MINISTRY OF AGRICULTURE OF THE RUSSIAN FEDERATION
Federal State Budgetary Educational Institution of Higher Education "St. Petersburg State Agrarian University" (FSBEI HE SPbSAU)

As a manuscript

AL-MALIKI ALI ABDULLAH SULTAN

BIOLOGICAL JUSTIFICATION FOR THE APPLICATION OF MODERN HERBICIDES FOR PROTECTION WINTER WHEAT IN THE CONDITIONS OF THE STEPPE ZONE OF THE CISCAUCASUS

Specialty 4. 1. 3. Agrochemistry, agrosoil science, plant protection and quarantine

Thesis for the candidate degree of biological sciences

Scientific Advisor:
Dolzhenko Tatyana Vasilievna,
Doctor of Biological Sciences, Professor

Saint Petersburg - 2024

МИНИСТЕРСТВО СЕЛЬСКОГО ХОЗЯЙСТВА РОССИЙСКОЙ ФЕДЕРАЦИИ
Федеральное государственное бюджетное образовательное учреждение высшего образования «Санкт-Петербургский государственный аграрный университет»
(ФГБОУ ВО СПбГАУ)

На правах рукописи

АЛЬ-МАЛИКИ АЛИ АБДУЛЛА СУЛТАН

БИОЛОГИЧЕСКОЕ ОБОСНОВАНИЕ ПРИМЕНЕНИЯ СОВРЕМЕННЫХ ГЕРБИЦИДОВ ДЛЯ ЗАЩИТЫ ПШЕНИЦЫ ОЗИМОЙ В УСЛОВИЯХ СТЕПНОЙ ЗОНЫ ПРЕДКАВКАЗЬЯ

Специальность 4.1.3. Агрохимия, агропочвоведение, защита и карантин растений

Диссертация на соискание учёной степени
кандидата биологических наук

Научный руководитель:
Долженко Татьяна Васильевна,
доктор биологических наук, профессор

Санкт-Петербург - 2024 г.

Contents

INTRODUCTION

Relevance of the topic. The Russian Federation's Strategy for Scientific and Technological Development, approved by Presidential Decree No. 642 on December 1, 2016, is one of the country's priority tasks, which is to transition to a highly productive and environmentally friendly agricultural sector. It is impossible to complete this task without conducting extensive scientific research into the efficacy and safety of new plant protection products.

The widespread use of herbicides to control weeds in wheat crops is causing concern these days, which has prompted researchers to look for less harmful and more environmentally friendly ways to manage weeds.

Regretfully, the overuse and frequently scientifically questionable application of chemical herbicides has resulted in a number of detrimental side effects, including weed resistance to these substances, groundwater and soil contamination, and detrimental effects on organisms that are not intended targets (Kubiak et al., 2022).

Compared with other pest control methods, the most important advantages of herbicides are ease of use, greater versatility, and faster results. However, it is necessary to consider the biological effectiveness and safe regulations for the use of herbicides (Rajmohan *et al.,* 2022).

Over the years, agriculture has been the main guarantee of preserving human life, as it is the cornerstone of providing various food products to meet the needs and desires of humankind. The development of agriculture in many countries has a long history.

In Mesopotamia, agriculture began approximately 10,000 years ago, which roughly corresponds to most of the regions of today's Iraq, Turkey, Syria, and Jordan. As populations became more sedentary, they began to grow a wide variety of crops, including wheat, barley, peas, lentils, chickpeas, and flax (Kislev *et al.,* 2004; Tudi *et al.,* 2021).

A strategic crop and vital component of food security is wheat (Triticum aestivum L.) (Jabran et al., 2017; Nekrasov et al., 2022). Wheat supplies proteins and carbohydrates to both people and animals.

Russia has become a major global producer and exporter of grain, and its grain market has been rapidly expanding in recent years. Russia grows the majority of its grain crops, with wheat making up the majority. 85.9 million tons of wheat were harvested in the Russian Federation in 2020 (Agapkin and Makhotina, 2021). Winter wheat holds a dominant position, especially in the North Caucasus steppe zone.

Worldwide, wheat provides more nutrients than any other food crop (IDRC, 2010; Grote *et al.,* 2022). This crop is widely grown under various agroecological conditions and cropping systems around the world. In line with the growing economic importance of wheat, governments have made significant investments in increasing wheat yields over the years. Spring and winter wheat occupy approximately 65% and 35% of the total area of global wheat production, respectively (Braun and Sãulescu, 2002; Braun *et al.,* 2010). It is a staple food for 40% of the world's population, mainly in Europe, North America, Africa, and western and northern Asia (Tadesse *et al.,* 2016).

Shiferaw et al. (2013) report that demand for wheat is increasing quickly in several parts of the world, including Southern Asia (4.3%), Western and Central Africa (4.7%), and Eastern and Southern Africa (5.8%). The traditional wheat-growing regions of North Africa (2.2%), Australia (2.2%), and Central Asia (5.6%) are also seeing increases in demand. According to Shiferaw et al. (2013), wheat is the most traded agricultural commodity in the world, with 144 million tons traded and a total value of US$36 billion as of 2010.

Many developing countries consider wheat a staple crop but are not self-sufficient in wheat production, making wheat their most important import. According to the FAO, wheat accounts for the largest share of emergency food assistance.

Baum et al. (2013) attributed the accelerated growth in wheat production to farmers' adoption of Green Revolution technology packages, particularly improved high-yielding varieties with better response to inputs (such as fertilizers), improved irrigation systems, improved disease resistance, and use of pesticides.

Pest damage is one of the biggest issues farmers faces, as it can result in lost revenue, lower crop yields, and lower crop quality (Ngoune Liliane, Shelton Charles, 2020).

Estimation of the yield losses due to insect pests, diseases caused by various pathogens, and competition from weeds, despite existing control methods, range from 26% to 40% for major crops, with weeds causing the highest possible losses (Oerke and Dehne, 2004).

According to Kubiak et al. (2022), worldwide, weeds cause significant crop yield losses and increase producer costs more than any other pests, including insects, plant pathogens, nematodes, birds, and rodents. Weeds are undesirable for agriculture for many reasons. They primarily reduce crop yields by competing directly with crops for space, sunlight, water, and other essential soil nutrients.

Additional issues with weeds in crop production include infestation-related crop quality reduction, allelopathy (natural substances that inhibit plant growth), and phytophagous and plant pathogen hosting. Based on sustaining crop production and yields, effective weed control is essential for preserving ecosystem balance and averting risks to public health.

In addition, for using resistant varieties and other pest control techniques, a variety of techniques, such as agricultural, biological, and chemical methods, have been employed to manage weeds that pose a threat to wheat plants. Moreover, integrated weed management (IWM) is applied (Montero, Santos, 2022).

Agricultural and biological management was not effective enough; therefore, farmers needed a faster and more reliable way to combat weeds and developed the active use of herbicides. Farmers insist on using insecticides because of their better effectiveness, lower cost and time, and no mechanical damage to plants that occurs during manual and mechanical weeding. Moreover, control is more effective because weeds are killed even within crop rows, which always remain under mechanical control (Chhokar *et al.,* 2014).

Effective weed control is based on the correct selection of herbicides depending on the type of weeds infesting the crop, and more herbicides should be applied at the optimal rate and at the right time using the appropriate application technique (Kraehmer *et al.,* 2014).

Depending on the crop and herbicide type, there is an ideal time to apply. Herbicides can be categorized according to their mode of action, chemical classes, spectrum of weed control, and application timing, among other factors. Herbicides have certain drawbacks in addition to their benefits for controlling weeds (Harasim *et al.,* 2014; Duke *et al.,* 2018; Ustuner *et al.,* 2022).

Being chemicals, herbicides can have negative effects on crops, subsequent crops, nontarget organisms, and soil. Excessive and frequent use of herbicides can also lead to residue issues, phytotoxicity, and health risks from herbicide residue buildup in soil, crop products, and groundwater. Pesticide residues are defined by the World Health Organization (WHO) as "any substance or mixture of substances in human or animal food resulting from the use of a pesticide and including any specified derivatives, such as degradation and conversion products, metabolites, reaction products, and impurities, which are considered to have toxicological significance" (Sondhia, 2014).

Concerns about environmental pollution, food safety, human health, soil, and water have led to the need to study pesticide residues. Many adverse effects have been observed as a result of the extensive use of pesticides, and effective residue management strategies are needed to address them (Pathak *et al*., 2022).

Monitoring herbicide residues in various products and environments is necessary to assess their accumulation, bioaccumulation, and adverse effects, if any. However, pesticides can be considered a cost-effective and effective tool for pest control (Aktar *et al.,* 2009).

The purpose of research: The goal of the research is to improve the range of winter wheat protection products in the steppe zone of Ciscaucasia by determining the biological effectiveness and developing regulations for the use of new combined herbicides.

The objectives of the study. In accordance with the aim of the scientific investigation, the subsequent goals were established:

1. develop a variety of novel combined preparations with active ingredients from various chemical classes to combat weeds on winter wheat;

2. evaluate the biological efficacy of new phytosanitary products for protecting winter wheat from weeds;

3. develop guidelines for the safe and efficient use of drugs to protect winter wheat from a complex of weeds;

4. assess the ecotoxicological properties of novel combined preparations for weed control in winter wheat**.**

Scientific novelty of the work. The effects of new combined preparations from different chemical classes on weeds in winter wheat crops were investigated for the first time in the conditions of the Ciscaucasia steppe zone. These preparations included Tarzek, water-soluble granules (WG), Pinta, oil dispersion (OD), Fortissimo, OD, Cayenne Turbo, OD, and Polian. These medications have a high biological effectiveness—up to 100%—that has been demonstrated. There are now developed regulations regarding the use of these five new drugs. As long as the usage guidelines for the drugs are followed, the ecotoxicological low hazard of the examined medications has been demonstrated.

Theoretical and practical significance. The research findings support theoretical notions regarding the potential application of novel herbicides in winter wheat protection schemes.

Research techniques and methodology. The principles of phytosanitary optimization of agrophytocenoses, literature analysis, goal and objective setting, laboratory and field experiment setup, mathematical processing of experimental data, and generalization of results obtained form the basis of methodological approaches to scientific research. The research was conducted strictly in compliance with industry standards for evaluating the efficacy and safety of pesticides. The section "Conditions, materials, and research methods" contains a thorough description of them.

Basic Provisions for defense:

- Effective modern methods for weed control on winter wheat in the steppe region of Ciscaucasia.
- Guidelines for the application of novel drugs to weed control.

The degree of reliability and testability of results. A sufficient amount of experimental data, statistical processing, and the determination of the reliability of differences were used to attain the degree of reliability of the research results. The dissertation's primary findings were presented at the following international conferences: the international scientific and practical conference of young scientists and students “Intellectual potential of young scientists as a driver for the development of the agro-industrial complex” (St. Petersburg, St. Petersburg State Agrarian University, 2022, 2023); and the international scientific and practical conference “Priorities for the development of the agro-industrial complex in the context of digitalization and structural changes in the national economy” (St. Petersburg, St. Petersburg State Agrarian University, 2022); international scientific and practical conference of young scientists “Integrated plant protection system: status and prospects” (Almaty, 2022); International University Scientific Forum “Practice Oriented Science: UAE – RUSSIA – INDIA” (UAE, 2022).

Publications. Seven published works were made using the dissertation materials; these included three peer-reviewed scientific journals listed in the Higher Attestation Commission's list.

Personal contribution by the author. The dissertation that is being presented is the product of the author's own scientific research conducted during his graduate studies. The dissertation author is in charge of organizing and carrying out field and laboratory research, keeping notes and observations, evaluating the data collected, and producing a dissertation as well as scholarly articles.

Structure and scope of the dissertation. The dissertation comprises an introduction, 4 chapters, a conclusion, recommendations for production, a list of references, and applications. The dissertation is presented on 159 pages and contains 61 tables, 34 figures, and 16 appendices. The list of cited literature includes 189 sources in foreign languages and in Russian.

Chapter 1. FEATURES OF AGROPHYTOCOENOSIS OF WINTER WHEAT. METHODS AND MEANS OF WEED CONTROL (literature review)

In order to live in a world free of hunger and malnutrition in all of its forms, we must overcome the new challenges that the 2030 Global Sustainable Development Goals bring with them. These goals lay out a transformative vision. The development of all agro-industrial complex sectors and the enhancement of the country's economic well-being are directly impacted by the state of grain cultivation. The amount of grain produced is contingent upon both generating the required government resources and satisfying the population's demand for raw materials. Currently, cereals are the most important food source for people worldwide. Annual wheat harvests provide about 21% of the world's food supply, with supplies being (Enghiad et al., 2017).

A staple of human civilization, wheat (Triticum aestivum L.) is essential to lowering world hunger and boosting food security. Wheat is one of the richest agricultural crops, giving humans and animals proteins and carbohydrates, so increasing the quantity and quality of products is required to increase food security. More nutrients are found in wheat than in any other food crop worldwide.

Worldwide, the wheat crop contributes about 20% of the total calories and protein in the food supply (Shiferaw *et al*., 2013; D'Odorico *et al*., 2014; Johansson *et al*., 2020). Wheat flour is used for making bread, confectionery, and noodles, and is also used for animal feed, processing into ethanol, etc.

Wheat is popular for the wide range of food products made from it, which partly explains its prevalence even in areas where wheat is not a traditional crop. According to STATISTA (2020), the world's wheat crop area is 215 million hectares, with a production of 765.41 million tons and a yield of 3.56 tons/ha (Gyawali *et al.,* 2022).

The main focus in Russia is on the production of food grains: it accounts for more than 60% of the gross harvest, while in the European Union, it is 50-56%, and in the USA, it is nomore than 30% (Orekhovskaya, 2022). Over the past twenty years, Russia has been steadily increasing grain production, while simultaneously reducing its dependence on natural and climatic conditions. Recently, the grain market in Russia has been developing rapidly; the country is one of the world leaders in the production and export of grain.

Among the grain crops grown in Russia, wheat occupies the largest share. In 2020, the Russian Federation harvested 85.9 million tons of wheat (Agapkin and Makhotina, 2021). According to Agapkin and Makhotina, (2021), wheat occupies the principal position among grain crops in all federal districts of Russia, the production volumes of which vary from 671.4 (Northwestern Federal District) to 24308.6 thousand tons (Southern).

Many authors argue that producing large wheat yields depends on being subjected to biotic and abiotic stresses (Yazdani, 2022). Both biotic (pests including weeds, arthropods, plant diseases, etc.) and abiotic (such as temperature, drought, salt content, etc.) factors can contribute to low wheat production, with weeds being one of the main culprits. Wheat production is predicted to be negatively impacted by rising temperatures brought on by climate change, as well as by anticipated increases in the frequency of hot, dry weather and periods of heavy rainfall.

Weeds are an integral natural component of agricultural crops that grow quickly and spread in fields. Weeds become competitors to crops when they require physical natural light, water, essential minerals sources, and area (Dmitriev *et al.,* 2022). Harvest is significantly impacted by this competition. Wheat crops that have vegetation present can experience yield losses of up to 30% (Mehdizadeh *et al.,* 2021). Around the world, weeds have a significant impact on the productivity of most crops.

The Food and Agriculture Organization (FAO) of the United Nations (FAO, Electronic Resource n. d.) states that its two main objectives are to: (1) promote sustainable agriculture, which will guarantee that everyone has access to food of equal quality; and (2) maintain global food security.

In the Russian Federation, winter wheat is regarded as the primary food crop. Many parts of the nation have generally good conditions for producing winter wheat products that are high and stable. However, one of the primary causes of agriculture's inability to realize its biological potential is a number of weeds in the crops (Zakharenko, 2005; Goryanin et al., 2014).

Even with the widespread application of chemical herbicides and preventive measures, weeds continue to pose a significant threat to the production of winter wheat. Consequently, a great deal of research has been done to comprehend the biology of weeds and create strategies for controlling them. It is undeniable that weeds predate agriculture, and farmers have always known that these plants impede the growth of the crops they hope to grow.

Wheat yield losses due to weeds can outshine damage caused by pests, pathogens, and unfavorable climatic conditions (Gyawali *et al.,* 2022). Effective weed management is critical not only for increasing crop yields and maintaining crop production but also for maintaining the balance of ecosystems and preventing public health hazards. The practice of various weed control measures has been followed by farmers since time immemorial. Ancient methods of weed control include hand-pulling, cutting, and physical suppression (Young and Pierce, 2014). Hand tools have been developed to control weeds. Currently, herbicides and other modern methods are used.

1.1 Winter wheat in the steppe region of Ciscaucasia

Wheat is considered one of the oldest agricultural crops in the world. Initially, this crop was domesticated in Western Asia, East Asia, and Central America, providing 60% of the human diet (Shewry, 2009). Wheat was first grown between 15 000 - 10 000 years BC and originates from wild relatives (Chong, Bible and Ju, 2001; Shewry, 2009). The development and spread of wheat had a profound impact on the course of human social evolution and contributed to the emergence of the first civilizations of the ancient world, such as Mesopotamia, Egypt, and India (Lu *et al.,* 2019). Shewry (2009) reported that wheat is widely cultivated from 67°N latitude in Scandinavia and Russia to 45°S latitude in Argentina, including highlands in the tropics and subtropics.

In the Russian Federation, over 10 years, the sown area has increased by 4.70 million hectares. Of all grains and leguminous crops, wheat occupies the largest sown area. Compared with 2020, the area under its crops amounted to 29.44 million hectares (Agapkin and Makhotina, 2021). In recent years, the share of sown areas allocated to winter wheat has been growing, whereas the share of spring wheat has been declining. In Russia, spring and winter wheat are grown, and due to the fact that the yield of winter wheat is two or more times higher than spring wheat, winter wheat is sown under favorable agroclimatic conditions (Filenko, 2016). If we compare winter and spring wheat by percentage of sown area, then in 2020 the share of winter wheat crops reached 57.44% of the total wheat crops, and spring wheat - 42.56% (EMISS, n. d.).

Variety variation is crucial for boosting yield and achieving high quality in seed production by cultivating high-quality varieties. In light of this, farmers should replace outdated common varieties with new, highly productive cultivars that exhibit both high economic and technological qualities. In 2014, 254 soft winter wheat varieties were admitted for selection, of which 131 were distributed in the North Caucasus region, including 63 in the Rostov region, according to the Russian Federation's Register of Breeding Achievements. According to Filenko et al. (2014), the most productive cultivars of winter wheat are Ermak, Governor of Donskoy, Stanishnaya, Grom, Severodonnsky Memorial, Tanya, and Tanis. (Filenko *et al.,* 2014).

Winter wheat is widely grown in a number of Russian regions. Generally, the Northern Caucasus (Krasnodar Territory and Rostov Region), the Central Chernozem Region, and the right portion of the Volga region are the primary distribution areas for winter wheat in Russia (Filenko, 2016; Boyko *et al.,* 2023). Southern Russia's greatest agricultural producer is the Ciscaucasia region, where winter wheat is the principal crop. The Rostov region is one of Russia's three primary grain-producing regions, along with the Krasnodar and Stavropol territories. With 9.8% of the total crop area devoted to wheat, the Rostov region is one of the leading regions in this regard (EMISS, n. d.).

Historically, the south and southeast regions of the Russian Federation have made an active contribution to the country's breadbasket. This is due to the presence of fertile soil and suitable climatic conditions in addition to high yield and quality (Kovtun, 2017). Due to its exceptional quality, wheat grain farmed in the steppe regions of south and southeast

Russia is highly prized on the international market. It should be mentioned that Russia leads the world in grain production and exports in this regard.

In 2020, the Rostov region topped the top 10 best regions for wheat harvesting. The total wheat harvest in 2020 in the region was approximately 10.55 million tons (Agapkin and Makhotina, 2021). In the total wheat harvest in Russia, the region accounts for 12.3%, which is slightly lower than in 2019 (13%) and 2018 (12.7%).

Another region located in the steppe zone of the Ciscaucasia is the Krasnodar region, which is also an important wheat growing region.

Wheat is an herbaceous plant that grows to a height of 30 to 150 cm. Its stems have five to seven nodes, which can be erect, hollow, or succulent. The length of the entire stem is determined by a number of factors, including soil fertility, humidity, rainfall, fertilizer application, and variety characteristics. Leaves are typically 3-20 mm wide. Flat, linear, broad linear, grooved, pubescent, or rough. The root system is fibrous; the majority of the roots are concentrated in the 15-25 cm layer of arable soil, but some roots extend deeper. Leaves form at each node of the stem, and their size and number vary greatly depending on the variety's biological characteristics and growing conditions (Matveev, 2015).

Winter wheat is sown in late summer or early autumn and harvested the following winter. Winter wheat, unlike spring wheat, can go into physiological dormancy and harden during the winter, ensuring resistance to low temperatures. Winter wheat seeds germinate at temperatures ranging from +12 to 16 degrees Celsius. Germination decreases as temperatures rise above 24°C (Kharkovsky and Gorbacheva, 2019).

1.2 Weeds in winter wheat crops

Keeping weeds out of winter wheat is essential to raising its quality and productivity. Wild plants known as weeds proliferate on agricultural land and lower crop yields and quality. Weeds are a vital natural element of agrocenosis because of their rapid growth and field-wide dispersal. When it comes to needs for physical moisture, daylight, nutrients, and area, it is in competition with grain crops (Dmitriev et al., 2022; Luneva, 2023). From an agronomic perspective, a "weed" is any plant that the grower has not cultivated or propagated and that needs to be managed to prevent interference with the production of crops or livestock (Schonbeck, 2011). In order to enhance weed control, a great deal of research has been done (Radicetti *et al.,* 2021; Monteiro *et al.,* 2022; Zakota and Luneva, 2023).

Weeds compete with wheat crops for nutrients, moisture, and light, posing a significant problem. Most cultivated lands' productive capacity is limited by the amount of moisture, which must be replenished or nutrients must be provided to plants in an easily digestible form, which can be costly (Ksykin, 2021).

Weeds compete with crops for environmental resources (Harasim *et al.,* 2014; Sawicka *et al.,* 2020; Chauhan *et al.,* 2020; Abd El Lateef *et al,.*2021). These plants have specific characteristics that make them more competitive in a wide range of environmental and climatic conditions. In addition, weeds behave differently in different ecosystems. Thus, weeds harbor insects and plant pathogens that can affect crop quality and increase the likelihood of crop failure (Baker *et al.,* 2018).

In addition, different tillage systems for weed control provide different types of natural and managed habitats. They increase the costs of various cultivation methods, reduce the efficiency of agricultural machinery, and reduce the germination of crop seeds due to allelopathy (Ahmad *et al.,*2016). An integral natural component of agrocenosis is weeds, which quickly grow and spread within the fields.

Weed density in grain crops is increasing as a result of oversaturation of crop rotations with grain crops and a preference for low tillage. In the Russian Federation, weeds infest more than 70% of cultivated areas to varying degrees. The most common weeds in Russian agroecosystems are estimated to be around 468 species, with 139 being economically important and 6 being particularly dangerous (GlavAgronom - TOP-20 wintering annual dicotyledonous weeds in grain crops, no date).

Weeds cause just as much damage by consuming water from the soil. By developing a stronger root system than cultivated plants, it turns out that they are more competitive in the fight for valuable moisture in these areas. One difference between weeds that grew during the formation of the crop is the difference in the amount of moisture and nutrients consumed.

For example, chickweed (*Stellaria media* (L.) Vill) consumes 1.2 times more moisture during development compared to winter wheat plants, this explains the decrease in soil moisture (Okazova, 2022).

Compared to crop diseases (25%) and insect pests (20%), weeds are the most expensive category of agricultural threats, accounting for over 45% of field crop yield losses (Gnanavel, 2015). Large amounts of crops are lost to weeds. Some argue that, grain yield in winter wheat drops by 20–30% when weediness exceeds 100 ind./m^2. (Ksykin, 2021).

Yield loss is influenced by a number of factors, including weed type, density, and timing of emergence. 100% crop loss can result from unchecked weeds (Chauhan, 2020).

According to Duary, in 2014, the movement of most weeds from one place to another occurs primarily through their seeds. In nature, this is facilitated by winds, water, or animals. However, globalization and the World Trade Organization (WTO) regime increase the possibility of weed seeds moving along with food grains from one country to another. In other words, the factor responsible for the spread of weeds is the crop seeds contaminated with their seeds (Chhokar *et al.,* 2014). Therefore, it is important for farmers to use certified seeds or pure seeds.

In the grain crops in the steppe zone of the Ciscaucasia, the most harmful group of oot and shoot weeds predominates - field thistle (*Cirsium arvense* (L.) Scop.), field sow thistle (*Sonchus arvensis* L.), field bindweed (*Convolvulus arvensis* L.), Tatarian lettuce (Molokan) (*Lactuca tatarica* (L.) C.A. Mey), euphorbia Waldstein (euphorbia vine) (*Euphorbia waldsteinii* (Sojak) Czer.). Winter wheat competes well with some types of annual dicotyledonous weeds, but has a low competitive ability to become clogged with wintering weeds (Sophia descuria, field bedstraw, field grass, etc.) (Illarionov, 2019).

The most common among juvenile dicotyledons are: catchweed bedstraw (*Galium aparine* L.), field pennycress (*Thlaspi arvense* L.), shepherd's purse (*Capsella bursapastoris* (L.) Medic.), field larkspur (*Consolida regalis* S.F. Gray), blue cornflower (*Centaurea cyanus* L.), common amaranth (*Amaranthus retroflexus* L.), white pigweed (*Chenopodium album* L.), perforated chamomile, odorless (*Matrikaria perforate* Merat), field mustard

(*Sinapis arvensis* L.), pickles (*Galeopsis spp*.), Convolvulus knotweed (*Polygonum convolvulus* L. = *Fallopia convolvulus* (L.) A. Love), rough knotweed (*Polygonum scabrum* Moench). The most common of the annual cereal weeds is wild oat (*Avena fatua* L.). There is a clear tendency to expand the areas contaminated by it. There is an increase in wintering weeds - small petal grass (*Erigeron canadensis* L.), hemlock (*Erodium cicutarium* (L.) L'Hér. ex Aiton), bluegrass (*Poa annua* L.).

In terms of occurrence, the dominant group is formed by 14 species of weeds, including common barnacle (*Echinochloa crusgalli* (L.) Beauv.) and field bindweed (*Convolvulus arvensis* L.) (Vlasova et al., 2018).

Unlike other pests, weeds can thrive in a wide range of environmental conditions, resulting in the greatest yield loss (Chauhan and Grand, 2020; Ustuner *et al.,* 2020 Arshad *et al.,* 2021; Majrashi, 2022).

It's becoming more and more clear that no weed-control strategy—agrotechnical, biological, or chemical—can completely eradicate weeds from wheat and land. Agricultural production has recently made extensive use of weed-free crop protection. Eliminating weeds is therefore one of the most crucial safeguards for the sensible use of land in agriculture, boosting the quality and potential yield of winter wheat ((Dolzhenko V.I., Dolzhenko T.V., 2004; Tansky, Dolzhenko, Goncharov et al., 2004).

1.3 Agrotechnical method of weed control

Agriculture began about 12,000 years ago with the cultivation of barley, lentils, wheat, and peas in the area known as the Fertile Crescent in modern Iraq (Bakker, 1980). These early farmers identified and selected beneficial plant traits (eg, larger thorns, higher yields, seed pods that did not collapse) and began the process of genetically modifying our crop plants.

Crop production in developed countries has steadily increased over the last century as a result of breeding programs and the adoption of new agricultural technologies. Plant breeders have used selective breeding to identify improved traits in numerous major crops. Farmers have been looking for ways to control weeds since crop farming first began. Weed control has been central to farmers' agricultural activities since antiquity (Scavo and Mauromicale, 2020). Weed control is a major issue in agriculture, and it is often complex, contentious, and costly. This agricultural practice goes beyond controlling existing weed problems and focuses on preventing weed spread, reducing weed emergence after crops are planted, and reducing weed competition with the crop (Ghosheh 2010).

Weed control in agricultural systems is currently split into two distinct directions, each with its own approach. On the one hand, synthetic herbicides are widely used, while weed control is primarily based on mechanical, cultural, and physical methods.

There are many ways to prevent weeds in agricultural activities that are well known, including limiting the opportunity for new weeds to enter and spread. Some important ones are: Farmers can decide about crop rotations and weed control practices by monitoring weed populations that will be most effective in specific areas. Field monitoring is a key component of an integrated weed management system. Systematic collection of data on the distribution of weed species is useful in the short term for making immediate weed control decisions to avoid crop losses (CropLife, 2012).

Sustainable weed management must be tailored to the specific situation. Ecological weed control is relatively well studied but underutilized (MacLaren *et al.* 2020).

Weed seeds serve as a major source for the spread of new populations (Diary, 2014).

The sowing time of wheat seeds should be adjusted so that it is unfavorable for the germination of weed seeds without compromising crop yield. Early maturing wheat reduces weed infestation compared to late maturing wheat (Singh *et al.,*1995). However, it is important not to change the timing of wheat sowing too much from the optimal one, otherwise, the yield will be reduced.

Crop rotation is a key factor in determining absolute weed levels in crops and also influences the relative abundance of different weed species. In monoculture conditions, weeds with the same life cycle as the crop increase in number. Some weed species often thrive in specific crops because they are well adapted to planting timing, tillage patterns, and crop competition. For example, perennial weeds are often associated with perennial crops, while annual weeds are associated with annual grain crops. It is reported that when alternative crops are grown in place of wheat for two or more years, the soil supply of weed seeds is reduced to low levels and they are easier to manage (Chhokar *at el*., 2014).

Crop rotation involves alternating different crops on the same land. Diverse crop rotations are better suited to disrupt the life cycle of weed populations. Different crops often require different planting times, tillage, and herbicide applications, and also differ in their competitiveness. Chhokar et al., (2014) documented that crop rotation is a very effective cultural practice for reducing the number of weeds, including problematic weeds such as *Phalaris minor* in wheat crops.

Rotating winter and spring grain crops is also a good crop rotation strategy for weed control. The benefits of crop rotations reduce the buildup of weed populations and prevent large shifts in weed species. Another advantage of crop rotation is the ability to use herbicides with different active ingredients and mechanisms of action, which slows down the development of weed resistance (CropLife, 2012).

Varieties of grain crops, including wheat, influence the ratio of cultivated and weed plants in crops due to morphological characteristics, growth rate, and sowing density (Chhokar *et al.,* 2014).

There are many advantages and disadvantages to using tillage for weed control. When approached strategically, tillage can be an effective way to reduce weed populations. However, mechanical tillage of the soil can lead to disruption of its structure, erosion, depletion of organic matter, reduced water infiltration, etc. These negative aspects of tillage have led farmers to reduce or even adopt no-till practices.

Understanding weed biology and ecology is critical when planning strategic tillage for weed control. For annual weeds, tillage is aimed at depleting seed reserves and preventing their reproduction. Tillage helps control weeds in several ways. Light tillage often encourages weeds to germinate, making them available for control by herbicides or subsequent tillage. Tillage can also cause their eradication (CropLife, 2012). For perennial weeds, the purpose of tillage is to deplete the nutrients found in the roots. Successive removal of aboveground parts by tillage or mowing can eventually deplete perennial plant nutrients.

Subsequent tillage is important because it cuts perennial plants into more pieces, which sometimes can give rise to new plants. Tillage exposes the roots of perennial plants to extreme influences - drying out or freezing (CropLife, 2012; Osipov, Logoida, 2023).

Some crops produce chemicals that are released from their roots or leached from stubble debris and inhibit the germination and/or growth of small seeded weeds. This chemical suppression is known as allelopathy (Polyak and Sukharevich, 2019). Barley and rye are crops that are highly competitive in part because of their ability to produce weed suppressant chemicals. These crops express their allelopathic potential by releasing substances that not only suppress weeds but also promote underground microbial activity (Narwal, 2000; Jabran *et al.,* 2015).

Thus, to ensure ecosystem sustainability, future weed control methods may reduce the use of herbicides and use allelopathic strategies.

Crops and weeds compete for nutrients (nitrogen, phosphorus, potassium, etc.), and some studies have shown that applied nutrients are beneficial to crops when applied directly to crops. Adequate application of fertilizers increases the competitiveness of wheat. By changing the timing and method of fertilization, competitive advantage can be shifted towards wheat (Reinertsen *et al.,* 1984; Kirkland and Beckie, 1998; Blackshaw, 2004; Chhokar *et al.,* 2014).

Applying fertilizer 2-3 cm below the wheat seeds helps give the crop a competitive advantage over weeds. There are many cases where weeds are better at using nitrogen than wheat, making them more competitive. For example, *Avena fatua* and *Setaria viridis* have been shown to utilize applied nitrogen better than wheat, giving them a competitive advantage in nitrogen treated plots (Carlson and Hill, 1986; Peterson and Nalewaja, 1992). In general, phosphorous fertilizers promote the growth of broadleaf weeds, while higher nitrogen levels increase the growth of turfgrass weeds. High nitrogen rates help suppress *Lathyrus aphaca.*

Therefore, it can be said that the agricultural method remains an important element in weed control.

1.4 Chemical method of weed control

Rising labor costs and labor shortages during peak agricultural activity have prompted the search for alternative weed control methods. As a result, chemical weed control is the most efficient and cost-effective (Sureshkumar and Durairaj, 2016). (Sureshkumar and Durairaj, 2016).

1.4.1 Trends in the development of the chemical method

With intensive wheat cultivation technology, chemical method of weed control is a very essential element. Weed control is an important component of agricultural cropping systems and is responsible for the significant growth in agricultural production since the discovery of herbicides in the 1940s.

One of the essential agricultural practices to prevent crop losses and preserve crop quality is chemical protection of grain crops from weeds, diseases, and pests. If chemical protection measures are not implemented, grain production losses may exceed 30–40%.

Due to logistical, technological, and financial challenges on a social and economic level, the elimination or reduction of individual protection systems results in a decline in the overall grain yield. Consequently, production costs rise dramatically, making grain production unprofitable given the current low selling prices. Given that wheat is regarded as a strategic crop, using efficient chemical weed control agents is a pressing national economic priority (Dolzhenko, Silaev, 2010).

Among the most efficient and economical ways to control weeds in grain crops is without a doubt the use of chemicals. Chemical weed control agents should be adapted according to their high biological and economic efficiency, strong selectivity, and maximum degree of environmental harm that can be caused by herbicides without impairing the agroecosystem's ability to function (Chichvarin, 2008).

The range of agrochemicals used for crop protection has undergone significant changes over the past few years. Qualitative and quantitative changes have been demonstrated by increasing herbicide diversity (Dolzhenko and Silaev, 2010).

Chemical weed control is preferred due to its better effectiveness and lower costs. It also does not cause any mechanical damage to the crop that occurs during manual weeding.

Significantly, when developing a successful chemical weed control program, it must be kept in mind that both crops and weeds have specific morphological and biological characteristics (McGiffenet *et al.,* 2014).

Chhokar *at el.,* (2014) reported that chemical control is more effective because weeds are controlled even within crop rows.

Weeds are easier to control with herbicides in the early stages of development than in the later stages. Annual weeds are easier to control than perennial weeds. Emerging seedlings can usually be controlled with a suitable herbicide applied to the leaves; they can be transported (systemically) or have contact activity. A contact herbicide may destroy only those tissues with which it comes into contact, while dormant broadleaf weed lateral buds or grassy weed growth points may be left undamaged, allowing plants to grow and recover (McGiffenet *et al.,* 2014).

Unlike contact herbicides, systemic herbicides move through the plant's vessels, reaching and destroying the growing parts, reducing the potential for further growth. Perennial weeds are the most difficult to control and require multiple applications of systemic herbicides.

Chemicals called herbicides are mixtures of organic compounds that are intended to either stop unwanted plants from growing or completely eradicate them. Herbicides are composed of active compounds that are most effective against weeds and an excipient that helps apply the herbicides more easily and increases its effectiveness (Harasim *et al.,* 2014; Ustuner *et al.,* 2020; Duke and Dayan, 2018).

Zinchenko (2012) reported that herbicides must have a high selectivity of action in order to destroy some plants without harming others, including plants belonging to the same family. For example, monocot weeds in cereals or white marjoram in beet crops. Insecticides can be used on many crops, while herbicides can only be used on resistant crops. In this regard, when using herbicides, it is necessary to take into account not only the sensitivity of weeds to them but also the degree of resistance (tolerance) of crops.

These chemicals can improve production efficiency, help reduce the number of tillage systems, and require less cost and human effort.

