

## Safety Usage of Encapsulated Mineral Fertilizers Based on Polymeric Waste

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### ABSTRACT

The research was conducted on the growth and vital functions of watercress under the conditions of encapsulated mineral fertilizers treatment. The cyclic application of mineral fertilizers during three vegetation periods was simulated in this paper. The used mineral fertilizers were encapsulated on the basis of polyethylene terephthalate and polystyrene waste. It was found that the intermediate products of the polymer covering decomposition do not have a negative impact on the soil environment and the use of encapsulated fertilizers is safe for growing plants.

**Keywords:** encapsulated fertilizers, polymer waste, polyethylene terephthalate, polystyrene

### INTRODUCTION

Usage of mineral fertilizers in agricultural production technologies is an important condition for maintaining the balance of plant nutrients in the soil environment. The volume of mineral fertilizers applied in Ukraine in recent years has increased to 125 kg/ha of active substance, which is close to the level of developed world agricultural production at 160 kg/ha (<https://superagronom.com>). On average, for all crops the fertilizer utilization rate is: nitrogen 50–60%, phosphorus 10–25%, potassium 50–60%. This leads to environmental pollution by residual agrochemicals (Horodnii and Melnyk, 2003). In order to reduce unproductive losses of mineral nutrients, various measures are used, among which the use of slow-release fertilizers is effective. Such fertilizers are characterized by the controlled release of nutrients, which increases the level of their assimilation by the root system of plants (Pasichnyk and

Marchuk, 2013). Generally, dissolution time of fertilizers is adjusted by covering their surface with a shell. The shell permeability is considered to be the main parameter that determines the duration of slow-release fertilizers. The permeability is numerically described by the coefficient of internal diffusion of fertilizer elements in the shell material (Nagursky and Gumnitsky, 2012a). In order to ensure the required duration of fertilizers action within 3–9 months with a minimum coating thickness of up to 50  $\mu\text{m}$ , the shell material must be characterized by an internal diffusion coefficient  $D = 1 \times 10^{-12} \div 3 \times 10^{-13} \text{ m}^2/\text{s}$  (Nagursky and Gumnitsky, 2012b). Such properties are possessed by polymeric materials (Nagursky and Malovanyy, 2016) which are a part of household waste: polyethylene, polypropylene, polyvinylchloride, polyethylene terephthalate (Yashchuk, 2011). The use of polymer waste to obtain slow-release fertilizers is expedient in terms of reducing the cost of the final product and improving

their availability for mass agricultural production. An important aspect of using polymers to prevent secondary soil contamination is the destruction of the shell. The destruction of the polymer in the soil environment is carried out mainly by using a biochemical method (Aamer, 2008). Destruction of plastic can occur under the influence of a microbial consortium found at the landfill (Yoshida et al., 2016), bacteria of the *Ideonella* genus (Tanasupawat and Takehana, 2016), cyanobacteria (Malovanyy, 2016). These bacteria are accumulated on plastic and use it as the main source of carbon and energy, degrading to  $\text{CO}_2$  and water. The decomposition of organic content to  $\text{CO}_2$  and  $\text{H}_2\text{O}$  takes place in several stages with the formation of intermediate compounds that can have a negative impact on flora and fauna. (Ivachenko, 2001). In addition to the release of chemical compounds in the process of disintegration, the polymer shell is destroyed by the formation of microplastic particles, which are classified as hazardous environmental pollutants (Harrison and Hester, 2018). The previous research with encapsulated polymer shell fertilizers has shown their agroefficiency and safety for plants during the growing season (Rusyn et al., 2020). Usually, the growing season of crops is up to 3 months, and the destruction of the shell material under natural conditions is 1–2 years. In the following growing seasons under the conditions of encapsulated mineral fertilizers application an increase in the content of intermediate decomposition products of the polymer base of the shell can be observed. This can adversely affect the soil environment. Therefore, it is important to study the impact of the shell material of slow-release fertilizers, obtained with the use of polymer waste, on the environment in the process of their destruction under the influence of environmental factors.

## MATERIALS AND METHODS

The influence of intermediate decomposition products of the processed polymer shell material on the soil environment condition during its complete degradation was investigated.

