

Research Article

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Relationship of potato yield and factors of influence on the background of herbological protection

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Abstract: The latest technologies for growing crops, including potatoes, are based on the use of modern mathematical models that can fairly accurately identify the impact of various factors of natural and technological nature on the object of study. Yield modeling makes it possible to adjust resource consumption indicators to obtain the maximum economic effect and minimize the negative impact on the environment. It was found that the lowest weediness of potato agroecosis (24 pcs/m^2) was formed by the complex application of Hezagard (4 L ha^{-1})

and Panthera (1 L ha^{-1}). The lowest level of actual weeds infestation had a positive effect on the yield of tubers – 27.6 t ha^{-1} (+26.6% to control) and was obtained in the variant of herbicide application. The results of correlations of potato tuber yield from factors such as weediness, density and productive moisture reserves in the arable soil layer are highlighted. It was found that the highest yield of 27.6 t ha^{-1} (+26.6% compared to the control) was obtained in the variant with the application of herbicides Hezagard (4 L ha^{-1}) and Panthera (1 L ha^{-1}). According to the results of multiple regression, it was found that the coefficient of multiple correlation is $R = 0.9985$, and the coefficient of determination is $R = 0.997$, i.e., the relationship between potato yield and experimental factors is quite close.

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1 Introduction

The study of the problem of the negative impact of weeds on crops dates back to the formation of agriculture and does not lose its relevance. The magnitude of crop losses, according to scientists and experts, varies widely and depends primarily on the level of agricultural culture [1,2].

The level of crop shortage and deterioration of the obtained products depends on the species composition of weed plants, allelopathic interaction, the size of the mass formed by them, the duration of the negative impact on cultivated plants and the period of competition during crop vegetation, weed plant height, area and density of projective cover weeds of cultivated plants, volumes of water absorption and mineral nutrition from the soil by weeds during the growing season and other factors [3–5].

Phytocenotic imperfections of modern agrophytocenoses are the reason for their constant overgrowing with weeds, the number of which has to be controlled by

agrotechnical, chemical, biological and other measures. In recent decades, the largest share has a chemical method of protection using herbicides of selective and nonselective action [6,7].

The weediness of potato agrocenosis has become so threatening that it is characterized as a national disaster and is a significant factor limiting the production of tubers. Due to the significant cost of weed protection, it is not possible to completely eradicate them, but it is necessary to reduce the number and harmfulness to a minimum [8,9].

In the technology of growing potato tubers, it is important to create optimal conditions in the soil environment. In particular, the optimal soil density for the germination of potato tubers on medium loam soils is 1–1.2 g/cm³, and on sandy 1.3–1.4 g/cm³. Due to the increase in soil density to 1.4 g/cm³ tuber yield decreases by 30–40%. The indicator of soil density affects not only the overall yield, but also the quality of tubers – their shape, size and storage capacity [10].

To obtain fast and uniform germination of potato plants, the tubers should be planted in moist soil or irrigated after planting to stimulate root development and more active germination of tubers in moist soil. Overwetting of the soil causes lack of oxygen and rot of seed tubers. On some compactive soils, heavy rainfall or irrigation can cause compaction or leaching to such an extent that tuber germination is delayed.

Excessive soil moisture during the period of “germination-beginning of tuber development” can cause the development of roots on the soil surface. Under these conditions, the root system of the culture does not penetrate deep into the soil, which is extremely important for the optimal provision of plants with moisture and the formation of above-ground mass [11,12].

From the time of planting to the emergence of potato seedlings, soil moisture should be maintained at 65–70% HB. As the potato bushes grow, their need for water increases and, reaching a peak before the budding-flowering period – 75–85% HB. During the ripening of tubers, soil moisture is maintained at the level of 60–65% HB, the processes of ripening of tubers are accelerated, and the skin on their surface is strengthened.

On light soils for a sufficient level of humidity in the range of 75–85% HB the arable soil layer requires 25–30 mm of water, on heavy soils in this soil layer – 35–40 mm of water is required. Potato – is a plant that is very demanding on soil moisture and soil aeration. This culture is hydrophilic, because it has a weak cuticle and low osmotic pressure, and potatoes are better adapted to humid conditions.