Vats (2015) pointed out that the history of controlling unwanted plants in agricultural fields began with the advent of agriculture. People had to expend large amounts of their energy weeding arable land in order to provide the conditions for optimal growth of desired crops. At the same time, the idea of weed control began to occupy the minds of farmers. There are six stages in the development of weed control, which are explained by Hay (1974):

1. 10,000 BC e. – manual weed removal.
2. 6000 BC e. – the use of primitive hand tools for cultivating the land and destroying weeds.
3. 1000 BC e. – implements driven by animals, such as harrows.
4. 1920 AD e. – mechanical implements such as cultivators, blades, harrows, rotary hoes, etc.
5. 1930 AD e. – biological control.
6. 1947 - chemical control, commercial development of organic herbicides.

Initially, the man used hand weeding, around 6000 BC. e. it was replaced by primitive hand tools. Then came the era of using animals such as bulls and horses to use mechanical tools. According to Lowery (1987), the Romans (circa 300 BC) used salt and olive oil to control weeds in crops and along roads after they noticed that the land had become barren under their olive oil presses.

Green et al. (1987) declared that petroleum waste, rock salts, ground arsenic ores, copper salts and sulfuric acid are used to control weeds on railways, highways and sawmills. To manage broadleaf weeds in cereal crops, inorganic substances like sulfuric acid, copper ferric sulphate, lead arsenate, copper nitrate, and sodium arsenate have been employed

(CropLife, 2012). These herbicides fall into the non-selective category because they are used to eradicate all plants. Furthermore, plants were poisoned by the treated area for a considerable amount of time.

Sprayers were developed to deliver herbicidal mist in 1880. Klingman et al., (1982) concluded that Bolli in the USA, Schultz in Germany, and Bonnett in France began research as early as 1900 on inorganic compounds and solutions of copper salts that selectively control broadleaf weeds in cereal crops.

Unfortunately, these chemicals could not be used on arable land because of their adverse effects on crop plants. Thus, the use of selective herbicides has emerged, which specifically kills only weeds.

Pokorny in 1941 described the chemical synthesis of 2, 4-dichlorophenoxyacetic acid (2, 4-D), after which other salts and esters of 2, 4-D were developed. According to CropLife (2012), synthetic herbicides (like 2,4-D and MCPA) were created during World War II and were first introduced to the market in 1944 as weed killers. In fact, this was the beginning of the “chemical era” for the development of herbicides. Templeman and Sexton in the 1940s reported that phenoxyacetic acids herbicides were toxic to dicotyledonous but not monocotyledonous plants.

Later, RAO (2000) reported that 2,4-D has been in commercial use in the US and MCPA for use in Europe since 1947. Farmers use 2,4-D as a selective killer of broadleaf dicots, but not monocots. In the 1950s, targeted research into herbicides began.

Kramer et al (2014) noted that mode of action studies did not play a major role in the chemical industry until the 1970s. However, in the 1990s and beyond, ever-increasing regulatory and economic pressures changed the entire industry landscape.

New herbicides must be registered with the appropriate regulatory authority in each country. This requires a wide range of testing and careful analysis of safety and effectiveness before registration of a new product. Herbicides must be registered for use on different crops. It should be noted that a weed may be susceptible to a particular herbicide, provided the quantity and application rate are appropriate (Sherwani, Arif and Khan, 2015).

The way chemical herbicides are sprayed, absorbed, transported, and broken down by weeds all affect how effective they are. The weed species and stage of development, along with environmental factors like temperature, humidity, and carbon dioxide levels, are the primary determinants of these products' effectiveness (Grzanka *et al.,* 2022). Any alteration in climatic conditions will impact plant physiology, which could have an adverse effect on herbicide efficacy, according to Varanasi et al. (2016).

The current range of herbicides has not fully meet the requirements of the times. Most preparations available on the market protect crops from only one group of weeds – cereals or dicots, while in the fields there are mixed types of weeds harmful to crops (Luneva and Zakota, 2018).

One of the few active ingredients that can cope with this kind of task is pyroxulam. This herbicide effectively destroys cereal weeds, such as *Bromus tectorum* L., *Avena fatua* L. *Lolium temulentum* L. (Geier *et al.,* 2011; Tekle *et al.,* 2018; El-Metwally, Gad, 2019). The herbicide is effective against dicotyledonous weeds, including *Descurainia sophia* L., *Chorispora tenella* (Pallas) DC., *Lamium amplexicaule* L. (Reddy *et al.,* 2013).

Despite the high effectiveness of pyroxsulam, 3 problems associated with its use have been identified these are:

First, some types of weeds were not very sensitive to pyroxulam. It was shown that pure pyroxulam was not effective enough to control *Amaranthus retroflexus* L. in winter wheat crops (Zargar et al., 2020). It also turned out that the sensitivity of weeds to pyroxulam may differ even within different species classified in the same genus. For example, the use of pyroxsulam resulted in >90% mortality of *Setaria pumila* (Poir.) Roem. & Schult. and *Setaria viridis* (L) Beauv. (Satchivi *et al.,* 2017).

Second, it has been discovered that high pyroxsulam application rates can have a negative impact on the crop plant. It was shown that when applied at doses of 15 and 18 g (actual)/ha, pyroxsulam did not cause visual damage of more than 10% in wheat. But pyroxsulam can damage wheat when applied at rates of 21, 30, 36 and 42 g (actual)/ha (Zobiole *et al.,* 2018).

Wheat treated with pyroxulam has fewer antioxidants, according to Zainulabdeen and Ibrahim (2020). As stated by Abdel-Wahab et al. (2021), pyroxulam use had a detrimental impact on the amount of total protein and total carbohydrates in grains as well as the amounts of N, P, and K.

Third, herbicide resistance is beginning to develop. Piroxolam (ALS-inhibiting herbicide) was first used to control weeds (such as *Alopecurus ssp*.) that had become resistant to ACCase-inhibiting herbicides. However, after some time, resistance to these herbicides emerged (Feng *et al.,* 2016; Guo *et al.,* 2016, Huang *et al.,* 2021). Over time, the number of resistant weed species increased, and such reports continue to be received today. In North Carolina, stable populations of *Lolium perenne* L. ssp have been found. *multiflorum* (Lam.) Husnot) (Jones *et al.,* 2021). A piroxolam resistant form of *Lolium rigumum* Gaud has been discovered in northeastern Tunisia. (Kutasi *et al.,* 2021).

Solving the identified problems is possible through the use of tank mixtures of herbicides based on active ingredients with different mechanisms of action (for example, inhibition of ALS- and ACCase) (Petersen, 2018), or through the emergence of combination preparations. Of particular interest in this regard are preparations based on new active substances or the use of a combination of agrochemicals discovered at the beginning of the 21st century (Epp *et al.,* 2016).

In modern pest control methods, herbicides are often combined with other agrochemicals, such as adjuvants, fertilizers, fungicides and insecticides, or with other herbicides from different chemical groups. Using a combination of agrochemicals is known to use to scale up control or to reduce application costs associated with pesticide use (Mitkov, *et al.,* 2017).

In terms of the impact of chemical herbicides on the environment and human health, less than 90% of chemical plant protection products reach the target organisms, and the effect of these toxins varies depending on the species and type of tissues to which the organism is exposed (Al-Nahal, 1st edition). Alnahal, Y. 2021; Yang et al., 2021).

Kulikova and Lebedeva (2010) state that there is no one standard classification for herbicides; instead, they are categorized based on a number of factors, including their chemical makeup, how they act on plants, when to apply them, how toxic they are, how long they remain toxic, and more. As stated by Zakharenko (1990), contemporary herbicides fall under a number of different organic compound classes.

1.4.2 Classification of herbicides

Today, in the scientific literature, we can find different systems of herbicide groups. Some herbicides contain one active ingredient, others contain two or more active ingredients, which may belong to more than one herbicide group.

Herbicides can be classified according to the class of chemicals, time of application, mode of action, composition, and selectivity (PAN, 2017). Like other pesticides, the active ingredients of herbicides are biologically active compounds. They pass through membranes and diffuse into living cells to produce the desired toxic effect.

The herbicide's activity, selectivity, persistence, and mode of action can all be altered by altering the functional group. Scientific publications have reported minor variations in the group classification system (DeBoer *et al.,* 2011).

It is important to note that not all herbicides in each group have the same weed control spectrum. Some products have very slight differences from each other, while other products in the same group may have significant differences. For example, hexazinone has a much wider range of weed control properties (herbaceous plants and woody perennials) than terbacil (some broadleaf and annual grasses) (Based on 2017).

Chemical herbicides can be categorized into two primary groups based on their selectivity and mode of action. Herbicides that are selective only target a particular kind of weed and do not harm other plants. Conversely, numerous plant species are impacted by non-selective drugs.

Herbicides are divided into three primary categories and are administered at various intervals. Substances added to the substrate prior to crop sowing are included in the first group. Pre-emergence measures that stop the germination of weeds are included in the second group. Post-emergence agents are utilized in the third group when crop plants are growing (Das and Mondal, 2014; Sherwani, *et al.,* 2015).

Chemical herbicides are not consistently categorized based on how they operate. Herbicides are categorized by Sherwani et al. (2015) into 11 major groups. A few years later, Dayan et al. (2019) suggested grouping herbicides into three primary categories, each of which has numerous subcategories, including agents for plant protection that target particular plant parts. There are currently 25 groups of chemical herbicides, according to the International Herbicide Control Committee (HRAC) (HRAC, n.d.).

Zakharenko (1990) proposed to divide herbicides:

A) First group:

I) Classification by chemical composition.

II) Classification according to their application.

III) Classification according to time of application.

IV) Classification by recipe.

V) Classification according to residual effect.

B) The second group is bio-herbicides.

C) The third group is herbicide mixtures.

Herbicide classification according to chemical characteristics or nature

First, inorganic pesticides. The first chemicals used for weed control before introducing of organic compounds, e.g.

a) Acids: sulfuric acid, arsenic trioxide, arsenic acid, and arsenous acid.

b) Salts: copper sulfate, copper nitrate, sodium chlorate, sodium arsenic, and ammonium sulfate.

19 Herbicides made of organic materials.

a) Oils: aromatic compounds, polycyclic oils, diesel fuel, xylene, standard solvent, etc.

b) Aliphatic: glyphosate methyl bromide, dalapon, TCA, and acrolein.

c) Amides: napthalam, diphenamide, propanil, butachlor, alachlor, CDAA, and propachlor.

d) Benzoins: phenac, chlorambine, diakampa, tricamba, 2, 3, and 6 TBA.

e) Paraquat and diquat are piperidiliums.

f) Carbamates: propane, brocham, and chloropham.

g) Tocarbamates: pentocarb, fernolate, dilate, EPTC, aslom, sycolate and butyl.

h) Dithiocarbamates: CDEC, metham.

i) Nitralines (benzonitrate): diclofenil, bromoxynil, euxyl.

j) nitroanilines (toluidine): beneven, trifluralin, butalene, dinitramine, flulorin, oxyzaline, benoxalin.

l) Phenoxy: 2,4-D, 2,4, 5-T, MCPB, 2,4-DB, 2,4-DP, 2,4, 5-TP (Sylvex)

n) Triazines: atrazine, simazine, ametrine, terbutryn, siprazinc, metribuzine, prometrin, propazine.

o) Ureas: monuron, diuron, fenuron, neburon, flumeturon, motabenzathiazuron-buturon, chlorpromoron, chloroxoron, noria-sedozone, mitoxoron.

p) Uracil: promasil, trabazil, linacil.

o) Diphenyl ethers.

q) Organic arsenic: cacodylic acid, MSMA, DSMA.

r) Others: pentazone, piclaram, pyrazone, pyrichlor, endothall, MH, DCPA.

Classification of herbicides according to their mechanism of action.

Herbicides kill plants through a biochemical or physical mechanism, which is known as their mechanism of action. Understanding the six modes of action of herbicides is crucial for comprehending their classification, hierarchy, regulation, and management (Sherwani *et al.,* 2015). Additionally, it sheds light on herbicide resistance, which is still a problem in sustainable agriculture. The effect of weed control peaks during the seedling stage and troughs at the maturity stage (Norsworthy *et al.,* 2016).

Herbicides are thought to share the same mechanism of action even though they may fall under a different chemical class or be part of a different group. The persistence, degradation, and mobility of herbicides in the environment, as well as their effects on crop yield, groundwater, water sterilization, soil, and public and environmental contamination, highlight the significance of using herbicides responsibly and in accordance with labeling, regulations, and guidelines. (Tudi, *et al.,* 2021).

Since photosynthesis is the primary source of oxygen for all living things on Earth, it is a crucial biochemical process. Herbicides that interfere with photosynthesis cause electron transport to be disrupted and redirected. This results in the accumulation of nitrites, the suppression of energy and carbon dioxide production, and the loss of ascorbate, chlorophyll, and carotenoids. Consequently, the leaves rapidly turn white or wither as a result of losing pigment. Atrazine, diuron, propanil, bromoxynil, monuron, isoproturon, linuron, simazine, chloridazone, bromacil, terbacil, lenacyl, phenmedipham, and metribuzin are among the herbicides that prevent photosynthesis. (Kraehmer *et al*. 2014; Duke and Dayan 2018; Dayan *et al*., 2019; Jugulam and Shyam, 2019).

Several categories have been established for herbicides, such as:

Group 1. Inhibitors of Acetyl Coenzyme A Carboxylase (ACCase): These products are typically herbicides that block lipid formation in roots and growing points. They typically work with actively growing grasses and are applied after emergence. Sherwani et al. (2015), illustrated that the chemical family of aryloxyphenoxypropionate, cyclohexanedione and phenylpyrazoline act by inhibiting the ACCase enzyme. For example, Fusilade Forte, EC (active ingredient: fluazifop-P-butyl), Select, EC (active ingredient: clethodim) (Sherwani, *et al.,* 2015).

Group 2: Inhibitors of acetolactate synthase (ALS): The acetolactate synthase (ALS) enzyme is inhibited by these herbicides, which are also referred to as amino acid synthesis inhibitors These foods prevent this enzyme from doing its regular job, which is essential for the production of proteins (amino acids) (Burgess, n.d.). Typically, this class of products—which are considered post-emergence herbicides are not soil-active, according to Sherwani et al. (2015). They are also referred to as AHAS inhibitors, or branched chain amino acid inhibitors.

It is made up of the triazolopyrimidine chemical family, imidazolinone, pyrimidinylthiobenzoate, sulfonylaminocarbonyltriazolinone, and sulfonylurea. The largest class of herbicides containing amino acids includes ALS inhibitors (Vats, 2015).

Group 3: Inhibitors of root growth: These herbicides, also referred to as seedling root growth inhibitors, work by inhibiting cell division as part of their mechanism of action, which eventually stops roots from sprouting and growing. These products should be applied to the soil prior to the emergence of weeds because they are applied pre-emergent or before planting (Burgess, n.d.). Several herbicides, such as Treflan, EC (trifluralin as the active ingredient), and Gaitan, EC (pendimethalin as the active ingredient), are members of this group. (https://www.agroxxi.ru/goshandbook).

Group 4: Synthetic auxins: They are also known as plant growth regulators. This group includes hormonal-based herbicides (Grossmann, 2010), and this group includes different types of herbicides, including: Alliance, BP (active ingredient: 2,4-D + dicamba) (dimethylamine salts), Lontrel Grand, VDG (active ingredient: clopyralid) and Staran Premium 330, EC (active ingredient: fluoroxipir) (https://www.agroxxi.ru/goshandbook).

Groups 5, 6 and 7: Inhibitors of photosynthesis - PSII (photosystem II) inhibitors: These herbicides work by inhibiting the pathways involved in photosynthetic processes, specifically Photosystem II (PSII). It has been noted that repeated application of the herbicide formulated using this metabolic principle has resulted in certain weeds developing resistance to it (Sherwani, *et al.,* 2015). The members of group 5 of this chemical family are pyridazinone, uracillate, phenylcarbamate, and triazine. Nitriles, benzothiadiazinones, and phenylpyridazines are examples of group 6, and amides and phenylureas are examples of group 7. All of these groups' comparisons revealed various binding patterns as well as some commonalities (Sherwani*, et al.,* 2015).

Groups 8 and 15: Shoot growth inhibitors: Also known as seedling inhibitors, herbicides manufactured in this way are used as part of soil preparation and are effective before weeds emerge. Sherwani et al. (2015) state that the mechanism of lipid synthesis in the cell membrane is connected to the mechanism of action of Group 8 herbicides. The chemical family of group 8 herbicides consists of phosphorodithioates and thiocarbamates and inhibits the biosynthesis of lipids, fatty acids, proteins, isoprenoids, flavonoids, and gibberellins (Colovi *et al.,* 2013). The chemical family that includes oxyacetamide, tetrazolinone, chloroacetamide, and acetamide represents group 15 herbicides (Based, 2017). Through thiocarbamate sulfoxides, these herbicides conjugate with acetyl COA and specific sulfhydryl-containing molecules, inhibiting the long-chain fatty acids during the plant's seedling shoot growth stage and influencing the weeds' preemergent growth (Sherwani, *et al.,* 2015).

Group 9: Aromatic amino acid inhibitors: These substances work by preventing the synthesis of amino acids. This class of chemicals must be applied to vegetable plants because of its broad range of activity and the fact that it is inert in soil. One pesticide in this class is glyphosate, also known as glycine; it acts as a non-specific herbicide by inhibiting amino acids, a mechanism unique to this pesticide (Sherwani, *et al.,* 2015).

Group 10: Glutamine synthesis inhibitors: This class of herbicides targets only glucosinolates, which are synthetic compounds, and works on nitrogen metabolism (Sherwani, *et al.,* 2015). Glycines, or glyphosate, are nonspecific herbicides that work by preventing the synthesis of amino acids. This mode of action is unique to glyphosate. Example: Basta, BP (active ingredient: ammonium glufosinate). This is a sustained-release herbicide (https://www.agroxxi.ru/goshandbook).

Groups 12, 13 and 27: Inhibitors of synthesis of pigments: According to Sherwani et al. (2015), these herbicides kill chlorophyll, a green pigment that is necessary for plant photosynthesis. The chemical family of amides, anilidex, furanones, phenoxybutan-amides, pyridiazinones, and pyridines are the members of group 12. The phytoene desaturase enzyme is inhibited by these herbicides, which interfere with the carotenoid biosynthesis pathway (Qin, *et al,.* 2007). Representatives of Group 13 include the chemical family Isoxazolidinone, whose site of action is where diterpene synthesis occurs. The chemical family Isoxazole, which also includes 4-hydroxyphenylpyruvate dioxygenase (HPPD) inhibitors, represents Group 27 (Sherwani, et al., 2015).

Group 14: PPO inhibitors, or cell membrane inhibitors: Certain pesticides are applied during the pre-emergence period, while the majority are used during the post-emergence stage. This kind of pesticide works by destroying cell membranes, and in the absence of light, it takes longer to effect. Protoporphyrinogen oxidase is inhibited by these herbicides (PPO). This chemical family is represented by herbicides, which include pyrimidinedione, oxadiazole, aryl triazolinone, oxadiazole, and oxazolidinedione (Sherwani et al., 2015).

Group 22: Inhibitors of photosynthesis: PSI, or photosystem I inhibitor: As these compounds have little to no impact on the soil and should suppress plant weeds, their method of action is to disrupt the inner cell membrane (Based, 2017). As stated by Sherwani and colleagues (2015), as members of the bipyridilium chemical family, these herbicides are also referred to as PSI electron diverters because they take up electrons from PSI and produce herbicide radicals in the process. Members of this group are Gramoxone (paraquat), Reglon Forte, SL (active ingredient: diquat (dibromide)) (https://www.agroxxi.ru/goshandbook).

Herbicides are separated into contact and systemic categories based on how they affect plants.

Upon direct contact, contact herbicides kill the above-ground parts of weeds. The majority of herbicides are classified as systemic. Because they enter plants through xylem or phloem vessels and kill the entire plant, they are applied to soil and used to treat vegetative plants.

Classification of herbicides according to timing of application:

- **Pre-planting:** It is used before planting crops (Vats, 2015). It is usually used to control weeds that have emerged before sowing. A series of studies have shown that these types of herbicides are used before sowing or transplanting cultivated plants (Kulikova, Lebedeva, 2010). Glyphosate is an example of an herbicide.
- **Pre-emergence:** Herbicides are applied after sowing or planting crops, but before crops emerge. This type of herbicide is applied before weed seedlings emerge from

the soil surface. Vats (2015) said that the herbicide kills weeds as they grow in the area treated with the pesticide by preventing cell division in the germinating seedlings and does not prevent the weeds from germinating. It should not be toxic to crops. Butachlor is an example of an herbicide.

- **Post-emergence herbicides:** This type of herbicide typically requires multiple applications for proper control and is applied after weed seedlings have emerged through the soil surface. In addition, Kulikova and Lebedeva (2010) indicated that it is used after the emergence of cultivated plants during different periods of the growing season. They are absorbed by leaves or roots and are selective or non-selective, contact or systemic.
-

1.4.3 Ensuring the safety and control of the use of herbicides on grain crops

It is important to understand the risks and hazards associated with the use of pesticides, as herbicides have phytotoxic effects (Spiridonov *et al.,* 2001; Gupta, 2012). Pesticides can be toxic to other organisms, including birds, fish, beneficial insects, and non-target plants (Baker *et al.,* 1996; Škrbic *et al.,* 2007; Gouin et al., 2008; Aktar *et al.,* 2009; Elgueta et al., 2017; Kim et al., 2017; Mingo et al., 2017).

Pesticides cause biochemical changes that disrupt normal cellular functions (Fishel *et al.,* 2016; Malalgoda and Simsek, 2021). The toxicity of any compound is dose dependent (Government of British Columbia, 2017; Kniss, 2017).

A common method for documenting toxicity is using oral LD50 (LD50) values. In other words, the semi-lethal dose, LD50, is the amount of active substance required to provide a "lethal dose" to 50% of the test population (Lebedeva, 2010; Fishel *et al.,* 2016). Toxicity studies of herbicides are well documented, and they are also well known to have higher LD50 values than many commonly used pesticides (Fishel *et al.,* 2016).

Based on the degree of toxicity (hazard to the environment), herbicides (and pesticides in general) were divided into classes (Table 1).

Table 1. Classification of pesticide toxicity (WHO, 2009)

Hazard class	**LD50 for rats (mg/kg body weight)**	
	Oral	Dermal
1a - extremely dangerous	< 5	<50
1b - highly dangerous	5–50	50–200
2 - moderately dangerous	50–2000	200–2000
3 - slightly dangerous	More than 2000	More than 2000
4- unlikely to pose a serious hazard	5000 and above	

Herbicides have two types of toxicity: acute and chronic toxicity. Many herbicides are mild to moderately toxic. It is estimated that chronic herbicide effects can be very significant and life-threatening, as with 2,4-D (Weisenburger, 1993).

Modern plant growing technologies involve the use of combined chemical plant protection products, which contain a number of substances, the content of which must be controlled in the resulting products.

They expected to feed 10 billion people worldwide by 2050 (Eddleston, 2000). Worldwide, approximately 2 million tons of pesticides are consumed annually for crop protection (45% in Europe, 25% in the USA, 25% in the rest of the world) (Ali *et al.,* 2021).

When these chemicals are discharged into the environment, they may migrate and experience processes of degradation (Singh, 2012; Liu et al., 2015). According to Marie et al. (2017), herbicide degradation can result in the production of hazardous materials.

Through various physical and microbiological processes, pesticides are degraded in the ecosystem into new chemical compounds called metabolites, which, depending on their chemical structure, can be hazardous or non-toxic (Liu *et al.,* 2015; Marie *et al.,* 2017).

According to Mehdizadeh et al. (2021), herbicides, as the most common pesticides, can threaten agricultural safety and affect water and soil resources, human and animal health, and food safety.

Herbicide residues can affect seed germination, flower production and plant viability during critical growth stages (Boutin *et al.,* 2014).

Pesticide residues are defined as "any substance found in food, agricultural commodities, or animal feed resulting from the use of a pesticide" in the Codex Alimentarius (CA). These substances are metabolites or derivatives of a particular pesticide (Malalgoda and Simsek, 2021).

Nowicki and Pascal noted in 2012 that pesticide residues have become a growing concern for the marketing safety of wheat since the early 1960s. For any compound, the residue may exist as an unchanged parent compound or as one or more degradation products, toxic or non-toxic.

Hundreds of pesticides, belonging to dozens of chemical classes and contained in thousands of formulations, are used throughout grain-producing countries to control pests (Kolberg *et al.,* 2011).

To ensure that the products that reach consumers are safe for human consumption, there are relevant rules and regulations applied by various official bodies. For this purpose, maximum residue levels (MRLs) have been determined for various pesticides used in food production (Malalgoda and Simsek, 2021).

Codex Alimentarius (CA) has defined Maximum Residue Levels (MRLs) as: “The maximum residue level of pesticide residue permitted by law in food or feed when the pesticide is properly applied in accordance with good agricultural practices”. Maximum Residue Levels (MRLs, mg/kg) is a standard established by national and international authorities (e.g., Codex Alimentarius).

Analysis of herbicide residues in wheat crops requires methods that allow the identification of not only the original structures but also their metabolites and degradation products.

Today, there are many methods for determining herbicide residues in cereal crops (MUK, 2006; Díez *et al.,* 2006; MUK, 2007).

Obviously, it is necessary to manage many substances in the analyzed products; Using of pesticide determination methods has several advantages, as the time required for sample preparation and chromatographic analysis can be significantly reduced, as well as the consumption of reagents and the cost of analyzes (Zajats, 2017).

According to Rejczak and Tuzimski (2015), there is a growing demand for high-performance multi-resident methods (MRM), which should be easy to perform, fast and inexpensive and allow analyzing a wide range of substances. There are many methods available to identify multiple agrochemical residues in agricultural products and food (Kohlberg *et al.,* 2011; Leyva-Morales *et al.,* 2015).

Gas chromatography with mass spectrometry (GC-MS, GC-MS/MS) with electron impact ionization (EI) and liquid chromatography with mass spectrometry (LC-MS) with electrospray ionization (ESI) are currently being combined - these are the methods most commonly used for the analysis of multiple pesticide residues in foods because of their high sensitivity and selectivity (Stachniuk and Fornal, 2016).

Previous studies have shown that the development of many chromatographic separation methods was essential for their successful analysis. This is due to the great diversity in the molecular structure of herbicides (Cserháti *et al.,* 2004). Choosing the most efficient extraction and concentration procedure is of paramount importance to reliably measure herbicides.

Several extractions methods have been developed and applied to measure herbicide residues. Since herbicides are a very heterogeneous group of compounds with different biological and physicochemical properties, the current trend in herbicide residue analysis is to develop multi-residue methods.

Modern sample preparation procedures have been developed:

1-Accelerated Solvent Extraction (ASE).
2- Supercritical fluid extraction (SFE).
3- Microwave extraction (MAE).
4- Solid phase extraction (SPE).
5- Solid phase microextraction (SPME).
6- Matrix solid phase dispersion (MSPD).

7- Extractions and QuEChERS.

Wang, et al., (2019) noted that Dusek, Jandovska and Olsovska in 2018 developed a rapid and simple approach for the simultaneous determination of 48 pesticides, including herbicide residues, by liquid chromatography–mass spectrometry/mass spectrometry (LC-MS/ MS). Du et al., (2018) used ultra-high performance liquid chromatography–quadrupole tandem mass spectrometry to identify structural compounds of herbicides such as cyanazine, simazine, atrazine and promethazine.

Thus, control of herbicide residues in different products and environments is an important component of ensuring the safety of pesticide use in grain production (Alekseev, Dolzhenko, 2023).

Chapter 2 Conditions, Materials and Research methods

The dissertation work was carried out at the Department of Plant Protection and Quarantine of St. Petersburg State Agrarian University.

The effectiveness of herbicides was studied during the growing seasons 2019-2022, in the Salsky district of the Rostov region.

2.1 Agroclimatic conditions of the research site

The formation and techniques for raising the yield of grain crops while enhancing farming culture are significantly influenced by the meteorological and natural characteristics of the area.

One of the Russian Federation's most crucial strategic areas is the Rostov Region. Situated at the forefront of agriculture (2nd in the nation), energy, industry, and mining, the region is distinguished by a significant level of human-induced change, encompassing geophysical aspects. Geographically, the Rostov region is located in the south of European Russia in the region of the South Russian Plain, and in its southern part it merges with the Cis-Caucasian plain steppes. Its area is about 100.97 thousand km^2, and it is a flat steppe, at an altitude of 30 to 300 m above sea level (Zhidkova, Kovyarova, 2019).

The climate of the region is moderately continental. It is characterized by a combination of excess heat with a relative lack of humidity. Average annual temperatures for the growing season range between 29 -31°C. There is relatively little rainfall, and thus most of the area is characterized by insufficient and unstable humidity; About a third of the region is characterized by drought.

There are two main types of soils in the Rostov region: chernozem and chestnut. Thick chernozems of carbonate are formed in the southwest of the region. A dry steppe with dark and chestnut soils can be found in the southeast of the Rostov region. In the Rostov region, chernozem soils (62%) and chestnut soils (23%) are the most common soil types.

According to the region's geographic location, soil and climate, agricultural production direction, and intensity, there are six distinct agricultural zones on its land (Agriculture and agro-industrial complex - The Government of the Rostov region, without date).

Meteorological data for the years of research are presented in the tables 2 -5.

Table 2. **Meteorological data for 2019 (based on agrometeostation data from Gigant village, Rostov region)**

Basic indicators	Months and decades											
	April			May			June			July		
	1	2	3	1	2	3	1	2	3	1	2	3
Air temperature, 0C a) average long-term	9,6	11,0	12,5	14,6	16,6	17,9	19,7	21,1	21,7	22,7	23,4	24,1
b) current year	8,5	10,2	14,3	16,3	19,6	20,0	24,6	26,0	25,9	24,5	20,6	24,0
Precipitation, mm a) average long-term	11	16	21	16	18	21	16	19	26	20	17	21
b) current year	3,3	29,3	3,2	43,2	0,0	37,4	0,5	0,0	3,3	0,2	31,4	47,7
Air humidity, % a) average long-term		66			60			58			54	
b) current year	74	74	48	72	63	65	49	35	41	42	69	62

Table 3. **Meteorological data for 2020(based on agrometeostation data from Gigant village, Rostov region)**

Basic indicators	Months and decades											
	April			May			June			July		
	1	2	3	1	2	3	1	2	3	1	2	3
Air temperature, 0C a) average long-term	9,6	11,0	12,5	14,6	16,6	17,9	19,7	21,1	21,7	22,7	23,4	24,1
b) current year	5,6	9,7	11,4	16,2	15,8	16,0	20,9	24,9	24,3	28,2	25,0	26,1
Precipitation, mm a) average long-term	11	16	21	16	18	21	16	19	26	20	17	21
b) current year	0	7,3	0,1	22,7	0,9	44,3	32,8	43,7	14,0	5,7	16,5	5,2
Air humidity, % a) average long-term		66			60			58			54	
b) current year	44	50	46	67	55	71	63	51	50	38	50	36

Table 4. **Meteorological data for 2021 (based on agrometeostation data from Gigant village, Rostov region)**

Basic indicators	Months and decades											
	April			May			June			July		
	1	2	3	1	2	3	1	2	3	1	2	3
Air temperature, 0C a) average long-term	9,6	11,0	12,5	14,6	16,6	17,9	19,7	21,1	21,7	22,7	23,4	24,1
b) current year	8,6	10,9	11,4	15,5	17,4	20,3	17,9	22,7	26,7	25,6	29,7	26,2
Precipitation, mm a) average long-term	11	16	21	16	18	21	16	19	26	20	17	21
b) current year	21,8	47,6	27,1	6,9	72,9	9,8	32,5	3,2	0,0	31,4	0,0	11,3
Air humidity, % a) average long-term		66			60			58			54	
b) current year	76	87	72	62	73	69	78	68	52	55	31	47

Table 5. **Meteorological data for 2022 (based on agrometeostation data from Gigant village, Rostov region)**

Basic indicators	Months and decades										
	April			May			June			July	
	1	2	3	1	2	3	1	2	3	1	2
Air temperature, 0C a) average long-term	9,6	11,0	12,5	14,6	16,6	17,9	19,7	21,1	21,7	22,7	23,4
b) current year	11,5	11,7	14,0	11,2	14,4	17,9	23,4	23,5	21,7	24,6	23,9
Precipitation, mm a) average long-term	11	16	21	16	18	21	16	19	26	20	17
b) current year	7,2	33,5	19,6	30,2	16,6	0,1	0,0	3,2	21,8	0,3	8,1
Air humidity, % a) average long-term		66			60			58			54
b) current year	63	76	70	67	63	64	48	48	62	38	57

2.2. Characteristics of active ingredients of herbicides

Pinta, OD

Trade name	*Pinta, OD*
Active ingredient (a.i.)	*flumetsulam 50 g/l + florasulam 36 g/l*
Empirical formula	*1) flumetsulam: C12H9F2N5O2S* *2) florasulam: C12H8F3N5SO* *(https://www.pesticidy.ru/active_substance)*

The active substance: **Flumetsulam** (ISO) (Figure 1).

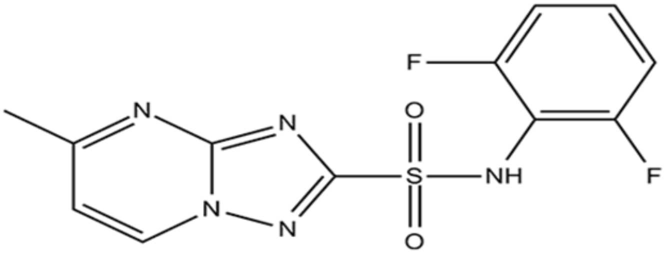

Figure 1. **Structural formula of flumetsulam (Pesticides.ru, https://www.pesticidy.ru/active_substance, 2022).**

IUPAC Name: [N-2,6-(difluorophenyl)-5-methyl [1,2,4] triazolo[1,5-A] pyrimidine-2-sulfonamide].

Relative molecular weight: 325.9

Chemical Class: Triazolpyrimidines

Physicochemical characteristics: whitish powder. It smells slightly sweet and dissolves in organic solvents. stable hydrolytically. In water, DT50 goes through photolysis for five to twelve months. Melting temperature: 235-254°C (decomposition); water solubility: 25°C, pH = 2.5 49.00 mg/l at 25°C and a pH of 7.0 5.65 g/l (www.pesticidy.ru).

Toxicological properties: Flumetsulam is a low-risk compound. LD50 for rats is more than 5000 mg/kg. The expression of cumulative properties is weak. mildly irritates the eye mucous membrane but does not cause skin irritation. does not show any teratogenic or mutagenic effects on rats. Flumetsulam-based preparations are categorized as hazard class 3 for bees and humans, respectively (https://www.agroxxi.ru).

Maximum Residue Level (MRL) for this active ingredient in foods (mg/kg): Cereal grain 1.0.

The mechanism of action: Acetolactate synthase activity is inhibited by the mechanism of action. The drug has a broad range of application, from the onset of tillering to the appearance of the flag leaf. It contains flumetsulam and florasulam. Additionally, it suppresses dicotyledonous weeds in their later stages of growth, even those species that might otherwise be resistant to other medications (https://www.agroxxi.ru).. There is no impact on crops that come after.

The active substance: **Florasulam** (ISO) (Figure 2).

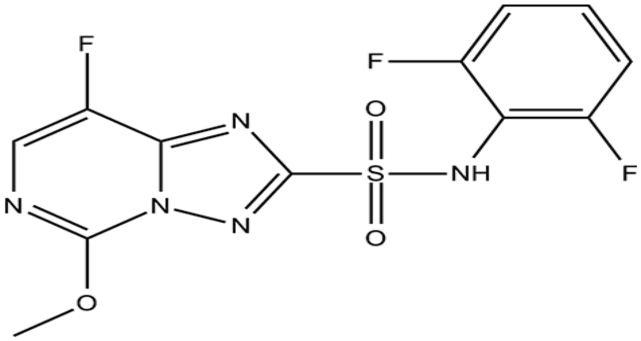

Figure 2. **Structural formula of florasulam**
(Pesticides.ru, https://www.pesticidy.ru/active_substance, 2022).

IUPAC Name: [N-2,6-(difluorophenyl)-5-methyl[1,2,4]triazolo[1,5-A]pyrimidine-2-sulfonamide].

Relative molecular weight: 359,3

Chemical Class: Triazolpyrimidines

Physicochemical characteristics: white crystals. Has no smell. At normal temperatures, soluble in organic solvents. Melting point 193.5-230.5°C (with decomposition); solubility in water (25°C, pH = 5.6-5.8) 0.121 g/dm3; vapor pressure (25°C) 1.0·105 Pa.

