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Original Paper

Influence of the Weather Conditions on the Efficiency of Absorbents in the Vegetable Crop Rotation System and on the Stock of Productive Soil Moisture

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The purpose of the research is to study the duration of the effective action of various forms of absorbents in the vegetable crop rotation in conditions of unstable moistening of the forest-steppe of Ukraine. Research on the productivity of vegetable crops under the influence of different forms of absorbents showed varying results on different crops. There was a significant (P <0.05) increase yield from 12.7 $t \cdot ha^{-1}$ in the Badyoryi cultivar to 16.4 $t \cdot ha^{-1}$, and from 9.9 $t \cdot ha^{-1}$ in the Rutan cultivar up to 12.5 $t \cdot ha^{-1}$ following the application of the gel in both varieties of basil. Pumpkin productivity also increased under the influence of absorbents. Yield increased by 16.4% in the Siryi Ukrainskyi cultivar and 14.8% in the Yuvilei cultivar under the influence of the powder. The yield of leafy vegetables (head lettuce, leaf lettuce and spinach) increased by 8.0–11.9 grown on the background of absorbent in powder form. The increase in productive moisture reserves depending on the form of the absorbent, the year of use and the weather conditions of vegetation when using the powder min.-max. was 7.2–8.1% in May; 9.8–17.1% in June; 13.2–15.4% in July. Conclusions. The absorbent in gel form is highly effective in the first year of use, but subsequently its effectiveness declined dramatically, while the powder was less effective in the first year but became more stable in subsequent years.

Keywords: hydrogel, soil moisture, yield, mass

1 Introduction

The use of moisture-swelling polymers is considered as one of the innovative non-traditional approaches in modern agricultural technologies. Polymer hydrogels are a hydrophilic polymer material of acrylate nature (Abdallah, 2019).

1.1 Classes of Hydrophilic Polymers

Hydrophilic polymers can be divided into three categories; however, each class's products can be chemically modified to have a different set of properties.

1. Starch-based polysaccarides, such as those generated from grains like corn and wheat, are naturally occurring polymers. In the food sector, natural polymers are most frequently utilised as thickening agents.

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2. Cellulose is mixed chemically with petrochemicals to create semisynthetic polymers. A polyethylene polymer mixed with sawdust was one of the first hydrogels especially created for horticulture.
3. Petrochemicals are used to create synthetic polymers, and one of the most well-known polymers that are chemically bonded to prevent aqueous dissolution is polyacrylamide (PAM). Crosslinked polyacrylamide hydrogels are most frequently employed in horticulture, while linear chain polyacrylamides are used for water purification, sealing of canals and erosion prevention.

Various groups of polymers:

1. Vinyl alcohol-acrylic acid co-polymers which later were realized to pose potential environmental hazards (Zhang et al., 2014).
2. Starch-polyacrylo-nitrile graft polymers (polyvinyl alcohols)
3. Cross-linked polyacrylamides with acrylamide sodium co-polymers.

1.2 Application of Hydrogel in Agriculture

In dry and semi-arid areas, hydrogel polymers are essential structural components for fostering an environment favorable to plant growth. They can also be used as retention ingredients in a variety of ways, such as the following:

1. Seed coatings or chemicals that help seeds germinate.
2. Roots of seedlings are dipped before establishing.
3. Preventing chemicals that help plants develop.
4. Slow-release coating of insecticides and herbicides for protection.
5. Biocides and herbicides made of polymers.
6. Water-insoluble polymers
7. Soil rehabilitating polymers.
8. Specifically, hydrogel collects water and soluble fertilizer before releasing them at the right time for plants.

When application in the soil, particles of the absorbent polymer are located in the inter-aggregate space and gradually absorb and retain water as it infiltrates. After drying, the absorbent takes on a crystalline form and upon rehydration, it reabsorbs moisture, restoring its water-absorbing capacity even after freezing. The water absorption capacity of the polymer ranges from 30 to 500 $l \cdot kg^{-1}$ of absorbent (Gholamhoseini et al., 2018). Absorbents can effectively function for up to 8 years, during which water exchange between the soil and the polymer occurs cyclically. The cyclic absorption and release of moisture are characteristic only of polyacrylamide-type absorbents (Kabir et al., 2018; Pereira et al., 2019).

Plants, both in natural environments and in cultivation, often face environmental stress (Supare & Mahanwar, 2022). Water-absorbing polymer gels are highly effective under conditions of elevated temperature and soil moisture deficit (Oladosu et al., 2022). Shortages or excesses of heat or moisture during specific stages of ontogenesis significantly impact plant growth and development, as well as crop yield and quality. By introducing hydrogels into the root zone of the soil, an additional reservoir of moisture is created, which is necessary during critical stages of development. Studies by Cheruiyot et al. (2014) confirmed that polymers contribute to maintaining soil moisture by altering the distribution of soil particles, liquid, and gaseous phases upon water addition, increasing the liquid fraction compared to gas.

A high percentage of moisture retention when using hydrogel during active growth promotes a high intensity of photosynthesis (Montesano et al., 2015; Khadem et al., 2010). In recent years, in Ukraine, a series of works on the study of the effectiveness of absorbents in spinach crops have been published, the yield of which increased by 2.0–6.1 $t \cdot ha^{-1}$, and profitability up to 84% (Ulyanych et al., 2020), celery, the yield of which increased by 4.1–5.8 $t \cdot ha^{-1}$ (Ulyanych & Didenko, 2017), winter garlic, where the yield from the use of absorbent increased by 0.2–5.2 $t \cdot ha^{-1}$ (Yatsenko et al., 2022), cucumber, the yield of which increased by 0.3–12.1 $t \cdot ha^{-1}$ (Ternavskyi et al., 2022) and Khaini et al. (2023) – *Capsicum annuum*, Montesano et al., 2015 – cucumber) whose results indicate that absorbents affect the productivity of the studied cultures in different ways, but all results indicate an increase in the productivity of vegetable plants. About half of the studies on the effectiveness of absorbents were conducted in open fields. Various methods of hydrogel application were used, including mixing with soil, dipping seedlings, and localized application in furrows. The absorbent rates ranged from 30 to 225 $kg \cdot ha^{-1}$. Regardless of the application method and rate, a positive response of plants was observed.

Many arid and semi-arid regions face the problems of uneven distribution and insufficient amount of precipitation (Supare & Mahanwar, 2022; Dhiman et al., 2023).

In arid climate zones, absorbents are one of the best methods for mitigating unstable weather conditions and increasing the productivity of agricultural crops. Hydrogels function as a system that controls the retention and release of water containing dissolved nutrients upon absorption (Dhiman et al., 2023).

Hydrogels are used as additional supplements in plant cultivation in regions where water resources are limiting factors. The use of superabsorbent polymers mitigates the consequences and promotes drought resistance in plants. The application of hydrogels significantly reduces the amount of irrigation, especially for soils with coarse structure (Banedjschafie & Durner, 2015).

On the basis of the above, it can be stated that the study of the duration of the effective action of various absorbents in the form of gel and powder in vegetable crop rotation is undoubtedly relevant. The purpose of the research is to study the duration of the effective action of various forms of absorbents in vegetable crop rotation (*Ocimum basilicum* L.; *Lycopersicum esculentum* Mill; *Cucurbita maxima* Duch.; *Lactuca sativa* L. var. *capitata*, *Lactuca sativa* L. var. *secalina*, *Spinacia oleracea* L.) in conditions of unstable moisture in the Forest-Steppe of Ukraine, to determine the productivity of vegetables and the effect of various forms of absorbents on the reserves of productive moisture during the growing season of plants.