In addition, potato is sensitive to sudden changes and differences in temperature and humidity. Potato plants are characterized by two critical periods for water consumption: the first – during the growth of stolons and tuber formation; and the second is the active formation and tubers growth [13–15].

An important task of statistics is to develop methods for studying economic, biological and technical patterns, which are subject to production, and their quantitative and qualitative indicators. For this purpose, quantitative methods of statistical and economic analysis, in particular, correlation and regression, are widely used. Using this method, the relationship between the phenomena is recorded analytically in the form of mathematical expressions that reflect the relationship of factor and performance traits [16–18].

The objective of the study is to determine the dependence of potato yield on crop weediness, soil density and reserves of productive moisture in the soil. Given the characteristics of potato plants in the process of growth and development and formation of tuber yields, the study of correlations will reveal the nature of changes in the relationship between potato yields depending on the factors influencing the growing conditions.

2 Materials and methods

2.1 Study area

The research was performed during 2017–2020 on dark gray podzolic medium loam soil of the research field of NNDC of Lviv National Agrarian University. It is characterized by the following agrochemical parameters: humus profile to a depth of 55–70 cm with a humus content in the arable (0–30 cm) layer of 2.0–2.5%. The reaction of the soil solution is weakly acidic (pH – 5.5–6.5), hydrolytic acidity – 2.0–4.2 mg-eq/100 g of soil. The degree of saturation of the bases is 75–90%, content of N (according to Cornfield) – 51.2, P₂O₅ (according to Chirikov) – 92.0 and K₂O (according to Maslova) – 107.0 mg/kg of soil.

2.2 Experimental design

The crop rotation in the experiment was as following: peas (variety Gotovsky) – winter wheat (variety Myronivska 65) – potatoes (variety Volya) – spring barley (variety Soncedar).

Variants in the experiment were arranged sequentially with three repetitions. The study used a completely randomized design. The sown area of the plot is 50 m², and the accounting area is 30 m². Experiment was performed in triplicate and repeated three times.

Agrotechnical conditions of potato cultivation are generally accepted for the zone of sufficient moisture of the western forest steppe of Ukraine. The object of research is the variety Volya selection of Lviv NAU.

Actual weeds were determined in the main phases of crop vegetation and before harvesting on fixed accounting sites with an area of 0.25 m in four places of each repetition of the variant, where the number of weed plants (pieces/m²) was determined, species were identified, established their number and dominant weeds.

Soil density was determined by the method of Kaczynski M.A. by taking samples from layers 0–10, 10–20 and 20–30 cm during the growing season and before harvesting. At the same time, the reserves of available moisture in the soil were determined by the thermo-static-weight method in layers of 0–10, 10–20, 20–30 and 30–100 cm.

Scheme of the experiment of herbicide application:

1. Control (without the use of herbicide);
2. Zenkor Liquid, 1 L ha⁻¹ + Titus, 50 g ha⁻¹;
3. Zenkor Liquid, 1 L ha⁻¹ + Titus, 30 g ha⁻¹ + through 8 days Titus, 20 g ha⁻¹;
4. Roundup, 4 L ha⁻¹;
5. Hezagard, 4 L ha⁻¹ + Panthera, 1 L ha⁻¹.

2.3 Statistical analysis

Multiple regression analysis was used to analyze the relationships between independent variables (moisture, soil density) and dependent variables (crop yield). Indicator

such as the correlation coefficient shows the closeness of the linear relationship and varies in the range from –1 to 1. Minus one (–1) means full (functional) linear feedback. Connections between signs can be weak and strong (close). Their criteria are evaluated according to the Chaddock scale: 0.1 < R < 0.3: weak; 0.3 < R < 0.5: moderate; 0.5 < R < 0.7: noticeable; 0.7 < R < 0.9: high; 0.9 < R < 1: quite high. The significances of differences mean were compared using the least significant difference (LSD) test at 5% level of probability. To perform these analyses, procedures of Statistical Analysis System version 9.2 were applied.

3 Results

According to the results of the study during 2017–2020 it was found that the following weed species predominated in the potato agroecosystem on average: *Polygonum convolvulus*, *Galeopsis tetrahit*, *Thlaspi arvense*, *Chenopodium album*, *Amaranthus retroflexus*, *Echinochloa crus-galli*, *Galinsoga parviflora*, *Sonchus arvensis*, *Stellaria media*, *Equisetum arvense*, *Elytrigia repens*, etc. (Figure 1).