Toxicological properties: Rapidly decomposes in soil (half-life in field conditions 2-18 days). Does not penetrate into groundwater. Practical experiments have proven that it is not harmful to bees. Low hazardous substance. LD50 for rats >6000 mg/kg. In rabbits it does not cause redness of the eyes and skin. Preparations based on florasulam belong to hazard classes 2 and 3 for humans and hazard class 3 for bees.

MRL in products (mg/kg): in cereal grains, 0.05.

Mechanism of action: florasulam has a systemic effect. Penetrates into plants through leaves and roots, but does not penetrate into the grain. The mechanism of action is the inhibition of acetolactate synthase. It is a key enzyme in the formation of valine, isoleucine and leucine.

U46-Combi fluid 6, SL

Trade name	*U46-Combi fluid 6, SL*
Active ingredient (a.i.)	*2,4-D acid 30% + MCPA 30%*
Empirical formula	*1) 2,4-D: C8H6Cl2O3* *2) MCPA: C9H9ClO3*

The active substance: **2,4-D acid** (ISO) (Figure 3).

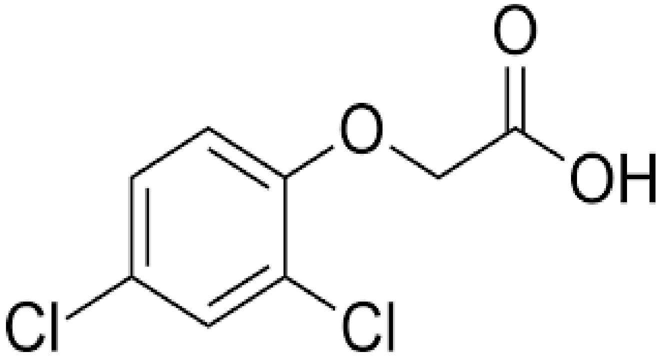

Figure 3. **Structural formula of 2,4-D acid (Pesticides.ru, https://www.pesticidy.ru/active_substance, 2022).**

IUPAC name: 2-(2,4-dichlorophenoxy) acetic acid.

Relative molecular weight: 221.0

Chemical class: Aryloxyalkanecarboxylic acids

Physical and chemical properties: 2,4-D crystals, white in color. It is mainly used in the form of esters, alkali salts and amino salts. It is hydrolytically stable and a strong acid. The dissociation constant is 23•10-4, and the melting point is -141°C. Boiling point - 160 °C at 50 PA (0.4 mmHg); Solubility in water - 540 mg / l (at 20 ° C).

Toxicological properties: The behavior of 2,4-D in animals, soil, plants and other environmental objects has been well studied, which is why it is widely used in various fields of plant cultivation. 2,4-D is metabolized in plants in several stages, the first stage being hydroxylation with the formation of 4-hydroxy-2,3- or 4-hydroxy-2,5-dichlorophenoxyacetic acids, which give fairly stable conjugates with the acids. Aminos and carbohydrates. They can remain in plants for a long time without major changes. The lethal dose of 50% for bees is more than 18 micrograms per capita, and it is classified as moderately toxic to fish. Toxicity depends on the form of application of the drug. Preparations based on 2,4-D are classified as Hazard Class 2 for humans and Hazard Class 3 for bees.

Mechanism of action: The plant can absorb the substance through the leaves and roots of plants, like other insecticides that contain phenoxycarboxylic acid. It exhibits post-absorptive herbicidal activity because the herbicide is transported through the plant by absorption or transpiration into infected tissues. 2,4-D is a hormone-like herbicide (synthetic auxins) that disrupts normal plant growth, causing tissue proliferation and deformation of phloem and xylem cells, as a result of which the movement of photosynthesis products is disrupted and the plant is damaged. He dies.

Pesticidal Properties: Post-emergence systemic herbicide to protect crops from dicotyledonous weeds.

Maximum residue limit of this active ingredient in foods (mg/kg): in cereals 0.05 mg/kg.

The active substance: **MCPA** (ISO) (Figure 4).

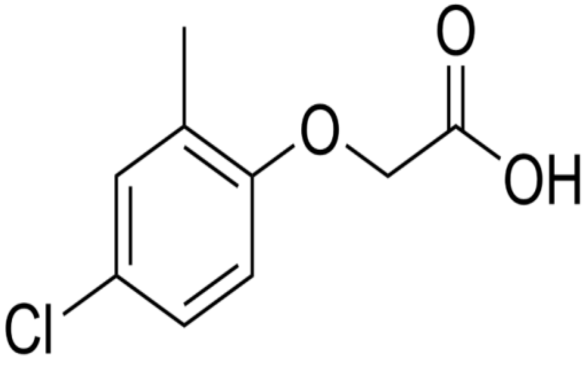

Figure 4. **The structural formula of the MCPA (Pesticides.ru, https://www.pesticidy.ru/active_substance, 2022).**

IUPAC name: 2-(4-chloro-2-methylphenoxy) acetic acid.

*Relative molecular weight:*200.6;

Chemical class: Aryloxyalkanecarboxylic acids.

Physical and chemical properties: In its pure form, it is a white crystalline substance with the smell of chlorocresol. The technical product contains up to 0.3% chlorocresol. The substance has a high solubility in water, ether, alcohol, benzene and other organic solvents and is stable during long-term storage in solution and in solid form. Physical properties: Melting point - 119-120.2°C; The melting point of the technical product is 118-119 °C; Solubility in water - 0.15 g/100 g water (at 25 °C); The dissociation constant is $5.4 \cdot 10^{-4}$.

Toxicological properties: MCPA preparations quickly decompose in soil. The half-life is 14 days - 1 month, 4-6 weeks and in drought conditions two to three months (Kulikova, 2010). Preparations based on MCPA belong to hazard class 2 for humans and hazard class 3 for bees.

Mechanism of action: Their action is selective because weeds accumulate metabolic products, especially nitrogen (20 times more than normal), while cultivated plants do not exhibit a discernible increase in this element. These medications interfere with the weeds' oxidative phosphorylation process. The energy produced in this process is lost rather than stored in dicotyledonous plants. The latter results in the loss of ATP, a substance that is high in energy, in plants (www.pesticidy.ru).

The MRL for this active ingredient in foods is 0.05 mg/kg in cereal grains.

Properties: Systemic herbicide.

Fortissimo, OD

Trade name	*Fortissimo, OD*
Active ingredient (a.i.)	*2,4-D acids /2-ethylhexyl ester 200 g/l / + aminopyralide 10 g/l + florasulam 5 g/l*
Empirical formula	*Aminopyralide: $C_6H_4Cl_2N_2O_2$*

The description of 2,4-D and florasulam is presented above.

The active substance: **Aminopyralide** (ISO) (Figure 5).

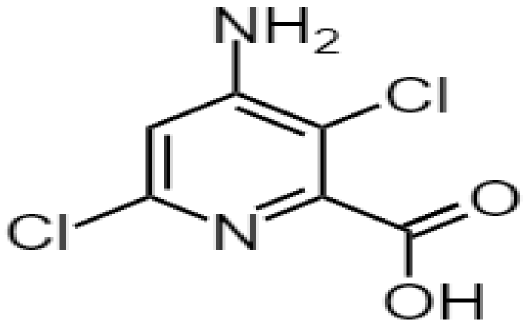

Figure 5. **Structural formula of aminopyralid (Pesticides.ru, https://www.pesticidy.ru/active_substance, 2022)**

IUPAC Name: [4-Amino-3,6-dichloropyridine-2-carboxylic acid].

Relative molecular weight: 207;

Chemical Class: Pyridine carboxylic acid.

Physical and chemical properties: It is a yellow powder. Resistant to hydrolysis at temperatures from 20 to 50 °C and pH from 5 to 9. Photosynthetically short-lived, as it is destroyed in light (half-life - 0.6 day). In terms of physical properties: melting point 163.5-165.2 °C and decomposes at the melting point; Vapor pressure (20°C) 9.52•10-9 Pa; Solubility in water (20 °C) depends on pH: 2.48 g/dm3 at pH = 2.35; 205-203 g/dm3 pH = 7 and 9.

Through its action, it slows down the process of cell division, which is why plants are very sensitive to it. The substance is considered an alternative to natural growth hormones. Researchers have shown that the drug can spread throughout the entire root system of the weed, helping in the fight against perennial weeds (yellow thistle, thistle) (https://www.agroxxi.ru/goshandbook). Aminopyralid has a similar mechanism of action to 2,4-D, dicamba, clopyralid, and picloram.

Toxicity: Warm-blooded - LD50 for rats greater than 5000 mg/kg. Irritates mucous membranes with prolonged contact. Maximum residues in products (mg/kg): in cereals 0.1.

Pesticidal properties: Aminopyralid is a systemic and post-emergence herbicide with an auxin-like effect and a broad spectrum of action. (Miller *et al.,* 2022). In addition, it also works against weeds in the soil for about four weeks. It is recommended for the treatment of cereal crops and pastures against a wide range of broad-leaved weeds in a mixture of florasulam (Baibekov and Kalinin, 2009).

Polian, OD

Trade name	*Polian, OD*
Active ingredient (a.i.)	*Tribenuron-methyl 225g/l + Thifensulfuron-methyl 76g/l*
Empirical formula	1) *Tribenuron-methyl: C12H13N5O6S2* *2) Thifensulfuron-methyl: C15H17N506S*

The active ingredient: **Tribenuron-methyl** (ISO) (Figure 6).

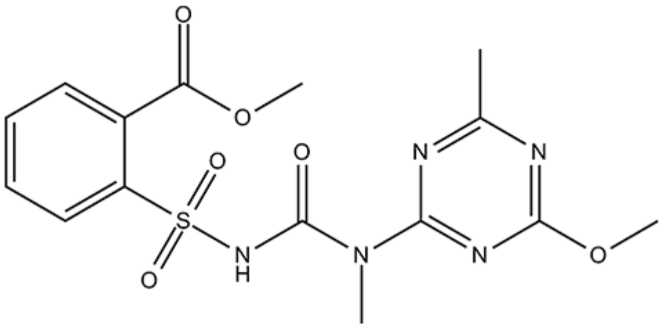

Figure 6. **Structural formula of tribenuron-methyl (Pesticides.ru, https://www.pesticidy.ru/active_substance. 2022)**

IUPAC Name: [2-[6-Methyl-4-methoxy-1,3,5-triazin-2-yl(methyl)carbamoylsulfamoyl] benzoic acid methyl ester].

Relative molecular weight: 395.39

Chemical class: Sulfonylureas.

Physical and chemical properties: Chemically pure substance - white crystals with a pungent odor. It reaches stability at 45°C and pH = 8-10. When the pH decreases or increases, it decomposes quickly. Relatively unstable in most organic solvents. Melting point 141°C; Vapor pressure (25°C) 5.2•10-5 MPa (www.agroxxi.ru).

The active ingredient works by blocking the enzyme acetolactate in susceptible grasses, an enzyme that promotes the formation of amino acids. Tribinuron methyl moves easily in plants and is absorbed by roots and leaves, and also leads to inhibition of acetolactate synthase, resulting in plant growth arrest and, as a result, plant death. A few hours after spraying, weeds stop growing.

Toxicological properties: The drug has low toxicity to animals and the environment. LD50 for mice is more than 5000 mg/kg. It does not affect the skin, and is non-mutagenic. Maximum residue limit in products (mg/kg): in grains 0.01.

Pesticidal properties: Trebinuron methyl is an ALS inhibitory herbicide and is the main type of sulfonylurea herbicide. In addition, terbinuron methyl is a selective systemic herbicide widely used to control broadleaf weeds in wheat fields (Lu *et al.,* 2022).

The active ingredient: **Thifensulfuron-methyl** (ISO) (Figure 7).

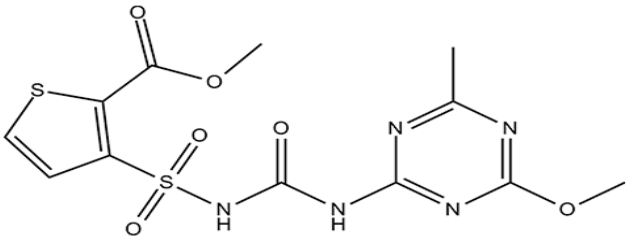

Figure 7. **Structural formula of thifensulfuron-methyl (Pesticides.ru, https://www.pesticidy.ru/active_substance. 2022)**

UPAC Name: 3- [[[[(4-methoxy-6-methyl-1,3,5-triazin 2-yl) amino] carbonyl] amino]sulfonyl)-2-thiophenecarboxylic acid].

Relative molecular weight: 387,4

Chemical class: Sulfonylureas.

Physical and chemical properties: White crystals that are chemically pure, odorless, and stable at 55 °C. a material that is breaking down, the pH of which dictates how long the material will last. 223 mg of solubility in water at 25 °C and pH of 5; 176 °C melting point; and 25 °C vapor pressure $1.7 \cdot 10^{-5}$ MPa.

The mechanism of action of this active substance is that it inhibits the biosynthesis of valine and isoleucine, which has a systemic effect, as it penetrates into plants through the leaves and roots.

Toxicological properties: The substance is low risk for warm-blooded animals. LD50 for mice is more than 5000 mg/kg. Maximum residues in products (mg/kg): in cereals 0.5.

Pesticidal properties: A selective, post-emergence herbicide that can be absorbed by foliage, stems and roots and moved throughout the plant.

Cayenne Turbo, OD

Trade name	*Cayenne Turbo, OD*
Active ingredient (a.i.)	*75 g/l tribenuron-methyl + 75 g/l thifensulfuron-methyl + 52 g/lflumetsulam*
Empirical formula	*1)Tribenuron-methyl: C12H13N5O6S2* *2) Thifensulfuron-methyl: C15H17N506S* *3) Flumetsulam: C12H9F2N5O2S*

The description of tribenuron-methyl, typhensulfuron-methyl and florasulam is presented above.

Tarzek, WG

Trade name	*Tarzec, WG*
Active ingredient (a.i.)	*Pyroxsulam 250 g/kg + Halauxifen-methyl 69.5 g/kg*
Empirical formula	*1) Pyroxsulam: C14H13F3N6O5S.* *2) Halauxifen-methyl: C14H11Cl2FN2O3*

Active ingredient: **Pyroxsulam** (ISO) (Figure 8).

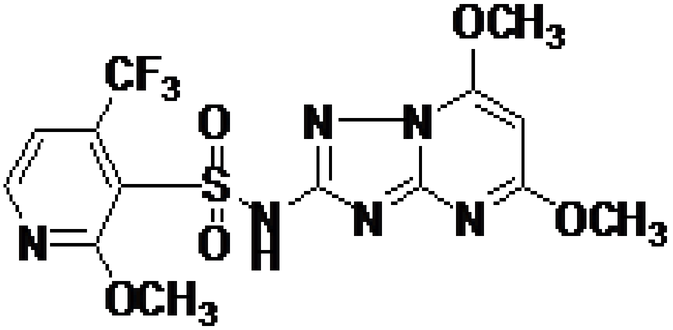

Figure 8. **Structural formula of pyroxsulam (EPA, 2008)**

IUPAC name: N-(5,7-dimethoxy- [1,2,4] triazolo [1,5-a] pyrimidin-2-yl)-2-methoxy-4-(trifluoromethyl) pyridine-3-sulfonamide.

Relative molecular weight: 434.4

Chemical class: Triazolopyrimidine

Physical and chemical properties: white powdery substance with a spicy odor. Soluble in organic solvents and water. It dissolves in water at a temperature of 20 degrees Celsius. Melting point 208.3°C. Vapor pressure is less than 1×10^{-7} Pa at 20°C.

Toxicological properties: Pyroxsulam has excellent selectivity and friendliness towards crops. As for spring and winter wheat crops, with acceptable application rates, there is no delay in crop growth. Acute oral toxicity in rats, LD50 > 2000 mg/kg (EPA, 2008). The Codex Alimentarius Commission has not established a maximum residue limit for pyroxsulam, but has established a tolerance for pyroxsulam n wheat and cereals of 0.01 mg/kg.

Mechanism of Action: Pyroxsulam is used as the active ingredient in herbicides intended to destroy the first wave of weeds in spring and winter wheat crops, including wild oats, broom, bromegrass, hay, goosefoot, and thistle species. Pyroxsulam inhibits the production of the ALS enzyme in plants. This enzyme is necessary for the production of certain amino acids essential for plant growth (EPA, 2008).

Pesticidal properties: Post-emergence herbicide for selective control of economically important annual cereals and broadleaf weeds in winter.

The active ingredient: **Halauxifen-methyl** (ISO) (Figure 9).

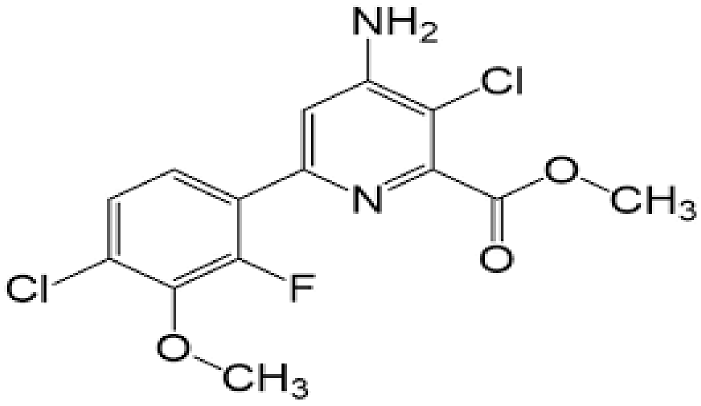

Figure 9. **Structural formula of halauxifene-methyl (McCauley et al., 2018)**

IUPAC name: 2-pyridinecarboxylic acid, 4-amino-3-chloro-6-(4-chloro-2-fluoro-3-methoxyphenyl), methyl ester.

Relative molecular weight: 331.1

Chemical class Arylpicolinate.

Physical and Chemical properties: Pure active ingredient - white powder at 24.2°C and slight odor. The melting point is about 145.5°C. The decomposition temperature is about 221.06°C. Vapor pressure 1.5×10-8 Pa at 25°C (1.1×10-10 mmHg) and 5.9×10-9 Pa at 20°C (4.4×10-11 mmHg) (purity 99.1%). Soluble in water and various solvents at 20°C.

Toxicity: Oral LD50 to rats greater than 2000 mg/kg; Prolonged contact with skin is unlikely to result in absorption of harmful amounts. Transdermal for mice > 2000 mg/kg (Corteva, 2020). A maximum residue limit of 0.01 mg/kg is suggested for haloxyphene-methyl in grains.

Mechanism of action: Binds to protein receptor sites that normally regulate plant processes. Haloxifene-methyl is rapidly absorbed by leaves and roots, moves systemically throughout the target plant in the xylem and phloem, and accumulates in meristematic tissues, where it disrupts the regulation of metabolic growth pathways.

Pesticidal properties: Halauxifen-methyl is a new synthetic auxin herbicide used for weed control in cereals and other crops (Xu *et al.,* 2022). It is also a selective post-emergence herbicide that is specifically formulated to control annual broadleaf weeds in cereals and other crops, and also has some activity against some species of perennial weeds (Corteva agrisciences, 2019).

2.3 Research methods

Field research was conducted in the Salsky district of the Rostov region in LLC "Success Agro". The farm mainly specializes in the cultivation of grain crops and uses the traditional technology of growing winter wheat. All agrotechnical work was carried out on the experimental field at the same time and at a high agrotechnical level.

The research objectives were the main types of weeds: Wild buckweed – *Fallopia convolvulus* (L.) A. Love, Flixweed – *Descurainia sophia* (L.) Webb ex Prantl, Common poppy – *Papaver rhoeas* L., Catchweed bedstraw – *Galium aparine* L., Field pennycress - *Thlaspi arvense* L., Field bindweed – *Convolvulus arvensis* L.

The experiments used two winter wheat varieties (Triticum aestivum L.), Svarog and Grom. The experimental plot's soil is dark chestnut and heavy loamy, with 3.1% humus content in the arable layer and a pH of 6.9. Plot size: 25 m^2, 4 replicates (Figure 10).

The development phase of wheat plants at the time of treatment is tillering or the exit into the tube phase. The development phase of wheat plants at the time of treatment is tillering or booting.

Methodology for conducting surveys of harmful objects: by quantitative-weight method on 4 survey sites measuring 0.25 m^2 on each experimental plot in accordance with the Guidelines for registration tests of herbicides in agriculture (2013) and Guidelines for conducting registration tests of herbicides (2020). Herbicides were applied with a manual low-volume sprayer (Solo 456) (Figure 11), the flow rate of the working fluid was 300 l/ha.

The sowing rate of winter wheat seeds in the experiments was 220 kg/ha. Soil treatment: plowing, two cultivations before sowing. Fertilizers: 1.0 c/ha of ammonium sulfate for cultivation, 0.6 c/ha of azophosphate for sowing, fertilizing UAN 32 at the rate of 15.0 l/ha. Measures to care for experimental plots using the following preparations: Polaris, ME (100 + 25 + 15 g/l) – 1.2 l/t; Imidor Pro, KS (200 g/l) – 1.25 l/ha; Triad, KS

(140 + 140 + 72 g/l) – 0.6 l/ha; Kinfos, EC (300 + 40 g/l) – 0.25 l/ha; Espero, KS (200 + 120 g/l) – 0.1 l/ha.

Harvesting was carried out at a humidity of 11-14%.

The number of weeds was counted and diagnosed before spraying, when they were at the germination or flowering stage.

Crop weed counts were carried out in 4 periods: 1st – before treatment (initial weediness), 2nd – 30 days after treatment, 3rd – 45 days after treatment, 4th – before harvesting.

Figure 10. **The breakdown of plots for conducting experiments**

Herbicides were used in normal weather conditions; plants were treated with herbicides in calm weather or in low winds.

Figure 11. **Filling the sprayer Solo 456**

Counting weeds using the quantitative-weight method: its essence is to allocate on plots (by placing a frame) counting areas of a certain size, on which the number of weeds was counted (in specimens per 1 m^2) and their wet weight was determined (in grams per 1 m^2). We used 4 counting areas measuring 0.25 m2 (0.5 x 0.5 m).

The effectiveness of herbicides was determined in relation to the untreated control using the formula:

$E = (K-V)/K*100$,

where: E is the effectiveness of the herbicide, %,

K – number or mass of weeds in the control, ind./m^2 or g/m^2

B – number or mass of weeds, ind./m^2 or g/m^2

Throughout the growing season, visual observations were made of their condition in areas treated with herbicides and compared with the condition in the control group. In addition, the main developmental phases and structure of winter wheat were noted to monitor the effect of herbicides on them.

Harvesting was done manually using test sheaves of 1 m2 in each plot (Figure 12). The obtained data were subjected to statistical processing using the analysis of variance method with the determination of LSD 05.

Figure 12. **Harvesting of winter wheat in an experimental plot**

Research in Iraq. The study was conducted in the winter of 2020–2021 on the Abu Ghraib agricultural farm in Iraq. Post-emergence treatments of wheat were carried out with herbicides: Tarzec, WDG and U46-Combi fluid 6, SL (standard) at different rates. The placement of experimental plots was randomized; the area of each plot was 20 m^2 (4 m × 5 m). The soil is clayey, organic matter content is 0.85%; pH – 7.8. Winter wheat, variety Iba 99, seeding rate – 120 kg/ha. The technology of growing the crop is traditional for the region. Treatment with herbicides was carried out on vegetating cereal weeds (phase from 2 leaves to the beginning of tillering) and in the phase of 6-8 leaves of dicotyledonous weeds. The development phase of winter wheat is from 4 leaves to the 2nd internode stage. We used a Mataba-16L backpack sprayer.

Methods for determining residual amounts of herbicide active ingredients in winter wheat

Method of sampling and storage conditions of samples. The "Unified Rules for Sampling of Agricultural Products, Food, and Environmental Objects to Determine Microquantities of Pesticides," approved on August 21, 1979, No. 2051-79, were followed when conducting the sampling.

Samples were taken separately from each repetition of the experiment, as well as from control variants not treated with pesticides. Selected seed samples were stored at room temperature in linen bags.

The samples were analyzed for the content of **Tribenuron-methyl** under the methodological instructions "Guidelines for the determination of residual amounts of tribenuron-methyl in water, soil, grain and straw of cereal crops using high-performance liquid chromatography", MUK 4.1.2022-05.

The limit of determination of tribenuron-methyl in cereal grain is 0.01 mg/kg, in straw - 0.04 mg/kg.

The content of Thifensulfuron-methyl in samples was determined in accordance with the "Temporary guidelines for the determination of harmonic residues in grain, straw, and green mass of cereal crops and corn, flax seeds, and straw by high-performance liquid chromatography," MU No. 6137-91 (Collection of methodological instructions No. 20, T. 2, P. 311).

The limit of determination of thifensulfuron-methyl in grain is 0.01 mg/kg, in straw 0.05 mg/kg.

Quantitative determination of tribenuron-methyl was carried out on an Alliance liquid chromatograph (Waters) with a UV detector. Working wavelength 230 nm. Sun Fire C-18 column (250 x 4.6) mm, 5 µm (Waters). Column temperature 25C° Mobile phase: acetonitrile - 0.005 M H3PO4 in a ratio of 60:40. Eluent flow rate: 1 ml/min. Injected sample volume 20 µl.

Quantitative determination of thifensulfuron-methyl was carried out on an Alliance liquid chromatograph (Waters) with a UV detector. Column Sun Fire C-18 column (250 x 4.6) mm, 5 µm (Waters). Column temperature 25C°. Mobile phase: acetonitrile – 0.005 M H3PO4 at a ratio of 50:50. Eluent flow rate 1 ml/min. Working wavelength 223 nm. Injected sample volume 10 µl.

Hygienic standards: MRL of tribenuron-methyl 0.01 mg/kg, MRL of thifensulfuron-methyl 0.05 mg/kg.

The methodological guidelines "Guidelines for the determination of residual amounts of Flumetsulam and Florasulam in water, soil, grain, and straw of cereal crops using high-performance liquid chromatography," MUK 4.1.1442-03, were followed in the analysis of the samples for Flumetsulam content.

The limit of determination of flumetsulam in grain is 0.025 mg/kg, in straw 0.05 mg/kg.

Samples were taken separately from each plot according to variants. An average sample was prepared from them (one per variant), and two parallel samples were made in the laboratory for each sample.

Quantitative determination of flumetsulam was carried out on an Alliance liquid chromatograph from Waters with a UV detector. Operating wavelength 260 nm. Column Sun Fire C-18 (250 x 4.6) mm, 5 µm (Waters). Column temperature 25C°. Mobile phase:

acetonitrile – 0.005 M H3PO4 at a ratio of 30:70. Eluent flow rate 1.0 ml/min. The volume of the injected sample is 10 μl.

Hygienic standards: MRL for tribenuron-methyl 0.01 mg/kg, MRL for thifensulfuron-methyl 0.05 mg/kg, MRL for flumetsulam 1.0 mg/kg.

One of the important criteria for the selection and evaluation of pesticides for sanitary, environmental and toxicological safety should be considered an integral indicator - toxic load (TL), expressed by the number of semi-lethal doses for warm-blooded animals applied per hectare of area during a single pesticide treatment. The lower this indicator, the more environmentally friendly and acceptable this drug is.

The calculation was carried out according to the formula proposed by Yu.N. Fadeev (1988):

$$\mathbf{TL}=\frac{\text{Rate of use of the active substance (a.i.) in mg/ha}}{\text{LD50 (mg/kg)}}$$

Taking into account the range of fluctuations in the TL indicator, 4 hazard classes of pesticides are distinguished:

I – low-hazard, when used, the TL does not exceed 100 semi-lethal doses per hectare;

II – moderately hazardous (TL from 100 to 1000 LD50/ha);

III – hazardous (TL 1000 to 10000 LD50/ha);

IV – especially dangerous, the use of which creates a TL per hectare of more than 10,000 semi-lethal doses (Fadeev,1988).

Chapter 3 The effectiveness of herbicides in winter wheat crops and the rules for their application

As a result of our research, the biological effectiveness of herbicides was assessed and regulations for their safe use were developed.

3.1 Pinta, OD (50 g/l flumetsulam + 36 g/l florasulam)

Research to assess the effectiveness of the herbicide Pinta, OD was carried out in 2020-2021, according to the scheme presented in Table 6.

Table 6. **Experimental scheme**

Experimental options	Application rates	Frequency of treatments
1. Pinta, OD	0,1 l/h	1
2. Pinta, OD	0,15 l/h	1
3. Derby 175, SC (standard)	0,05 l/h	1
4. Derby 175, SC (standard)	0,07 l/h	1
5. Control	-	-

Before applying herbicides, a quantitative count of weeds was carried out in order to establish the number and species composition of weeds (Table 7).

Table 7. **Types of weeds in experiments 2020-2021**

Types of weeds	Latin name
Descurainia sophia	*Descurainia sophia* (L.) Webb ex Prantl
Catchweed Bedstraw	*Galium aparine* L.
Field pennycress	*Thlaspi arvense* L
Field bindweed	*Convolvulus arvensis* L.
Black Bindweed	*Fallopia convolvulus* (L.) A. Love

Under the conditions of 2020, before introducing the herbicides into the tillering phase of winter wheat, the initial infestation of the experimental plot with annual weeds was 64 ind./m^2. The sowing was dominated by annual dicotyledonous weeds: Descurainia sophia, Catchweed Bedstraw, Field pennycress. The number of perennial dicotyledonous weeds of the field bindweed species was 7 ind./m^2. The development phases of weeds at the time of treatment are presented in Table 8.

Table 8. **Phases of development of weeds at the time of processing winter wheat in the tillering phase (2020)**

Types of weeds	Stages of weed development	Number, samples/m^2
Descurainia sophia	stemming, 10-12 cm	23
Catchweed Bedstraw	2-4 whorls, up to 6 cm	12
Field pennycress	rosette of leaves, up to 14 cm	29
Field bindweed	whip up to 6 cm long	7

During the exit into the tube phase, the initial infestation of the experimental plot with annual weeds was 76 ind./m^2. The sowing was dominated by annual dicotyledonous weeds: Descurainia sophia, Catchweed Bedstraw and Field bindweed. The number of perennial dicotyledonous weeds field bindweed was 9 ind./m^2. The development phases of weeds at the time of treatment are presented in Table 9.

Table 9. **Phases of weed development at the time of winter wheat processing in the tube phase (2020)**

Types of weeds	Stages of weed development	Number, samples/m^2
Descurainia sophia	stemming, up to 17 cm	29
Catchweed Bedstraw	up to 7 whorls, 10-15 cm	11
Field pennycress	stemming, 13-16 cm	36
Field bindweed	whip up to 12 cm long	9

Herbicides applied during the crop's tillering phase significantly suppressed weeds. The total number of weeds was reduced by 85.2 - 100% in variants that used the studied herbicide at application rates of 0.1 and 0.15 l/ha (Figure 13). The mass of annual weeds was reduced by 92.1 - 99.4%, while the mass of perennial species was reduced by 76.1 -

97.1%, corresponding to the standard Derby 175, SC level of efficiency (Appendix, Table 1).

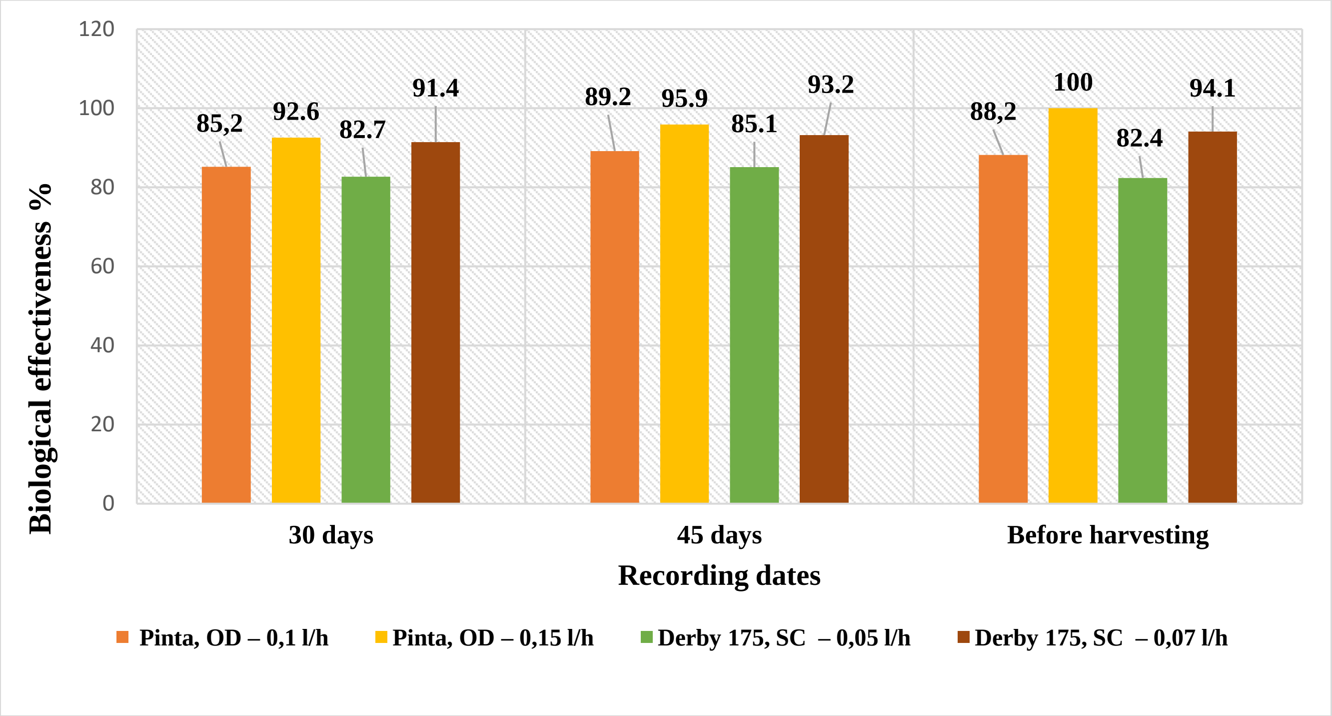

Figure 13. **Biological efficacy of the herbicide Pinta, OD (tillering phase, Rostov region, 2020)**

Most species of weeds showed high sensitivity to the herbicide Pinta, OD (Table 10).

Table 10. **Efficacy of the herbicide Pinta, OD against certain types of weeds in winter wheat crops (tillering phase, Rostov region, 2020)**

Experimental options	Recording dates	Reduction of the number of weeds, % of the control			
		Descurainia sophia	*Galium aparine*	*Thlaspi arvense*	*Convolvulus arvensis*
1. Pinta, OD – 0,1 l/h	30th	88,0	72,7	97,1	50,0
	45th	90,9	76,9	100	72,7
	90th	100	80,0	100	85,7
2. Pinta, OD – 0,15 l/h	30th	92,0	90,9	100	70,0
	45th	100	92,3	100	81,8
	90th	100	100	100	100
	30th	84,0	72,7	94,3	50,0

3. Derby 175, SC – 0,05 l/h	45th	86,4	76,9	96,4	63,6
	90th	100	80,0	100	71,4
4. Derby 175, SC – 0,07 l/h	30th	96,0	81,8	100	60,0
	45th	95,5	84,6	100	81,8
	90th	100	100	100	85,7
5. Control *	30th	25	11	35	10
	45th	22	13	28	11
	90th	2	5	3	7

*The controls provide data on the number of weeds, copies/m^2

The use of herbicides during the exit into the tube also significantly reduced the number of weeds: in both cases, the total number of weeds was reduced by 75.9 - 94.7% (Figure 14), the mass of annual weeds was reduced by 89.5 - 98.3%, and the mass of perennial species was reduced by 67.0 - 92.8% (Appendix, Table 2).