Granular complex ANP fertilizer, encapsulated with shells of modified polyethylene terephthalate and a mixture of polystyrene and hydrolyzed lignin was used for the research. Polyethylene terephthalate and polystyrene are widely used in the manufacturing of containers for beverages

and food products and in foam form (expanded polystyrene) as a packaging material. These products are used for their intended purpose in a short time period and are immediately converted into waste. ANP fertilizer is a universal complex fertilizer that contains all three basic nutrients necessary for plant life in easily digestible form. Watercress was used as a bioindicator. Watercress (*Lepidium sativum* L.) is an annual plant of the Brassicaceae family. An adult watercress plant reaches 60 cm in height. This is a cold-resistant culture, the optimum temperature for its growth is about 15–18 °C. Watercress is moderately demanding to moisture, but a good harvest is obtained only on moist soil. In the hot summer months, the plants quickly turn to the stem extension stage. The plant likes light, especially in the early stages of development, although it grows well with partial shade (Horodnii and Melnyk, 2003). Light fertile soils are the most suitable for watercress (pH = 6.5–6.8). Watercress, as a bioindicator, is also convenient in that the effects of stress can be studied simultaneously on a large number of plants in a small area of the workplace. The shoots and roots of this plant under the action of contaminants are morphologically changing: growth retardation, curvature of shoots, reducing the length and weight of roots, as well as the number of germinated seeds (Horodnii and Melnyk, 2003).

In order to characterize the effect of decomposition products of the processed polymer shell on the germination of watercress seeds in the research process, the following were determined: seed germination energy, seed germination, number of abnormal seedlings, average length of sprouts of each sample, pH of soil solution.

Germination energy is determined by the number of germinated seeds and the number of discarded seeds during germination. According to the obtained data, the seed germination energy  $E_k$  (%) of each sample is determined:

$$E_k = \frac{N_{ke}}{N_k} \cdot 100 \quad (1)$$

where:  $N_{ke}$  – the number of germinated seeds in the  $k$ -th sample, pcs;  $N_k$  – the number of full-fledged seeds for germination (not infected with rot), pcs.;  $k$  – the number of repetitions of the experiment from one average sample.

The average value of seed germination energy  $E$  (%) is determined by the dependence of:

$$E = \frac{(E_1 + E_2 + E_3 + \dots + E_k)}{k} \quad (2)$$

In order to determine the germination of seeds the number of normally germinated seeds separately  $n_{kp}$  and the number of rejected  $n_{kb}$  in each sample are calculated after laying, on the day specified by DSTU 4138-2002. According to the obtained data, the germination of seeds  $C_k$  (%) for each sample is determined, by the dependence of:

$$C_k = \frac{n_{kp}}{N_{kp}} \cdot 100 \quad (3)$$

where:  $N_{kp}$  – the number of full-fledged seeds laid for germination (not infected with rot at the time of germinated seeds counting), which is determined by formula:

$$N_{kp} = N_k - n_{kb} \quad (4)$$

The average value of springing up  $C$  (%) is calculated by formula:

$$C = \frac{(C_1 + C_2 + C_3 + \dots + C_k)}{k} \quad (5)$$

Active acidity was determined in the water-soil extract. For this research, 40 g of the test soil sample was added to the flask and mixed with distilled water in a ratio of 1 to 3. The resulting suspension was well shaken and allowed to precipitate. A portable *pH* meter was added to the peeled liquid, according to the readings of which the soil *pH* was determined.