Note that the application of herbicides affected the state of weediness of potatoes in the experimental variants, and study indicators such as soil density and moisture depended more on climatic factors, which in the years of research differed slightly from long-term, but were typical for the western forest-steppe zone and contributed to the cultivation of potatoes (Tables 1 and 2).

Thus, it is worth noting that the density and reserves of productive soil moisture did not change significantly over the years of research and did not differ according to the experiment options. In addition, the use of herbicides affects the reduction of weediness, because in all variants of the experiment, except for the control, a 45–80% smaller

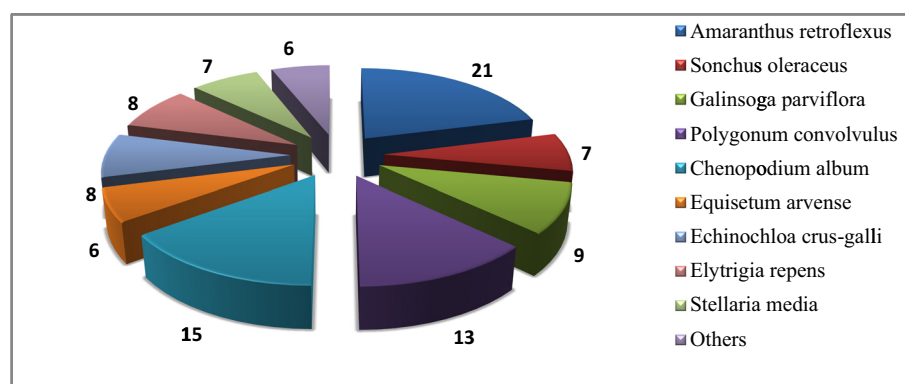


Figure 1: Species composition of weeds in the potato agroecosystem at harvesting, pcs/m² (average for 2017–2020).

Table 1: Long-term dynamics of the main climatic indicators in the western forest steppe of Ukraine

Climate indicator	Period (years)				Multi-year average value
	1981–1990	1991–2000	2001–2010	2011–2020	
Air temperature (average) (°C)	7.3	7.4	8.1	8.9	6.8
Relative air humidity (average annual on) (%)	78.9	79.4	78.3	76.6	79.6
Amount of precipitation (average) (mm)	598.2	656.1	678.5	870.1	553.4

number of weeds is observed. Also, the use of herbicides had an effect on increasing potato yields from 7 to 23% depending on the variant.

3.1 Multiple correlation coefficient

Using the multiple correlation index the proximity of the joint influence of the factors involved on the result can be estimated. This index can take values from 0 to 1, compared to the even correlation coefficient, which can take negative values.

For this reason, R cannot be used to interpret the direction of communication. The denser the actual values of the result relative to the regression line, the greater the value of $R_y(x_1, \dots, x_m)$ and the smaller the variance of the residue.

Thus, for a value of R that is close to 1, the regression equation will more clearly describe the actual data, and the influencing factors will have a stronger impact on the result. If the value of R is low and close to 0, then the studied factors have little effect on the result, and the regression equation poorly describes the actual data.

In our case, the multiple correlation coefficient is:

$$R = \sqrt{1 - \frac{s_e^2}{\sum(y_i - \bar{y})^2}} = \sqrt{1 - \frac{0.0703}{23.41}} = 0.9985.$$

Since in the experiment $R = 0.9985$, the relationship between the trait Y and factors X_i is quite strong.

The coefficient of determination is:

$$R^2 = 0.9985^2 = 0.997.$$

The closer this coefficient is to unity, the stronger the regression equation describes the behavior of Y . The coefficient of determination $R^2 = 0.997$ shows that 99.7% of the variation (fluctuations) of the effective trait – yield of potato tubers by 99.7% due to variation of independent (factor) traits, and 0.3% of variation in yield depends on the variation of factors that are not included in the regression model.

The model obtained by us according to the results of the research fully fits into the generally accepted conclusions of scientists.