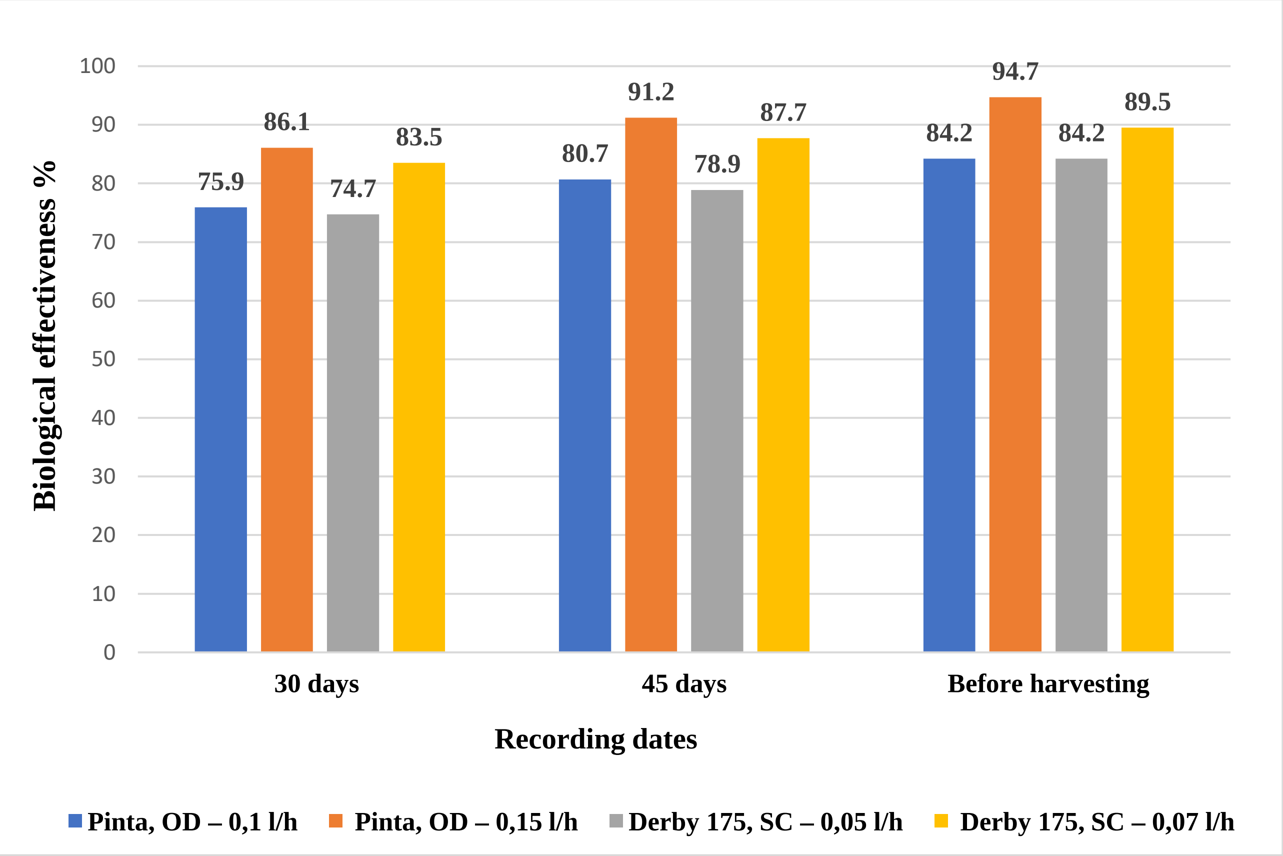

Figure 14. **Biological effectiveness of the herbicide, Pinta, OD (phase exit into the tube, Rostov region, 2020).**

Most species of weeds showed high sensitivity to the herbicide Pinta, OD (Table 11).

Table 11. **Efficacy of the herbicide Pinta, OD against certain types of weeds in winter wheat crops (heading phase, Rostov region, 2020)**

Experimental options	Recording dates	Reduction of the number of weeds, % of the control			
		Descurainia sophia	*Galium aparine*	*Thlaspi arvense*	*Convolvulus arvensis*
1. Pinta, OD – 0,1 l/h	30th	80,0	66,7	90,0	41,7
	45th	90,5	70,0	93,8	50,0
	90th	100	80,0	100	75,0
2. Pinta, OD – 0,15 l/h	30th	92,0	75,0	96,7	58,3
	45th	95,2	90,0	100	70,0
	90th	100	100	100	87,5
3. Derby 175, SC – 0,05 l/h	30th	84,0	58,3	90,0	33,3
	45th	85,7	70,0	100	40,0
	90th	100	80,0	100	75,0
4. Derby 175, SC – 0,07 l/h	30th	92,0	75,0	93,3	50,0
	45th	95,2	80,0	100	60,0
	90th	100	100	100	75,0
5. Control *	30th	25	12	30	12
	45th	21	10	16	10
	90th	4	5	2	8

* The controls provide data on the number of weeds, ind./m².

The initial infestation of the experimental plot in 2021 (tillering phase) with annual weeds was 67 ind./m2. The sowing was dominated by annual dicotyledonous weeds:

Convolvulus buckwheat, Descurainia Sofia and tenacious bedstraw. The number of perennial dicotyledonous weeds field bindweed was 14 ind./m^2 (Table 12).

Table 12. **Phases of weed development at the time of winter wheat processing in the tillering phase**

Types of weeds	Stages of weed development	Number, samples/m^2
Buckwheat bindweed	cotyledons - 1-2 true leaves, 4-6 cm	34
Descurainia Sofia	stemming, 6-14 cm	23
The bedstraw is tenacious	up to 5 whorls, 5-10 cm	10
Field bindweed	cotyledons - a lash up to 10 cm long	14

When the studied herbicide was used in the experimental variants, the total number of weeds decreased by 81.1 - 96.2% (Figure 15), the mass of annual weeds decreased by 86.099.1%, and the mass of perennial species decreased by 55.5 - 89.3% (Appendix, Table3).

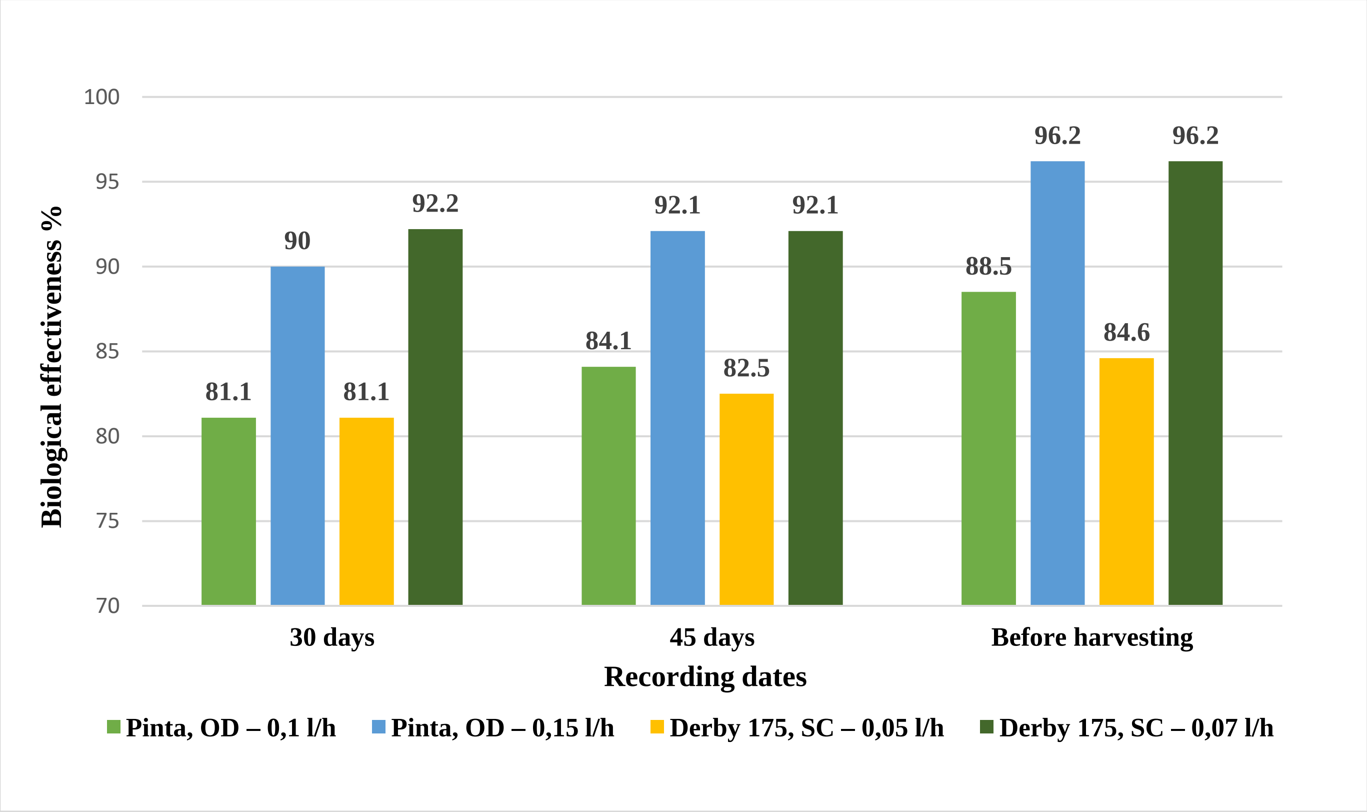

Figure 15. **Biological effectiveness of the herbicide, Pinta, OD (tillering phase, Rostov region, 2021)**

The majority of weed species exhibited high susceptibility to Pinta, OD (Table 13).

Table 13. **Efficacy of the herbicide Pinta, OD against certain types of weeds in winter wheat crops (tillering phase, Rostov region, 2021)**

Experimental options	Recording dates	Reduction of the number of weeds, % of the control			
		Fallopia convolvulus	*Descurainia sophia*	*Galium aparine*	*Convolvulus arvensis*
1. Pinta, OD – 0,1 l/h	30th	90,2	91,7	77,8	43,8
	45th	92,6	100	85,7	50,0
	90th	100	100	100	70,0
2. Pinta, OD – 0,15 l/h	30th	95,1	95,8	88,9	68,8
	45th	96,3	100	100	71,4
	90th	100	100	100	90,0
3. Derby 175, SC – 0,05 l/h	30th	92,7	83,3	77,8	50,0
	45th	88,9	93,3	85,7	57,1
	90th	85,7	100	100	70,0
4. Derby 175, SC – 0,07 l/h	30th	97,6	95,8	88,9	75,0
	45th	96,3	100	100	71,4
	90th	100	100	100	90,0
5. Control *	30th	41	24	9	16
	45th	27	15	7	14
	90th	7	4	5	10

* The controls provide data on the number of weeds, ind./m².

The infestation of the experimental plot with annual weeds was 80 ind./m^2 (wheat phase - exit into the tube). The sowing was dominated by annual dicotyledonous weeds:

Convolvulus buckwheat, Descurainia Sofia and tenacious bedstraw. The number of perennial dicotyledonous weeds field bindweed was 10 ind./m^2 (Table 14).

Table 14. **Phases of development of weeds at the time of processing winter wheat in the exit into the tube phase**

Types of weeds	Stages of weed development	Number, samples/m^2
Buckwheat bindweed	cotyledons - 1-5 true leaves, 5-8 cm	45
Descurainia Sofia	stemming, 8-20 cm	22
The bedstraw is tenacious	up to 7 whorls, 7-14 cm	13
Field bindweed	whip up to 13 cm long	10

The application of the herbicide under study at both rates produced the following outcomes: a reduction in the overall number of weeds, 73.7 - 92.9% (Figure 16); a reduction in the mass of annual weeds, 84.1 - 97.4%; and a reduction in the mass of perennial weed species, 48.2 - 79.4% (Appendix, Table 4).

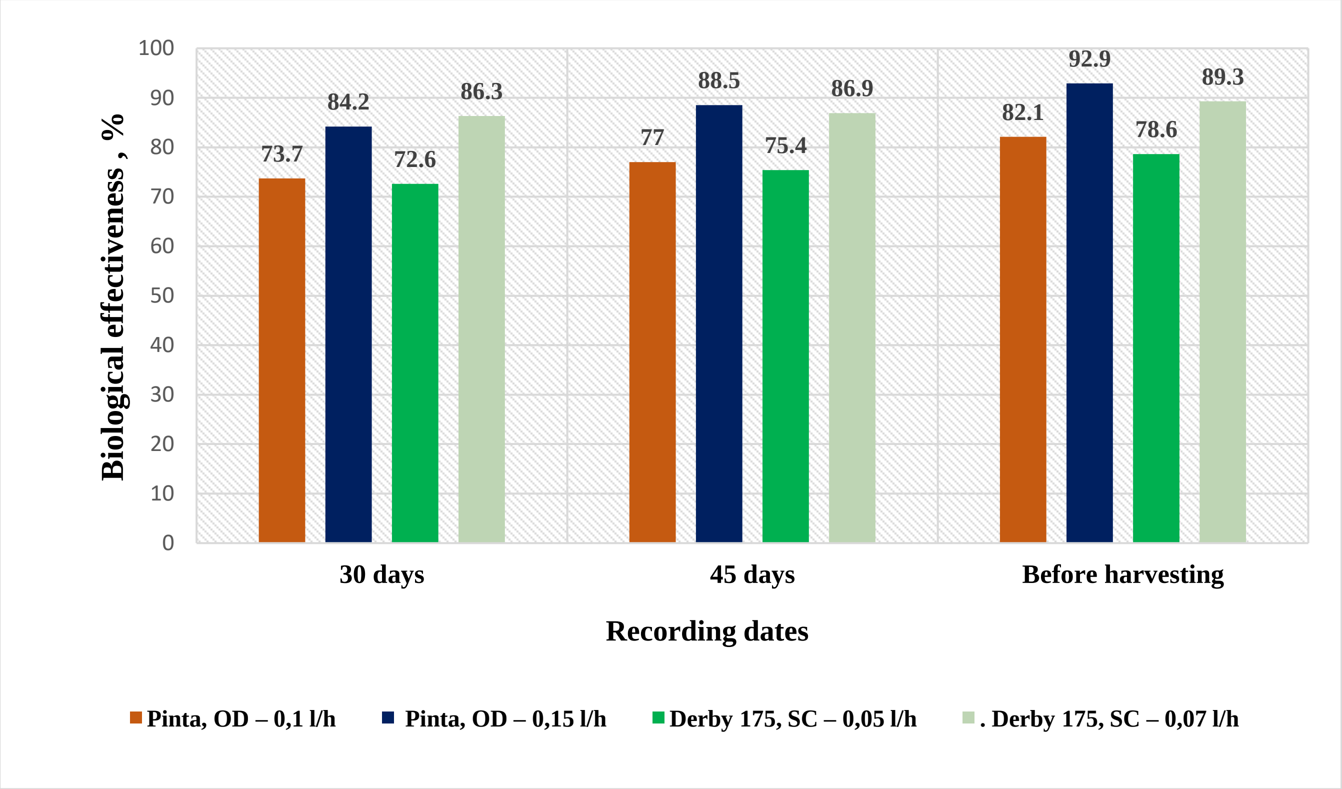

Figure 16**. Biological effectiveness of the herbicide Pinta, OD (exit into the tube phase, Rostov region, 2021)**

The majority of weed species were highly sensitive to the herbicide Pinta, OD (Table 15).

Table 15. **Efficacy of the herbicide Pinta, OD against certain types of weeds in winter wheat crops (exit into the tube phase, Rostov region, 2021)**

Experimental options	Recording dates	Reduction of the number of weeds, % of the control			
		Fallopia convolvulus	*Descurainia sophia*	*Galium aparine*	*Convolvulus arvensis*
1. Pinta, OD – 0,1 l/h	30th	84,8	83,3	71,4	35,3
	45th	84,6	91,7	80,0	46,2
	90th	100	100	83,3	63,6
2. Pinta, OD – 0,15 l/h	30th	91,3	88,9	85,7	58,8
	45th	92,3	100	90,0	69,2
	90th	100	100	100	81,8
3. Derby 175, SC – 0,05 l/h	30th	80,4	77,8	78,6	41,2
	45th	80,8	83,3	80,0	53,8
	90th	87,5	100	83,3	63,6
4. Derby 175, SC – 0,07 l/h	30th	89,1	94,4	85,7	70,6
	45th	96,2	91,7	90,0	61,5
	90th	100	100	83,3	81,8
5. Control *	30th	46	18	14	17
	45th	26	12	10	13
	90th	8	3	6	11

* The controls provide data on the number of weeds, ind./m².

During the trials, visual observations of wheat plants revealed that the new pesticide had no adverse effects on their growth or development.

All treatments with the studied herbicide had a significant effect on wheat grain yield compared to the control (LSD_{05} = 0.66 c/ha and LSD_{05} = 1.3 c/ha, respectively). The results are presented in Figures 17 and 18.

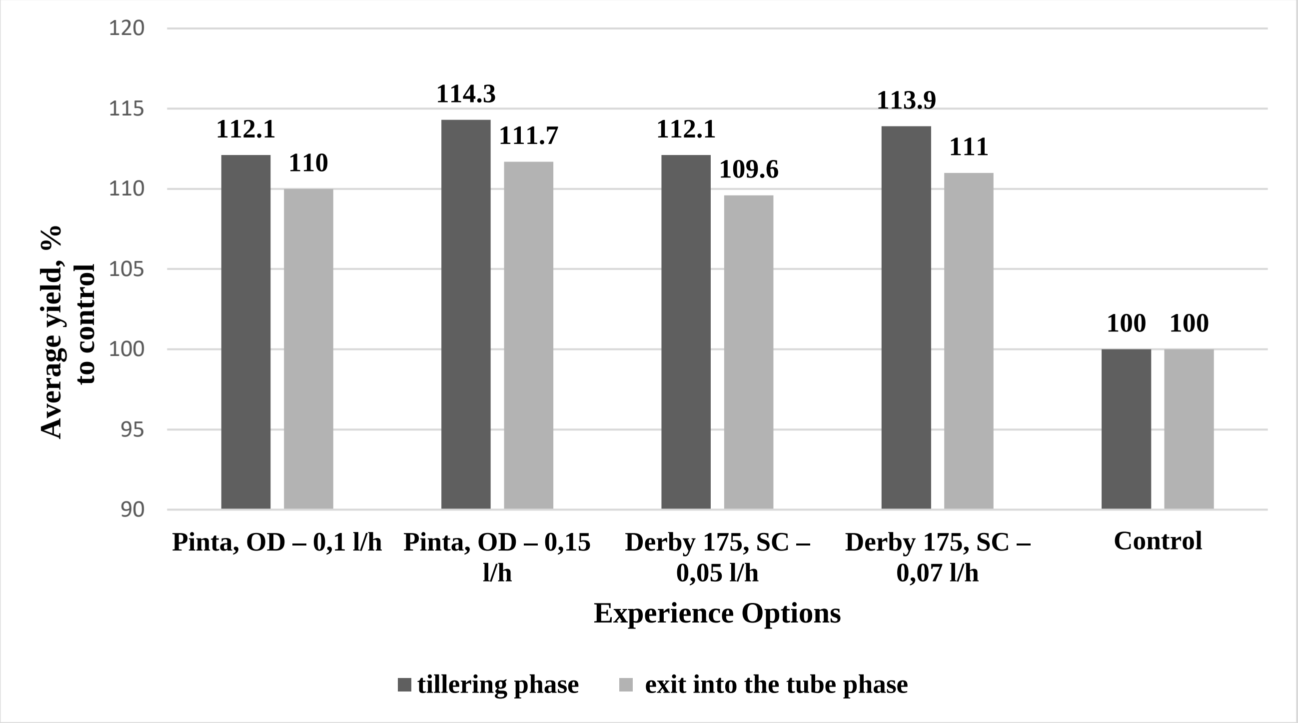

Figure 17. **Grain yield of winter wheat variety Grom treated with the herbicide Pinta, OD (Rostov region, 2020)**

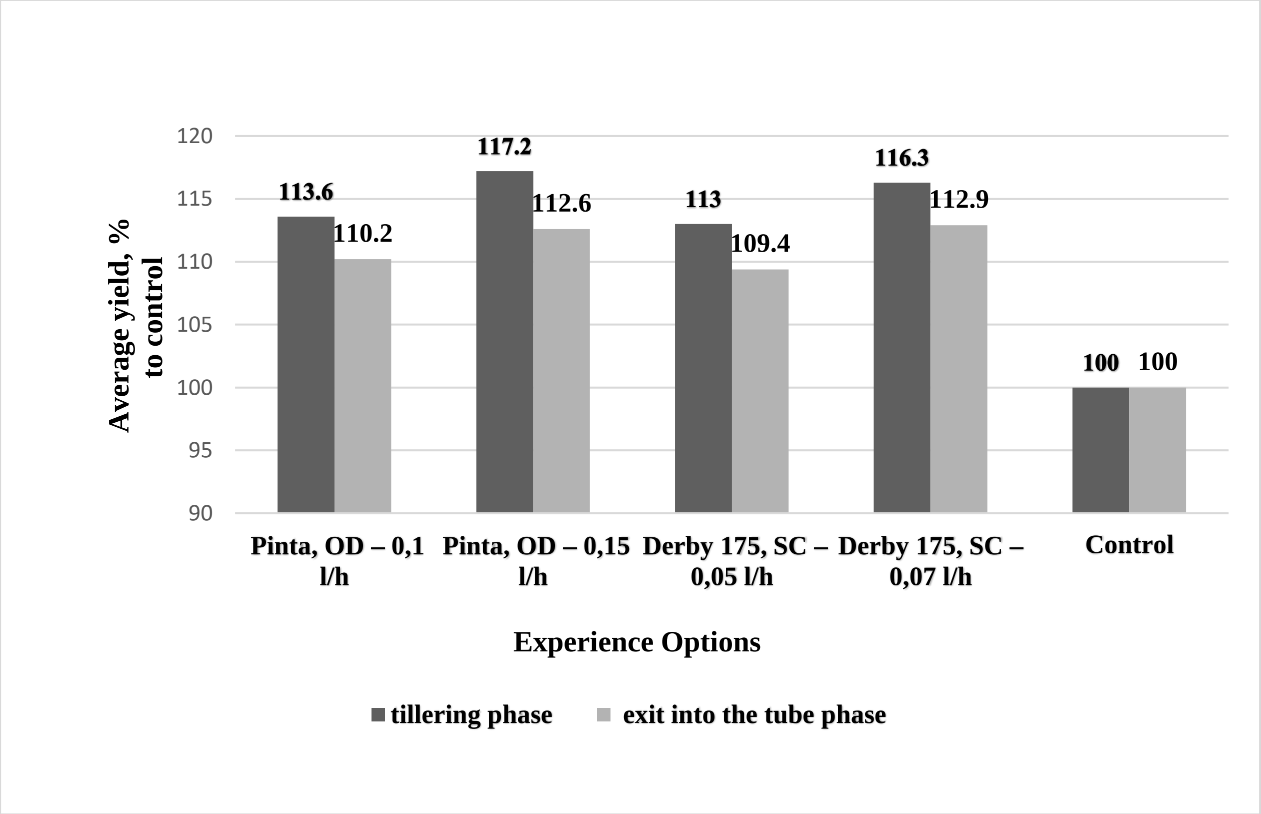

Figure 18. **Grain yield of winter wheat variety Svarog treated with the herbicide Pinta, OD (Rostov region, 2021)**

Conclusion. According to the research findings, the biological effectiveness of the new combined herbicide Pinta, OD (50 g/l flumetsulam + 36 g/l florasulam) at rates of 0.1 and 0.15 l/ha in the tillering and exit into the tube phases were comparable to the standard Derby 175, SC in the relevant regulations for use, ensuring crop protection and increased yield (Al-Maliki, A.A. *et al.,* 2023).

3.2 Fortissimo, OD (200 g/l 2,4-D acid/2-ethylhexyl ester/+10 g/l aminopyralid+5 g/l florasulam)

In 2021–2022, research was conducted to evaluate the efficacy of the herbicide Fortissimo, OD. based on the plans shown in Tables 16 and 17.

Table 16. **Experiment scheme (winter wheat in the tillering phase)**

No p p.	Experimental options	Application rates of the drug	Frequency of treatments
1	Fortissimo, OD	0,4 l/h	1
2	Fortissimo, OD	0,5 l/h	1
3	Fortissimo, OD	0,7 l/h	1
4	Prima Forte 195, SE (standard)	0,5 l/h	1
5	Prima Forte 195, SE (standard	0,7 l/h	1
6	Control	-	-

Table 17. **The scheme of the experiment (winter wheat in the phase exit into the tube)**

No p p	Experimental options	Application rates of the drug	Frequency of treatments
1	Fortissimo, OD	0,4 l/h	1
2	Fortissimo, OD	0,5 l/h	1
3	Fortissimo, OD	0,7 l/h	1
4	Lancelot 450, WDG (standard)	0,03 kg/l	1
5	Lancelot 450, WDG (standard)	0,033 kg/h	1
6	Control	-	-

To determine the quantity and species composition of weeds, a quantitative count of weeds was conducted prior to the application of herbicides (Table 18).

Table 18. **Types of weeds in experiments**

Types of weeds	Latin name
Descurainia Sofia	*Descurainia sophia* (L.) Webb ex Prantl
Catchweed bedstraw	*Galium aparine* L.
Corn poppy	*Papaver rhoeas* L.
Field bindweed	*Convolvulus arvensis* L.
Black Bindweed	*Fallopia convolvulus* (L.) A. Love

The initial infestation of annual weeds in the experimental plot of winter wheat during the tillering phase in 2021 was 67 ind./m^2. The sowing was dominated by annual dicotyledonous weeds: Field bindweed, Descurainia Sofia and tenacious bedstraw. The number of perennial dicotyledonous weeds (field bindweed) was 14 ind./m^2 (Table 19).

Table 19. **Phases of weed development in winter wheat crops in the tillering phase (2021)**

Types of weeds	Stages of weed development	Number, samples/m^2
Black Bindweed	cotyledons - 1-2 true leaves, 4-6 cm	34
Descurainia Sofia	stemming, 6-14 cm	23
Catchweed bedstraw	up to 5 whorls, 5-10 cm	10
Field bindweed	cotyledons - a lash up to 10 cm long	14

Using the herbicide Fortissimo, OD contributed to significant weed suppression in variants with an application rate of 0.4 - 0.5 - 0.7 l/ha. The maximum efficiency was achieved at a rate of 0.7 l/ha (Figure 19). The mass of annual weeds was reduced by 89.9 to 100%, while the mass of perennial species was reduced by 76.6 to 97.7%. The studied herbicide was applied at the same level of effectiveness as the standard Prima Forte 195 SE.

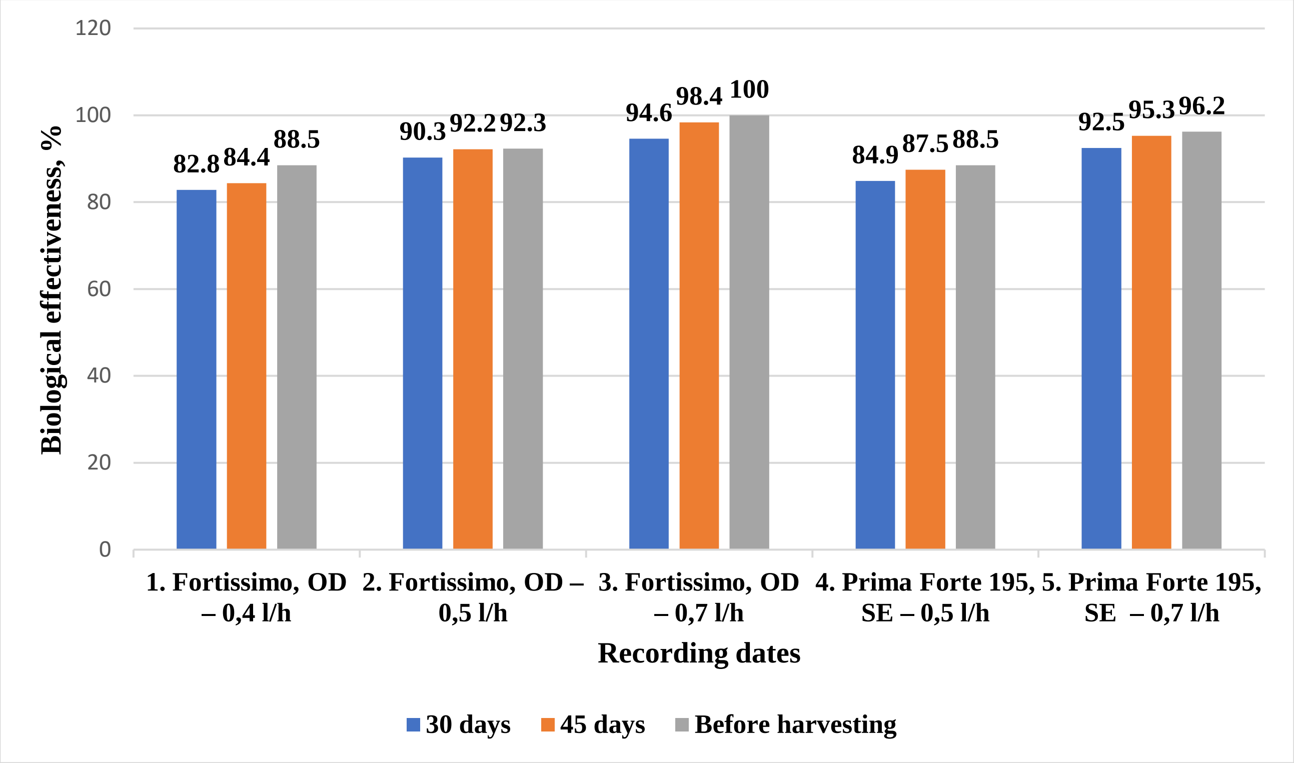

Figure 19. **Biological effectiveness of the herbicide Fortissimo, OD in the tillering phase of winter wheat (Rostov region, 2021)**

According to Table 20, most species of weeds exhibited high sensitivity to the herbicide Fortissimo, OD.

Table 20. **Efficacy of the herbicide Fortissimo, OD against certain types of weeds in winter wheat crops (tillering phase, Rostov region, 2021)**

Experimental options	Recording dates	Reduction of the number of weeds, % of the control			
		Fallopia convolvulus	*Descurainia sophia*	*Galium aparine*	*Convolvulus arvensis*
1. Fortissimo, OD – 0,4 l/h	30th	92,1	88,9	81,8	52,9
	45th	95,7	92,9	83,3	60,0
	90th	100	100	100	66,7
2. Fortissimo, OD – 0,5 l/h	30th	97,4	92,6	90,9	70,6
	45th	100	92,9	91,7	80,0
	90th	100	100	100	77,8

3. Fortissimo, OD – 0,7 l/h	30th	100	100	90,9	76,5
	45th	100	100	100	93,3
	90th	100	100	100	100
4. Prima Forte 195, SE – 0,5 l/h	30th	97,4	92,6	81,8	47,1
	45th	100	100	91,7	53,3
	90th	100	100	100	66,7
5. Prima Forte 195, SE – 0,7 l/h	30th	97,4	96,3	90,9	76,5
	45th	100	100	91,7	86,7
	90th	100	100	100	88,9
6. Control*	30th	38	27	11	17
	45th	23	14	12	15
	90th	7	3	7	9

*The controls provide data on the number of weeds, copies/m^2

The initial infestation of the experimental plot of winter wheat with annual weeds in the exit into the tube phase was 80 ind./m^2 in 2021. The sowing was dominated by annual dicotyledonous weeds: Field bindweed, Descurainia Sofia and Catchweed bedstraw. The number of perennial dicotyledonous weeds field bindweed was 10 ind./m^2 (Table 21).

Table 21. **Phases of weed development in winter wheat crops in the tube phase (2021)**

Types of weeds	Stages of weed development	Number, samples/m^2
Black Bindweed	cotyledons - 1-5 true leaves, 5-8 cm	45
Descurainia Sofia	stalking, 8-20 cm	22
Catchweed bedstraw	to 7 whorls, 7-14 cm	13
Field bindweed	whip up to 13 cm long	10

Herbicide use played a major role in significantly suppressing weed growth. In variations where 0.4 – 0.5 – 0.7 l/ha Fortissimo, OD was applied, the mass of annual weeds was reduced by 80.8 – 97.3%, the mass of perennial species was reduced by 59.5 – 91.2%, and the overall number of weeds was reduced by 74.2 – 92.3% (Figure 20). The studied herbicide's application matched the standard Lancelot 450, WDG's degree of efficacy.

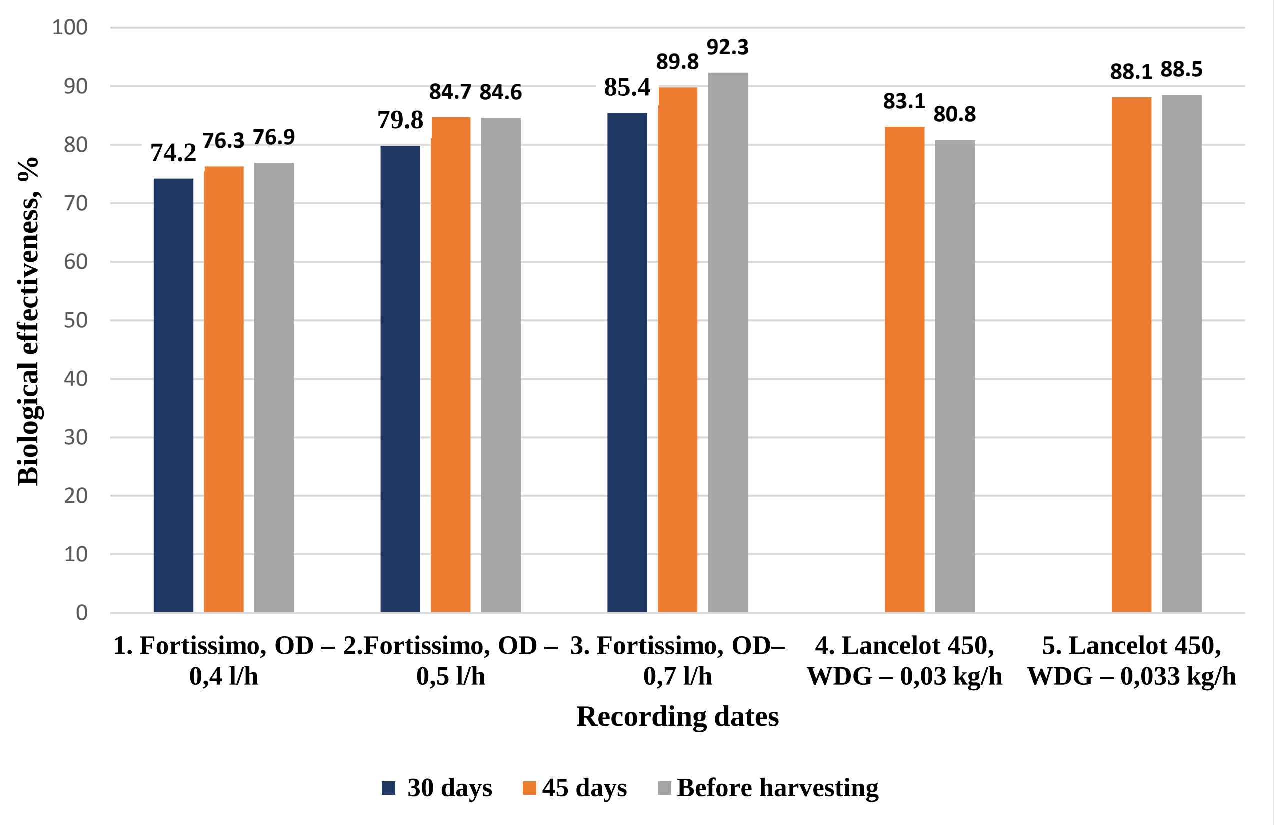

Figure 20. **Biological effectiveness of the herbicide Fortissimo, OD in the exit into the tube phase of winter wheat (Rostov region, 2021)**

Table 22 shows that a majority of weed species exhibited high sensitivity to the herbicide Fortissimo, OD.

Table 22. **Efficacy of the herbicide Fortissimo, OD against certain types of weeds In winter wheat crops (in the exit into the tube phase, Rostov region, 2021)**

Experimental options	Recording dates	Reduction of the number of weeds, % of the control			
		Fallopia convolvulus	*Descurainia sophia*	*Galium aparine*	*Convolvulus arvensis*
1. Fortissimo, OD – 0,4 l/h	30th	87,2	81,3	68,8	44,4
	45th	87,0	90,9	72,7	50,0
	90th	100	100	83,3	58,3
2. Fortissimo, OD – 0,5 l/h	30th	89,7	87,5	75,0	55,6
	45th	91,3	100	81,8	64,3

	90th	100	100	83,3	75,0
3. Fortissimo, OD – 0,7 l/h	30th	92,3	93,8	81,3	66,7
	45th	95,7	100	81,8	78,6
	90th	100	100	100	83,3
4. Lancelot 450, WDG – 0,03 kg/h	30th	87,2	93,8	75,0	61,1
	45th	91,3	90,9	72,7	71,4
	90th	83,3	100	66,7	83,3
5. Lancelot 450, WDG – 0,033 kg/h	30th	89,7	93,8	75,0	72,2
	45th	91,3	100	81,8	78,6
	90th	83,3	100	83,3	91,7
6. Control*	30th	39	16	16	18
	45th	23	11	11	14
	90th	6	2	6	12

*The controls provide data on the number of weeds, copies/m^2.

The yield of winter wheat treated with the herbicide during the tillering phase in the control variant was 34.3 c/ha (Table 23). Statistically reliable values of the retained yield in the variants with herbicide application ranged from 14.3 to 18.4%.