2 Material and Methods

2.1 Location of Study

Research on the influence of various forms of superabsorbent was conducted in 2019–2023 in the research field of Vegetable Growing Department of Uman National University of Horticulture according to the methods described by Bondarenko & Yakovenko (2001). Geographical coordinates in Greenwich Mean Time: 48° 46′ north latitude, 30° 14′ east longitude and 245 m above sea level.

2.2 Test Crop

Ocimum basilicum L. (2019–2021). The total area of the experiment was 400 m^2, the plot size was 10 m^2. Seedlings of basil cultivars Badyoryi and Rutan were grown in a cassette method with a cell size of 6 × 6 cm. The plants were transplanted in open ground in the phase of three leaves (May 15–20). Row spacing adopted was 50 × 30 cm, totaling 66,667 thousand plants·ha^{-1}. The two-factor experiment consisted in the use of TM "MaxiMarin" superabsorbent in the form of gel and powder.

Lycopersicum esculentum Mill (2020–2022). The area of the experimental site is 400 m^2. Tomatoes were sown on May 5–10 according to the scheme of 70 × 30 cm. The scheme of the two-factor experiment included hybrids of Bobcat F_1 and Usman F_1 tomatoes, which were grown according to generally accepted technology, and "MaxiMarin" absorbents in the form of granules and gel. Absorbents were used under the predecessor – basil.

Cucurbita maxima Duch. (2021–2023). The area of the experimental site is 400 m^2. Large-fruited pumpkin was sown on May 5–10 according to the scheme of 1.4 × 1.4 m (5.1 thousand units·ha^{-1}). The scheme of the two-factor experiment included large-fruited pumpkin cultivars Siryi Ukrainskyi and Yuvilei, which were grown according to generally accepted technology, and "MaxiMarin" absorbents in the form of granules and gel. Absorbents were used under the forerunner – basil in 2019–2021.

Lactuca sativa L. var. *capitata*, *Lactuca sativa* L. var. *secalina*, *Spinacia oleracea* L. (2022–2023) were grown in the experimental field of Vegetable Growing Department of Uman National University of Horticulture according to a scheme that included six options. Leaf and head lettuce were sown according to the 45 × 20 cm scheme, which amounted to 111,111 thousand pieces plant·ha^{-1} Dublyanskyi and Akane lettuce cultivars were used; head salad – Godar and Fairly cultivars. Spinach hybrids Gnu F_1 and Spiros F_1 were sown according to the scheme of 45 × 10 cm, which amounted to 222,222 thousand pieces plant·ha^{-1}.

2.3 Experimental Materials

Absorbents TM "MaxiMarin" in the form of a gel is a cationic polyacrylamide copolymer – a highly effective drug is a complex of extracts of plant origin containing polysaccharides, glucosides, amino acids and betaines, enriched with vitamins and microelements. The composition includes a biostimulator of the development of the root system Radifarm (manufactured by Valagro). The composition of the gel includes the insecticide Aktara 25 WG (manufactured by Syngenta). MaxiMarin complex gel works in the soil regardless of weather conditions. Absorbent in the form of powder (granules) is an anionic polyacrylamide copolymer without additional components. According to the data provided by the manufacturer, the coefficient of effectiveness of both forms of absorbents TM "MaxiMarin" is 400.

2.4 Application Methods

During transplantation, an absorbent in the form of a gel was used, thoroughly mixing 2 g of hydrogel·1 L^{-1} of water to prepare, let the solution stand for half an hour. Plant roots were immersed in the solution, and then transplanted into the field. Absorbent in the form of granules – 15 kg·ha^{-1}, applied locally in furrows to a depth of 20–25 cm before planting seedlings.

The study was carried out by the method of a two-factor (indicate the factors and their levels Factor A: cultivar (hybrid) – 2; Factor B: growing method – 3 (without

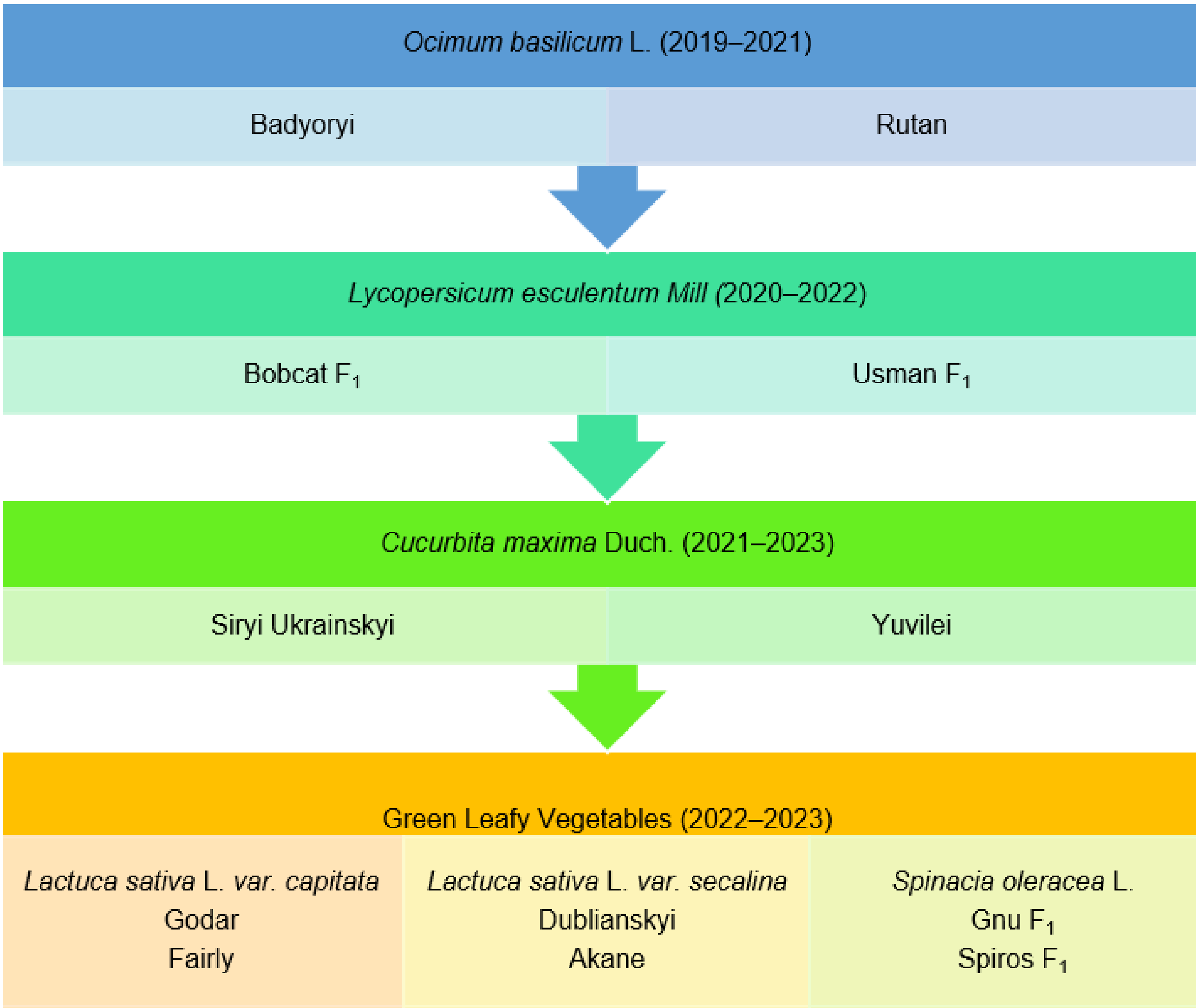

Figure 1 Logical diagram of placement of experiment variants in time

absorbent; absorbent in the form of a gel; absorbent in the form of powder)) experiment with randomized complete block design in four replications.

