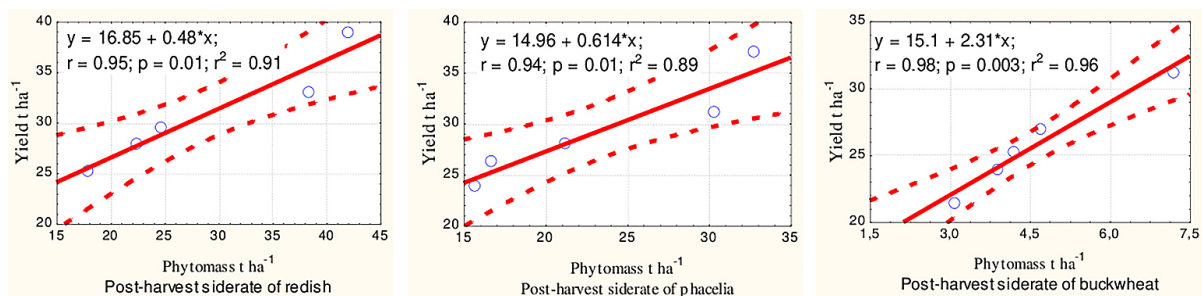


Figure 2. Correlation between potato yield and phytomass of post-harvest siderates

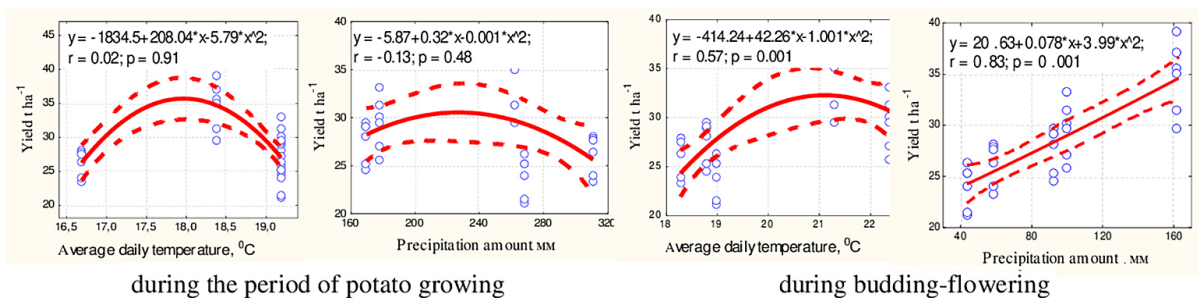


Figure 3. Correlation between weather elements and potato yield

during the growing period were generally insignificant. Potato productivity depended more on weather elements in critical phases of growth and development. In the phase of budding and flowering potatoes suffered from a lack of moisture, as indicated by a direct close correlation between the level of crop yield and precipitation amount – $r = 0.83$. Although air temperature in the critical periods of potato development correlated with the crop yields, it did not negatively affect the yield. It is evidenced by the stationary area of the yield response curve within the average long-term indices – 20.5–21.5 °C.

Potatoes are mainly grown for starch production. Its content in tubers is a very important indicator of quality which depends on both the level and balance of plant nutrition and are higher on organic fertilizer backgrounds (Table 1).

The starch content in potato tubers ranged from 12.7 to 13.2%. Compared to the control, it was significantly lower (0.4%) in the variant with application of mineral fertilizer $N_{125}P_{63}K_{150}$. With organic fertilizer the increase of starch content in

tubers dominated over the control without siderates by 0.1%, exception was for green manure of *Fagopyrum sagittatum*.

Starch gathering on all fertilizer backgrounds was significantly higher than the control without green manure, except *Fagopyrum sagittatum* green manure. The influence share of fertilizers on starch gathering was 52%, weather conditions – 42%, and other factors – 6%.

According to the yield data of our research, the value of potatoes calculated at Ukrainian prices in 2021 (2361.3–2493.5 € ha⁻¹) indicates a high financial potential of post-harvest siderates of *Raphanus sativum* and *Phacelia tanacetifolia*. These green fertilizers are equivalent to application of 25 t·ha⁻¹ of manure or mineral fertilizer $N_{125}P_{63}K_{150}$, significantly prevailed control without green manure by the cost of production by 17–25%; in the variant of *Fagopyrum sagittatum* greens, the increase of grown production cost was only within 4% (Table 2).

Additional production costs for application of green manures increased compared to the control

Table 1. Technological indices of potato quality on different fertilizer backgrounds

Technological indices	Variant						
	Without siderate (control)	Post-harvest siderate				$N_{125}P_{63}K_{150}$	LSD _{0.05}
		<i>Raphanus sativum</i>	<i>Phacelia tanacetifolia</i>	<i>Fagopyrum sagittatum</i>	Manure 25 t·ha ⁻¹		
Starch content, %	13.1	13.2	13.2	13.1	13.2	12.7	0.14
Starch gathering, t·ha ⁻¹	3.25	4.08	3.87	3.37	3.92	3.71	0.25

Table 2. Economic efficiency of potato growing on different fertilizer backgrounds