Table 23. **Grain yield of winter wheat, variety Svarog, treated with the herbicide Fortissimo, OD (tillering phase, Rostov region, 2021)**

Variants	Average productivity	
	c/h	% to control
1. Fortissimo, OD – 0,4 l/h	39,2	114,3
2. Fortissimo, OD – 0,5 l/h	39,8	116,0
3. Fortissimo, OD – 0,7 l/h	40,6	118,4
4. Prima Forte 195, SE – 0,5 l/h	39,5	115,2
5. Prima Forte 195, SE – 0,7 l/h	40,3	117,5
6.Control	34,3	100
LSD$_{05}$	1,41	

The yield of winter wheat treated with the herbicide in the exit into the tube phase in the control variant was 34.0 c/ha (Table 24). Statistically reliable values of the retained yield in the variants with the application of herbicide ranged from 11.8 to 14.4%.

Table 24. **Grain yield of winter wheat, variety Svarog, treated with the herbicide Fortissimo, OD (phase exit into the tube, Rostov region, 2021)**

Variants	Average productivity	
	c/h	% to control
1. Fortissimo, OD – 0,4 l/h	38,0	111,8
2. Fortissimo, OD – 0,5 l/h	38,4	112,9
3. Fortissimo, OD – 0,7 l/h	38,9	114,4
4. Lancelot 450, WDG – 0,03 kg/h	38,5	113,2
5. Lancelot 450, WDG – 0,033 kg/h	39,1	115,0
6.Control	34,0	100
LSD_{05}	1,27	

The initial infestation of the experimental plot of winter wheat with annual weeds during the tillering phase in 2022 was 58 ind./m^2. The sowing was dominated by annual dicotyledonous weeds: Descurainia Sofia, Corn poppy and Catchweed bedstraw. The number of perennial dicotyledonous weeds field bindweed was 8 ind./m^2 (Table 25).

Table 25. **Phases of development of weeds in winter wheat crops during the tillering phase (2022)**

Types of weeds	Stages of weed development	Number, samples/m^2
Descurainia Sofia	stemming, 5-12 cm	19
Corn poppy	stemming, up to 13 cm	14
Catchweed bedstraw	up to 4 whorls, 4-10 cm	25
Field bindweed	cotyledons - a lash up to 8 cm long	8

Herbicide use played a major role in significantly suppressing weed growth. The application of 0.4, 0.5, and 0.7 l/ha Fortissimo resulted in a reduction of 83.1-100% in the overall number of weeds (Figure 21), 85.6-100% in the mass of annual dicotyledonous weeds, and 96.2% in the mass of perennial species (Appendix, Table 7).

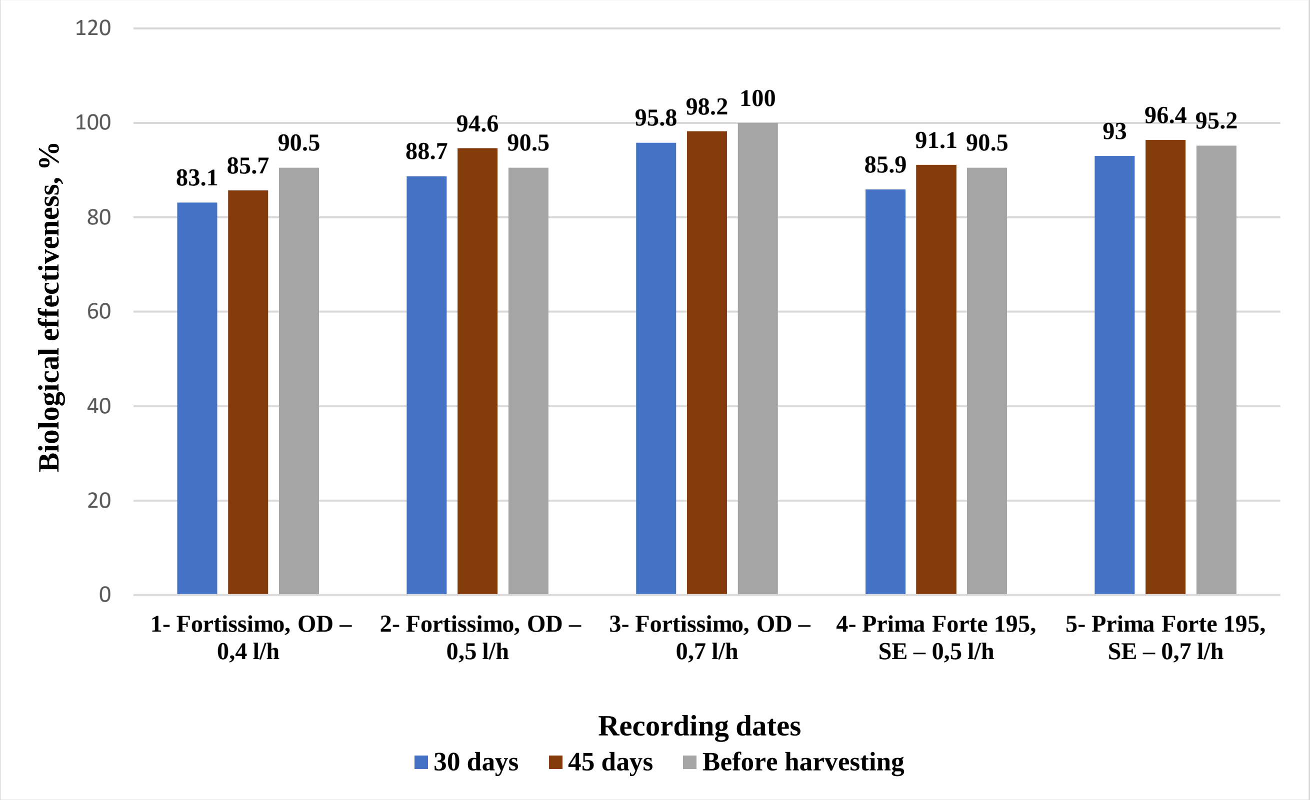

Figure 21. **Biological effectiveness of the herbicide Fortissimo, OD in the tillering phase of winter wheat (Rostov region, 2022)**

Nearly all species of weeds showed high sensitivity to the herbicide Fortissimo, OD (Table 26).

Table 26. **Efficacy of the herbicide Fortissimo, OD against certain types of weeds in winter wheat crops (tillering phase, Rostov region, 2022)**

Experimental options	Recording dates	Reduction of the number of weeds, % of the control			
		Descurainia sophia	*Papaver rhoeas*	*Galium aparine*	*Convolvulus arvensis*
1. Fortissimo, OD – 0,4 l/h	30th	90,5	91,7	80,0	54,5
	45th	94,4	93,3	84,6	60,0
	90th	100	100	100	75,0
2. Fortissimo, OD – 0,5 l/h	30th	95,2	95,8	86,7	63,6
	45th	100	100	92,3	80,0

	90th	100	100	100	75,0
3. Fortissimo, OD – 0,7 l/h	30th	100	100	100	72,7
	45th	100	100	100	90,0
	90th	100	100	100	100
4. Prima Forte 195, SE – 0,5 l/h	30th	90,5	95,8	86,7	54,5
	45th	94,4	100	92,3	70,0
	90th	100	100	100	75,0
5. Prima Forte 195, SE – 0,7 l/h	30th	100	100	93,3	63,6
	45th	100	100	100	80,0
	90th	100	100	100	87,5
6. Control*	30th	21	24	15	11
	45th	18	15	13	10
	90th	5	2	6	8

*The controls provide data on the number of weeds, copies/m^2.

The initial contamination of the experimental area of winter wheat in the phase of exit into the tube by annual weeds was 60 copies / m^2. Annual dicotyledonous weeds prevailed in sowing: Descurainia Sofia, Corn poppy and Catchweed bedstraw. The number of perennial dicotyledonous weeds of the field loach was 9 copies/m^2 (Table 27).

Table 27. **Phases of weed development in winter wheat crops in the tube phase (2022)**

Types of weeds	Stages of weed development	Number, samples/m^2
Descurainia Sofia	stemming, 7-18 cm	24
Corn poppy	stemming, 12-19 cm	16
Catchweed bedstraw	up to 7 whorls, 8-12 cm	20
Field bindweed	whip up to 12 cm long	9

The application of herbicides resulted in significant weed suppression. In variants with the application of 0.4, 0.5, and 0.7 l/ha Fortissimo, the OD reduction in the total number of weeds was 77.0 - 95.7% (Figure 22), the mass of annual dicotyledonous weeds was 83.1 - 97.8%, and the mass of perennial species was 69.3 - 90.1% (Appendix, Table 8). The studied herbicide was applied at the same level of effectiveness as the standard Lancelot 450, WDG.

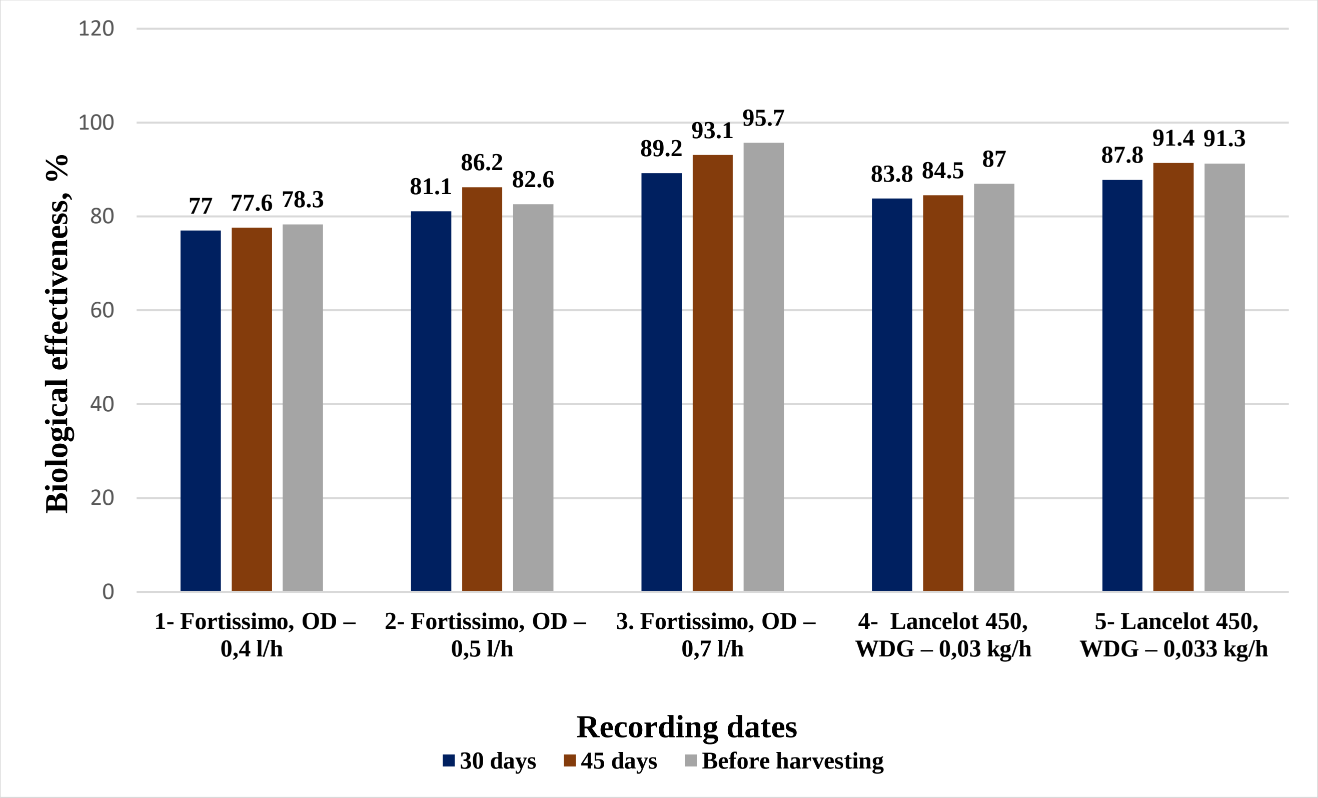

Figure 22. **Biological effectiveness of the herbicide Fortissimo, OD in the phase of winter wheat exit into the tube (Rostov region, 2022)**

Most species of weeds showed high sensitivity to the herbicide fortissimo OD (Table 28).

Table 28. **Efficacy of the herbicide Fortissimo, OD against certain types of weeds in winter wheat crops (exit into the tube phase, Rostov region, 2022)**

Experimental options	Recording dates	Reduction of the number of weeds, % of the control			
		Descurainia sophia	*Papaver rhoeas*	*Galium aparine*	*Convolvulus arvensis*
1. Fortissimo, OD – 0,4 l/h	30th	84,0	89,5	72,2	50,0
	45th	85,0	92,3	71,4	54,5
	90th	83,3	100	83,3	62,5
2. Fortissimo, OD – 0,5 l/h	30th	88,0	94,7	77,8	50,0

	45th	95,0	100	78,6	63,6
	90th	83,3	100	83,3	75,0
3. Fortissimo, OD – 0,7 l/h	30th	96,0	100	83,3	66,7
	45th	100	100	92,9	72,7
	90th	100	100	100	87,5
4. Lancelot 450, WDG – 0,03 kg/h	30th	92,0	94,7	77,8	58,3
	45th	95,0	92,3	78,6	63,6
	90th	100	100	83,3	75,0
5. Lancelot 450, WDG – 0,033 kg/h	30th	96,0	94,7	83,3	66,7
	45th	100	100	85,7	72,7
	90th	100	100	83,3	87,5
6. Control*	30th	25	19	18	12
	45th	20	13	14	11
	90th	6	3	6	8

*The controls provide data on the number of weeds, copies/m^2.

The yield of winter wheat treated with the herbicide during the tillering phase in the control variant was 37.0 c/ha (Table 29). Statistically reliable values of the retained yield in the variants with herbicide application ranged from 15.7 to 20.3%.

Table 29. **Grain yield of winter wheat, variety Yuca, treated with the herbicide Fortissimo, OD (tillering phase, Rostov region, 2022)**

Variants	Average productivity	
	c/h	% to control
1. Fortissimo, OD – 0,4 l/h	42,8	115,7
2. Fortissimo, OD – 0,5 l/h	43,3	117,0
3. Fortissimo, OD – 0,7 l/h	44,5	120,3
4. Prima Forte 195, SE – 0,5 l/h	43,1	116,5
5. Prima Forte 195, SE – 0,7 l/h	44,1	119,2
6. Control	37,0	100
LSD$_{05}$	1,57	

The yield of winter wheat treated with herbicide in the exit into the tube phase in the control variant was 36.8 c/ha (Table 30). Statistically significant values of the harvested crop in the variants with the introduction of herbicide ranged from 13.0 to 16.8%.

Table 30 - **Grain yield of winter wheat, variety Yuca, treated with the herbicide Fortissimo, OD (phase exit into the tube, Rostov region, 2022)**

Variants	Average productivity	
	c/h	% to control
1. Fortissimo, OD – 0,4 l/h	41,6	113,0
2. Fortissimo, OD – 0,5 l/h	42,1	114,4
3. Fortissimo, OD – 0,7 l/h	43,0	116,8
4. Lancelot 450, WDG – 0,03 kg/h	42,3	114,9
5. Lancelot 450, WDG – 0,033 kg/h	42,8	116,3
6. Контроль	36,8	100
HCP_{05}	1,39	

Conclusion. The biological effectiveness of the herbicide Fortissimo, OD was at the level of effectiveness of the standards in the relevant regulations for use. Applying the herbicide was safe for the protected crops.

3.3 Cayenne Turbo, OD (Tribenuron-methyl 75 g/l + Thifensulfuron-methyl 75 g/l + Flumetsulam 52 g/l)

Research to assess the effectiveness of the herbicide Cayenne Turbo, OD was carried out in 2021-2022, according to the diagram presented in table 31.

Table 31**. Experiment scheme**

Experiemental options	Application rats
1 Cayenne Turbo, OD	0,15 l/ha
2. Cayenne Turbo, OD	0,25 l/ha
3. Cayenne Turbo, OD	0,35 l/ha
4. Cayenne Turbo, OD + SURFACTANT Bit-90, L	0,15 l/ha + 0,2 l/ha
5. Cayenne Turbo, OD + SURFACTANT Bit-90, L	0,25 l/ha + 0,2 l/ha
6. Cayenne Turbo, OD + SURFACTANT Bit-90, L	0,35 l/ha + 0,2 l/ha
7. Status Max, WDG (standard)	0,03 kg/ha
8. Status Max, WDG (standard)	0,05 kg/ha
9. Control	-

Before applying herbicides, a quantitative count of weeds was carried out in order to establish the number and species composition of weeds (Table 32).

Table 32. **Initial contamination of winter wheat crops in the tillering phase (Rostov region, 2021-2022)**

Types of weeds	Quantity, samples/m^2		
	2021	2022	Average
Descurainia Sofia	34	19	26
(Black) bindweed	23	0	11
Catchweed Bedstraw	10	14	12
Corn poppy	0	25	12
Field bindweed	14	8	11
Total	81	66	72

From the data in Table 32, it can be seen that the initial infestation in 2021 was 81 plants per 1 m^2, and in 2022 - 66 plants per 1 m^2.

The initial infestation of the experimental plot with annual weeds in 2021 was 67 ind./m^2. The sowing was dominated by annual dicotyledonous weeds: *(*Black) bindweed, Descurainia Sofia and Catchweed Bedstraw. The number of perennial dicotyledonous weeds field bindweed was 14 ind./m^2 (Table 33).

Table 33. **Stages of weed development when preparing winter wheat at the tillering stage (2021)**

Types of weeds	Stages of weed development	Number, samples/m^2
(Black) bindweed	cotyledons - 1-2 true leaves, 4-6 cm	34
Descurainia Sofia	stemming, 6-14 cm	23
Catchweed Bedstraw	up to 5 whorls, 5-10 cm	10
Field bindweed	cotyledons - a lash up to 10 cm long	14

The introduction of herbicides helped to significantly reduce weed growth. The addition of Cayenne Turbo, OD, both in a mixture with surfactants Bit-90, L, and in pure form, resulted in an 82.7 - 97.2% decline in the total number of weeds (Figure 23), an 89.9 - 100% in the mass of annual dicotyledonous weeds, and a 51.9 - 96.6% in the mass of perennial species.

The application of the studied herbicide corresponded to the level of effectiveness of the standard Status Max, WDG.

The trials indicated that the drug's efficacy improved with the use of surfactants: at an herbicide application rate of 0.15 l/ha, it achieved a maximum of 84.5%, and with the addition of surfactants, it rose to 89.7%; at 0.25 l/ha, it was 90.1 and 94.4%, respectively; at 0.35 l/ha, it was 93.1 and 97.2%.

The greatest reduction in the overall weediness of winter wheat crops was observed with the application of 0.35 l/ha + 0.2 l/ha of the drug Cayenne Turbo, OD + surfactant Bit-90, L– 97.2%, which was not inferior to the standard Status Max, WDG – 0.05 kg/ha (96.6%).

Based on the results obtained, it can be said that the decrease in the number of weeds when using Cayenne Turbo OD increases with increasing application rates and adding surfactants.

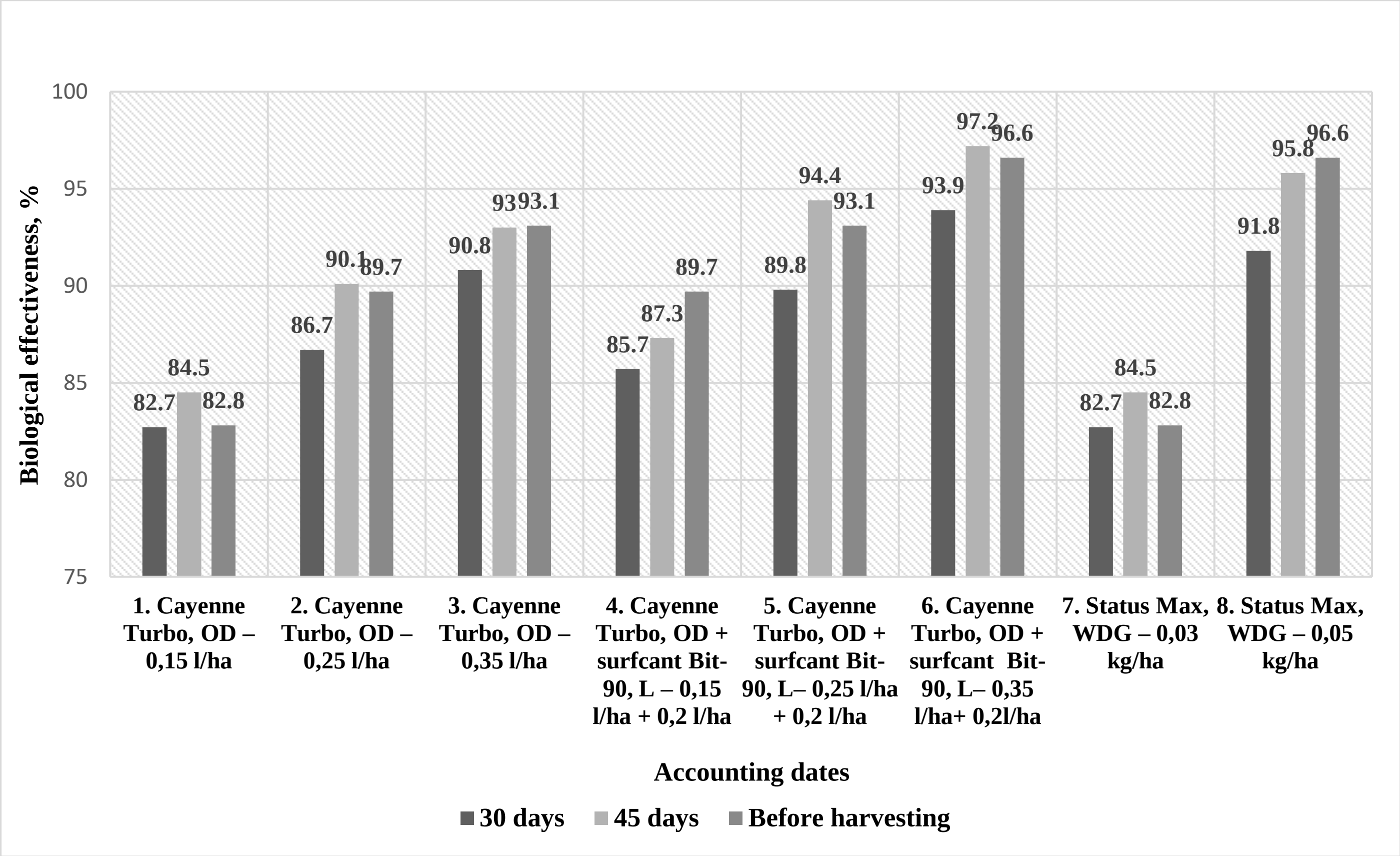

Figure 23. **Biological effectiveness of the herbicide Cayenne Turbo, OD on winter wheat (tillering phase, Rostov region, 2021)**

Table 34 indicates that a majority of weed species exhibited high sensitivity to the herbicide Cayenne Turbo, OD.

Table 34. **Efficacy of the herbicide Cayenne Turbo, OD against certain types of weeds in winter wheat (tillage stage Rostov Region 2021)**

Experimental options	Recording dates	A % decrease in the number of weeds compared to control			
		Fallopia Convolvulus	*Descurainia sophia*	*Galium aparine*	*Convolvulus arvensis*
1. Cayenne Turbo, OD – 0,15 l/ha	30th	92,9	93,1	72,7	43,8
	45th	96,0	94,1	78,6	60,0
	90th	100	100	87,5	63,6
	30th	95,2	96,6	81,8	50,0

2. Cayenne Turbo, OD – 0,25 l/ha	45th	100	100	85,7	66,7
	90th	100	100	100	72,7
3. Cayenne Turbo, OD – 0,35 l/ha	30th	97,6	100	90,9	56,3
	45th	100	100	92,9	73,3
	90th	100	100	100	81,8
4. Cayenne Turbo, OD + SURFACTANT Bit-90, L – 0,15 l/ha + 0,2 l/ha	30th	95,2	93,1	81,8	50,0
	45th	92,0	100	85,7	66,7
	90th	100	100	100	72,7
5. Cayenne Turbo, OD + SURFACTANT Bit-90, L– 0,25 l/ha + 0,2 l/ha	30th	95,2	100	90,9	56,3
	45th	100	100	92,9	80,0
	90th	100	100	100	81,8
6. Cayenne Turbo, OD + SURFACTANT Bit-90, L– 0,35 l/ha+ 0,2l/ha	30th	97,6	100	100	68,8
	45th	100	100	100	86,7
	90th	100	100	100	90,9
7. Status Max, WDG – 0,03 kg/ha	30th	90,5	89,7	63,6	62,5
	45th	92,0	94,1	78,6	66,7
	90th	100	100	75,0	72,7
8. Status Max, WDG – 0,05 kg/ha	30th	95,2	96,6	81,8	81,3
	45th	100	100	92,9	86,7
	90th	100	100	100	90,9
9. Control*	30th	42	29	11	16
	45th	25	17	14	15
	90th	8	2	8	11

*Controls provide data on the number of artificial weeds/m²

The total initial incidence of winter wheat during the tillering stage in 2022 was 66 plants per 1 m^2. The initial infection of the experimental plot with annual grasses was 58 ind/m^2. Annual dicotyledonous weeds dominated the sowing: Descurainia Sofia, Corn poppy, and Catchweed Bedstraw. The number of field perennial dicotyledonous weeds was 8 strands/m2 (Table 35).

Table 35. **Stages of weed development when preparing winter wheat at the tillering stage (2022)**

Types of weeds	Stages of weed development	Number, samples/m^2
Descurainia Sofia	stalking, 5-12 cm	19
Corn poppy	stalking, up to 13 cm	14
Catchweed Bedstraw	up to 4 whorls, 4-10 cm	25
Field bindweed	cotyledons - a whip up to 8 cm long	8

Using of herbicides has significantly eliminated weeds. In variants with the introduction of Cayenne Turbo, OD, both mixed with surfactants Bit-90, W, and in its pure form, the reduction in the total number of weeds was 82.1-100% (Figure 24).

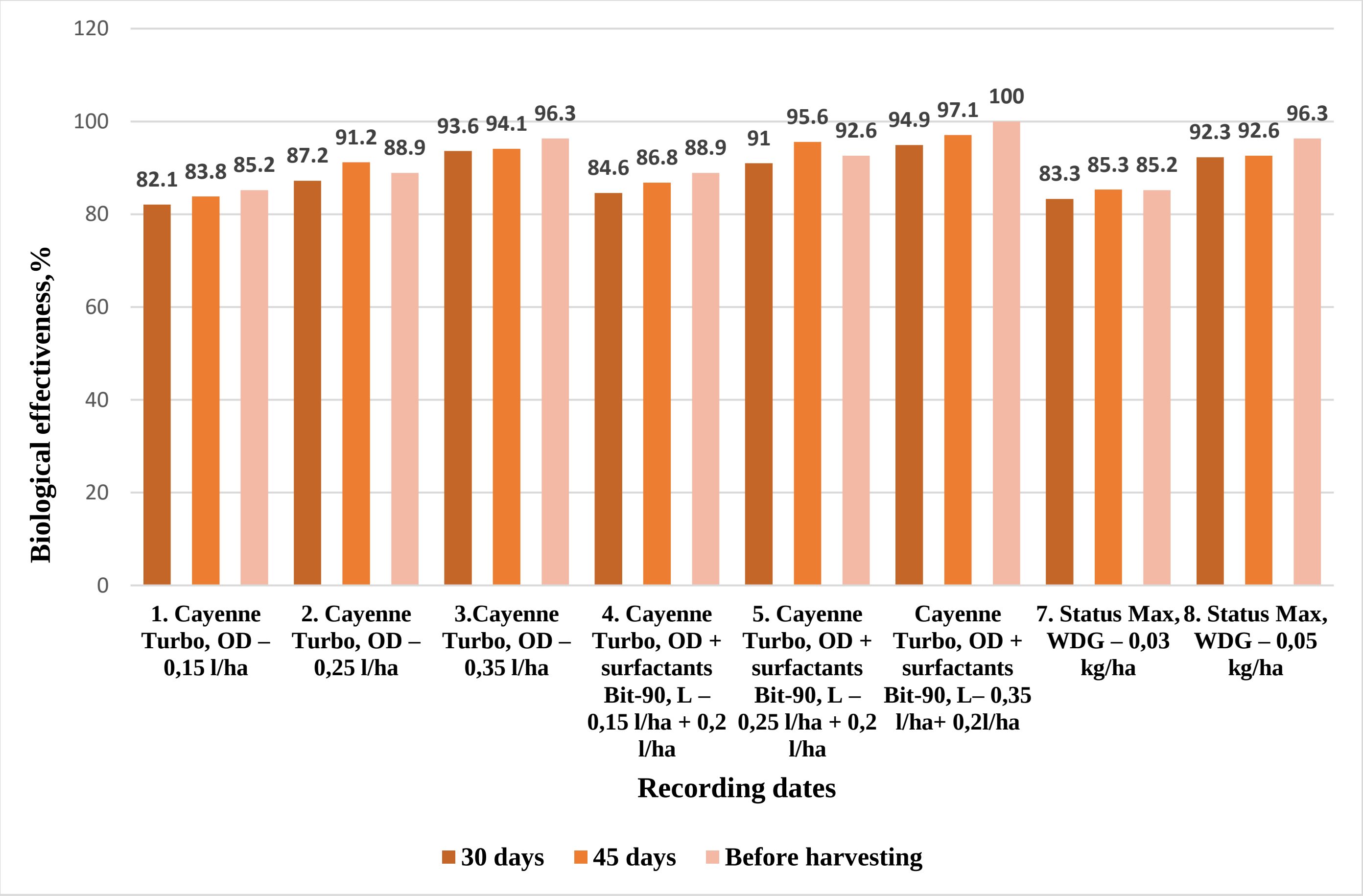

Figure 24. **Biological effectiveness of the herbicide Cayenne Turbo, OD on winter wheat (tillage stage, Rostov region, 2022)**

The mass reduction of annual dicotyledon grasses were 86.2-100%, and the mass reduction of perennial species were 65.8-97.3%. The herbicide test application complies with the effectiveness level of the Status Max standard, WDG (Appendix, Table 11).

According to the studies, the drug's effectiveness rose when surfactants were added. At an herbicide application rate of 0.15 l/ha, the drug's effectiveness reached a maximum of 85.2%; when surfactants were added, that number increased to 88.9%. Typically, 0.25 l/ha produced results of 91.2 and 95.6%, respectively; Typically, 0.35 l/ha produced results of 96.3 and 100%.

The greatest reduction in total weeds of winter wheat crops was observed when using 0.35 l/ha + 0.2 l/ha of Cayenne Turbo, OD + surfactant Bit-90, L – 100%, which exceeds the standard case efficiency Max, WDG – 0.05 kg/ha (96.3%).

According to the results got, it can be said that the decrease in the number of weeds when using Cayenne Turbo OD increases with increasing application rates and adding surfactants.

Almost all weed species were highly sensitive to Cayenne Turbo, OD herbicide (Table 36).

Table 36. **Efficacy of the herbicide Cayenne Turbo, OD against certain types of weeds in winter wheat (tillage stage, Rostov region, 2022)**

Experiemental options	Recording dates	A % decrease in the number of weeds compared to control			
		Descurainia sophia	*Papaver rhoeas*	*Galium aparine*	*Convolvulus arvensis*
1. Cayenne Turbo, OD – 0,15 l/ha	30th	87,5	92,9	78,6	50,0
	45th	90,0	95,5	80,0	54,5
	90th	100	100	88,9	66,7
2. Cayenne Turbo, OD – 0,25 l/ha	30th	91,7	96,4	85,7	58,3
	45th	100	100	86,7	63,6
	90th	100	100	88,9	77,8
	30th	95,8	100	92,9	75,0

3. Cayenne Turbo, OD – 0,35 l/ha	45th	100	100	93,3	72,7
	90th	100	100	100	88,9
4. Cayenne Turbo, OD + SURFACTANT Bit-90, L – 0,15 l/ha + 0,2 l/ha	30th	91,7	96,4	78,6	50,0
	45th	95,0	100	80,0	54,5
	90th	100	100	100	66,7
5. Cayenne Turbo, OD + SURFACTANT Bit-90, L – 0,25 l/ha + 0,2 l/ha	30th	95,8	100	85,7	66,7
	45th	100	100	100	72,7
	90th	100	100	100	77,8
6. Cayenne Turbo, OD + SURFACTANT Bit-90, L – 0,35 l/ha+ 0,2 l/ha	30th	100	100	85,7	83,3
	45th	100	100	100	81,8
	90th	100	100	100	100
7. Status Max, WDG – 0,03 kg/ha	30th	87,5	92,9	85,7	50,0
	45th	95,0	100	80,0	45,5
	90th	100	100	100	55,6
8. Status Max, WDG – 0,05 kg/ha	30th	95,8	100	92,9	66,7
	45th	100	100	86,7	72,7
	90th	100	100	100	88,9
9. Control*	30th	24	28	14	12
	45th	20	22	15	11
	90th	6	3	9	9

*Controls provide data on the number of artificial weeds/m²

Winter wheat production in the control phase (tillage phase 2021) reached 34.2 cm/ha. Statistically kept values for yield retained in the variables with herbicide application ranged from 14.0 to 16.7%. The control yield in 2022 was 36.7 cm/ha. Statistically reliable values for retained yield in the variables with herbicide application ranged from 15.0 to 18.5% (Figure 25).

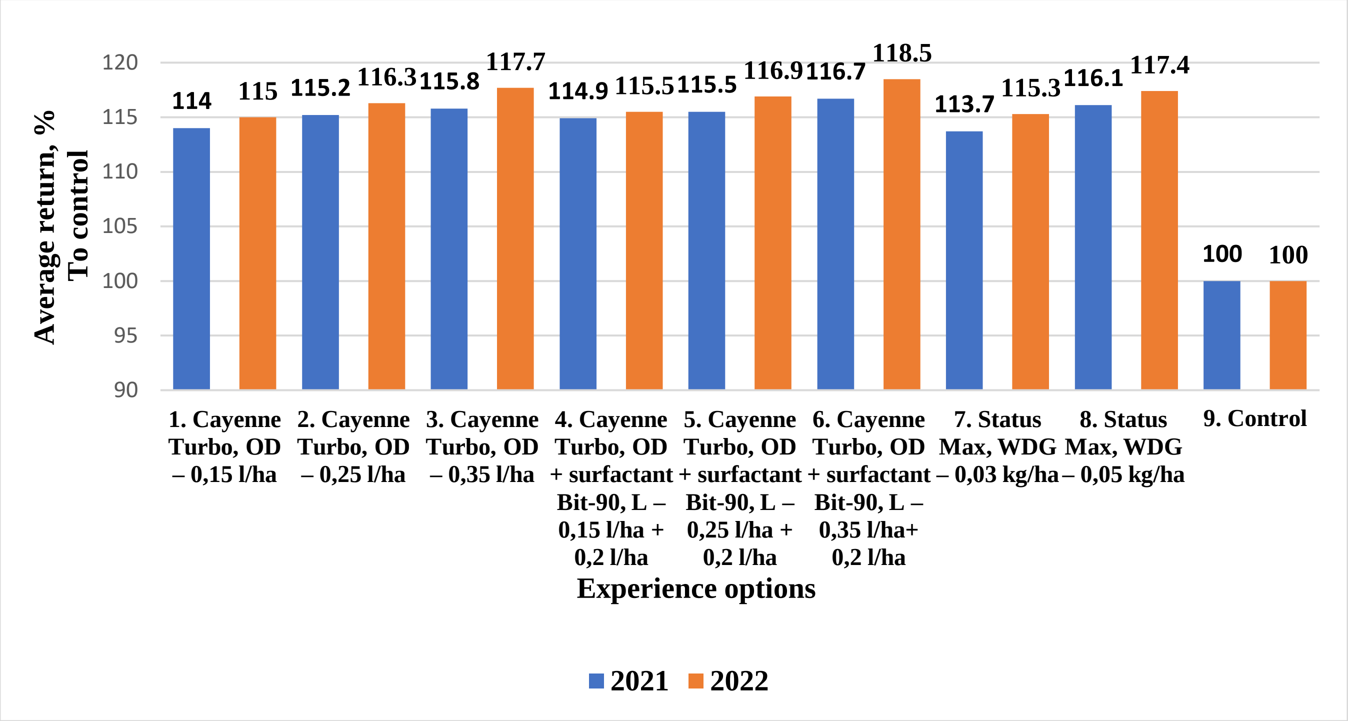

Figure 25. **Grain yield of winter wheat, varieties Svarog and Yuka, treated with the herbicides at the tillering stage (Rostov region, 2021-2022)**

The initial infestation of the experimental plot of winter wheat with annual weeds during the exit into the tube phase (2021) was 80 ind./m^2. The sowing was dominated by annual dicotyledonous weeds: Field bindweed, Descurainia Sofia and Catchweed Bedstraw. The number of perennial dicotyledonous weeds field bindweed was 10 ind./m^2 (Table 37).