Soil moisture was determined by thermostatic weight method according to the formula:

$$W\ (\%) = \frac{(A-B)}{(B-C)} \times 100 \qquad (1)$$

where: A – the mass of the box with raw soil (g); B – weight of the box with dry soil (g); C – the mass of the empty box (g)

For description of growing conditions of trees hydrothermal coefficient (HTC) has been used, it is correlation between amount of precipitation in the time period, when average day temperature exceeds +10 °C, and sum of temperature in degrees in the very same period. Hydrothermal coefficient has been calculated by applying formula:

$$HTC = \frac{\sum x}{\sum t} \times 100 \qquad (2)$$

where: $\sum x$ and $\sum t$ – accordingly sum of precipitations and temperatures in the period, when the temperature has not been lower than 10 °C (HTC from 1.0 till 2.0 – humidity is sufficient; HTC >2.0 – immoderately humid; HTC <1.0 – insufficient humidity; HTC from 1.0 till 0.7 – dry; HTC from 0.7 till 0.4 – very dry

2.5 The Weather Conditions in the Years of Research

The analysis of the given data on air temperature and the amount of atmospheric precipitation during the research period was generally characterized as favorable for the growth and development of the test crops. A characteristic feature of the 2019–2020 agricultural year was the elevated temperature background, insufficient precipitation in the summer and autumn periods. The average air temperature of the agricultural year was 10.8 °C, i. e. it was 3.4 °C higher than the long-term average. The long summer rainfall deficit was a limiting factor for the growth and development of agricultural crops. A characteristic feature of the 2020–2021 agricultural year was a favorable temperature background and a sufficient amount of precipitation.

The average air temperature of the agricultural year was 9.2 °C, i.e. it was only 0.4 °C higher than the long-term average. At the same time, in the cold period (December–March), the total increase in temperature was 1.4 °C, and in the warm period (April–September), the total decrease was 1.9 °C. The total amount of precipitation for the year was 655.7 mm, which exceeded the long-term average by 69 mm. The weather conditions of the 2021–2022 agricultural year were characterized by a significantly lower level of precipitation compared to previous years and multi-year average data, and the temperature regime was close to the multi-year average data. In general, weather conditions significantly influenced the formation of the productivity of vegetable crops.The growing season of 2020 was quite favorable for the growth and development of plants, as it had a sufficient amount of precipitation and, accordingly, a sufficient amount of reserves of productive moisture in the soil, which created optimal conditions. Thus, the growing season of plants for 2021 was characterized as the most favorable due to a large amount of precipitation. The vegetation period of 2022 was characterized as unfavorable for growth and development due to long droughts and insufficient precipitation in critical periods. Analysis of weather conditions for the 2022–2023 agricultural year showed that the current year was significantly lower than the long-term average in terms of precipitation, and the average monthly temperature for the year was 1.6 °C higher than the long-term average.

The analysis of weather conditions and the level of their variability for the period 2019–2023 was carried out on the basis of the coefficient of significance of deviations (C_{sd}) of the elements of the agrometeorological regime of each of the studied years from the multi-year average per year according to the formula:

$$C_{sd} = \frac{(Xi - X^{-})}{\sigma} \quad (3)$$

where: C_{sd} – coefficient of materiality of deviations; Xi – elements of current weather; X – an indicator

Table 1 Climate chart for the study period (2019–2023), (data of the Meteorological Station 'Uman')

Year / Month	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
	precipitation (mm)											
Average (1970–2023)	38.0	34.0	36.0	41.0	52.0	81.0	68.0	49.0	61.0	43.0	43.0	40.0
2019	55.1	23,8	16.3	14.0	35.6	69.8	33.8	19.2	30.6	10.3	14.0	45.7
2020	12.7	50.5	23.9	21.0	101.0	70.4	21.4	17.1	27.4	81.5	19.4	32.6
2021	59.7	43.2	32.4	49.9	56.4	104.7	89.8	69.9	16.2	7.0	21.2	91.2
2022	23.9	7.2	13.4	57.7	22.4	36.3	28.1	44.4	99.2	10.0	71.8	53.1
2023	6.0	20.5	27.2	129.6	42.4	15.8	92.5	51.3	40.0	22.0	17.2	39.4
	air temperature (°C)											
Average (1970–2023)	-3.4	-2.3	2.5	9.7	15.4	19.0	20.9	21.1	14.5	8.3	2.8	-1.8
2019	-4.7	0.5	4.5	9.6	17.0	23.0	20.0	20.7	15.6	10.0	5.5	2.2
2020	0.4	2.2	6.3	9.2	12.5	20.9	2.6	21.2	17.8	12.7	3.7	0.0
2021	-2.3	-3.8	2.0	7.4	14.0	19.8	23.0	20.3	13.0	7.2	4.7	-1.0
2022	-1.3	1.8	2.0	8.6	14.5	20.5	21.0	21.7	13.1	10.0	3.7	-0.4
2023	0.2	-0.2	5.1	8.8	15.4	19.6	21.3	21.1	16.9	13.0	4.4	-0.2
	hydrothermal coefficient (HTC), norm – 1.0											
2019	–	–	–	–	0.7	1.0	0.5	0.3	0.7	0.3	–	–
2020	–	–	–	–	2.6	1.1	0.3	0.3	0.5	2.1	–	–
2021	–	–	–	–	1.3	1.8	1.3	1.1	0.4	–	–	–
2022	–	–	–	–	0.5	0.6	0.4	0.7	2.5	0.3	–	–
2023	–	–	–	–	0.6	0.5	1.4	0.7	0.7	0.3	–	–

of the average multi-year value; σ – the mean square deviation

The level of coefficients of materiality of deviations corresponds to the gradation:

- C_{sd} = <1 – conditions are close to long-term averages;
- C_{sd} = 1.1–2 – the conditions differ significantly from the long-term averages;
- C_{sd} >2 – rare conditions close to extreme.

The results of the analysis of the course of weather conditions for the studied period.

The course of agrometeorological factors over the years of research created suitable conditions for the growth, development and yield formation of the studied vegetable crops. The analysis of the typicality of weather conditions during the growing season (March–August) by the amount of precipitation and the coefficient of significance of deviations (C_{sd}) showed that most months were close to the average multi-year data, namely March 2020, 2021, 2023, April 2019, 2020, 2021, March 2019 and 2022, May 2020 and 2022, June 2022, July 2020 and 2022, and August 2020. April and June 2023 were characterized by extreme rainfall (Table 2).

The analysis of the typicality of weather conditions during the growing season (March–August) in terms of air temperature and the coefficient of significance of deviations (C_{sd}) showed that most months were close to the average multi-year data, namely March 2019, 2021, 2022, 2023, April 2019, 2020, 2022, 2023, May 2019, 2021, 2022, 2023, June 2021, 2023, July 2019, 2020, 2022, 2023, August 2019, 2020, 2021, 2022, 2023 To the conditions, which significantly differed from long-term data, we can include March 2020, April 2021, May 2020, June 2020 and 2022. June 2019 and July 2021 were characterized by extreme conditions in terms of air temperature (Table 2).

The weather conditions of the growing seasons of 2019–2023 differed according to the main meteorological indicators, so the effectiveness of the studied measures was objectively evaluated, and the obtained data were reliable.

The soil was black, puddle, heavy loam with a well-developed humus horizon (about 2.9% of humus) (Krupskiy&Polupan,2018)(Table3),inthedeepof40–45cm. Soil pH was determined in water (soil to water ratio 1 : 1). The electrical conductivity (EC) of the soil suspension was measured using the conductivity meter. The P and K were determined by the ammonium bicarbonate--diethylenetriaminepentaacetic acid (ABDTPA) method (Ryan et al., 2001).

