

Experimental area

The study was conducted on an experimental field of Dmytro Motornyi Tavria State Agrotechnological University in the Zaporizhzhia region.

Pea (*Pisum sativum* L.) cv. Oplot, a mid-season leafless variety developed by the V. Ya. Yuryev Institute of Plant Industry was used in the experiment.

The soil of the experimental plots is a southern alluvial chernozem, characterised by the following indicators: humus content (according to Tyurin) – 2.6 %, easily hydrolysable nitrogen (according to Kornfield) – 111.3 mg kg⁻¹, mobile phosphorus (according to Chirikov) – 153.7 mg kg⁻¹ and exchangeable potassium (according to Chirikov) – 255 mg kg⁻¹ of dry soil, neutral pH (water/salt – 7.0/7.3), 7 % exchangeable sodium of CEC, without salinity.

Description of the preparations

Azotophyt-P (AZPH) is a preparation produced by “BTU Center” (Ukraine) and contains cells of the bacterium *Azotobacter chroococcum* in the amount of $(1-9) \times 10^9$ CFO cm⁻³, as well as micro- and macroelements, biologically active products of bacterial life: enzymes, amino acids, vitamins, phytohormones, and fungicidal substances.

Biostimulants Stimp (ST) and Regoplant (RP) were developed by the State Enterprise "Agrobiotech" (Ukraine) and are approved for use in organic production in accordance with the MAOS Standard for Organic Production and Processing, which is equivalent to EU Regulations No. 834/2007 and No. 889/2008, Regulation of the European Parliament and of the Council (EU) No. 2018/848, the National Standard of Canada (COR), the Law of Ukraine "On the Basic Principles and Requirements for Organic Production, Circulation and Labeling of Organic Products". Stimp and Regoplant are composite multifunctional preparations, the bioprotective properties of which are due to the synergistic effect of the interaction of the products of vital activity in the in vitro culture of the micromycete fungus *Cylindrocarpon obtusiusculum* 680, isolated from the root system of ginseng (saturated and unsaturated fatty acids (C₁₄-C₂₈), polysaccharides, 15 amino acids, analogues of phytohormones of cytokinin and auxin nature), a complex of biogenic trace elements – 1.75 g l⁻¹, potassium salt of alpha-naphthylacetic acid – 1.0 mg l⁻¹ and aversectin C – a metabolic product of the soil streptomyces *Streptomyces avermitilis*.

Experimental design

The experimental design included six variants. The variants of experimental plots were arranged systematically (Randomized Complete Block Design) with four replications. The pea seeds of the control group (variant 1) were treated by spraying with Liposam solution (5 g l⁻¹) before sowing. Pea seeds of variant 2 were treated by spraying before sowing with AZPH (10 ml l⁻¹); variant 3 – ST (25 ml t⁻¹); variant 4 – RP (250 ml t⁻¹); variant 5 – ST (25 ml t⁻¹) + AZPH (10 ml l⁻¹); variant 6 – RP (250 ml t⁻¹) + AZPH (10 ml l⁻¹). Solutions of ST and RP were prepared on the Liposam solution (5 g l⁻¹). After the seeds dried, sowing was carried out in well-prepared soil with a seeding rate of 1.1 million pcs ha⁻¹. The area of each plot was 10 m², and the row spacing was 15 cm. Foliar treatments were carried out at the 5–6 stipule phase and the budding phase using the recommended rates for ST – 20 ml ha⁻¹, RP – 50 ml ha⁻¹, and AZPH (10 mL l⁻¹). The working solution consumption was 300 L ha⁻¹ during foliar treatment of pea crops. Pea crops were grown using the technology generally accepted for the region, without irrigation.

Measurements and data collection

Plant samples were collected during the growing season of pea plants in 5 phases according to the BBCH code: 12–13 (2–3 pairs of stipules), 16–17 (6–7 pairs of stipules), 51–55 (budding), 61–65 (flowering), 75–79 (bean formation). The Biologische Bundesanstalt, Bundessortenamt, and Chemical industry (BBCH) scale was used to describe the phenological development stages of plants.

The determination of the number and weight of the nodules.

To check for nodulation, gently clear the soil from the root mass of 10 plants from each plot. Nodules were detached from the primary root and the lateral roots. Root nodules were counted and weighed.

The determination of the leaf area index.

The leaf surface area of pea plants was determined gravimetrically by the «cuts» method. The gravimetric method relates the weight of leaves from 10 plant samples to the weight of leaf cuttings. Incisions were made in the leaf area with a special key of a certain diameter ($D = 10$ mm). Knowing the area of the leaf cuttings, the leaf surface area was calculated by an equation:

$$S = \frac{P \cdot S_1 \cdot n}{P_1},$$

where S is the total leaf area, cm^2 ; S_1 is the area of one section, cm^2 ; P is the total leaf weight, g; n is the number of slices; and P_1 is the weight of the sections, g.