Table 37. **Stages of weed development during processing of winter wheat the exit into the tube phase (2021)**

Types of weeds	Stages of weed development	Number of samples/m^2
(Black) bindweed	Cotyledons - 1-5 true leaves, 5-8 cm long	45
Descurainia Sofia	Stems, 8-20 cm	22
Catchweed Bedstraw	Up to 7 crumbs, 7-14 cm	13
Field bindweed	Whip up to 13 cm long	10

Herbicides have significantly reduced the number of weeds. In variants containing Cayenne Turbo, OD, both mixed with surfactant Bit-90, L and in its pure form, the overall number of weeds was reduced by 72.1 - 93.5% (Figure 26). The mass reduction of annual dicot weeds was reduced by 85.8 - 99.6%, and the mass of perennial species decreased. The herbicides studied were applied at the level of effectiveness specified by the Status Max standard, WDG (Appendix, Table 10).

The smallest reduction in the total number of weeds in winter wheat crops was observed on the 30th day after treatment when using Cayenne Turbo, OD in its pure form at an application rate of 0.15 l/ha (72.1%), and Cayenne Turbo, OD mixed with surfactant. Bit-90, L application rate is 0.15 L/ha + 0.2 L/ha -75.6%.

The maximum reduction in crop injury was observed when applying Cayenne Turbo, OD surfactant Bit-90, L, 0.35 l/ha + 0.2 l/ha (93.5%) (Figure 26).

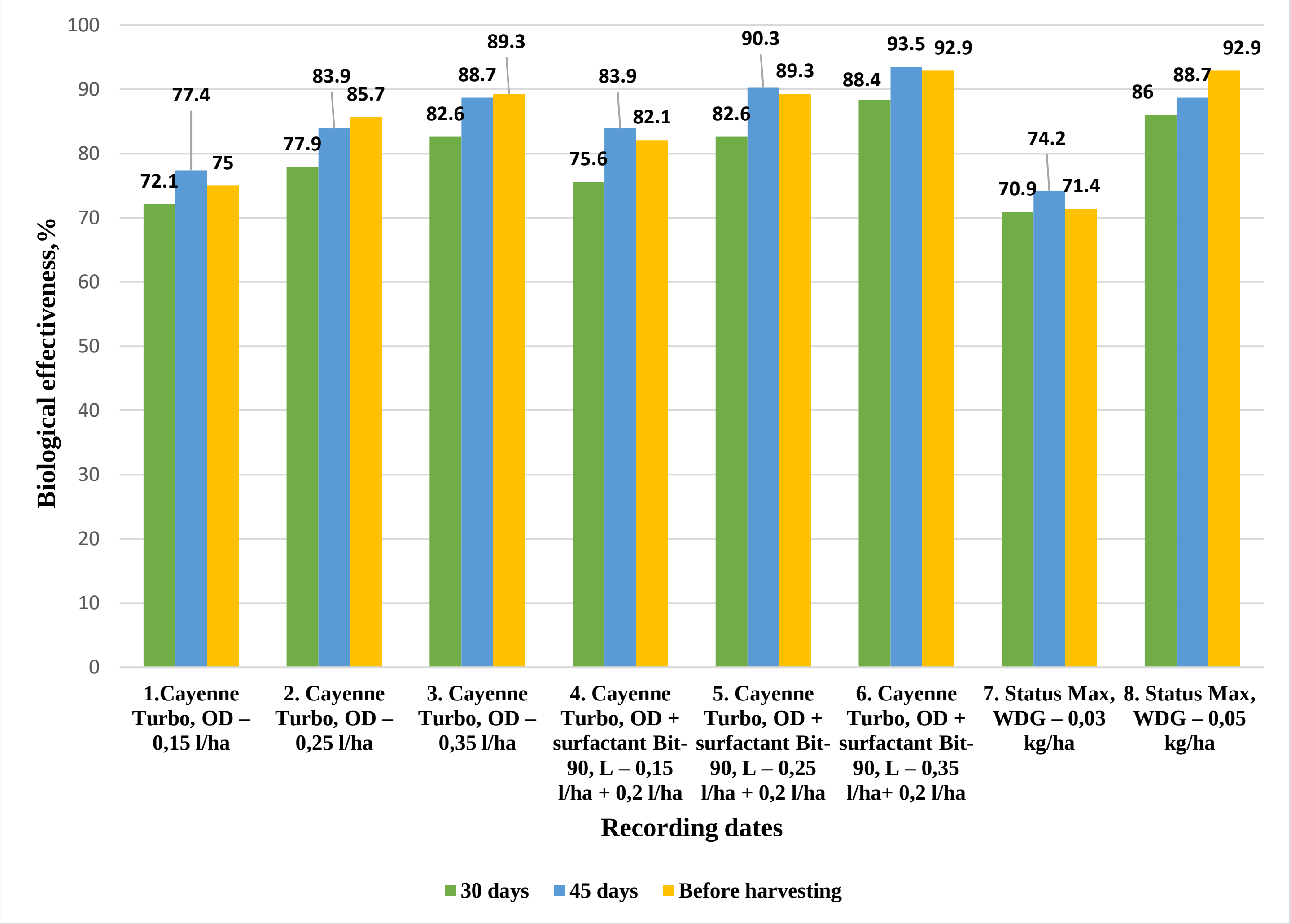

Figure 26. **Biological effectiveness of the herbicide Cayenne Turbo, OD on winter wheat (the exit into the tube phase, Rostov region, 2021)**

The majority of weed species were extremely sensitive to the Cayenne Turbo, OD herbicide (Table 38).

Table 38. **Efficacy of the herbicide Cayenne Turbo, OD against certain types of weeds in winter wheat (Rostov region, 2021)**

Experimental options	Recording dates	A % decrease in the number of weeds compared to control			
		Fallopia convolvulus	*Descurainia sophia*	*Galium aparine*	*Convolvulus arvensis*
1. Cayenne Turbo, OD – 0,15 l/ha	30th	85,3	88,2	61,1	41,2
	45th	92,3	100	69,2	42,9
	90th	87,5	100	85,7	54,5
2. Cayenne Turbo, OD – 0,25 l/ha	30th	88,2	94,1	72,2	47,1
	45th	96,2	100	76,9	57,1
	90th	100	100	100	63,6
3. Cayenne Turbo, OD – 0,35 l/ha	30th	94,1	94,1	77,8	52,9
	45th	100	100	84,6	64,3
	90th	100	100	100	72,7
4. Cayenne Turbo, OD + SURFACTANT Bit-90, L – 0,15 l/ha + 0,2 l/ha	30th	88,2	88,2	66,7	47,1
	45th	96,2	100	76,9	57,1
	90th	100	100	85,7	63,6
5 Cayenne Turbo, OD + SURFACTANT Bit-90, L– 0,25 l/ha + 0,2 l/ha	30th	91,2	94,1	83,3	52,9
	45th	100	100	84,6	71,4
	90th	100	100	100	72,7
6. Cayenne Turbo, OD + SURFACTANT Bit-90, L – 0,35 l/ha+ 0,2l/ha	30th	97,1	94,1	88,9	64,7
	45th	100	100	92,3	78,6
	90th	100	100	100	81,8
7. Status Max, WDG – 0,03 kg/ha	30th	82,4	76,5	61,1	52,9
	45th	88,5	88,9	61,5	50,0

	90th	87,5	100	71,4	54,5
8. Status Max, WDG – 0,05 kg/ha	30th	94,1	88,2	83,3	70,6
	45th	96,2	100	84,6	71,4
	90th	100	100	100	81,8
9. Control*	30th	34	17	18	17
	45th	26	9	13	14
	90th	8	2	7	11

*Controls provide data on the number of artificial weeds/m^2

The initial infestation of the winter wheat experimental plot (the exit into the tube phase, 2022) with annual weeds was 60 ind/m^2. Annual dicotyledonous weeds dominated the sowing: Descurainia Sofia, Corn poppy, and Catchweed Bedstraw. The number of field perennial dicotyledonous weeds was 9 strands/m^2 (Table 39).

Table 39. **Stages of weed plant development at the time of processing winter wheat at the exit into the tube phase (2022)**

Types of weeds	Stages of weed development	Number of samples/m^2
Descurainia Sofia	stalking, 7-18 cm	24
Corn poppy	stalking, 12-19 cm	16
Catchweed Bedstraw	up to 7 whorls, 8-12 cm	20
Field bindweed	whip length up to 12 cm	9

The application of herbicides has significantly eliminated weeds. In variants with introducing of Cayenne Turbo, OD, both mixed with surfactant Bit-90, L and in its pure form, the reduction in the mass of annual dicot weeds was 82.8%–98.9%, while the reduction in the mass of perennial species was 58.6%–92.9%. The overall number of weeds was reduced by 74.3–93.5% (Fig. 27). Using the studied herbicides corresponds to the effectiveness level of the Status Max, WDG standard (Appendix, Table 12).

As a result of the research, it was revealed that the least reduction in the total number of weeds in winter wheat crops on the 30th day after treatment was observed when using

Cayenne Turbo, OD - 0.15 l/ha (74.3%) in pure form while when using Cayenne Turbo OD + Surfactant Bit-90, L – 0.15 l/ha + 0.2 l/ha had the smallest reduction in total weed counts (77.0%).

Total crop damage was reduced somewhat more strongly when Cayenne Turbo, OD was used at application rates of 0.25 and 0.35 l/ha. The combination of Cayenne Turbo and OD + surfactants Bit-90, L provided the maximum reduction in total weed counts (93.5%).

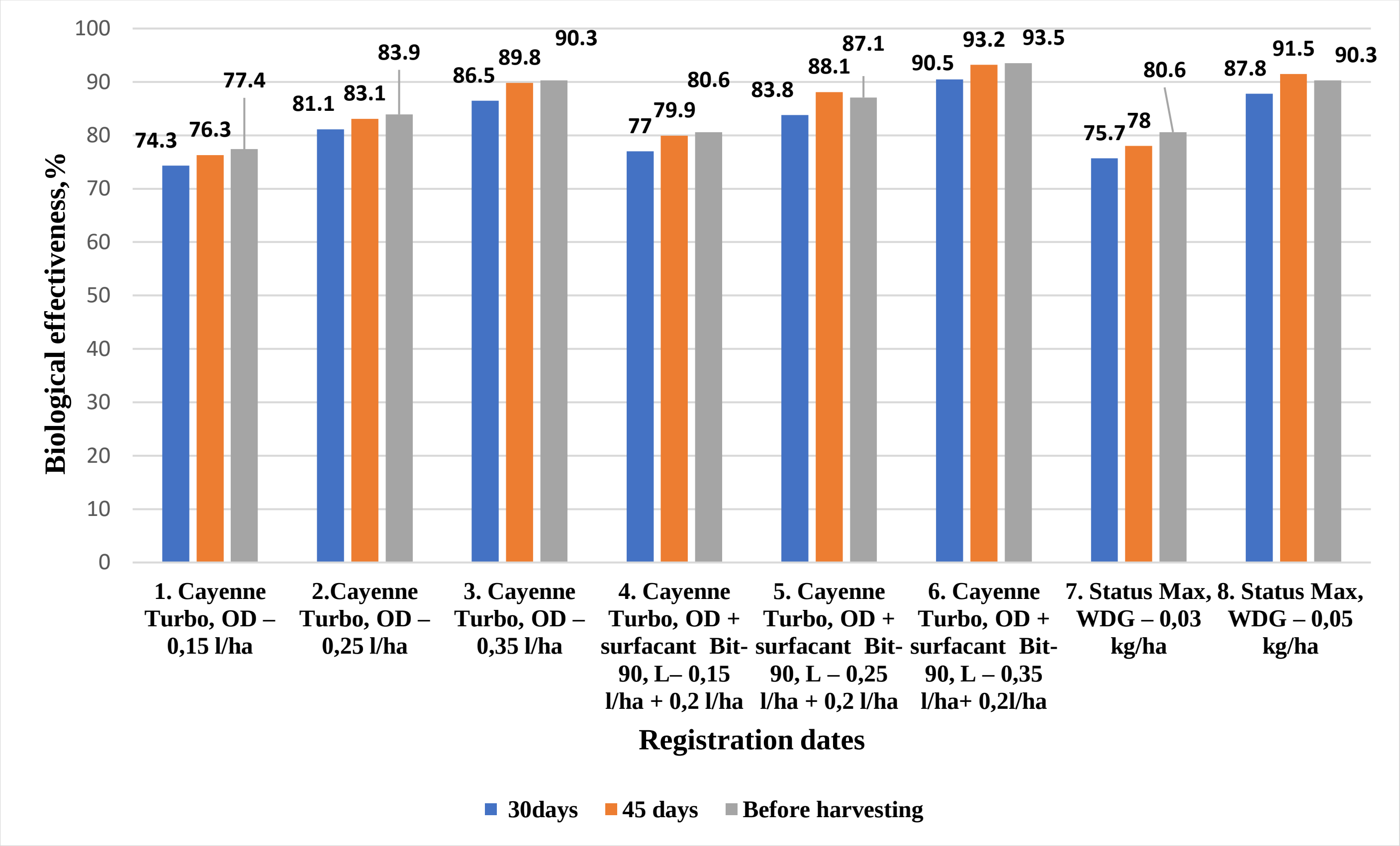

Figure 27. **Biological effectiveness of the herbicide Cayenne Turbo, OD on winter wheat (the exit into the tube phase, Rostov region, 2022)**

The effectiveness of herbicides against the most common annual and perennial weed species in winter wheat crops is determined by the sensitivity of individual species to these drugs (Table 40).

Table 40. **Efficacy of the herbicide Cayenne Turbo, OD against certain certain types of weeds in winter wheat crops (the exit into the tube phase, Rostov region, 2022)**

Experimental options	Recording dates	A % decrease in the number of weeds compared to control			
		Descurainia sophia	*Papaver rhoeas*	*Galium aparine*	*Convolvulus arvensis*
1. Cayenne Turbo, OD – 0,15 l/ha	30th	85,7	87,0	68,8	42,9
	45th	88,9	93,8	66,7	46,2
	90th	85,7	100	87,5	58,3
2. Cayenne Turbo, OD – 0,25 l/ha	30th	90,5	95,7	75,0	50,0
	45th	94,4	100	75,0	53,8
	90th	100	100	87,5	66,7
3. Cayenne Turbo, OD – 0,35 l/ha	30th	95,2	95,7	81,3	64,3
	45th	100	100	83,3	69,2
	90th	100	100	100	75,0
4. Cayenne Turbo, OD + SURFACTANT Bit-90, L – 0,15 l/ha + 0,2 l/ha	30th	85,7	91,3	68,8	50,0
	45th	94,4	87,5	75,0	53,8
	90th	100	100	87,5	58,3
5. Cayenne Turbo, OD + SURFACTANT Bit-90, L – 0,25 l/ha + 0,2 l/ha	30th	90,5	95,7	81,3	57,1
	45th	94,4	100	83,3	69,2
	90th	100	100	100	66,7
6. Cayenne Turbo, OD + SURFACTANT Bit-90, L – 0,35 l/ha+ 0,2l/ha	30th	95,2	100	87,5	71,4
	45th	100	100	91,7	76,9
	90th	100	100	100	83,3
7. Status Max, WDG – 0,03 kg/ha	30th	85,7	91,3	68,8	42,9
	45th	94,4	87,5	66,7	53,8
	90th	100	100	87,5	58,3
8. Status Max, WDG – 0,05 kg/ha	30th	95,2	100	81,3	64,3
	45th	100	100	91,7	69,2
	90th	100	100	100	75,0
9. Control*	30th	21	23	16	14
	45th	18	16	12	13
	90th	7	4	8	12

*Controls provide data on the number of artificial weeds/m²

Data on the wheat yield in experiments using herbicides at the exit stage to the tube are presented in Figure 28.

During the research study, the lowest value of the winter wheat yield was observed in the control variant of 33.9 c/ha. Statistically significant values of the harvested crop in the variants with introducing of herbicide ranged from 11.8 to 14.7% in the 2021 season. In the 2022 season, the yield of winter wheat in the control was 36.5 c/ha. Statistically significant values of the harvested crop in the variants with the introduction of herbicide ranged from 12.3 to 16.7%.

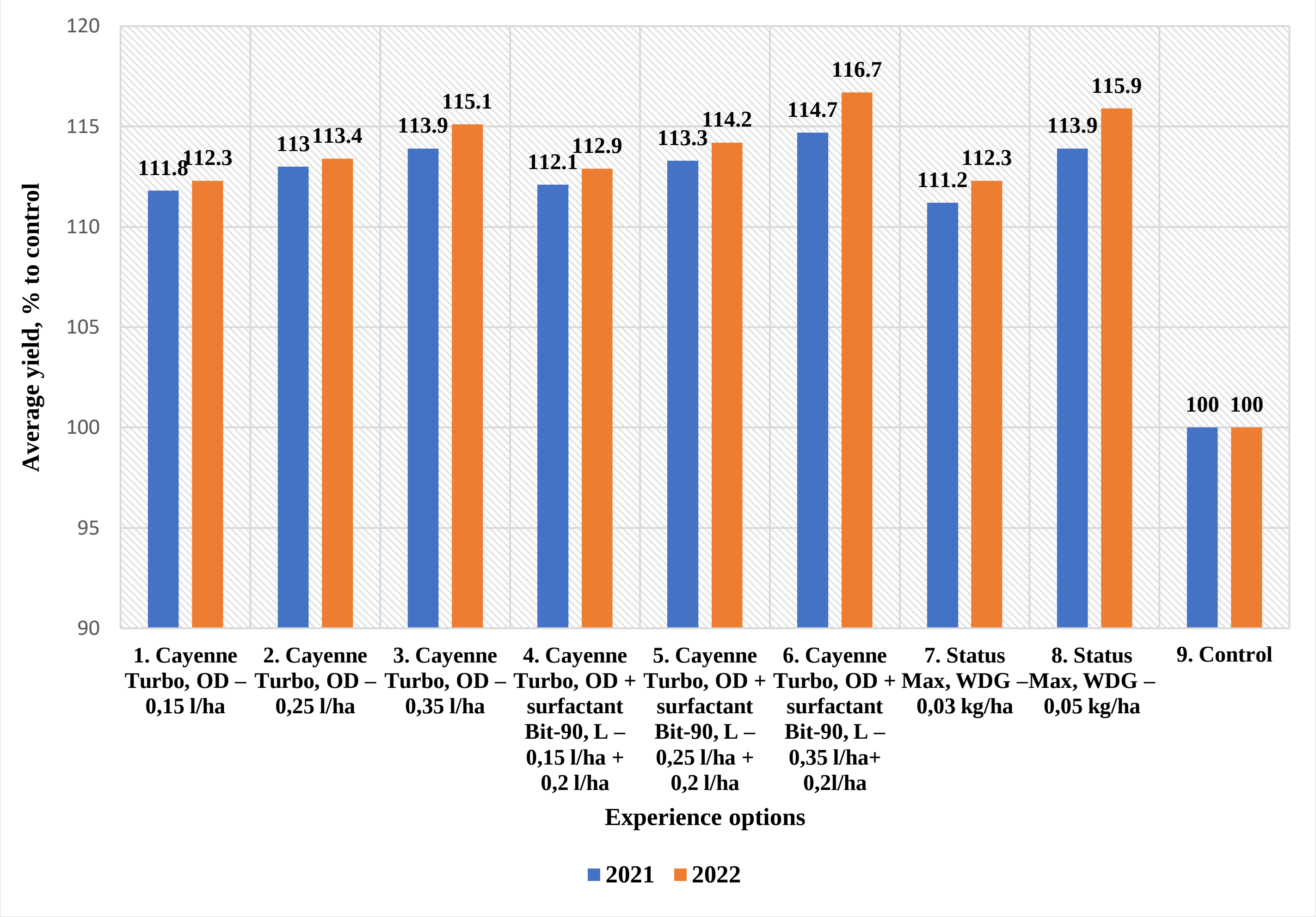

Figure 28**. Grain yield of winter wheat, varieties Svarog and Yuka, treated with the herbicides, exit into the tube phase (Rostov region, 2021-2022)**

Conclusion. The biological effectiveness of the herbicide Cayenne Turbo, OD, mixed with the surfactant Bit-90, W and in its pure form, was at the level of effectiveness of the Status Max, WDG standard in the relevant regulations for use. The effectiveness of the herbicide and surfactant mixture was higher than that of the pure and standard herbicide. Applying the drug was safe for the protected crops.

3.4 Polian, OD (Tribenuron-methyl 225 g/l + Thifensulfuron-methyl 76 g/l)

Research was conducted to evaluate the effectiveness and establish regulations for the use of Polian, OD herbicide in 2021-2022. According to the scheme shown in Table 41.

Table 41. **Experiment scheme**

№ п.п.	Experimental options	Norms for using the drug	The multiplicity of treatments
1	Polian, OD	0,05 l/ha	1
2	Polian, OD	0,075 l/ha	1
3	Polian, OD	0,1 l/ha	1
4	Polian, OD + surfactant Bit-90, L	0,05 l/ha + 0,2 l/ha	1
5	Polian, OD + surfactant Bit-90, L	0,075 l/ha + 0,2 l/ha	1
6	Polian, OD + surfactant Bit-90, L	0,1 l/ha + 0,2 l/ha	1
7	Caliber Gold, WDG + surfactant Trend 90, L (standard)	0,03 kg/ha + 0,2 l/ha	1
8	Caliber Gold, WDG (standard)	0,05 kg/ha	1
9	Control	-	-

The initiative infestation of the winter wheat trial plot at tillering stage (2021) with annual weeds was 67 ind/m^2. Annual dicotyledonous weeds dominated the sowing process: Black bindweed, Descurainia Sofia and Catchweed Bedstraw. The number of field perennial dicotyledonous weeds was 14 individuals/m^2 (Table 42).

Table 42**. Stages of weed development at the time of processing winter wheat (tillering stage, 2021)**

Types of weeds	Stages of weed development	Quantity, samples/m^2
Black bindweed	cotyledons - 1-2 true leaves, 4-6 cm	34
Descurainia Sofia	stalking, 6-14 cm	23
Catchweed Bedstraw	to 5 whorls, 5-10 cm	10
Field bindweed	cotyledons - a whip up to 10 cm long	14

The use of herbicides has significantly reduced the number of weeds. In the variants using the application of Polian, OD, both mixed with surfactant Bit-90, L in its pure form, As shown in Figure 29, the overall weed population ranged from 72.5 to 94.0%. The annual dicot weeds accounted for 87.2 percent of the weed mass decrease. 100% as well as a drop in the mass of species that are perennial 44.2 – 88.1%. The application of the studied herbicides corresponds to the effectiveness level of Caliber Gold standard, WDG, both in mixture with Trend 90 surfactant, L and in pure form (Appendix, Table 13).

On account of our research, it was revealed that the smallest reduction in the total number of weeds in winter wheat crops on the 30th day after treatment was observed when using 0.05 l/ha of Polian, OD (72.5%). Total crop injury was significantly reduced when using Polian, OD + surfactant Bit-90, L – 0.1 l/ha + 0.2 l/ha (94.0%) on the 45th day after treatment.

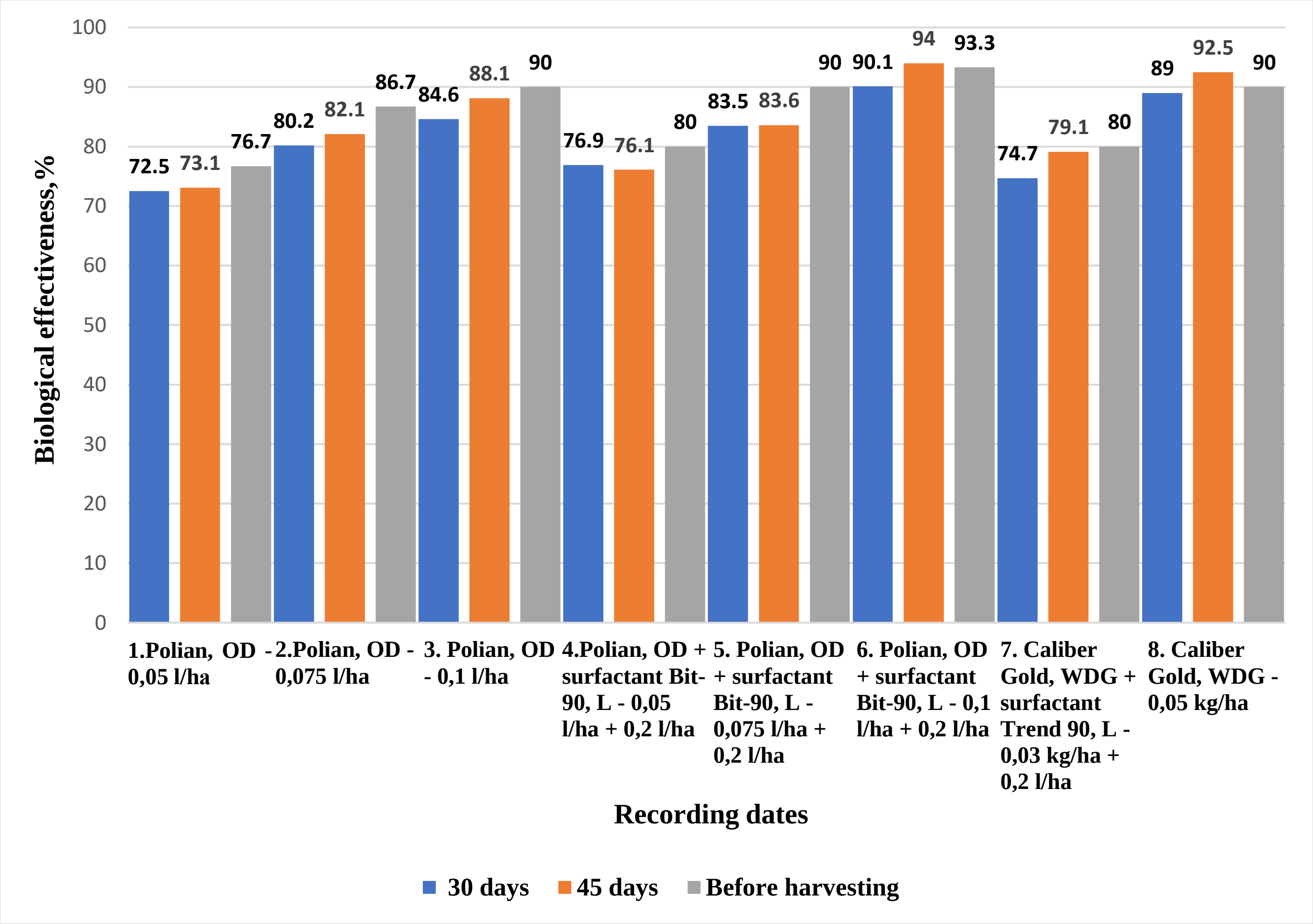

Figure 29. **Biological effectiveness of the herbicide Polian, OD at the tillering stage of winter wheat (Rostov Region, 2021)**

Most weed species showed high sensitivity to the herbicide Polian, OD (Table 43).

Table 43. **Efficacy of the herbicide Polian, OD against certain types of weeds in winter wheat crops (tillering stage, Rostov region, 2021)**

Experimental options	Recording dates	A % decrease in the number of weeds compared to control			
		Fallopia convolvulus	*Descurainia sophia*	*Galium aparine*	*Convolvulus arvensis*
1. Polian, OD - 0,05 l/ha	30th	80,0	82,6	72,7	41,2
	45th	81,5	78,6	75,0	50,0
	90th	88,9	100	85,7	54,5
2. Polian, OD - 0,075 l/ha	30th	90,0	87,0	81,8	47,1
	45th	85,2	92,9	83,3	64,3
	90th	100	100	100	63,6
3. Polian, OD – 0,1 l/ha	30th	95,0	91,3	81,8	52,9
	45th	92,6	100	83,3	71,4
	90th	100	100	100	72,7
4. Polian, OD + surfactant Bit-90, L – 0,05 l/ha + 0,2 l/ha	30th	87,5	82,6	72,7	47,1
	45th	85,2	78,6	75,0	57,1
	90th	88,9	100	85,7	63,6
5. Polian, OD + surfactant Bit-90, L – 0,075 l/ha + 0,2 l/ha	30th	92,5	91,3	81,8	52,9
	45th	88,9	92,9	83,3	64,3
	90th	100	100	100	72,7
6. Polian, OD + surfactant Bit-90, L – 0,1 l/ha + 0,2 l/ha	30th	97,5	95,7	90,9	64,7
	45th	100	100	100	71,4
	90th	100	100	100	81,8
7. Caliber Gold, WDG + surfactant Trend 90, L – 0,03 kg/ha + 0,2 l/ha	30th	85,0	78,3	63,6	52,9
	45th	88,9	85,7	66,7	64,3
	90th	88,9	100	85,7	63,6
8. Caliber Gold, WDG – 0,05 kg/ha	30th	95,0	95,7	90,9	64,7
	45th	100	100	91,7	71,4
	90th	100	100	100	72,7
9. Control*	30th	40	23	11	17
	45th	27	14	12	14
	90th	9	3	7	11

*Controls provide data on the number of weeds, ind./m^2

The winter wheat yield in the control was 33.6 c/ha (Table 44). Statistically reliable values of the retained yield in the variants with the application of herbicide ranged from 13.1 to 15.2%.

Table 44. **Grain yield of winter wheat, variety Svarog, treated with the herbicide Polian, OD at the tillering stage (Rostov Region, 2021)**

Variants	Average yield	
	c/ha	% to control
1. Polian, OD - 0,05 l/ha	38,0	113,1
2. Polian, OD - 0,075 l/ha	38,4	114,3
3. Polian, OD – 0,1 l/ha	38,5	114,6
4. Polian, OD + surfactant Bit-90, L – 0,05 l/ha + 0,2 l/ha	38,2	113,7
5. Polian, OD + surfactant Bit-90, L – 0,075 l/ha + 0,2 l/ha	38,4	114,3
6. Polian, OD + surfactant Bit-90, L – 0,1 l/ha + 0,2 l/ha	38,7	115,2
7. Caliber Gold, WDG + surfactant Trend 90, L – 0,03 kg/ha + 0,2 l/ha	38,1	113,4
8. Caliber Gold, WDG – 0,05 kg/ha	38,6	114,9
9. Control	33,6	100
LSD_{05} =	0,81	

Initial infestation of the winter wheat experimental plot with annual weeds during in the exit into the tube phase (2021) was 80 ind/m^2. Annual dicotyledonous weeds dominated the sowing process: Black bindweed, Descurainia Sofia and Catchweed Bedstraw. The number of field perennial dicotyledonous weeds was 10 strands/m^2 (Table 45).

Table 45. **Stages of weed plant development at the time of processing winter wheat (in the exit into the tube phase, 2021)**

Types of weeds	Stages of weed development	Quantity, samples/m^2
Black bindweed	cotyledons - 1-5 true leaves, 5-8 cm	45
Descurainia Sofia	stalking, 8-20 cm	22
Catchweed Bedstraw	to 7 whorls, 7-14 cm	13
Field bindweed	whip up to 13 cm long	10

Our investigation revealed that the substantial eradication of weeds was largely attributable to the application of herbicides. In variations where Polian is added, both in pure form and in a mixture with surfactants Bit-90, L. Using 0.05 l/ha of Polian, OD (64.2%) resulted in the smallest decrease in the total number of weeds in the winter wheat crop on the thirty-first day after treatment.

The total number of weeds was reduced as much as possible when using Polian, OD + surfactant Bit-90, L – 0.1 l/ha + 0.2 l/ha (88.5%) (Figure 30; Appendix, Table 14).

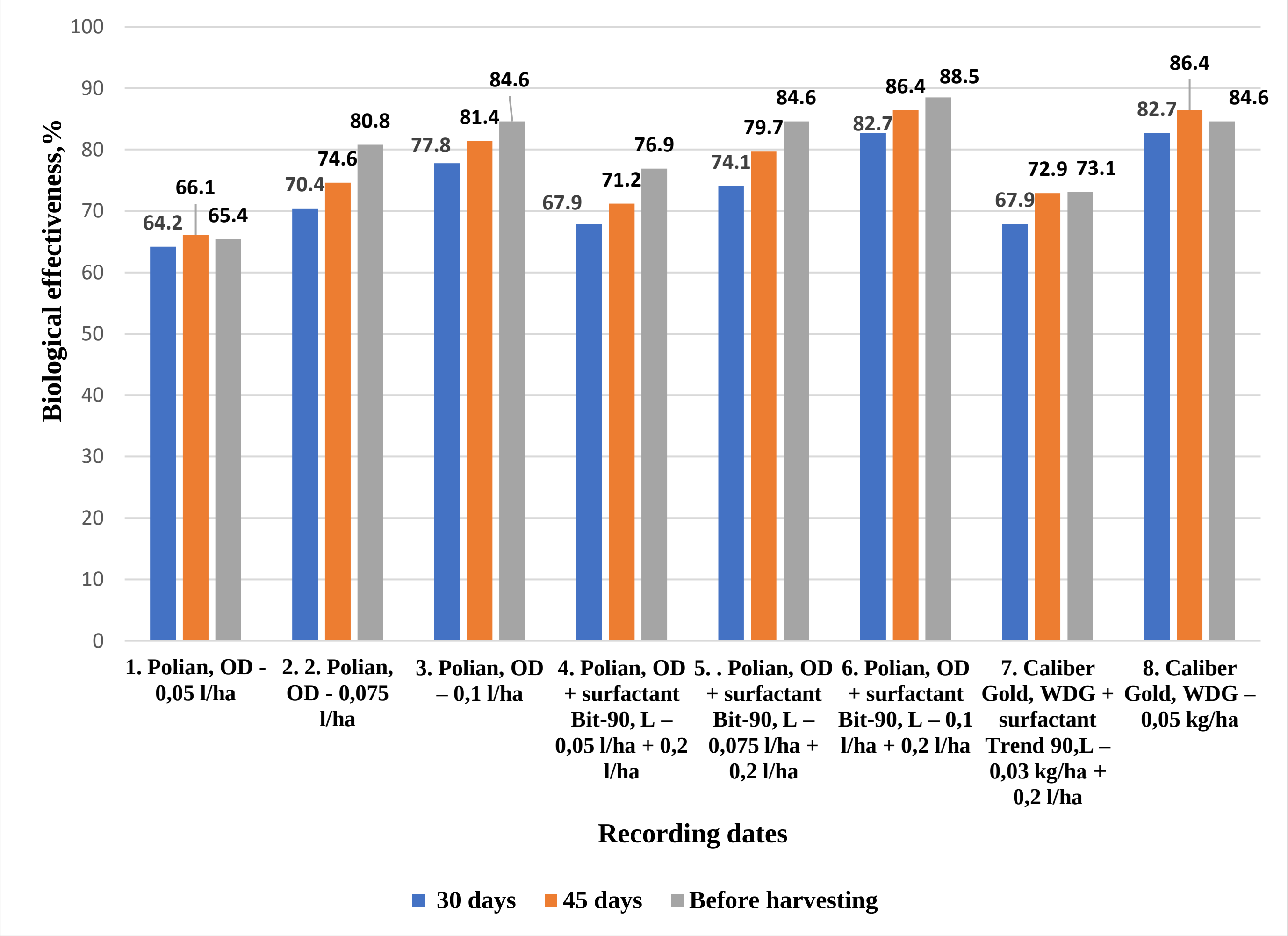

Figure 30. **Biological effectiveness of the herbicide Polian, OD in the exit into the tube phase of winter wheat (Rostov Region, 2021)**

The majority weed species showed high sensitivity to the herbicide Polian, OD (Table 46).