Air-dry soil was used for analysis 16 samples were taken from each site, mixed to a homogeneous mass and 4 samples weighing 200 g were taken, which were then analyzed in four repetitions.

2.6 *Water Absorbency*

There are different methods to determine the water absorbency or swelling (times) or swelling degree (%). Jamnongkan & Kaewpirom (2010) and Latif et al. (2016) both reported the following method: The dry hydrogel is weighed and immersed in deionised water. Soaking was carried out for 300 minutes. At regular time intervals, the swollen hydrogel is taken out, wiped gently on the surface with tissue/filter paper to remove

Table 2 Coefficients of significance (C_{sd}) of precipitation and air temperature deviations from multi-year averages (2019–2023)

Month	Precipitation					Air temperature				
	2019	2020	2021	2022	2023	2019	2020	2021	2022	2023
I	0.8	-1.2	1.0	-0.7	-1.5	-0.6	1.9	0.5	1.0	1.8
II	-0.7	1.1	0.6	-1.9	-0.9	1.1	1.8	-0.6	1.7	0.8
III	-1.2	-0.8	-0.2	-1.4	-0.5	0.7	1.3	-0.2	-0.2	0.9
IV	-0.7	-0.5	0.2	0.5	2.4	-0.1	-0.3	-1.3	-0.6	-0.5
V	-0.6	1.9	0.2	-1.2	-0.4	0.9	-1.6	-0.8	-0.5	0.0
VI	-0.4	-0.4	0.8	-1.6	-2.3	3.5	1.5	0.6	1.2	0.5
VII	-1.1	-1.6	0.7	-1.3	0.8	-1.0	0.7	2.2	0.1	0.4
VIII	-1.4	-1.5	1.0	-0.2	0.1	-0.3	0.1	-0.6	0.4	0.0
IX	-0.9	-1.0	-1.3	1.2	-0.6	0.6	1.8	-0.8	-0,8	1.3
X	-1.2	1.5	-1.4	-1.3	-0.8	0.7	1.8	-0.4	0.7	1.9
XI	-1.5	-1.2	-1.1	1.5	-1.3	1.4	0.5	1.0	0.5	0.8
XII	0.2	-0.3	2.1	0.5	0.0	2.4	1.1	0.5	0.8	1.0

Table 3 Chemical properties of soil

Parameter	Value				
	2019	2020	2021	2022	2023
Organic carbon %	2.02	2.07	2.09	1.90	2.05
Acidity (pH)	6.33	6.28	5.91	6.10	6.41
Electrical conductivity (EC) (μS·cm^{-1})	23.12	23.96	23.52	24.52	24.20
Extractable P (ABDTPA) (mg·kg^{-1})	116.40	107.07	98.24	100.69	102.8
Extractable K (ABDTPA) (mg·kg^{-1})	132.02	128.90	116.94	123.15	119.55
NO_3N (mg·kg^{-1})	70.43	61.74	61.55	68.71	61.48

excess water, weighed and re-immersed in the water. The formula used is 4.

Degree of swelling:

$$SD\% = \frac{(Ws - Wd)}{Wd} \times 100 \tag{4}$$

where: *Ws* – the swollen weight; *Wd* – the dry weight of hydrogel (Jamnongkan & Kaewpirom (2010), Latif et al. (2016)

The statistical processing of the obtained results was carried out with the calculation of the arithmetic mean (*x*) and the standard deviation (SD), calculated using Microsoft Excel 2019. Correlation dependencies were determined using the Statistica 12 program.

3 Results and Discussion

The studies conducted on basil crops showed a significant impact of different forms of hydrogels on productivity indicators. It was found that the application of hydrogel in gel form was more effective for the varieties Badyoryi and Rutan during the years of the study. In 2019, the plant weight index when using absorbent in the form of a gel was 319.6 g, which is 6.7% more than the control in Badyoryi cultivar, and 217.7 g, which is 3.8% more than the control in Rutan cultivar. The same trend can be seen in 2020 and 2021 (+7.7 in Badyoryi cultivar and 11.6% in Rutan cultivar; depending on the variety in 2020 and 6.5 and 5.5% according to the variety in 2021). Absorbent in powder form also caused an increase in this indicator in both grades (+3.3 and 2.1% in 2019, 4.5 and 7.3% in 2020 and 1.0 and 3.7% in 2021 to control depending on the variety). A statistically significant increase in the mass of leaves was obtained in Rutan cultivar on the variant with the application of an absorbent in the form of a gel during the entire period of research, and in Badyoryi cultivar only in 2020. In both varieties, a significant increase in leaf mass was observed only in 2020.

The "MaxiMarin" absorbent in granular (powder) form increased the yield of basil for both varieties by (+1.9 and 1.8 t·ha^{-1}). Higher yield figures were recorded when the absorbent was applied in gel form. Thus, the yield of the Badyoryi and Rutan varieties was 16.4 and 12.5 t·ha^{-1}, respectively, exceeding the control for each variety by 29.6% and 26.5%, or by 3.7 and 2.6 t·ha^{-1}, respectively (Table 4).

Table 4 Productivity of *Ocimum basilicum* L. (1 year of application of absorbents), (2019–2021)

Cultivar (Factor A)	Form of absorbent (Factor B)	Mass of leaves (g)				Yield (t·ha^{-1})			
		2019	2020	2021	Xmed	2019	2020	2021	Xmed
Badyoryi	control	299.6	354.1	369.4	341.0	9.9	11.2	16.8	12.7
	gel	319.6	381.5	393.5	364.9	15.3	17.0	16.9	16.4
	powder	309.6	370.0	373.2	351.0	13.2	13.7	16.8	14.6
Rutan	control	209.7	259.2	346.2	276.0	6.9	7.7	15.0	9.9
	gel	217.7	289.6	363.7	290.4	10.3	11.6	15.6	12.5
	powder	214.2	278.2	359.1	279.5	9.1	10.3	15.5	11.7
	Xmed	261.8	322.1	367.5	317.0	10.8	11.9	16.1	12.9
	SD	48.3	47.9	14.4	36.1	2.74	2.88	0.75	2.07
	CV (%)	18	15	4	11	25	24	5	16
	$LSD_{0.5}$ A	6.84	9.17	12.94	10.94	0.46	0.69	0.76	0.36
	B	8.38	11.23	15.85	13.40	0.56	0.84	0.93	0.44
	A × B	11.85	15.88	22.42	18.95	0.79	1.19	1.31	0.63

Table 5 Productivity of *Lycopersicum esculentum* Mill (2 years after application of absorbents), (2020–2022)

Cultivar (Factor A)	Form of absorbent (Factor B)	Mass of fruit, g				Yield, t ha-1			
		2020	2021	2022	Xmed	2020	2021	2022	Xmed
Bobcat F_1	control	180.0	130.0	152.0	154.0	50.4	23.7	35.6	36.5
	gel	189.0	135.0	160.0	161.3	64.3	27.8	38.1	43.4
	powder	184.0	133.0	170.0	162.3	58.9	29.7	42.2	43.6
Usman F_1	control	155.0	119.0	147.0	140.3	49.6	24.8	40.1	38.2
	gel	162.0	124.0	155.0	147.0	61.6	28.5	41.1	43.7
	powder	159.0	122.0	164.0	148.3	57.2	30.6	44.7	44.2
	Xmed	171.5	127.2	158.0	152.2	57.0	27.5	40.3	41.6
	SD	15	6	8	9	6	3	3	3
	CV (%)	8	5	5	6	10	10	8	8
	$LSD_{0.5}$ A	7.70	4.90	4.22	7.11	2.17	1.05	1.55	1.72
	B	9.44	6.01	5.17	8.70	2.66	1.29	1.90	2.11
	A × B	13.35	8.50	7.31	12.31	3.76	1.83	270	2.98

In 2019 and 2020, due to climatic conditions close to long-term data and typical for the research area, the absorbent materials showed reliable effectiveness. In 2021, due to an atypically large amount of precipitation relative to the climatic norm, the impact of absorbent materials was minimal, as can be seen from the coefficient of variation, which was large in 2019 and 2020 – 25 and 24% and small in 2021 – 5%.