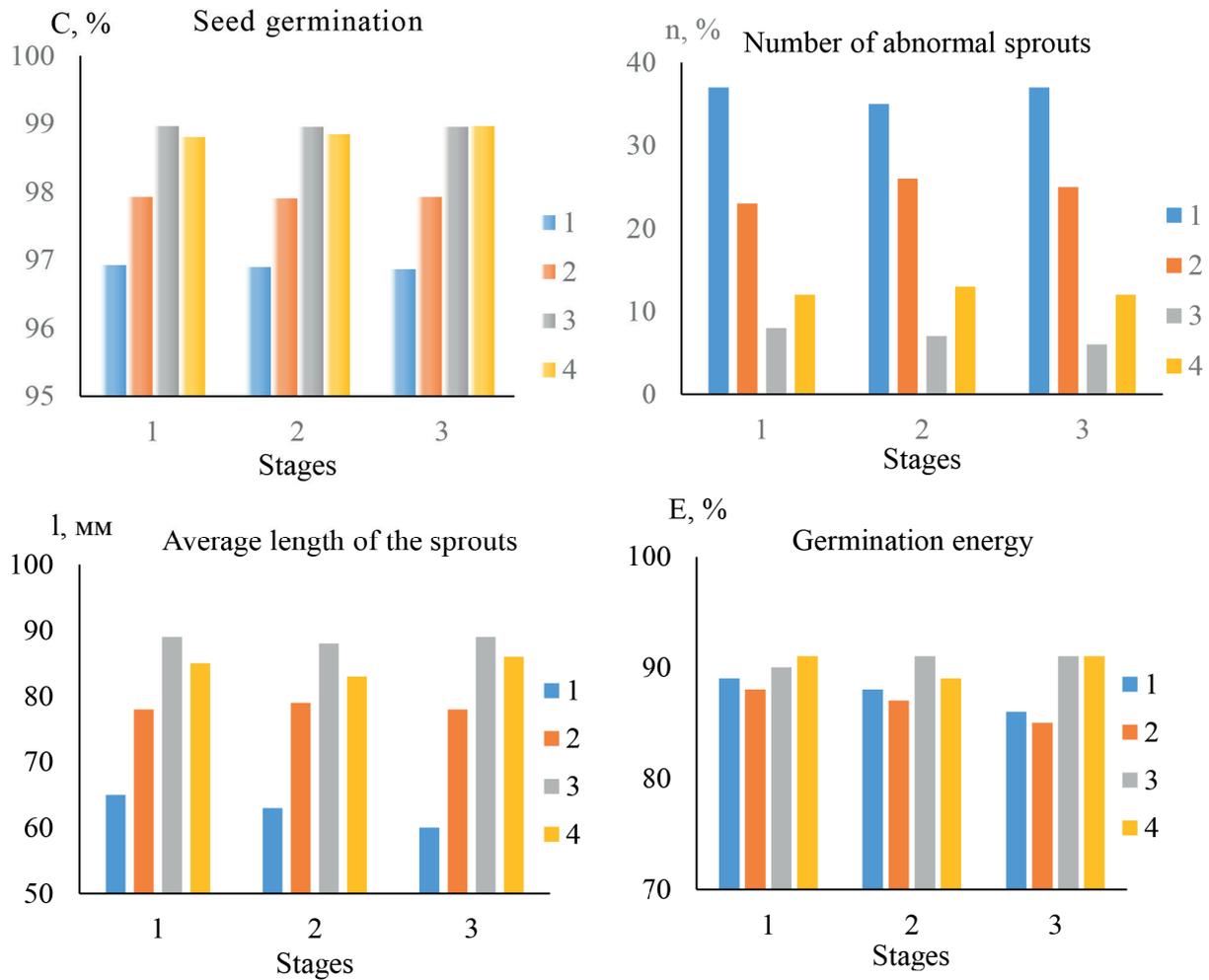
## RESULTS AND DISCUSSION

The study of the effect of the encapsulated fertilizer shell decomposition products was carried out during 3 vegetation periods of watercress growth. For this purpose, the growth of watercress without the use of mineral fertilizers was studied in parallel; using granular ANP fertilizer as well as encapsulated ANP fertilizer. The granular fertilizer was added in an amount of 6 g, whereas encapsulated – 4.8 g, which was 80% of the norm of granular fertilizers (Rusyn et al., 2020). The entire ANP fertilizer was from one batch for the purity of the experiment. The whole experiment was divided into three stages. In the first stage, watercress was grown for 15 days with observation of the seeds germination and maintaining the moisture of the substrates at the same level. The length of watercress shoots was measured daily starting from the 5<sup>th</sup> day of the experiment. The number of samples that died during growth and soil acidity were also noted. After the end of

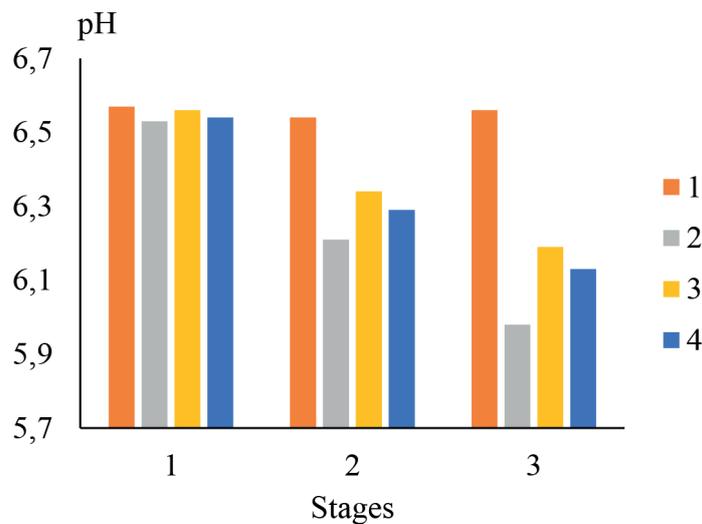
the growing season, the plants were extracted. The pots with soil were left unchanged for 30 days, where under the action of environmental conditions, the polymer shell of encapsulated fertilizers was decomposed. The watercress was grown under the same conditions with the addition of fertilizers in the second and third stages. The results of studies of physiological parameters of watercress growth are presented in Figure 1 and soil acidity in Figure 2.