Table 46. **Efficacy of the herbicide Polian, OD against certain types of weeds in winter wheat crops (in the exit into the tube phase, Rostov Region, 2021)**

Research options	Recording dates	A % decrease in the number of weeds compared to control			
		Fallopia convolvulus	*Descurainia sophia*	*Galium aparine*	*Convolvulus arvensis*
1. Polian, OD - 0,05 l/ha	30th	71,9	78,6	63,2	37,5
	45th	73,9	75,0	73,3	38,5
	90th	85,7	100	71,4	45,5
2. Polian, OD - 0,075 l/ha	30th	78,1	85,7	68,4	43,8
	45th	82,6	87,5	80,0	46,2
	90th	100	100	100	54,5
3. Polian, OD – 0,1 l/ha	30th	84,4	92,9	78,9	50,0
	45th	87,0	100	86,7	53,8
	90th	100	100	100	63,6
4. Polian, OD + surfactant Bit-90, L – 0,05 l/ha + 0,2 l/ha	30th	75,0	78,6	68,4	43,8
	45th	78,3	87,5	73,3	46,2
	90th	100	100	85,7	54,5
5. Polian, OD + surfactant Bit-90, L – 0,075 l/ha + 0,2 l/ha	30th	81,3	85,7	73,7	50,0
	45th	87,0	100	80,0	53,8
	90th	100	100	100	63,6
6.. Polian, OD + surfactant Bit-90, L – 0,1 l/ha + 0,2 l/ha	30th	87,5	92,9	84,2	62,5
	45th	91,3	100	93,3	61,5
	90th	100	100	100	72,7
7. Caliber Gold, WDG + surfactant Trend 90, L – 0,03 kg/ha + 0,2 l/ha	30th	81,3	71,4	57,9	50,0
	45th	87,0	75,0	66,7	53,8
	90th	100	100	71,4	54,5
8. Caliber Gold, WDG – 0,05 kg/ha	30th	90,6	85,7	84,2	62,5
	45th	95,7	100	86,7	61,5
	90th	100	100	85,7	72,7
9. Control *	30th	32	14	19	16
	45th	23	8	15	13
	90th	7	1	7	11

*Controls provide data on the number of weeds, ind./m²

The of winter wheat yield in the control was 33.9 c/ha (Table 47). Statistically reliable values of the retained yield in the variants with the application of herbicide ranged from 11.2 to 13.6%.

Table 47. **Grain yield of winter wheat, variety Svarog, treated with the herbicide Polian, OD the exit into the tube phase (Rostov Region, 2021)**

Variants	Average yield	
	c/ha	% to control
1. Polian, OD - 0,05 l/ha	37,7	111,2
2. Polian, OD - 0,075 l/ha	38,0	112,1
3. Polian, OD – 0,1 l/ha	38,3	113,0
4. Polian, OD + surfactant Bit-90, L – 0,05 l/ha + 0,2 l/ha	37,8	111,5
5. Polian, OD + surfactant Bit-90, L – 0,075 l/ha + 0,2 l/ha	38,2	112,7
6. Polian, OD + surfactant Bit-90, L – 0,1 l/ha + 0,2 l/ha	38,5	113,6
7. Caliber Gold, WDG + surfactant Trend 90, L – 0,03 kg/ha + 0,2 l/ha	37,9	111,8
8. Caliber Gold, WDG – 0,05 kg/ha	38,4	113,3
9. Control	33,9	100
LSD_{05}	0,93	

The initial infestation of the experimental plot of winter wheat in the tillering phase (2022) with annual weeds was 58 ind./m^2. The sowing was dominated by annual dicotyledonous weeds: Descurainia Sofia, Corn poppy and Catchweed Bedstraw. The number of perennial dicotyledonous weeds field bindweed was 8 ind./m^2 (Table 48).

Table 48. **Stages of weed development at the time of processing winter wheat (tillering stage, 2022)**

Types of weeds	Stages of weed development	Number of samples/m^2
Descurainia Sofia	stemming, 5-12 cm	19
Corn poppy	stemming, up to 13 cm	14
Catchweed Bedstraw	up to 4 whorls, 4-10 cm	25
Field bindweed	cotyledons - a lash up to 8 cm long	8

The application of the herbicides assists to remarkably terminate dangerous weeds in different ways through the use of Polian, OD, both in a mixture with the surfactant Bit-90, L and in pure form. The smallest reduction in the total number of weeds in winter wheat crops was observed when using 0.05 l/ha Polian, OD (75.0%) on the 30th day after treatment.

Total crop infection decreased as much as possible when applying Polian, OD + surfactant Bit-90, L – 0.1 l/ha + 0.2 l/ha and amounted to 96.6% (Figure 31; Appendix, Table 15).

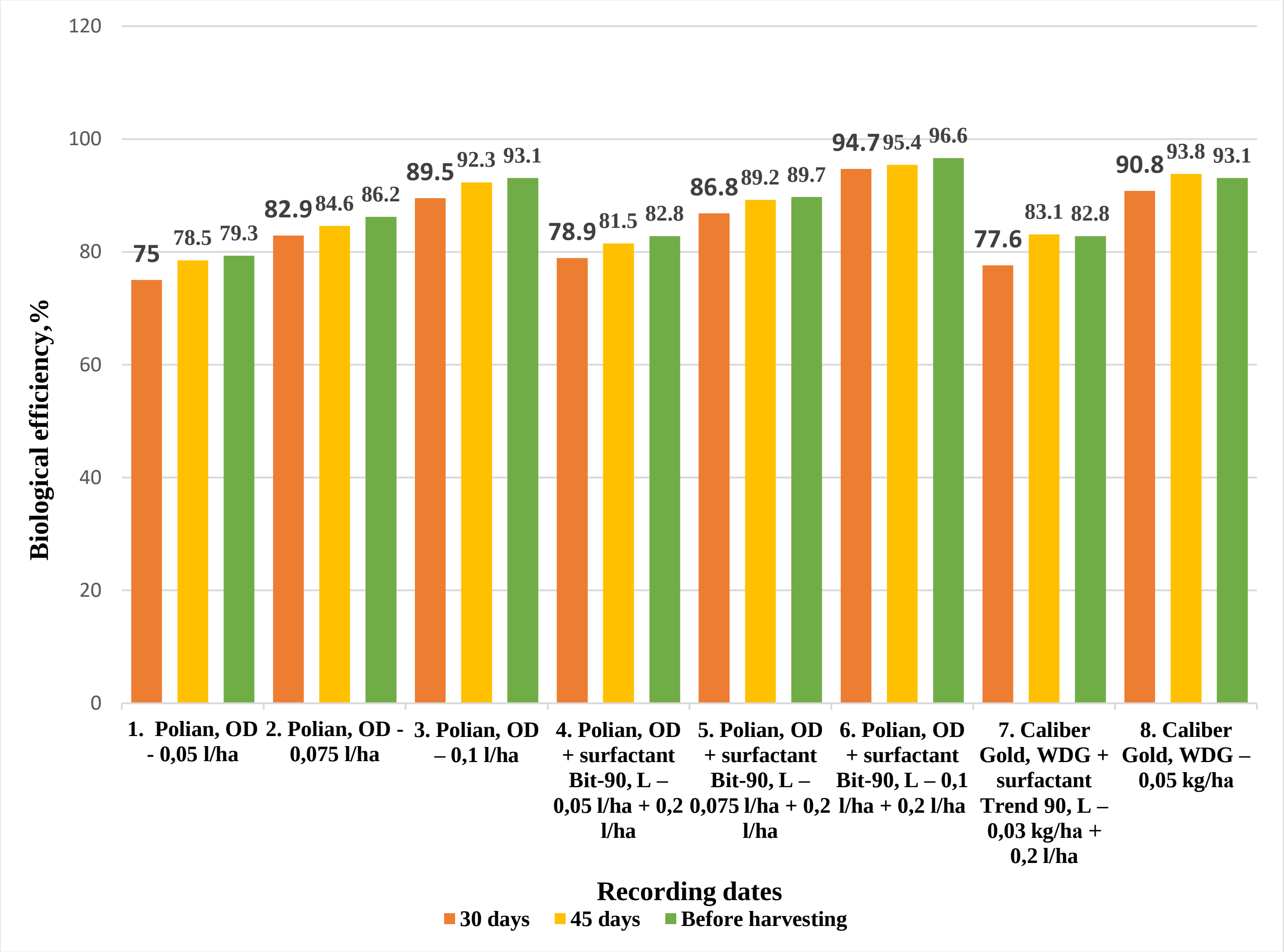

Figure 31. **Biological effectiveness of the herbicide Polian, OD at the tillering stage of winter wheat (Rostov Region, 2022)**

Almost all weed species showed high sensitivity to the herbicide Polian, OD (Table 49).

Table 49. **Efficacy of the herbicide Polian, OD against certain types of weeds in winter wheat crops (tillering stage, Rostov Region, 2022)**

Research options	Recording dates	A % decrease in the number of weeds compared to control			
		Descurainia sophia	*Papaver rhoeas*	*Galium aparine*	*Convolvulus arvensis*
1. Polian, OD - 0,05 l/ha	30th	85,2	86,4	64,3	46,2
	45th	90,5	88,2	73,3	50,0
	90th	100	100	75,0	55,6
2. Polian, OD - 0,075 l/ha	30th	92,6	90,9	78,6	53,8
	45th	95,2	94,1	80,0	58,3
	90th	100	100	87,5	66,7
3. Polian, OD – 0,1 l/ha	30th	96,3	95,5	85,7	69,2
	45th	100	100	86,7	75,0
	90th	100	100	100	77,8
4. Polian, OD + surfactant Bit-90, L – 0,05 l/ha + 0,2 l/ha	30th	88,9	90,9	71,4	46,2
	45th	90,5	94,1	80,0	50,0
	90th	100	100	75,0	66,7
5. Polian, OD + surfactant Bit-90, L – 0,075 l/ha + 0,2 l/ha	30th	96,3	95,5	78,6	61,5
	45th	95,2	100	86,7	66,7
	90th	100	100	100	66,7
6.. Polian, OD + surfactant Bit-90, L– 0,1 l/ha + 0,2 l/ha	30th	100	100	92,9	76,9
	45th	100	100	93,3	83,3
	90th	100	100	100	88,9
7. Caliber Gold, WDG + surfactant Trend 90, L – 0,03 kg/ha + 0,2 l/ha	30th	88,9	90,9	57,1	53,8
	45th	90,5	94,1	80,0	58,3
	90th	100	100	75,0	66,7
8. Caliber Gold, WDG – 0,05 kg/ha	30th	96,3	100	85,7	69,2
	45th	100	100	93,3	75,0
	90th	100	100	100	77,8
9. Control *	30th	27	22	14	13
	45th	21	17	15	12
	90th	10	2	8	9

*Controls provide data on the number of weeds, ind./m²

Data on the harvested grain yield in experiments using herbicides in the tillering phase are given in Table 50. During the research, the lowest value of winter wheat yield was observed in the control variant of 37.3 c/ha.

The grain yield of winter wheat in all experimental variants fluctuated at the level of 42.5 - 43.7 c/ha.

Table 50. **Grain yield of winter wheat, variety Yuka, treated with the herbicide Polian, OD (tillering phase, Rostov region, 2022)**

Variants	Yield by repetitions, c/ha				Average productivity	
	1	2	3	4	c/ha	% to control
1. Polian, OD - 0,05 l/ha	41,8	42,8	42,0	43,3	42,5	113,9
2. Polian, OD - 0,075 l/ha	42,9	43,7	42,8	42,3	42,9	115,0
3. Polian, OD – 0,1 l/ha	43,6	43,0	41,8	44,8	43,3	116,1
4. Polian, OD + surfactant Bit-90, L – 0,05 l/ha + 0,2 l/ha	42,2	41,9	43,5	43,1	42,7	114,5
5. Polian, OD + surfactant Bit-90, L – 0,075 l/ha + 0,2 l/ha	42,6	43,7	44,0	42,1	43,1	115,5
6. Polian, OD + surfactant Bit-90, L– 0,1 l/ha + 0,2 l/ha	44,8	43,3	44,0	42,8	43,7	117,2
7. Caliber Gold, WDG + surfactant Trend 90, L – 0,03 kg/ha + 0,2 l/ha	42,9	41,8	42,2	43,5	42,6	114,2
8. Caliber Gold, WDG – 0,05 kg/ha	42,2	44,7	43,8	42,8	43,4	116,4
9. Control	36,5	37,7	36,7	38,1	37,3	100
LSD_{05} = 0,97 c/ha						

The primary infestation of the experimental plot of winter wheat in the exit into the tube phase (2022) with annual weeds was 60 ind./m^2. The sowing was dominated by annual dicotyledonous weeds: Descurainia Sofia, Corn poppy and Catchweed Bedstraw. The number of perennial dicotyledonous weeds field bindweed was 9 ind./m^2 (Table 51).

Table 51. **Stages of weed development during winter wheat processing (in the exit into the tube phase, 2022)**

Types of weeds	Stages of weed development	Number of samples/m^2
Descurainia Sofia	stemming, 7-18 cm	24
Corn poppy	stemming, 12-19 cm	16
Catchweed Bedstraw	up to 7 whorls, 8-12 cm	20
Field bindweed	whip up to 12 cm long	9

The results obtained on the biological effectiveness of herbicides are presented in Figure 32.

As a result of our study applying Polian, OD in the exit into the tube phase of winter wheat, the smallest reduction in total weed counts in winter wheat crops at day 30 after treatment was observed when using 0.05 l/ha Polian, OD (68.1%). Total crop infestation was significantly reduced when 0.1 L/ha of urea was applied before harvest (89.7%).

The greatest reduction in total crop weeding was observed during the exiting into the tube phase of winter wheat before harvest when Polian, OD + surfactant Bit-90, L - 0.1 l/ha + 0.2 l/ha (93.1%) was applied.

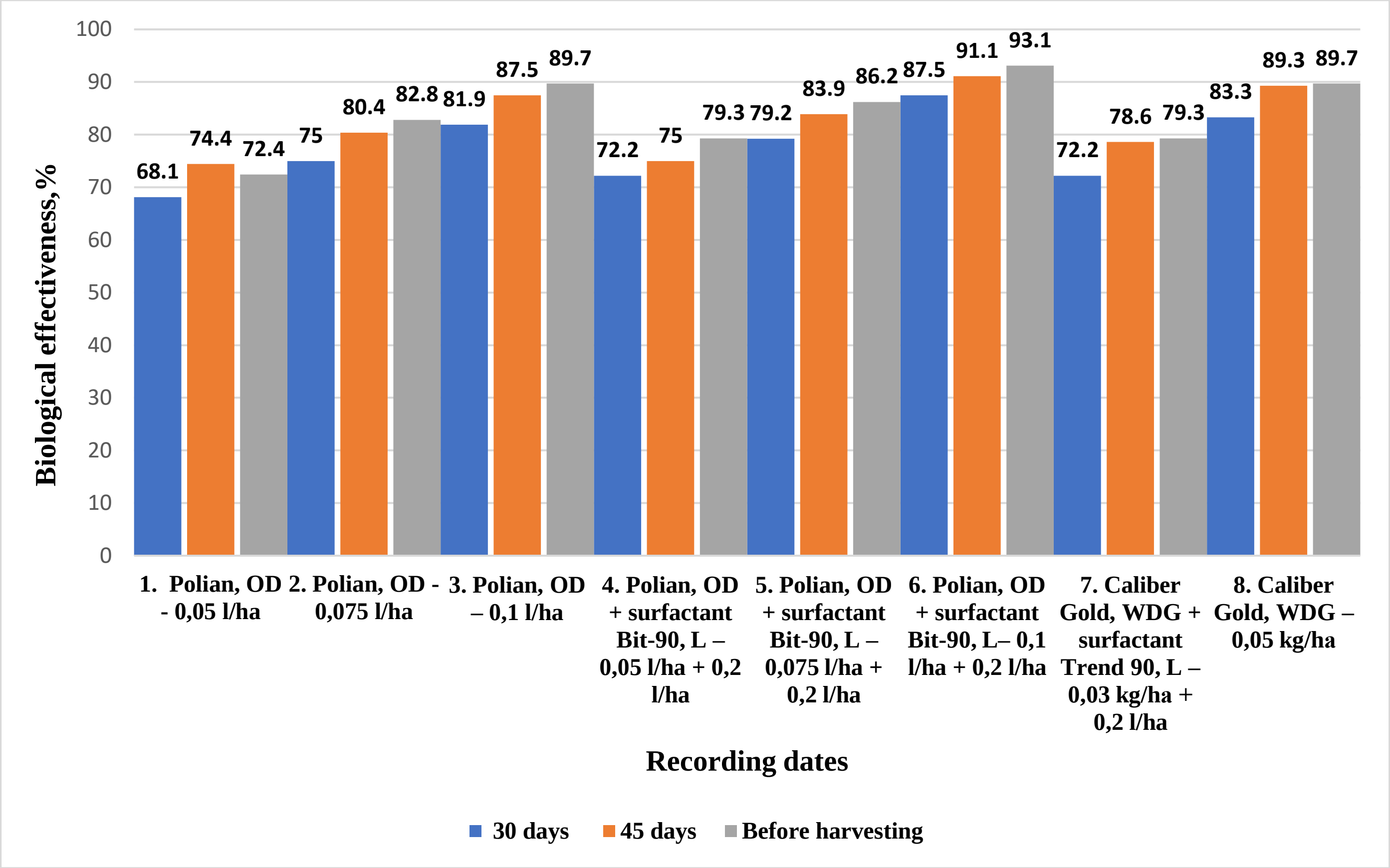

Figure 32. **Biological effectiveness of the herbicide Polian, OD in the exit into the tube phase of winter wheat (Rostov Region, 2022)**

Pretty much all weed species showed high sensitivity to the herbicide Polian, MD (Table 52).

Table 52. **Efficacy of the herbicide Polian, OD against certain types of weeds in winter wheat crops (in the exit into the tube, Rostov region, 2022)**

Research options	Recording dates	A % decrease in the number of weeds compared to control			
		Descurainia sophia	*Papaver rhoeas*	*Galium aparine*	*Convolvulus arvensis*
1. Polian, OD - 0,05 l/ha	30th	78,3	84,2	58,8	38,5
	45th	84,2	84,6	61,5	45,5
	90th	87,5	100	77,8	50,0
2. Polian, OD - 0,075 l/ha	30th	82,6	94,7	64,7	46,2

	45th	89,5	100	69,2	54,5
	90th	100	100	88,9	60,0
3. Polian, OD – 0,1 l/ha	30th	87,0	100	70,6	61,5
	45th	94,7	100	76,9	72,7
	90th	100	100	88,9	80,0
4. Polian, OD + surfactant Bit-90, L – 0,05 l/ha + 0,2 l/ha	30th	82,6	89,5	58,8	46,2
	45th	84,2	92,3	69,2	45,5
	90th	100	100	77,8	60,0
5. Polian, OD + surfactant Bit-90, L – 0,075 l/ha + 0,2 l/ha	30th	87,0	94,7	70,6	53,8
	45th	94,7	92,3	76,9	63,6
	90th	100	100	88,9	70,0
6.. Polian, OD + surfactant Bit-90, L – 0,1 l/ha + 0,2 l/ha	30th	95,7	100	76,5	69,2
	45th	100	100	84,6	72,7
	90th	100	100	100	80,0
7. Caliber Gold, WDG + surfactant Trend 90, L – 0,03 kg/ha + 0,2 l/ha	30th	82,6	89,5	58,8	46,2
	45th	89,5	92,3	69,2	54,5
	90th	87,5	100	88,9	60,0
8. Caliber Gold, WDG – 0,05 kg/ha	30th	91,3	94,7	76,5	61,5
	45th	94,7	100	84,6	72,7
	90th	100	100	88,9	80,0
9. Control *	30th	23	19	17	13
	45th	19	13	13	11
	90th	8	2	9	10

*Controls provide data on the number of weeds, ind./m²

Decreases in the masses of perennial species (49.9-91.3%) and annual dicotyledonous weeds (80.6-97.3%). The application of the investigated herbicides complies with the standard's level of effectiveness (Appendix, Table 16).

During the research period, the lowest winter wheat productivity was observed in the control version of 37.0 cents/ha. Winter wheat grain production in all experimental varieties ranged between 12.2 and 15.1% of the control (Table 53).

Table 53. **Grain yield of winter wheat, variety Yuka, treated with the herbicide Polian, OD (in the exit into the tube,Rostov region, 2022)**

Variants	Average yield	
	c/ha	% of control
1. Polian, OD - 0,05 l/ha	41,5	112,2
2. Polian, OD - 0,075 l/ha	41,9	113,2
3. Polian, OD – 0,1 l/ha	42,3	114,3
4. Polian, OD + surfactant Bit-90, L – 0,05 l/ha + 0,2 l/ha	41,7	112,7
5. Polian, OD + surfactant Bit-90, L – 0,075 l/ha + 0,2 l/ha	42,1	113,8
6. Polian, OD + surfactant Bit-90, L – 0,1 l/ha + 0,2 l/ha	42,6	115,1
7. Caliber Gold, WDG + surfactant Trend 90, L – 0,03 kg/ha + 0,2 l/ha	41,6	112,4
8. Caliber Gold, WDG – 0,05 kg/ha	42,5	114,9
9. Control	37,0	100
LSD_{05}	1,21	

Conclusion. The biological effectiveness of the herbicide Polian, OD, mixed with the surfactant Bit-90, L and in its pure form was at the level of effectiveness of the standard Caliber Gold, WDG both in the mixture with the surfactant Trend 90, L and in its pure form in the relevant regulations. Relevance to use. Using the drug was safe for the protected crops.

3.5 Tarzek WG, (Halauxifen-methyl 69.5 g/kg + Pyroxsulam 250 g/kg)

Both in the Russian Federation and in Iraq, the efficacy of the herbicide Tarzec, WG, was investigated. Experiments were carried out in the Russian Federation in accordance with the following plan (Table 54).

Table 54. **Experiment scheme**

Experimental options	Application rates
1. Tarzec, WG + Surfer (adjuvant) SL	0,075 kg/ha + 1,0 l/ha
1. Tarzec, WG + Surfer (adjuvant) SL	0,09 kg/ha + 1,0 l/ha
3. Pallas 45, OD (standard)	0,5 l/ha
4. Verdict, WDG+ adjuvant BioPower, SL (standard)	0,3 kg/ha + 0,5 l/ha

Prior to the treatment in 2019, the experimental plot contained weeds from two groups: dicotyledons and cereals. The first group included the following species: tenacious bedstraw - *Galium aparine* L. (17 ind./m^2), Corn poppy - *Papaver rhoeas* L. (12 ind./m^2), oak woodleaf - *Cerastium nemorale* M. Bieb. (9 ind/m^2). The second group included: common wild oat – *Avena fatua* L. (18 ind./m^2) and prominent foxtail mousetail – *Alopecurus myosuroides* Huds. (37 ind/m^2). In 2020, before the treatment, the species composition of weeds was similar, but their total number was 17% lower (77 ind./m^2).

A significant increase in the effectiveness of the combined drug compared to the standard Pallas 45, OD was observed in its effect on two types of weeds - *Gallium aparin,* especially *Papaver Royas.*

Pyroxsulam in its pure form had a negligible impact on papaver: during the first year of the study, there was a 5.5-24.0% decrease in the quantity of these species; however, in the second year, Pallas 45, OD had no effect at all (Appendix, Table 17).

The use of Tarzek, WG herbicides against *Papaver rhoeas* was significantly more effective: in the first year of research, the effectiveness of both application rates exceeded the effectiveness of both standards (91.8-100%); In the second year - the efficiency of 0.075 kg/ha of the herbicide Tarzek, WG was at the standard level of Verdict WDG, and the efficiency of 0.09 kg/ha was the highest in the experiment (89.3-95.5%).

Papaver rhoeas L. has known to have developed resistance to acetolactate synthase inhibitor herbicides, especially in Mediterranean countries and the UK (Stankiewicz-Kosyl *et al*., 2020). Therefore, the benefit of herbicide mixtures with halauxifen-methyl for the control of poppy resistant to ALS herbicides (group 2) as well as 2,4-D (Sleugh *et al.,* 2021).

The application of the drug Tarzek, WG at both rates of application in 2019 made it possible to destroy all gallium aparine plants (100%) after 28 and 56 days of treatment (Appendix, Table 17). The efficiency of the standard Pallas 45, OD was well below this level. The standard herbicide Verdict, WDG was the least effective in the trial (72.8-81.5%).

In 2020, the effectiveness of the herbicide Tarzekc, WG (0.075 kg/ha) overtaken the effectiveness of the Pallas criterion after 28 and 56 days of application, and the effectiveness of the studied drug at a rate of 0.09 kg/ha exceeded the effectiveness of all other herbicide options during the entire monitoring period.

In relation to *Cerastium nemorale*, in the first year of research, the effectiveness of pyroxsulam in its pure form (93.8-100%) was at the level of effectiveness of the combined drug in both application rates. All these options significantly exceeded the indicators of the standard Verdict, WDG.

Tarzek, WG was also effective in combating the cereal weeds *Avena fatua* L. and *Alopecurus myosuroides* Huds: in 2019, it was not inferior to the standard in the norm of application of 0.09 kg/ha, and in 2020 exceeded it in both norms.

Data on grain yield in experiments using herbicides are shown in Figure 33.

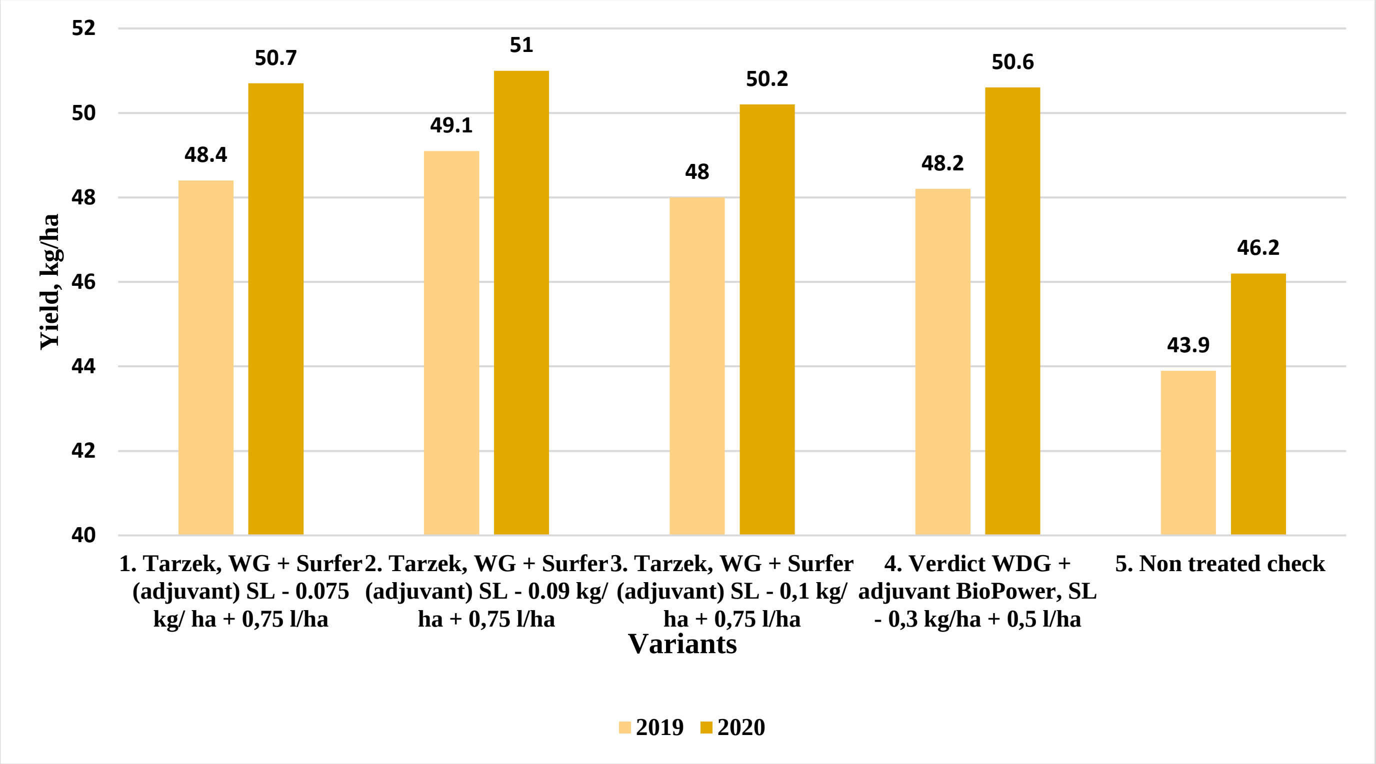

Figure 33. **Grain yield of winter wheat, variety Kalym, treated with the herbicide Tarzek, WG (Rostov region, 2019, 2020)**

In the untreated control, the yield of winter wheat was 43.9 c/ha (in 2019) and 46.2 c/ha (in 2020). For all herbicide options, a significant increase in yield was noted: by 9.3–11.8% in 2019; by 8.7–10.4% in 2020. Despite the stronger inhibition of some weed species compared to the standard in the options for using the herbicide Tarzek, WG, the yield of winter wheat in all options of the herbicide was at the same level.

Research in Iraq was carried out in 2021 according to the following scheme (Table 55).

Table 55. **The scheme of experience (Iraq, 2021)**

Experimental options	Application rates
1. Tarzek, WG + Surfer (adjuvant) SL	0.075 kg/ ha + 0,75 l/ha
2. Tarzek, WG + Surfer (adjuvant) SL	0.09 kg/ ha + 0,75 l/ha
3. Tarzek, WG + Surfer (adjuvant) SL	0,1 kg/ ha + 0,75 l/ha
4. U46-Combi fluid 6, SL (standard)	0,9 l/ha
5. U46-Combi fluid 6, SL (standard)	1,0 l/ha
6. U46-Combi fluid 6, SL (standard)	1,25 l/ha
7.Control	-

Before starting the experiment, the weeds types in the plots were determined. At the experimental site, weeds from two groups were found: dicotyledons: *Beta vulgaris*, *Malva pravi* flora, *Silybum marianum*, *Convolvulus arvensis*, *Chenopodium murale*, *Daucus carota* and Monocotyledons: *Lolium rigidum, Lolium temulentum*. The high effectiveness of the combined drug Tarzek, WG was noted for both groups of weeds, and the drug U46-Combi fluid 6, SL - only for dicotyledons.

Figure 34 displays the findings from the assessment of herbicides' biological efficacy. The effectiveness of various dosages of the same drugs did not differ significantly.

Tarzek, WG showed the highest efficiency at a maximum rate of 0.1 kg/ha (90.5%, 89.4%, and 88.5%, depending on the recording day).

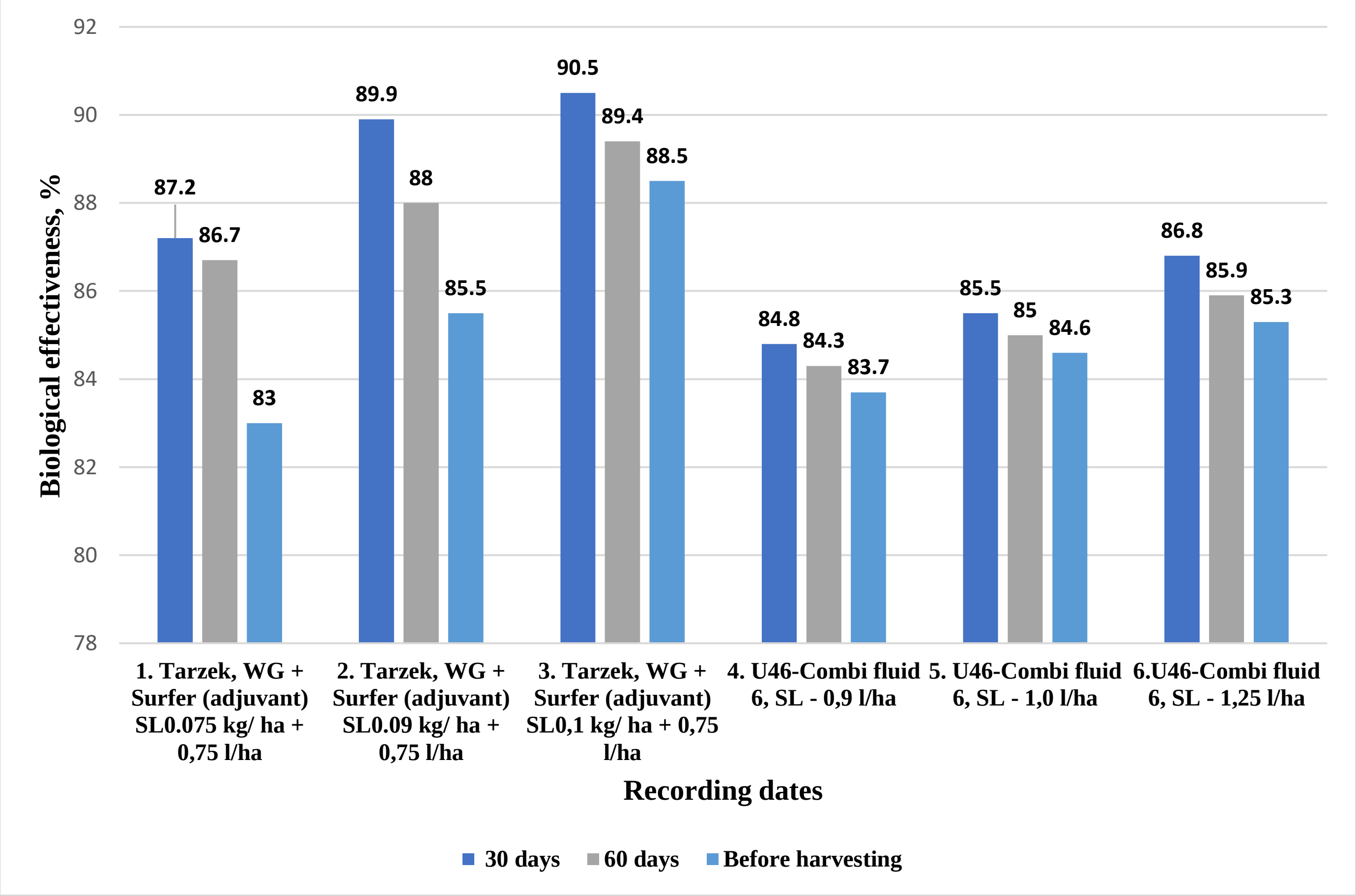

Figure 34. **Biological effectiveness of the herbicide Tarzek, WG on winter wheat (Iraq, 2021)**

It can be concluded that the use of the herbicide Tarzek, WG + surfactant made it possible to reliably and effectively protect winter wheat crops from dicotyledonous and monocotyledonous weeds in the Russian Federation and in Iraq (Ali Abdullah Sultan Al-Maliki *et al.,* 2022; Golubev, A.S et *al.*, 2023).

Chapter 4. Ecotoxicological Safety of Herbicides

A lot of the research conducted in herbicide control aims to reduce the risks of herbicide use on crops and thus improve the selectivity and safety of herbicides.

The main behaviors of pesticides in the environment are transformation and degradation, as well as movement (Froud-Williams, 1996; Holmsgaard, 2017).

Violation of application regulations and transfer of active components of herbicides lead to negative consequences (Bolbukh, 2008).

The main environmental issues arising because of the unwise use of herbicides are the contamination of agricultural products. Environmental pollution with herbicides. Accumulation of residual amounts of herbicides in the soil. Formation of biotypes of resistant weeds (Kulikova, Lebedeva, 2015, Chulkina *et al.*, 2017).

One of the most significant direct risks to humans is the contamination of agricultural products with agricultural chemical residues. Therefore, determining the routes of transfer of herbicides to agricultural plants is an urgent task of modern science (Lunev, 1992).

Thus, an important area of research on herbicide use is the development of methods to determine residual amounts of herbicides in protected crops and the environment in order to monitor the potential negative consequences of their use.

4.1 Residual amounts of herbicides in plant material of winter wheat

The safe use of herbicides from an environmental point of view requires a detailed study of their behavior in specific agro-climatic conditions. The main behaviors of pesticides in the environment are transformation and degradation, as well as movement (Froud-Williams, 1996; Holmsgaard, 2017). It is clear that when selecting herbicides for practical use in agriculture, one should take into account the preference, other things being equal, for drugs that degrade more rapidly to form non-toxic products.

In light of the significance of this data for pesticide regulation, we looked into the existence of two drug residues in winter wheat grains and straw as part of our research.

Residual amounts of Tribenuron-methyl and Thifensulfuron-methyl, active ingredients of the herbicide Polian, OD

Research has shown that the herbicide residual amounts of active substances (Tribenuron-methyl and Thifensulfuron-methyl) were not found during harvesting in the grain and straw of winter wheat from the Rostov region, both in the variants with the drugs and in the control (Tables 56, 57).