Index	Fertilizer background					
	Without siderate (control)	Post-harvest siderate			Manure 25 t·ha ⁻¹	$N_{125}P_{63}K_{150}$
		<i>Raphanus sativum</i>	<i>Phacelia tanacetifolia</i>	<i>Fagopyrum sagittatum</i>		
Yield, t·ha ⁻¹	24.8	30.9	29.3	25.7	29.7	29.2
Sales price, €·t ⁻¹	80.64	80.64	80.64	80.64	80.64	80.64
Cost of production, €·ha ⁻¹	1996.77	2493.55	2361.29	2075.80	2391.94	2358.06
Production costs, €·ha ⁻¹	1087.77	1124.55	1134.48	1129.65	1362.71	1374.90
Additional costs in total, €·ha ⁻¹	–	36.77	46.71	41.87	274.93	287.13
Including application of fertilizers, €·ha ⁻¹	–	3.87	3.87	3.87	97.84	3.26
Purchase of fertilizers, €·ha ⁻¹	–	14.52	29.03	34.84	161.29	269.35
Net profit, €·ha ⁻¹	909	1369	1226.80	946.16	1029.23	983.16
Additional income, €·ha ⁻¹	–	460	317.81	37.16	120.23	74.16
The cost of 1 ton, €	43.94	36.35	38.74	43.87	45.94	47.03
Cost of yield increase, €·t ⁻¹	–	5.97	10.32	42.74	56.10	64.10
Profitability level, %	83.6	122	108	83.8	75.5	71.5
Payback of additional costs, €/€	–	0.44	0.25	0.06	0.05	0.04

without siderate by 36.77–46.71 €·ha⁻¹, at the same time for application of 25 t·ha⁻¹ of manure or N₁₂₅P₆₃K₁₅₀ they were almost 6–8 times higher and reached the level of 274.93–287.13 €·ha⁻¹, due to modern high prices for manure, mineral fertilizers and work related to manure application.

Due to the lowest seed cost, the increase in production costs for *Raphanus sativum* siderate was the smallest – by 3.8%, compared to the control without siderate, where they were 1087.77 € ha⁻¹. For *Phacelia tanacetifolia* siderate the costs increased by 4.3%, and for *Fagopyrum sagittatum* sowing – by 3.8%.

The largest net profit was obtained when growing potatoes on the background of *Raphanus sativum* green fertilizer – 1369 €·ha⁻¹, as well as additional profit – 460 €·ha⁻¹. Lower profitability was found on the background of *Phacelia tanacetifolia* green manure – net profit from growing potatoes was – 1226.80 €·ha⁻¹, and additional – 317.81 €·ha⁻¹. *Fagopyrum sagittatum* siderate provided lower additional income – 37.16 €·ha⁻¹.

Profit for the technology of growing potatoes with manure was determined in amount 1029.23 €·ha⁻¹ or for mineral fertilizers – 983.16 €·ha⁻¹. There was an additional income of 120.23 and 74.16 €·ha⁻¹, which was by 4 and 6 times less than for siderate of *Raphanus sativum*.

For *Raphanus sativum* siderate was the lowest prime cost of growing potato tubers – 36.35 € per ton. Prime cost of yield increase for potato growing on the background of *Phacelia tanacetifolia* green fertilizer, compared to *Raphanus sativum*, increased – by 4.36 € t⁻¹. Prime cost for green manure of *Fagopyrum sagittatum* was equal to the level of control without green manure – 43.87 €·t⁻¹, and the cost of yield increment increased, compared to *Raphanus sativum*, by 6–7 times to 42.74 €·t⁻¹ of potato tubers.

Application of manure 25 t·ha⁻¹ increased the cost of potato tubers – by 5% to 45.94 €·t⁻¹ compared to the control without green manure, and with mineral fertilizer N₁₂₅P₆₃K₁₅₀ the prime cost increased by 7% to 47.03 €·t⁻¹. Compared to *Raphanus sativum* siderate, prime cost of yield growth with application of traditional organic or mineral fertilizers was by 8–10 times more expensive.

On the background of post-harvest *Raphanus sativum* siderate the maximum level of profitability for potato growing was set – 122%, which differed from the control without siderate by 38%. For green manure of *Phacelia tanacetifolia* was determined lower profitability level of potato

growing technology – 108%, which prevailed the control without green manure in terms of profitability level by 24%. Plowing green manure of *Fagopyrum sagittatum* under potatoes provided profitability level equal to the level of control without green manure – 83.6%.

The lowest profitability was determined for application of manure 25 t·ha⁻¹ under potatoes – 75.5% and mineral fertilizer N₁₂₅P₆₃K₁₅₀ – 71.5%, which was 2 times less than in the control without green manure and 3 times less compared to siderate of *Raphanus sativum*.

High economic efficiency of *Raphanus sativum* siderate is evidenced by payback calculations of additional costs for its use in potato growing. Financial return of invested money on application of *Raphanus sativum* green fertilizer was the largest – 0.44 €/€; payback of additional costs for green manure of *Phacelia tanacetifolia*, compared to *Raphanus sativum*, decreased by 60% to 0.25 €/€. Among the siderates, *Fagopyrum sagittatum* had the lowest payback – 0.06 €/€.

Additional costs were also recouped with application of manure 25 t·ha⁻¹ under potatoes – 1.44 times or mineral fertilizer N₁₂₅P₆₃K₁₅₀ – 1.26 times, but comparing to *Raphanus sativum* siderate, they were by 9.4 and 10.7 times lower.

Thus, among the backgrounds of potato fertilization, post-harvest siderate of *Raphanus sativum* prevailed by all economic indices.

CONCLUSIONS

Thus, in unstable moisture zone of the Left-Bank Forest-Steppe on the typical black soils, the most optimal conditions for the formation of the maximum potato yield and starch gathering were created with application of *Raphanus sativum* siderate. So, application of intermediate crops *Raphanus sativum* as siderate in crop rotation is a low-cost agricultural measure with maximum payback, which provides high economic efficiency of growing crops due to obtaining the lowest prime cost of production and the highest net profit and profitability.

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