The use of absorbents contributed to an increase in fruit weight by 2.3–4.5% compared to the control. The hybrid Bobcat F_1 reacted more noticeably, the increase in fruit weight when using powder was 4.5%, gel – 2.3% (Table 5).

In Usman F_1 hybrid, the weight of the fruit increased by 4.4 and 2.6%, respectively, according to the variant with the application of powder and gel. Usman F_1 hybrid was characterized by a 11.4–11.7% lower fruit mass compared to Bobcat F_1 hybrid. A significant increase in fruit mass was noted only in 2022, when the amount of precipitation was significantly lower than the multi-year mark, while the yield increased significantly during the entire period of research only in the option of growing tomatoes on the background of absorbent in the form of powder.

The yield of tomatoes with the use of absorbent materials increased significantly. Thus, when using an absorbent in the form of granules, the yield increased by 27.1 and 24.0%, respectively, for the hybrids Bobcat F_1 and Usman F_1.

According to the obtained data it can be seen that in the future the influence of absorbents was significantly

Table 6 Productivity of *Cucurbita maxima* Duch. (3 years after application of absorbents), (2021–2023)

Cultivar (Factor A)	Form of absorbent (Factor B)	Mass of fruit (kg)				Yield ($t \cdot ha^{-1}$)			
		2021	2022	2023	Xmed	2021	2022	2023	Xmed
Siryi Ukrainskyi	control	9.24	7.44	9.50	9.24	36.3	26.6	40.7	36.3
	gel	9.75	8.00	9.83	9.75	38.3	31.4	42.8	38.3
	powder	10.01	8.18	9.88	10.01	41.1	33.6	45.9	41.1
Yuvilei	control	9.68	7.81	9.90	9.68	34.6	27.9	42.4	34.6
	gel	10.12	8.05	10.15	10.12	37.9	28.8	47.1	37.9
	powder	10.34	8.37	10.35	10.34	39.5	32.9	48.0	39.5
	Xmed	9.86	7.98	9.94	9.86	37.9	30.2	44.5	37.9
	SD	0.4	03	0.3	0.3	2.1	2.6	2.7	2.2
	CV (%)	4	4	3	3	6	9	6	6
	$LSD_{0.5}$ A	0.35	0.29	0.44	0.28	0.97	1.13	2.42	1.23
	B	0.43	0.35	0.54	0.35	1.19	1.39	2.96	1.51
	A × B	0.61	0.50	0.76	0.49	1.68	1.96	4.19	2.13

less and the productivity of plants was more dependent on weather conditions. The effect of different forms of absorbent on the third year after application showed a more significant effect of the powder compared to the gel. So, on average, over the years of research, the weight of the large-fruited pumpkin fruit increased by 7.2% (0.6 kg) in Siryi Ukrainskyi cultivar and 6.1% (0.6 kg) in Yuvilei cultivar, while on the background of the absorbent in the form of a gel, the increase fruit weight was 5.3% (0.5 kg) and 3.4% (0.3 kg) according to the variety. The yield of fruits increased to 16.4%, the variants with absorbents in the form of powder were more effective, where the yield of pumpkin cultivar Siryi Ukrainskyi increased by 5.7 t·ha^{-1} (16.4%), and of Yuvilei cultivar by 5.2 t·ha^{-1} (14.8%). Cultivation of pumpkin on the background of absorbent in the form of a gel contributed to an increase in yield by only 3.0% in both varieties, or 8.6 and 8.5%, respectively, according to the variety. The data show that during the entire period of research, a s significantly higher yield was obtained in the variant with an absorbent in the form of a powder (Table 6).

Several marker crops were planted in 2022 and 2023, namely head lettuce, leaf lettuce and spinach, as these crops have a short growing season and can show reliable results.

The mass of lettuce heads increased significantly only in 2023, which was influenced by the weather conditions during the research period. Growing head lettuce on the background of an absorbent in the form of powder increased this indicator by 8.5 and 6.1%, according to the cultivar, and the yield increased by 11.9 and 10.2%, or 1.9 t·ha^{-1} in both cultivars.

Thus, on average over the years, the weight of lettuce leaves when grown on the background of absorbent in the form of powder increased by 8.3% or 13.8 g in Dublyanskyi cultivar and by 8.7% or 16.2 g in Akane, while on the background of absorbent in in the gel form, the weight of the leaves increased by only 4.9% or 8.1 g and 4.6% or 8.6 g, respectively, according to the variety. The yield of leaf lettuce grown on the background of absorbent in the form of powder increased by 9.3% or 1.7 t·ha^{-1} in Dublyansky cultivar and 9.7% or 2.0 t·ha^{-1} in Akane cultivar. A significant increase in yield over the years was noted in both varieties grown on the background of absorbent in the form of powder (Table 7).

The mass of spinach leaves grown on the background of absorbent in the form of powder increased by 7.0 and 9.2% or 4.3 and 5.5 g·plant^{-1}. according to the hybrid Gnu F$_1$ and Spiros F$_1$, while the yield increased by 1.6 and 1.9