The energy of seed germination remains virtually unchanged in all options for growing watercress. Acidification of soil in the case of granular ANP fertilizer slightly reduces this indicator. Seed germination remains unchanged in all studies. There is an increase in the number of abnormal sprouts in the absence of mineral fertilizers and in the application of granular ANP fertilizer. In the first case, this is caused by a lack of nutrients, and in the second, by an increase in soil acidity. A similar relationship is observed in the case of the average length of sprouts. A series of experiments using the ANP fertilizer encapsulated in a shell based on polyethylene terephthalate showed better results than for a shell based on polystyrene. The difference in the agronomic efficiency of these fertilizers is due to the different permeability of the coating. In the investigated case, the comparison of the fertilizers effectiveness for this parameter was not included in the purpose of the research. The use of mineral fertilizers that contain an ammonium group leads to acidification of the soil. This pattern is reflected in the presented results (Fig. 2). Thus, in the control experiment without the use of fertilizers the *pH* remains unchanged. In the case of granular ANP fertilizer use, the soil *pH* level decreases from 6.53 to 5.98. During the application of encapsulated fertilizers there is a less intense increase in soil acidity. This can be explained by the presence of a natural sorbent – zeolite – in the shell, which partially absorbs excess ammonium from the soil solution (Malovanyy and Oleksandr 2019).

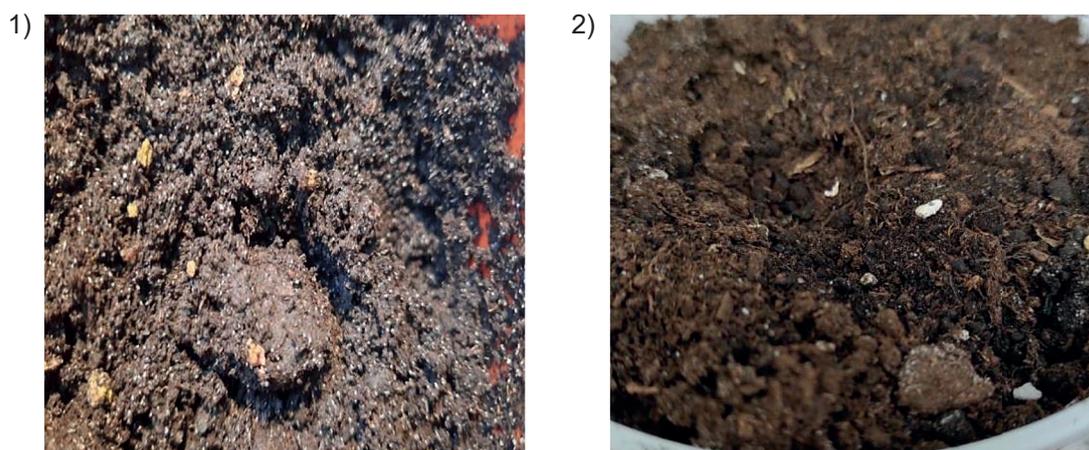
The visual observations of visible changes in plastic and changes in mechanical properties were performed to confirm the process of the shell polymer destruction. As a result of such studies, the violation of the integrity of the shell, its disintegration into separate fragments and loss of mechanical strength were revealed. The number of fragments of the polymer shell on



**Figure 1.** Physiological parameters of watercress growth in the studied samples under different conditions: 1 – without fertilizers, 2 – granular ANP fertilizer, 3 – granular ANP fertilizer, encapsulated with a shell based on polyethyl terephthalate, 4 – granular ANP fertilizer, encapsulated with a shell based on polystyrene



**Figure 2.** Soil acidity depending on the growing conditions of watercress: 1 – without fertilizers, 2 – granular ANP fertilizer, 3 – granular ANP fertilizer, encapsulated with a shell based on polyethyl terephthalate, 4 – granular ANP fertilizer, encapsulated with a shell based on polystyrene



**Figure 3.** View of the soil surface after the completion of the third stage of research in the case of encapsulated mineral fertilizers based on:  
1 – modified polyethylene terephthalate, 2 – polystyrene

the soil surface remained virtually unchanged with each stage of research. Figure 3 shows the photographs of the soil surface after the completion of the third stage of research. The presented images show the remnants of shells fragments, the number of which corresponds to approximately the number of granules of encapsulated fertilizers introduced in the third stage of research.