Once the leaf surface area of each plant was determined, the leaf area index (LAI) for each site was calculated ($\text{m}^2 \text{m}^{-2}$). To do this, the average leaf surface area per plant was taken and multiplied by the number of plants per 1 m^2 of sown area.

The determination of the leaf area duration.

Leaf area duration (LAD) measures the ability to produce leaf area on a unit of land throughout its life. It was calculated using the LAI at each sampling date according to the equation and presented in $\text{m}^2 \text{m}^{-2} \text{day}$:

$$LAD = \frac{(LAI_1 + LAI_2)}{2} \cdot (t_2 - t_1)$$

where, LAI_1 and LAI_2 are canopy leaf area index at the time t_1 and t_2 , respectively.

The determination of the total chlorophyll content.

The total chlorophyll content was determined by the fluorometric method using an N-tester (Yara, Japan). The measurement point was chosen in the middle of the first developed leaf. Based on the results of 30 random measurements performed according to the usual 'W' scheme, the average value was obtained, and the results were presented in conventional units.

The determination of the net photosynthetic productivity.

The net photosynthetic productivity (NPP) was calculated as the ratio of the growth of plant dry matter mass over a certain period to the half-sum of the leaf surface areas at the beginning and at the end of the period. The NPP was calculated using the following equation:

$$NPP = \frac{B_2 - B_1}{0.5 \cdot (S_1 + S_2) \cdot n}$$

where NPP is the net productivity of photosynthesis, $\text{g m}^{-2} \text{day}^{-1}$; B_1 and B_2 are the dry mass of plants at the beginning and end of the period, g; $(B_2 - B_1)$ is the growth of dry weight of plants for n number of days, g; S_1 and S_2 are the leaf surface area at the beginning and end of the period,

m^2 ; $0.5 (S_1 + S_2)$ is the average area of the leaf surface during the experiment; n is the period between two observations, days.

The dry mass of the substance was determined gravimetrically according to generally accepted methods.

The elements of yield structure were determined, namely: the average number of plants per 1 m^2 , the average number of beans per plant, the average number of seeds per bean, the weight of 1000 seeds, seed moisture, and biological yield was calculated. The yield coefficient was calculated as the ratio of pea grain mass to total aboveground plant biomass in the plot, with a base moisture content of 14 %.

The determination of the biological yield of pea

Assessment Procedure

Determination of the sampling area. Prior to harvest, designated sampling plots are delineated within each experimental replicate, or plants are collected from a predetermined area. Assessments are conducted separately for each treatment and replicate. The size of the sampling area and the number of plants assessed must be sufficient to ensure the representativeness of the results.

Determination of plant density. The actual number of pea plants within the sampling area is counted and expressed per square metre. Where necessary, plants surviving until harvest are recorded separately.

Selection of plants for yield structure analysis. Representative plants are selected from each replicate, excluding border rows and atypical areas of the crop stand. For each plant, the following parameters are determined: the number of pods, the number of seeds per pod or the total number of seeds per plant, the seed weight per plant and, where required, the thousand-seed weight.

Determination of seed weight. Seeds from the sampled plants are separated from the pods, cleaned and weighed. To ensure a valid comparison among treatments, seed weight is determined under uniform conditions. Where the results are to be compared with actual yield, seed moisture content is adjusted to a standard value.

Calculation of biological yield. Biological yield is calculated from the actual plant density and the mean seed weight per plant, or from the total weight of seeds obtained from a known sampling area.

Where plant density and mean seed weight per plant are known, biological yield is calculated using the following formula:

$$Y_b = (N \times m) / 10$$

where: Y_b – biological yield, q/ha; N – number of plants per 1 m^2 , plants; m – mean seed weight per plant, g; 10 – conversion factor from g/m^2 to q/ha.

Where seeds are weighed from the entire sampling area, the following formula is used:

$$Y_b = (M \times 100) / S$$

where: Y_b – biological yield, q/ha; M – seed weight from the sampling area, kg; S – sampling area, m^2 ; 100 – conversion factor from kg/m^2 to q/ha.

Statistical analysis

Data analysis was carried out using GraphPad Prism 10 and Agrostat software. All measurements represent the means and standard deviation ($\pm SD$). The data were analyzed using a 2-way ANOVA test, where factor A (growth phase) and factor B (treatment). Statistically significant differences between means were compared at the 0.05 probability level using Tukey's post-hoc test. In the statistical analysis of crop elements and yield, the arithmetic means and least significant differences ($LSD_{0.95}$) were calculated.