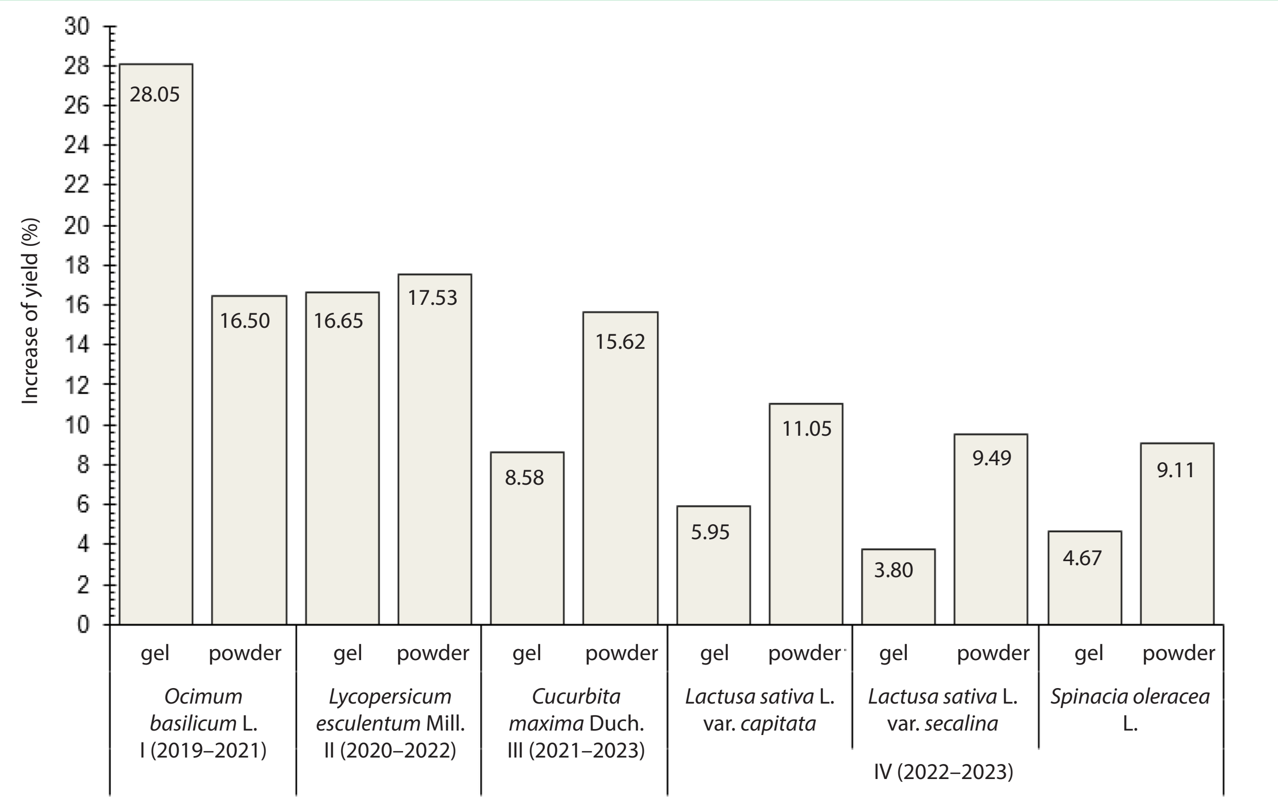

Figure 2 Dynamics of yield growth of the studied crops under the influence of various forms of absorbents
I – a year of application of absorbents; II – a year after the application of absorbents; III – a year after the application of absorbents; IV – a year after the application of absorbents

Table 7 Productivity of salad vegetables (4th year after application of absorbents), (2022–2023)

Lactuca sativa L. var. *capitata*							
Cultivar/hybrid (Factor A)	Form of absorbent (Factor B)	Mass of leaves (head), (g)			Yield ($t \cdot ha^{-1}$)		
		2022	2023	Xmed	2022	2023	Xmed
Godar	control	212.4	199.3	205.9	17.0	15.9	15.9
	gel	220.1	212.2	216.2	17.6	17.0	17.0
	powder	229.0	217.6	223.3	18.8	17.8	17.8
Fairly	control	260.2	234.4	247.3	20.8	18.8	18.8
	gel	269.1	247.1	258.1	21.5	19.8	19.8
	powder	273.0	252.0	262.5	22.4	20.7	20.7
	Xmed	244.0	227.1	235.5	19.7	18.3	18.3
	SD	24.2	19.0	21.5	2.0	1.6	1.6
	CV (%)	10	8	9	10	9	9
	$LSD_{0.5}$ A	10.82	7.19	6.34	0.63	0.45	0.67
	B	13.25	8.81	7.76	0.77	0.55	0.83
	A × B	18.74	12.45	10.98	1.09	0.78	1.17
Lactuca sativa L. var. *secalina*							
Dublyanskyi	control	198.3	134.6	166.5	21.6	14.7	18.1
	gel	205.1	144.0	174.6	22.2	15.6	18.9
	powder	212.4	148.0	180.2	23.4	16.3	19.8
Akane	control	208.0	162.0	185.0	22.7	17.7	20.2
	gel	216.0	171.2	193.6	23.3	18.5	20.9
	powder	223.3	179.0	201.2	24.6	19.7	22.1
	Xmed	210.5	156.5	183.5	22.9	17.1	20.0
	SD	8.0	15.6	11.5	1.0	1.7	1.3
	CV (%)	4	10	6	4	10	7
	$LSD_{0.5}$ A	8.01	5.99	5.07	0.74	0.35	0.76
	B	10.71	7.33	6.21	0.90	0.43	0.93
	A × B	13.88	10.37	8.78	1.28	0.62	1.32
Spinacia oleracea L.							
Gnu F_1	control	68.7	56.2	62.5	21.8	17.8	19.8
	gel	70.3	59.1	64.7	22.5	18.9	20.7
	powder	71.6	62.0	66.8	22.9	19.8	21.4
Spiros F_1	control	64.5	55.0	59.8	20.4	17.4	18.9
	gel	65.9	58.1	62.0	21.1	18.6	19.8
	powder	68.5	62.0	65.3	21.9	19.8	20.9
	Xmed	68.3	58.7	63.5	21.8	18.7	20.3
	SD	2.4	2.7	2.3	0.8	0.9	0.8
	CV (%)	4	5	4	4	5	4
	$LSD_{0.5}$ A	2.92	1.49	1.68	0.91	0.45	0.48
	B	3.58	1.82	2.06	1.11	0.55	0.59
	A × B	5.06	2.58	2.92	1.58	0.78	0.84

t·ha^{-1} or 8.0 and 10.2%. Analyzing the obtained data by year, it can be seen that the mass of leaves increased statistically significantly only in 2023 on the background of absorbent in the form of powder, while on average over the years significantly higher indicators of spinach productivity were obtained in variants on the background of both forms of absorbents.

The significant increase in the productivity of salad vegetables in 2023 on the background of absorbent in the form of a gel is explained by a significantly lower amount of precipitation compared to 2022, where a large amount of precipitation neutralized the effect of absorbents.

The high increase in tomato yield is explained by the sufficient amount of precipitation during the research period and the powder was applied locally under the predecessor, and after tillage the absorbents were distributed more evenly in the plow layer, which obviously influenced the greater efficiency compared to the previous crop (basil). The averaged data show that the absorbent in the gel form is highly effective only in the first year of use, while the absorbent in the powder form is less effective than the gel in the first year of use, but it provides a stable duration of its effective action, which is longer, which confirmed by the increase in productivity (yield) of vegetable crops (Fig. 2).

The study of reserves of productive moisture in the arable layer showed a significant difference both between cultivars/hybrids of the studied crops and between crops in general. Determination of moisture reserves in the basal layer of the soil in basil showed a significant increase in moisture reserves during the growing season, regardless of the form of the absorbent in Badyoryi cultivar and only in June and July in Rutan cultivar (Table 8).

Tomato cultivation on the background of absorbents introduced under the predecessor also contributed to a significant increase in soil moisture reserves in May and June, regardless of the absorbent and the hybrid, and in July, the amount of productive moisture in the hybrid Usman F_1 on the background of the gel was less, from which it can be assumed that this hybrid needs and consumes more moisture (Table 9).

The effectiveness of absorbents for the accumulation and preservation of productive moisture in the arable layer of the soil under the pumpkin varied significantly, both between varieties and between months of vegetation. A significantly higher amount of moisture was observed in May–June only in Siryi Ukrainskyi cultivar against the background of the absorbent in the form of powder, and in Yuvilei cultivar – only in May, but in July the moisture reserves leveled off due to precipitation and its amount increased significantly regardless of the variety or form of the absorbent (table 10).

The reserves of productive moisture in the crops of salad vegetables in most variants increased significantly against the background of both forms of absorbent, only in *Lactuca sativa* L. var. *capitata* this indicator increased significantly on the background of powder in May and insignificantly on any variant in June (table 11).