4 Discussion

In Ukraine potatoes have a very important economic importance. It is an important food, fodder and technical crop. However, it has its own requirements for growing conditions. Potatoes are quite picky about moisture, as they form a large above-ground mass due to an under-developed root system. Therefore, its high productivity is observed only with sufficient soil moisture during the growing season. If soil moisture is halved, the yield of

Table 2: Factors included for the development of the regression model (average for 2017–2020)

Variant of the experiment	Actual weeds infestation (harvest) (pcs/m ²)	Soil density (0–30 cm) (planting potatoes) (g/cm ³)	Stocks of productive soil moisture (0–30 cm) (planting potatoes) (mm)	Yield of tubers (t ha ⁻¹)
1. Control (without the use of herbicide)	111	1.18	40.9	21.8
2. Zenkor Liquid, 1 L ha ⁻¹ + Titus, 50 g ha ⁻¹	29	1.21	40.1	26.1
3. Zenkor Liquid, 1 L ha ⁻¹ + Titus, 30 g ha ⁻¹ + through 8 days Titus, 20 g ha ⁻¹	26	1.19	39.2	26.4
4. Roundup, 4 L ha ⁻¹	62	1.21	39.3	23.2
5. Hezagard, 4 L ha ⁻¹ + Panthera, 1 L ha ⁻¹	24	1.20	40.6	27.6
LSD _{0.05}	0.47	0.65	0.54	0.81

potatoes decreases by 3–25%. The lowest requirements for moisture in potatoes are observed in the initial phase of growth – during germination and emergence, when seedlings and young plants form tissues using the water of the mother tuber. Potato is a semi-cold-resistant plant, most sensitive to lack of moisture during budding and tuber formation. During this period, it intensively uses various nutrients, so the lack of moisture in the soil has a significant effect on the reduction of the yield [19,20].

Also, the potato yield is affected by indicator such as the density of the soil. The high density of the soil provokes a lack of air in the soil and prevents the normal development of the underground part of the plant, thus leads to the deformation of the tubers. Soils with a low density (not more than 1.25 g/cm^3) are most suitable for potatoes. Therefore, the conditions of our study were generally favorable for obtaining a good harvest of potatoes [6,10].

In order to successfully control weeds in potato crops, it is important to know their species composition, to apply methods to control them and to conduct agriculture correctly in compliance with the system of preventing the appearance of weeds and maintaining a low level of their seeds in the soil. Chemical weed control must be based on a detailed knowledge of the environmental factors that affect the effectiveness of herbicides, both during and after their application [10,21].

Scientists have established that the effectiveness of herbicides is influenced by weather conditions, because with a sufficient level of humidity and elevated temperatures, the drug breaks down faster and is more easily absorbed by the root system of weeds. In addition, many researchers are inclined to believe that soil density also affects the effectiveness of soil herbicides, which is clearly observed in our study [21–24].

Statistical correlation–regression analysis is increasingly used in agronomy to establish regularities of relationships between quantitative and qualitative traits, to clarify the complex interrelationships of many different causes and their mutual influence on each other. With this approach, the functional dependence between traits is determined by a mathematical linear equation. Correlation–regression analysis is most often used to establish the dependence of yield, as the most effective feature, on other economic and valuable features or conditions of crop cultivation [25].

Using the coefficient of multiple correlation and the coefficient of determination, we can check the statistical significance of the equation. Thus, it is established that in the study the change of influencing factors explains 99.7% of the total variability of the result.

5 Conclusions

The latest technologies for growing crops, including potatoes, are based on the use of modern mathematical models that can fairly accurately identify the impact of various factors of natural and technological nature on the object of study.

Yield modeling makes it possible to adjust resource consumption indicators to obtain the maximum economic effect and minimize the negative impact on the environment.

It was found that the lowest weediness of potato agrocenosis (24 pcs/m^2) was formed by the complex application of Hezagard (4 L ha^{-1}) and Panthera (1 L ha^{-1}). The lowest level of actual weeds infestation had a positive effect on the yield of tubers – 27.6 t ha^{-1} (+26.6% to control) and was obtained in the variant of herbicide application.

Over the years, the climatic conditions were favorable for growing the crop: soil density and reserves of productive moisture in the arable (0–30 cm) layer of soil during planting of potato tubers were within optimal limits and were, respectively, $1.18\text{--}1.21 \text{ g/cm}^3$ and 39.2–40.9 mm.

The coefficient of multiple correlation is $R = 0.9985$, and the coefficient of determination is $R = 0.997$, which indicates a fairly close relationship between potato yield and research factors.

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