## CONCLUSIONS

The kinetics of watercress growth, its vital functions remain stable under conditions of cyclic application of encapsulated fertilizers. This confirms the absence of harmful effects of intermediate decomposition products of the polymer shell on the soil environment. The agrotechnical efficiency of encapsulated mineral fertilizers correlates with the results of other studies. In general, studies have shown the safety of using encapsulated mineral fertilizers in agricultural production. The use of polyethylene terephthalate and polystyrene waste in the technologies of encapsulated fertilizers application can be considered as a method of their safe disposal with final biodegradation.

## REFERENCES

1. Aamer A.S. 2008. Biological degradation of plastics: A comprehensive review. *Biotechnology Advances*, 26, 246–265.

2. Harrison, R. M.; Hester, R. E. 2018. *Plastics and the Environment*. Royal Society of Chemistry.
3. Hiraga K., Taniguchi I. 2019. Biodegradation of waste PET.
4. Horodnii M.M., Melnyk S.I. 2003. *Ahrokhimiia*. K.: Alefa, 778.
5. <https://superagronom.com/news/6894-za-os-tanni-10-rokiv-obsyagi-vnesennya-mindobriv-v-ukrayini-zrosli-vdvichi>
6. Ivashhenko G.V. 2001. Ispolzovanie bakterij destruktorovrodov *Pseudomonas* i *Achromobacter* dlya detektirovaniya i destrukcii policiklicheskih i aromaticskeh uglevodorodov. *Ukrayinskij bihimichnij zhurnal*, 73(1), 148-152.
7. Malovanyy M., Oleksandr M. 2019. Perspective Technologies of the Treatment of the Wastewaters with High Content of Organic Pollutants and Ammoniacal Nitrogen. *Journal of Ecological Engineering*, 20(2), 8-15.
8. Malovanyy, M. 2016. Production of renewable energy resources via complex treatment of cyanobacteria biomass. *Chemistry & Chemical Technology*, 10(2), 251-254.
9. Nagursky O., Gumnitsky Ya.M. 2012a. Theoretical model of compounds release out of capsulated particles and its experimental check. *Chemistry & Chemical Technology*, 6(1), 101-103.
10. Nagursky, O., Gumnitsky, Ya.M. 2012b. Release of capsulated mineral fertilizers components. Process simulation. *Chemistry and Chemical Technology*, 6(3), 320-325.
11. Nagursky O., Malovanyy M. 2016. Prospects of using pet waste for environmentally friendly mineral fertilizers. *Environmental problems*, 1(1), 19-21.
12. Pasichnyk N.A., Marchuk I.U. 2013. Zastosuvannya KAS dlia pidzhyvlennia pshenytsi ozymoi na

- luchno-chornozemnomu karbonatnomu grunti. Visnyk KhNAU: Ahrokhimiia, 1, 140–143.
13. Rusyn, I., Malovanyy, M., Tymchuk, I. 2020. Effect of mineral fertilizers encapsulated with zeolite and polyethylene terephthalate on the oil microbiota, pH and plant germination. *Ecological Questions*, 32(1).
  14. Tanasupawat S, Takehana T. 2016. *Ideonella sakaiensis* sp. nov., isolated from a microbial consortium that degrades PET. *Int J Syst Evol Microbiol*, 66, 2813–2818.
  15. Yashchuk L.B. 2011. Utvorennia vidkhodiv ta pererobka polimernoi vtorynnoi syrovyny v Cherkaskii oblasti. Zbirnyk naukovykh statei “III-ho Vseukrainskoho zizdu ekolohiv z mizhnarodnoiu uchastiu”. Vinnytsia, Vol. 1, 39–41.
  16. Yoshida S, Hiraga K, Takehana T. 2016. A bacterium that degrades and assimilates poly(ethylene terephthalate), 351, 1196–1199.