The given data on the dynamics of the growth of productive moisture reserves depending on the form of the absorbent, the year of use and the weather conditions of vegetation and vegetable crops indicate that the absorbent in the form of a powder is more

Table 8 Stock of productive moisture in the basal layer of *Ocimum basilicum* L. (1 year of application of absorbents), (2019–2021)

Cultivar (Factor A)	Form of absorbent (Factor B)	May	June	July
Badyoryi	control	44.2	32.4	14.1
	gel	58.7	39.7	17.5
	powder	49.9	37.3	15.8
Rutan	control	44.0	27.0	11.8
	gel	55.5	35.7	14.8
	powder	45.5	32.1	13.5
	Xmed	49.6	34.0	14.6
	SD	5.7	4.1	1.8
	CV (%)	12%	12%	12%
	$LSD_{0.5}$ A	1.31	1.14	0.49
	B	1.61	1.39	0.60
	A × B	2.28	1.97	0.85

Table 9 Stock of productive moisture in the basal layer of *Lycopersicum esculentum* Mill (2 years after application of absorbents), (2020–2022)

Hybrid (Factor A)	Form of absorbent (Factor B)	May	June	July
Bobkat F_1	control	34.4	31.6	13.6
	gel	38.9	33.5	15.2
	powder	39.7	34.3	16.1
Usman F_1	control	33.2	27.0	12.8
	gel	36.2	28.7	13.3
	powder	36.7	29.9	14.4
	Xmed	36.5	30.8	14.2
	SD	2.3	2.6	1.1
	CV (%)	6%	8%	8%
	$LSD_{0.5}$ A	1.14	0.97	0.45
	B	1.40	1.19	0.55
	A × B	1.98	1.69	0.78

Table 10 Stock of productive moisture in the basal layer of *Cucurbita maxima* Duch. (3 years after application of absorbents), (2021–2023)

Cultivar (Factor A)	Form of absorbent (Factor B)	May	June	July
Siryi Ukrainskyi	control	34.0	31.0	20.5
	gel	36.8	32.9	21.7
	powder	38.5	34.1	22.6
Yuvilei	control	32.1	30.5	17.9
	gel	33.6	33.1	20.9
	powder	35.2	33.8	21.9
	Xmed	35.0	32.6	20.9
	SD	2.1	1.3	1.5
	CV (%)	6	4%	7
	$LSD_{0.5}$ A	1.73	1.19	0.44
	B	2.12	1.46	0.55
	A × B	3.00	2.07	0.77

Table 11 Stock of productive moisture in the basal layer of salad vegetables (4th year after the application of absorbents), (2022–2023)

Cultivar/Hybrid (Factor A)	Form of absorbent (Factor B)	*Lactuca sativa* L. var. *capitata*		*Lactuca sativa* L. var. *secalina*		*Spinacia oleracea* L.	
		May	June	May	June	May	June
Godar/ Dublianskyi/ Gnu F_1	control	36.3	29.6	35.1	30.6	34.2	27.5
	gel	37.6	30.8	38.0	32.0	36.0	29.5
	powder	39.5	31.9	39.0	34.1	36.5	31.4
Fairly/ Akane/ Spiros F_1	control	34.3	27.0	33.3	29.8	33.0	25.6
	gel	35.9	32.1	36.5	31.7	34.6	29.0
	powder	37.0	34.0	37.4	33.7	35.5	30.8
	Xmed	36.8	30.9	36.8	30.9	36.8	30.9
	SD	1.6	2.2	1.6	2.2	1.6	2.2
	CV (%)	4%	7%	4%	7%	4%	7%
	$LSD_{0.5}$ A	1.33	1.53	1.47	0.73	0.93	0.93
	B	1.63	1.88	1.81	0.89	1.14	1.15
	A × B	2.31	2.66	2.56	1.27	1.61	1.62

effective in terms of duration of action in crop rotation (Fig. 2). The increase in the reserves of productive moisture with using of absorbent in the form of gel was noted in the following min.-max. ranges: 4.2–29.5% in May; 5.3–27.5% in June; 8.0–25.1% in July; for the use of powder min.-max. was 7.2–8.1% in May; 9.8–17.1% in June; 13.2–15.4% in July.

The analysis of the averaged percentages of the increase in moisture reserves again showed that the absorbent in gel form is highly effective in the first year of using, but subsequently its effectiveness decreases sharply relative to the first year and relative to the powder, while the powder is less effective in the first year but more stable during the following years (Fig. 3).

In the process of statistical analysis, a high correlation was found according to the Chaddock scale – $r = 0.77$ between the reserves of productive moisture in the soil (mm) and the hydrothermal coefficient: $y = 7.5071 + 20.8985*x$, where x is an indicator of the hydrothermal coefficient, y – reserves of productive moisture in the arable layer of the soil (0–30 cm), mm (Figure 4).

According to the results of earlier studies, the absorbent applied to the soil is most effective in arid conditions. Therefore, the weather conditions in years with the amount of precipitation higher than the long-term data did not contribute to the full disclosure of the moisture storage potential of the hydrogel composite. In addition, the physical indicators of

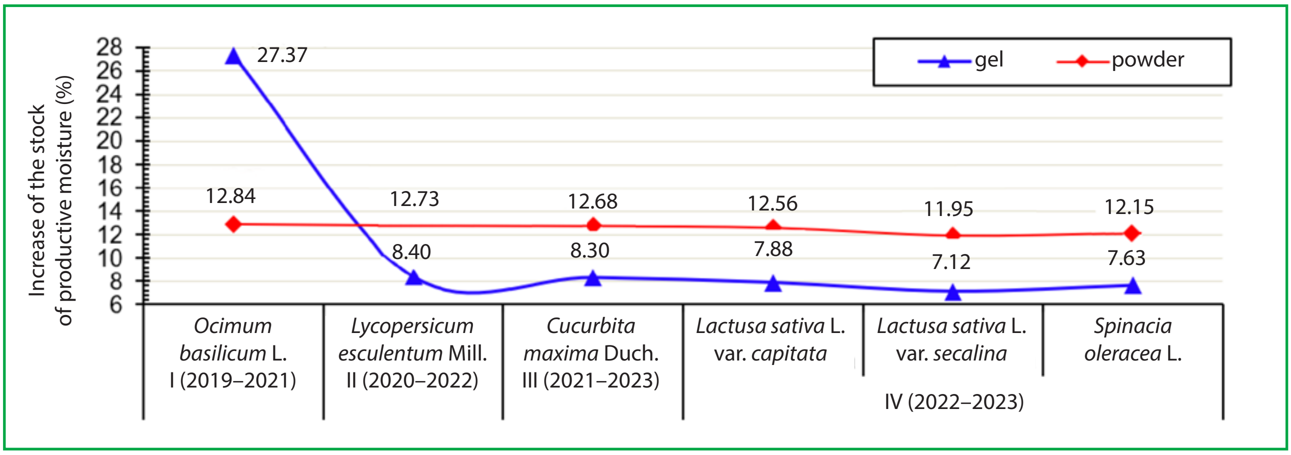

Figure 3 Averaged data on the increase of the stock of productive moisture in the basal soil layer (0–30 cm) of the studied crops relative to the control of the effects of various forms of absorbents (%)
I – year of application of absorbents; II – year after the application of absorbents; III – year after the application of absorbents; IV – year after the application of absorbents

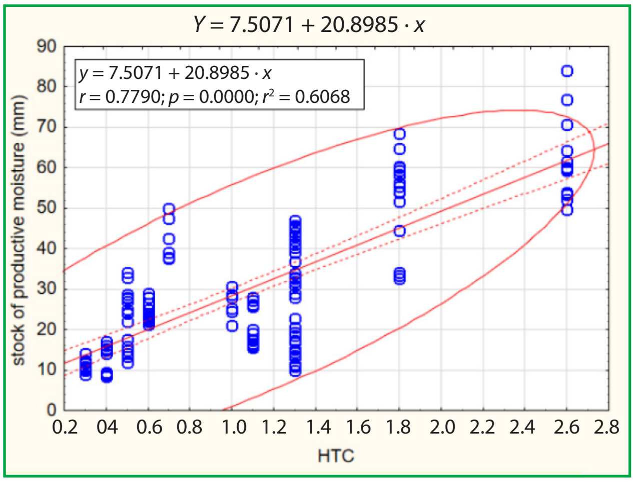

Figure 4 Dot plot and theoretical regression line for linear correlation between indicators of productive moisture reserves and hydrothermal coefficient (%)

the hydrogel declared by the manufacturer did not correspond to those in practice. Thus, the degree of swelling of the polymer hydrogel depends significantly on the concentration of salts in the aqueous solution. Figure 5 shows the graphic curves of swelling of TM ‚MaxiMarin' hydrogel in the form of gel and powder of different years of use in distilled water. The maximum swelling (334 times) was obtained only in the first year of using the absorbent in the form of a gel. The study of the water absorption capacity for the second year showed that there was more swelling in the absorbent in the form of powder – 308 times against the gel – 265 times, that is, the effectiveness of the gel in one year of use decreased by 26.0%, and the powder by only 8.4%. The rate of moisture absorption capacity of the absorbents also differed. Thus, on the fourth year of use, the maximum swelling of the gel was noted 240 minutes after soaking, and the increase in its mass was 173 times, which is 93.1% less than the initial data. The swelling capacity of the powder was quite high even in the fourth year of use – 271 times after 300 minutes of soaking, which is 13.7% less than the initial data.

The study of the water-absorbing capacity of absorbents showed its changes depending on both the duration of soaking and the year of use of the absorbent.

It is important to investigate the impact of water-soil interactions induced by the use of absorbents on plant productivity. Numerous studies have been conducted in this area, providing sufficient data for comparing standard cultivation methods with absorbent use (Montesano et al., 2015; Dehkordi, 2018; Ulyanych et al., 2020; Yatsenko et al., 2022). Overall, absorbents have positively influenced the cultivation of agricultural crops and no cases of phytotoxicity have been reported for vegetables and ornamental species when absorbents were applied. Trials on cucumbers have shown a doubling in plant height, plant and fruit biomass (Montesano et al., 2015). Ternavskyi et al. (2022) stated that the combined use of mulching film and absorbent gel led to a 15.2% increase in main stem length, a 43.9% increase in leaf number, and a 26.5% increase in leaf area in cucumber. This application of absorbent also contributed to a 27.5–27.9% increase in yield and a marketability of 99.2–99.4% of cucumber. Scientists have found that absorbents improved seed germination similarly for radish, cucumber,

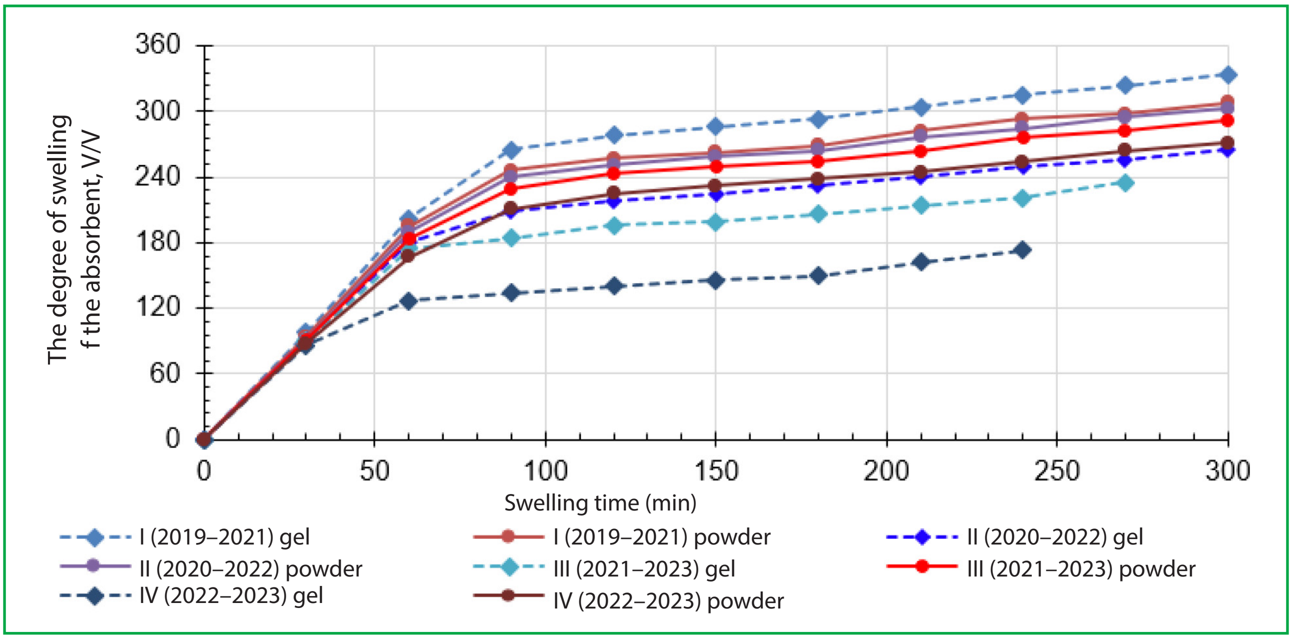

Figure 5 Graphic curve of swelling of different forms of absorbent depending on the year of use

and vetch. An increase in basil plant mass by 156% at 46 DAS was reported for perlite supplemented with 3% cellulose-based absorbent. This indicator increased to 177% with an increase in absorbent concentration to 6% (Montesano et al., 2015).

It was noted that there was an increase in fresh weight by 156% at 46 DAS for perlite supplemented with 3% cellulose-based hydrogel, as opposed to perlite without additives. This figure increased to 177% when using a 6% concentration of hydrogel instead. However, this difference becomes less pronounced at 63 DAS, showing only a 113% increase in the same parameter (Montesano et al., 2015).

The studies have shown that biodegradation is the most desirable mechanism for the decomposition of absorbents. A 12-week study by Qureshi & Khatoon (2015) on the biodegradation of chitosan-based absorbent confirmed its biodegradability. Absorbents based on natural polymers degrade easily in soil, whereas synthetic polymers degrade very slowly, prolonging their period of effectiveness and use in agriculture. Currently, absorbent production is focused on synthetic polymers such as acrylic acid or acrylamide, which pose a potential threat to the environment due to their long period of biodegradation (approximately 10% per year) (Zhang et al., 2014).

The water content in the soil and its water retention capacity can increase with the use of hydrogels, providing more available moisture for plants from 3.6% to 6.1% and 8.8% with the addition of 1 and 3 $g \cdot dm^{-3}$ of hydrogel, respectively (Abrisham et al., 2018). Studies by Banedjschafie & Durner (2015) found that by adding absorbent to sand at rates of 0.3, 0.6, and 1% SAP/soil volume, the soil water content increased by 560, 200, and 270 $g \cdot kg^{-1}$, respectively. When applying 200 $kg \cdot ha^{-1}$ of SAP, the moisture content increased in wheat crops from 12% to 14.4–15.1% (Li et al., 2014). Similar results were reported in the studies by Dehkordi (2018) and Bai et al. (2010).

4 Conclusions

Sustainable development of agriculture is important for strengthening food security, especially in unstable climate conditions. Nowadays, farmers and amateur vegetable growers are busy with the question of using polymer absorbents in agriculture. Absorbents are widely used in agriculture: effective soil conditioner in arid conditions; ingredient for seed dressing, to improve their germination.

The results of this study showed a significant impact on increasing the yield of the test crops and productive moisture reserves, which contributed to this.

Comparative studies of plant growth have proven extremely valuable. Hydrogels are good soil conditioners that can improve water use efficiency, plant health and yield, and can reduce the need for irrigation water. Thus, the application of hydrogel would be useful for crops such as basil, tomato, pumpkin, salad leafy vegetables.

Polymer absorbent materials used in agriculture need to be investigated in more detail to improve water absorption capacity and biodegradation. A better understanding of this process will help regions such as Europe improve irrigation efficiency for sustainable food production. Further research on laboratory methods to test the duration of the absorbent's effectiveness is a necessity to make it widely available to food producers of all ownerships.

The study of the degradation of polymeric absorbents shows the need for testing the properties of their effectiveness in various conditions in the context of environmental safety.

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