Table 56. **Content of residual amounts of Tribenuron-methyl in winter wheat when using the drug Polian, OD (Rostov region, 2021)**

A drug. Rate of use according to the drug and a. i	Sampling time, days after treatment	Object Analysis	The content of the detected substance in the analyzed object, mg/kg
Polian, OD (225 + 76) g/l 0,1 l/ ha, 22,5 g/ha tribenuron-methyl	processing day	green mass	Not detected
	10	green mass	Not detected
	20	green mass	Not detected
	30	seed	Not detected
	30	straw	Not detected
	harvest	seed	Not detected
	harvest	straw	Not detected

Table 57. **The content of residual amounts of Thifensulfuron-methyl in winter wheat when using the drug Polyene, OD (Rostov region, 2021)**

A drug. Rate of use according to the drug and a. i	Sampling time, days after treatment	Object Analysis	The content of the detected substance in the analyzed object, mg/kg
Polian, OD (225 + 76) g/l 0,1 l/ha, 7,6 g/ha Thifensulfuron-methyl	processing day	green mass	less than 0,05
	10	green mass	Not detected
	20	green mass	Not detected
	30	seed	Not detected
	30	straw	Not detected
	harvest	seed	Not detected
	harvest	straw	Not detected

Residual amounts of Tribenuron-methyl, Thifensulfuron-methyl and Flumetsulam, active ingredients of the herbicide Cayenne Turbo, OD

According to studies, the winter wheat crop in the Rostov region contained no traces of flumetsulam, thifensulfuron-methyl, or tribenuron-methyl (Tables 58, 59, 60).

Table 58. **Content of residual amounts of Tribenuron-methyl in winter wheat when using the drug Cayenne Turbo, OD in the conditions of the Rostov region**

A drug. Rate of use according to the drug and a. i	Sampling time frame	Object Analysis	The content of the detected substance in the analyzed object, mg/kg
Cayenne Turbo, OD (75+75+52) g/l 0,35 l/ha, 26,25 g/ha tribenuron-methyl	harvest	seed	Not detected
	harvest	straw	Not detected

Table 59. **Content of residual amounts of Thifensulfuron-methyl in winter wheat when using the drug Cayenne Turbo, OD in the conditions of the Rostov region**

A drug. Rate of use according to the drug and a. i	Sampling time frame	Object Analysis	The content of the detected substance in the analyzed object, mg/kg
Cayenne Turbo, OD (75+75+52) g/l 0,35 l/ha, 26,25 g/ha thifensulfuron-methyl	harvest	seed	Not detected
	harvest	straw	Not detected

Table 60. **Content of residual amounts of Flumetsulam in winter wheat when using the drug Cayenne Turbo, OD in the conditions of the Rostov region**

A drug. Rate of use according to the drug and a. i	Sampling time frame	Object Analysis	The content of the detected substance in the analyzed object, mg/kg
Cayenne Turbo, OD (75+75+52) g/l 0,35 l/ha, 18,2 g/ha flumetsulam	harvest	seed	Not detected
	harvest	straw	Not detected

4.2 Study of the toxic load of herbicides

Increasing the efficiency of winter wheat production in intensive technologies depends not only on the use of agricultural practices necessary for a particular region, but also on the use of agrochemical plant protection products at optimal application rates. It must be remembered that the use of pesticides is associated with real and potential risks.

Pest control is essential to protect food security and ensure farmers' income from their production. At the same time, it is necessary to reduce risks to people and the environment (Taylor *et al*., 2002; Sharma *et al.,* 2017).

Herbicide applicators must understand the risks associated with the herbicides they use. Toxicity depends on the chemical and physical properties of a substance and can be defined as the property of being toxic or harmful to animals or plants (Ministry of Agriculture, Food and Fisheries, 2022).

Any compound's toxicity varies according to its dose. Even at low doses, a highly toxic substance can produce severe poisoning symptoms. Large doses are typically necessary for a substance with low toxicity to produce mild symptoms. If consumed in excess, even commonplace items like salt or coffee can turn toxic (Zinchenko, 2012).

By examining this indicator, it can be seen that, with the exception of 2,4-D, all of the active ingredients in the table of the main toxicological characteristics of the herbicides we studied are herbicides with weak toxicity, meaning that all of the drugs used in the study fall into the same category.

The drugs, according to the average LD50 (in ascending order of this indicator) are arranged in the following sequence: 1360 mg/kg (U46-Combi fluid 6, SL); 2000 mg/kg (Tarzek, WG); 3906 mg/kg (Fortissimo, OD; Prima Forte 195, SE); 5000 mg/kg (Polian, OD; Caliber Gold, WDG; Status Max, WDG); 5300 mg/kg (Cayenne Turbo, OD); 5500 mg/kg (Pinta, OD; Lancelot 450, WDG; Derby 175, SC).

The table 61 illustrates the results of calculating the toxic load of the studied herbicides at their maximum application rates.

Based on the data given in the table, among the studied drugs, the drugs Tarzek, WG are classified as low-hazard; Pinta, OD; Polian, OD and Cayenne Turbo, OD. The herbicide Fortissimo, OD, in terms of toxic load, is classified as moderately hazardous at the maximum rate of use. When comparing the studied herbicides with standards in terms of toxic load at their maximum application rates, the results were similar and were: low-hazard drugs include Caliber Gold, WDG; Lancelot 450, WDG; Derby 175, SC and Status Max, WDG. The herbicide U46-Combi fluid 6, SL (standard) belongs to the category of moderately hazardous.

Table 61. **The toxic load of the studied herbicides**

Name of the drugs	Application rates l/ha	Toxic load, number of semi-lethal doses per ha	Characteristic
1. Tarzek, WG (halauxifen-methyl 70 g/kg + pyroxsulam 250 g/kg)	0,09	14,4	L-H*
2. Pinta, OD (50 g/l flumetsulam + 36 g/l florasulam)	0,15	2,4	L-H*
3. Fortissimo, OD (200 g/l 2,4-D acid/2-ethylhexyl ester/+10 g/l aminopyralid+ 5 g/l florasulam)	0,7	196	M-H**
4. Polian, OD (225 g/l tribenuron-methyl + 76 g/l thifensulfuron-methyl)	0,1	6,2	L-H*
5. Cayenne Turbo, OD (75 g/l tribenuron-methyl + 75 g/l thifensulfuron-methyl + 52 g/l flumetsulam)	0,35	13,5	L-H*
6. Caliber Duo Gold, WDG (375 g/l tifenesulfuron-methyl + 375 g/l tribenuron-methyl) (the standard)	0,05	7,5	L-H*
7. Prima Forte 195, SE (180 g/l 2,4-D (2-ethylhexyl ether) + 10 g/l aminopyralide + 5 g/L florasulam) (standard)	0,7	177	M-H**

8. Lancelot 450, WDG (300 g/l aminopyralide + 150 g/l florasulam) (standard)	0,033	2,8	L-H*
9. Derby 175, SC (100 g/l flumetsulam + 75 g/l florasulam) (standard)	0,07	2,2	L-H*
10. Max status, WDG (500 g/ kg tifenesulfuron-methyl + 250 g/ kg tribenuron-methyl + 80 g/kg florasulam) (standard)	0,05	8,1	L-H*
11. U46-combo fluid 6, SL (300 g/L 2,4-D + 300 g/L MCPA) (standard)	1,25	708,3	M-H**

Note: *l-h - low-risk; m-h** - moderately dangerous.

CONCLUSION

1. As a result of the study of new herbicides, a range of new combined preparations for protecting winter wheat has been developed: Pint, oil dispersion (OD) (50 g/l flumetsulam + 36 g/l florasulam); Fortissimo, OD (200 g/l 2,4-D acid /2-ethylhexyl ester/ + 10 g/l aminopyralid + 5 g/l florasulam); Cayenne Turbo, OD (75 g/l tribenuron-methyl + 75 g/l thifensulfuron-methyl + 52 g/l flumetsulam), Polian, OD (225 g/l tribenuron-methyl + 76 g/l thifensulfuron-methyl) and Tarzek , WG (galauxifen-methyl 69.5 g/kg + piroxulam 250 g/kg).
2. In the steppe regions of the Ciscaucasia, high biological effectiveness on winter wheat against the main types of weeds: Black bindweed, Descurainia Sofia, Corn poppy, Catchweed Bedstraw, field grass, field bindweed, is ensured by the use of new herbicides: Pint, OD – 81.1-100% (tillering phase), 73.7-94.7% (exit into the tube phase); Fortissimo, OD – 82.8-100% (tillering phase), 77.0-95.7% (exit into the tube phase); Cayenne Turbo, OD - 82.1-96.3% (tillering phase), 72.1-90.3% (exit into the tube phase); Polyane, OD – 72.5-93.1 % (tillering phase), 64.2-89.7% (exit into the tube phase).
3. Regulations have been developed for the effective and safe use of combined herbicides for protecting winter wheat (tillering - exit into the tube) in the steppe zone of the Ciscaucasia: Pinta, OD - 0.1-0.15 l/ha; Fortissimo, OD – 0.4-0.7 l/ha; Cayenne Turbo, OD – 0.15-0.35 l/ha; Polian, OD – 0.05-0.1 l/ha; Tarzec, WDG – 0.075-0.09 kg/ha.
4. A comparative study of the effectiveness of the drug Tarzek, WG in Russia and Iraq made it possible to establish that the use of the herbicide can reliably and effectively protect winter wheat crops from dicotyledonous and monocotyledonous weeds. In Russia, the effectiveness reached 100%, in Iraq 90.5%.
5. The environmental safety of the final product and its compliance with hygienic standards GN 1.2.2890-11 is ensured by the fact that the active ingredients of the

drugs (tribenuron-methyl, thifensulfuron-methyl and flumetsulam) are not detected in the winter wheat crop (grain and straw).

6. According to the toxic load indicator, the studied drugs can be classified as: - low-hazardous: Pinta, OD; Polian, OD; Cayenne Turbo, OD; Tarzek, WG; - to moderately dangerous: Fortissimo, OD.

PRACTICAL RECOMMENDATIONS

1. Winter wheat can be protected from annual and perennial dicotyledonous weeds by using the new herbicide Pinta, oil dispersion (OD) (50 g/l flumetsulam + 36 g/l florasulam), which is listed in the State catalog of pesticides and agrochemicals authorized for use in the Russian Federation (2023).

2. The findings from the examination of new herbicides Fortissimo, OD (200 g/l 2,4-D acid /2-ethylhexyl ester + 10 g/l aminopyralid + 5 g/l florasulam); Cayenne Turbo, OD (75 g/l tribenuron-methyl + 75 g/l thifensulfuron-methyl + 52 g/l flumetsulam); Polian, OD (225 g/l tribenuron-methyl + 76 g/l thifensulfuron-methyl); and Tarzek, WG (halauxifen-methyl 69.5 g/kg + piroxulam 250 g/kg) can be utilized in the State registration procedure as promising herbicides for winter wheat.

Bibliography

1. Abd El Lateef, E.M. Effect of different single herbicide doses on sugar beet yield, quality and associated weeds // B.B. Mekki, M.S. Abd El-Salam, I.M. El-Metwally //. Bull. Natl. Res. Cent. - 2021. - № 45. – 21 p.

2.Agapkin, A. M. The grain market of Russia / I. A. Makhotina // IOP Conference Series: Earth and Environmental Science. - 2021- 839(2). doi: 10.1088/1755-1315/839/2/022023.

3. Ahmad, Z. Weed species composition and distribution pattern in the maize crop under the influence of edaphic factors and farming practices: A case study from Mardan, Pakistan / S. M. Khan, E. F.Abd Allah, A. A. Alqarawi, A .Hashem // Saudi journal of biological sciences.-2016 - № 23(6). - P. 741–748.

4. Aktar M.W. Impact of pesticides use in agriculture: their benefits and hazards / D. Sengupta, A. Chowdhury // Interdiscip Toxicol. - 2009.- № Mar; 2(1). - P.- 1-12.

5.Ali, S. Environmental and Health Effects of Pesticide Residues / M. I. Ullah, Q. Shakeel, A. Hussain // ResarchGate.- 2021.- № (January), P. 311–336. doi: 10.1007/978-3-030-54719-6_8.

6. Arshad, N. A Review on Wheat Management, Strategies, Current Problems and Future Perspectives / N. Ansari, M. Umar, A. Arshad, M. Adil, N. Dilbar // Haya Saudi J Life Sci. -2021.- № 6(1).- P.14-18.

7. Baker, C.Weed species composition and density under conservation agriculture with varying fertiliser rate / I.C. Madakadze, C.M.Swanepoel, Z. Mavunganidze // South African Journal of Plant and Soil.- 2018.- № 35(5). - P. 329 - 336.

8. Baker, L.W. Ambient Air Concentrations of Pesticides in California./ D.L. Fitzell, J.N. Seiber, T.R. Parker, T. Shibamoto, M.W. Poore, K.E. Longley, R.P. Tomlin, R. Propper, D.W. Duncan// Environ. Sci. Technol. -1996. - № 30.- P.1365–1368.

9. Boutin, C. Herbicide impact on non-target plant reproduction: What are the toxicological and ecological implications?/ B. Strandberg, D. Carpenter, S.K. Mathiassen, P.J. Thomas // Environmental Pollution. - 2014.- № 185. - P. 295–306.

10. British Standard. Foods of plant origin Determination of pesticide residues using GC-MS and / or LC-MS / MS following acetonitrile extraction / 2008. partiti CEN15662.

11. Burgess, P.Herbicide Group Classification / Perennia.- 2018. - Доступно на: http://www.omafra.gov.on.ca/english/crops/pub75/pub75toc.htm.

12. Chauhan, B.S. Grand Challenges in Weed Management // In Frontiers in Agronomy; Frontiers Media SA: Lausanne, Switzerland - 2020.- Volume 1. - № 1. - 3 P.

13. Chhokar, R. C. Effects of crop establishment techniques on weeds and rice yield./ R. K. Sharma, M.K. Gathala, A. Kumar// Crop Protection. - 2014.- Volume 64.- P. 7-12.

14. Chong, C. Germination and emergence / Bible, B. B. и Ju, H. Y. // Handbook of Plant and Crop Physiology, Second Edition. - 2001. - P. 57–116.

15. Corteva Agricultural Sciences. Safety data sheet ELEVORE™ Herbicide/ Corteva Canadian Agricultural Company. - 2020.- P. 1-11.

16. Corteva agriscience. Arylex™ active Technical Bulletin/ Dow AgroSciences USA. - 2019.- P. 1-14.

17. CropLife International. Implementing Integrated Weed Management for Herbicide Tolerant Crops / Training manual. 2012, 62 p.

18. Cserháti, T. Chromatographic determination of herbicide residues in various matrices / Forgács, E., Deyl, Z., Miksik, I., & Eckhardt, A. // Biomedical chromatography : BMC.- 2004.- № 18(6).- P. 350–359.

19. Darwent, A. L. Effect of preharvest applications of glyphosate on the drying, yield and quality of wheat./ K. J. Kirkland, L. Townleysmith, K. N. Harker, A. J. Cessna, O. M. Lukow, L. P. Lefkovitch // Can. J. Plant Sci.- 1994.- № 74. - P. 221-230.

20. Das, S.K. Mode of action of herbicides and recent trends in development: A reappraisal / T. Mondal // Int. J. Agric. Soil Sci. - 2014. - № 27. - P. 27–32.

21. Dayan, F.E. Herbicide mechanisms of action and resistance /A. Barker, R. Bough, M. Ortiz, H.Takano, S.O. Duke // Compr. Biotechnol. - 2019. - № 3. - P. 36–48.

22. Díez, C.Comparison of an acetonitrile extraction/partitioning and "dispersive solid-phase extraction" method with classical multi-residue methods for the extraction of

herbicide residues in barley samples./ W. A. Traag, P. Zommer, P. Marinero, J. Atienza //Journal of chromatography. A.- 2006. - № 1131(1-2). - P.11–23.

23. Dmitriev, P.A. Assessmentof Invasive and Weed Species by Hyperspectral Imagery in Agrocenoses Ecosystem / Kozlovsky, B.L., Kupriushkin, D.P.; Dmitrieva, A.A.; Rajput, V.D.; Chokheli, V.A.; Tarik, E.P.; Kapralova, O.A.; Tokhtar, V.K.; Minkina, T.M.; et al.// Remote Sens. - 2022. - № 14. - P. 1- 23.

24. D'Odorico, P. Feeding humanity through global food trade,/ J. A. Carr, F. Laio, L. Ridolfi, and S. Vandoni // Earth's Future. - 2014.- № 2. - P. 1-12.

25. Duhoux, A. Herbicide Safeners Decrease Sensitivity to Herbicides Inhibiting Acetolactate-Synthase and Likely Activate Non-Target-Site-Based Resistance Pathways in the Major Grass Weed Lolium sp. (Rye-Grass) / Pernin, F., Desserre, D. and Délye, C.// Front. Plant Sci. - 2017.- № 8. - 1310 p.

26. Duke, S.O. Herbicides / F.E. Dayan / In eLS; Wiley: Hoboken, NJ, USA. - 2018 . - № 1. - P. 1–9.

27. Elgueta, S. Pesticide residues in leafy vegetables and human health risk assessment in North Central agricultural areas of Chile. / S. Moyano, P. Sepúlveda, C. Quiroz, A. Correa // Food Addit. Contam.- Part B - 2017.- № 10. - P.105–112.

28. El-Nahhal, I. Pesticide residues in drinking water, their potential risk to human health and removal options / Y. El-Nahhal // J. Environ. Manag. - 2021. - № 299. - 113611.

29.EMISS (без даты). Доступно на: https://www.fedstat.ru/indicator/31328 (Просмотрено: 29 ноябрь 2022 г.).

30. Enghiad, A. An Overview of Global Wheat Market Fundamentals in an Era of Climate Concerns./ D. Ufer, A.M. Countryman, D.D. Thilmany// International Journal of Agronomy. - 2017.- Volume 2017. - 15 p.

31. EPA. Pesticide Fact Sheet : Pyroxsulam/ United States Office of Prevention, Pesticides Environmental Protection and Toxic Substances Agency. - 2008.- P. 1-56.

32.Epp, J. B. The discovery of Arylex™ active and Rinskor™ active: Two novel auxin herbicides. / A. L.Alexander, T. W. Balko, A. M.Buysse, W. K. Brewster, K. Bryan, J. F.

Daeuble, S. C. Fields, R. E. Gast, R. A.Green, N. M. Irvine, W. C. Lo, C. T. Lowe, J. M. Renga, J. S. Richburg, J. M. Ruiz, N. M. Satchivi, P. R. Schmitzer, T. L. Siddall, J. D. Webster, M. R. Weimer, G. T.Whiteker, C. N.Yerkes // Bioorganic & Medicinal Chemistry. - 2016.- № 24 (3).- P. 362-371.

33. FAO (Food and Agriculture Organization of the United Nations). Available online: https://www.fao.org/home/en/ (accessed on 12 June 2022).

34. FAOSTAT (Food and Agriculture Organization Corporate Statistical Database). Wheat, Sugar Beet, Maize Production Statistics.Available online: https://www.fao.org/faostat/en/#data/QCL (accessed on 12 June 2022).

35. Feng, Y. Mechanisms of Resistance to Pyroxsulam and ACCase Inhibitors in Japanese Foxtail (Alopecurus japonicus) / Gao, Y., Zhang, Y., Dong, L., Li, J. // Weed Science.- 2016.- № 64(4).- P. 695-704.

36. Fishel, F. Herbicides : How Toxic Are They ?/ J. Ferrell, G. MacDonald, B. Sellers // University of Florida.- 2016.- P. 1–2.

37. Froud-Williams, R. Weeds and climate change: Implications for their ecology and control / Asp. Appl. Biol. - 1996. - № 45. - P. 187–196.

38. Ministry of Agriculture, Food and Fisheries. Pesticide Toxicity and Hazard. // *British Columbia*. - 2017.- P. 1–9.

39. Golubev, A.S. Evaluation the Efficiency of Newly Combined Herbicide Pyroxsulam and Galaxifen-methyl in Winter Wheat (Triticum aestivum L.)/ A.A.S. Al-Maliki, V.I. Dolzhenko, A.P. Savva, T.V. Dolzhenko, // Indian Journal of Agricultural Research. - 2023. doi:10.18805/IJARe.AF-770.-P. 1-6.

40 Grote, U. Food Security and the Dynamics of Wheat and MaizeValue Chains in Africa and Asia / A . Fasse, T.T. Nguyen , O. Erenstein // Front. Sustain. Food. Syst. – 2021. – № 4. – P. 1-17.

41 Guo, W. Herbicides cross resistance of a multiple resistant short-awn foxtail (*Alopecurus aequalis* Sobol.) population in wheat field. / Lv, L., Zhang, L., Li, Q., Wu, C., Xingtao, L., Liu, W., Wang, J. // Chilean Journal of Agricultural Research.- 2016.- №76. -

P. 163-169.

42. Gouin, T. Atmospheric concentrations of current-use pesticides across south-central Ontario using monthly-resolved passive air samplers./ M. Shoeib, T. Harner // Atmos. Environ. - 2008. - № 42. - P.8096–8104.

43. Harasim, E. The effect of reduced growth retardant rates on weed infestation of a winter wheat (Triticum aestivum L.) crop / M.Wesołowski, C. Kwiatkowski // Rom. Agric. Res. - 2014. - № 31. - P. 271–281.

44. Holmsgaard, P.N. The bacterial community in an on-farm biopurification system, to which diverse pesticides are introduced over an agricultural season / Environ. S. Dealtry, V. Dunon, H. Heuer, L.H. Hansen, D. Springael, K. Smalla, L. Riber, S.J. Sørensen // Response of Pollut. - 2017. - № 229. - P. 854–862.

45. HRAC.Herbicide Resistance Action Committee / Available online: https://hracglobal.com/ (accessed on 12 June 2022).

46. IDRC (2010). Facts and Figures on Food and Biodiversity. Canada: IDRC Communications, International Development Research Centre. Availble online at: https://www.idrc.ca/en/research-in-action/facts-figures-food-and biodiversity.

47. Grzanka, M. Effect of the Time of Herbicide Application and the Properties of the Spray Solution on the Efficacy of Weed Control in Maize (Zea mays L.) Cultivation / Ł. Sobiech, R. Idziak, G. E Skrzypczak// Agriculture. - 2022.- № 12.- 353 p.

48. Ghosheh, H. Precision Weed Management Research Advancement in the Near East Global Proliferation of Precision Agriculture and its Applications. 2010. Available online: https://www.ispag.org/proceedings

49. Gnanavel, I.Eco-Friendly Weed Control Options for Sustainable Agriculture / Gnanavel, I.// Sci. Int. - 2015 . - № 3. - P. 37–47.

50. Gupta, P. K. Toxicity of herbicides // Veterinary Toxicology.- 2012. - P. 631–652.

51. Gurmanchuk, O. Effectiveness of Herbicides in Winter Wheat Crops / N. Plotnytska, O. Nevmerzhytska, I. Pavlyuk, A. Moshkivska// Наукові горизонти. - 2022. - № 24(10).- P. 35-42. https://doi.org/10.48077/scihor.24(10).2021.35-42

52. Gyawali, A. A Review on Effect of Weeds in Wheat (Triticum aestivum L.) and Their Management Practices./ R. Bhandari, P.Budhathoki, S. Bhattrai // Food and Agri Economics Review. - 2022.- №. 2(2). - P. 34-40.

53.Hamouda, S. S. A. Efficiency of Certain Herbicides and Adjuvants Combinations Against Weeds in Wheat Fields. / M. F. El-Tawil, E. M. A. Marzouk, H. M. S.Khalifa // Egypt. Acad. J. Biolog. Sci. (F. Toxicology & Pest control). - 2021. - №. 13(1). - P. 1-14.

54. Harasim, E. The effect of reduced growth retardant rates on weed infestation of a winter wheat (Triticum aestivum L.) crop / M. Wesołowski, C. Kwiatkowski // Rom. Agric. Res. - 2014. - № 31. – P. 271–281.

55. Huat, G. Sample Preparation in the Analysis of Pesticides Residue in Food by Chromatographic Techniques. / M.-K.Chai // Pesticides - Strategies for Pesticides Analysis. - 2011. - doi: 10.5772/13497.

56.Huang, Z. The target-site based resistance mechanism of Alopecurus myosuroides Huds. to pyroxsulam / X. Lu, S. Wei, C. Zhang, C. Jiang, W. Li, , M. Saeed, H. Huang. // Crop Protection. - 2021. - . № 147 (3). - 105707.

57. Jabran, K. Weed dynamics and management in wheat / K. Mahmood, B. Melander, A.A. Bajwa, P. Adv. Kudsk // Agron. - 2017. - №145. - P. 97–166.

58. Johansson, E. Wheat Quality for Improving Processing and Human Health/ , G. Branlard, M. Cuniberti, Z. Flagella, A. Hüsken, E. Nurit, R. J. Pena, M. Sisson, D. Vazquez // Wheat Quality For Improving Processing And Human Health. - 2020. - P. 171-204.

59.Jones, E. A. L. Distribution and Control of Herbicide-Resistant Italian Ryegrass [*Lolium perenne* L. ssp. multiflorum (Lam.) Husnot] in Winter Wheat (*Triticum aestivum* L.) in North Carolina. / Z. R.Taylor, W. J. Everman. // Front. Agron. - 2021. - № 2. - P.1-8.

60. Jursík, M. Effects of adjuvants and carriers on propoxycarbazone and pyroxsulam efficacy on Bromus sterilis in winter wheat./ M. Kolářová, J. Soukup, V. Žďárková. // Plant Soil Environ. - 2016. - № 62. - P. 447-452.

61. Jugulam, M. Non-target-site resistance to herbicides: Recent developments / C.Shyam // Plants. - 2019. - №.8 -.P 417.

62. Kraehmer, H. Focus on Weed Control: Herbicides as Weed Control Agents: State of the Art: I. Weed Control Research and Safener Technology: The Path to Modern Agriculture / B. Laber, C. Rosinger, A. Schulz // Plant Physiology. - 2014. - № 166(3). – P. 1119-1131.

63. Karaman, M. Theoretical and Practical New Approaches in Cereal Scince and Technology / K. Caglayan, M. Gazel. // Iksad Publishing house. - 2022.- ISBN: 978-625-7562-37-9

64. Kim, K.-H. Exposure to pesticides and the associated human health effects. Sci. Total Environ/ E. Kabir, S.A. Jahan. - 2017. - № 575. - P. 525–535.

65. Kislev, M. E. Impetus for sowing and beginning of agriculture: Ground collecting of wild cereals / E. Weiss, A. Hartmann // Proceedings of the National Academy of Sciences of the United States of America. - 2004. - №101(9).- P. 2692–2695.

65. Kolberg, D. I. Development of a fast multiresidue method for the determination of pesticides in dry samples (wheat grains, flour and bran) using QuEChERS based method and GC-MS/ D. O. Prestes, M.B. Adaime, R. Zanella // Food Chemistry. - 2011. - №125(4). - P. 1436–1442.

67. Kubiak, A. The Problem of Weed Infestation of Agricultural Plantations vs. the Assumptions of the European Biodiversity Strategy / A. Wolna-Maruwka, A. Niewiadomska, A.A.T. Pilarska // Agronomy. – 2022. - № 12. - P. 1-29.

68. Kutasy, B. Pro 197Thr Substitution in Ahas Gene Causing Resistance to Pyroxsulam Herbicide in Rigid Ryegrass (*Lolium Rigidum* Gaud.) / Z. Takács, J. Kovács, V. Bogaj, S. A. Razak, G. Hegedűs, K. Decsi, K. Székvári, E. Virág // Sustainability. -2021. - № 13(12). - P. 6648.

69. Kumar, V. Mycoherbicide control strategy: Concept, constraints, and advancements / M.Singh, N. Sehrawat, N. Atri, R.Singh, S.K. Upadhyay, M.Yadav // Biopestic. Int. - 2021. - №17. - P. 29–40.

70. Leyva-Morales, J. B.Validation and Application of a Multi-residue Method, Using Accelerated Solvent Extraction Followed by Gas Chromatography, for Pesticides

Quantification in Soil / J.B. Valdez-Torres, P.J. Bastidas-Bastidas, M. Betancourt-Lozano. // Journal of Chromatographic Science.- 2015.- № 53(10). - P. 1623–1630.

71. Liu, Y. Influence of different formulations on chlorpyrifos behavior and risk assessment in bamboo forest of China / R. Mo, F. Tang, Y. Fu, Y. Guo // Environ. Sci. Pollut. Res. -2015.- № 22. - P.20245–20254.

72 Lou, T. Survey Reveals Frequency of Multiple Resistance to Tribenuron-Methyl, Bensulfuron-Methyl and Halosulfuron-Methyl in Cleavers (Galium aparine L.) / K. Wang, J. Chen, J. Cao, T. Gu, L. Jiang, Y. Lou, R.Cao, H. Wang // Agronomy. - 2022.- № 12. - P. 2695.

73. Lu, M. A brief history of wheat utilization in China / L. Chen, J. Wang, R. Liu, Y. Yang, M. Wei. // Frontiers of Agricultural Science and Engineering. - 2019. - № 6(3). - P. 288–295. doi: 10.15302/J-FASE-2019266.

74. Luneva, N. N. Weed species composition and quantitative parameters of weed infestation of winter wheat crops in the steppe zone of Krasnodar Territory / T.Y. Zakota // Plant Protection News. - 2018. - № 1(95). - P. 45-52.

75. Maclaren C. An ecological future for weed science to sustain crop production and the environment. A review / J. Storkey, A. Menegat, H. Metcalfe, K. Dehnen-Schmutz // Agron Sustain Dev. - 2020. - № 40(4). - P. 1-29.

76. Majrashi, A.A. Preliminary assessment of weed population in vegetable and fruit farms of Taif,Saudi Arabia / Braz. J. Biol. - 2022. - № 82. - e255816.

77. Malalgoda, M. Pesticide residue in grain-based food: Effects on health, grain quality, and chemical pr operties of biomacromolecules / S. Simsek // Cereal Chemistry. - 2021. - № 98(1).- P. 8–16. doi: 10.1002/cche.10355.

78. Marie, L. Degradation and Transport of the Chiral Herbicide S-Metolachlor at the Catchment Scale: Combining Observation Scales and Analytical Approaches / S. Payraudeau, G. Benoit, M. Maurice, I. Gwenaël // Environ. Sci. Technol. - 2017. - №51. - P. 13231–13240.

79. Marwat, S. K. Weeds of Wheat Crop and Their Control Strategies in Dera Ismail

Khan District, Khyber Pakhtun Khwa, Pakistan. / K. Usman, N. Khan, M.U. r Khan. // American Journal of Plant Sciences. - 2013. - № 04(01). - P. 66–76. doi: 10.4236/ajps.2013.41011.

80. Mehdizadeh, M. Herbicide residues in agroecosystems: Fate, detection, and effect on non-target plants / W. Mushtaq, S.A. Siddiqui, S. Ayadi, P. Kaur, S. Yeboah, S. Mazraedoost, D.K.A. AL-Taey, K. Tampubolon // Reviews in Agricultural Science.- 2021. - № 9. - P. 157–167. doi: 10.7831/ras.9.0_157.

81. Mingo, V. The impact of land use intensity and associated pesticide applications on fitness and enzymatic activity in reptiles—A field study / S. Lötters, N. Wagner // Sci. Total Environ. - 2017. - №590. - P. 114–124.

82. Minisitry of Agriculture. Food and Fisheries. Pesticide Toxicity and Hazard/ British Columbia. - February 2022. - P. 1-9.

83. Miller, A. J. Forage Legume Establishment under Exposure to Progressive Declines in Aminocyclopyrachlor and Aminopyralid in Temperate Pastures / M. L. Vagner, M.H. Linda,W. B. Edward // Agronomy. - 2020. - № 10(3).- P. 392.

84. Mitkov, A. Opportunities for single and combine application of herbicides at winter wheat / M. Yanev, M. Neshtv, A. Tonev // Scientific Papers-Series, Agronomy. - 2017. - № 60. - P. 314–319.

85. Monteiro, A. Sustainable Approach to Weed Management: The Role of Precision Weed Management / S.Santos / Agronomy. - 2022. - №12. - P. 1-14.

86. McCauley C. L. Efficacy of Halauxifen Methyl on Glyphosate-Resistant Horseweed (*Erigeron canadensis*) / W. G. Johnson, B.G. Young // Weed Sci. - 2018. - № 66. - P.758–763. doi: 10.1017/wsc.2018.43

87. Mahmoud, S. M.Combination of Halauxifen - Methyl + Florasulam with Other Grassy Herbicides Against Complex Weed Flora in Wheat (*Triticum aestivum*)/ F. S.Soliman, M. Elsheik // J. Plant Prot. and Path., Mansoura Univ. - 2016. - №7(5). - P. 315-320.

88. Morderer Ye. Yu. Effectiveness of auxin-like herbicide halauxifen-methyl

mixtures with other herbicides for canada thistle (*Cirsium arvense*) control in wheat crops / A. M.Sychuk, O. P. Rodzevych, V.V. Pavlenko, O. M.Sarbash// Fiziol. rast. genet.- 2018. - № 50(6). - P. 508-516.

89. PAN—Pesticide Action Network Europe. Alternative Methods in Weed Managment to Glyphosate; Intergrated Weed Management. Pesticide Action Network Europe: Brussels, Belgium / 2017. Available online:

90. National Center for Biotechnology Information (2022) *PubChem* Compound Summary for CID 11571555, Pyroxsulam. Доступно на: https://pubchem.ncbi.nlm.nih.gov/compound/Pyroxsulam.

91. Ngoune Liliane, T. Factors Affecting Yield of Crops. Agronomy - Climate Change and Food Security / M. Shelton Charles // IntechOpen. - 2020. - P. 1-17.

92. Ni, Y. Analysis of four sulfonylurea herbicides in cereals using modified Quick, Easy, Cheap, Effective, Rugged, and Safe sample preparation method coupled with liquid chromatography-tandem mass spectrometry / H. Yang, H. Zhang, Q. He, S. Huang, M. Qin, S. Chai, H. Gao, Y. Ma // Journal of chromatography. A. - 2018. - № 1537. - P. 27–34. https://doi.org/10.1016/j.chroma.2018.01.01750.

93. Norsworthy, J. K. Educing the Risks of Herbicide Resistance : Best Management Practices / S. M. Sarah, D.R. Shaw, R.S. Llewellyn, R.L. Nichols, T.M. Webster, K.W, Bradley, G. Frisvold, S.B. Powles, N.R. Burgos, W.W. Witt, M. Barrett // Weed Science. - 2012. - Special Issue. - P. 31–62.

94. Obenland, O. A. Identification of chromosomes in *Triticum aestivum* possessing genes that confer tolerance to the synthetic auxin herbicide halauxifen-methyl / D. E.Riechers // Sci Rep. - 2020.- № 10. - P.8713.

95. Orekhovskaya, A. A. Assessment of winter wheat yield depending on agrotechnical techniques and fertility of typical chernozem / IOP Conference Series: Earth and Environmental Science. - 2022. - № 996(1). doi: 10.1088/1755-1315/996/1/012006.

96. Pathak, V.M. Current status of pesticide effects on environment, human health and it’s eco-friendly management as bioremediation: A comprehensive review / V.K. Verma,

B.S. Rawat, B. Kaur, N. Babu, A. Sharma, S. Dewali, M .Yadav, R . Kumari, S. Singh, A . Mohapatra, V. Pandey, N. Rana, J.M. Cunill // Front. Microbiol. - 2022. - № 13. - P. 1-29.

97. Perennia Food and Agriculture Corporation, [Electronic resource].- https://www.perennia.ca/ (date of application: 1/7/2022).

98. Qian, Y. Dissipation, occurrence and risk assessment of a phenylurea herbicide tebuthiuron in sugarcane and aquatic ecosystems in South China / H. Matsumoto, X. Liu, S. Li // Environmental Pollution. - 2017. - № 227. - P. 389–396. do 10.1016/j.envpol.2017.04.082.

99. Qin, G. Disruption of phytoene desaturase gene results in albino and dwarf phenotypes in Arabidopsis by impairing chlor ophyll, carotenoid, and gibberellin biosynthesis/ H. Gu, Y. Peng, XW. Deng, Z. Chen, L-J. Qu// Cell Research. - 2007.- № 17. - P. 471–482. DOI:10.1038/cr.2007.40.

100. Radivojević, L. Impact of Different Adjuvants and Modes of Application on Efficacy of Rimsulfuron in Maize / S. Gašić, J. Gajić Umiljendić, L. Šantrić, D. Brkić // Pestic. Phytomed. - 2011. - №26(3). - P. 255-263.

101. Rajmohan, K.S. A Review on Occurrence of Pesticides in Environment and Current Technologies for Their Remediation and Management / R . Chandrasekaran, S.Varjani // Indian J Microbiol. – 2020. – № 60(2) - P. 125-138.

102. Reddy, S. S. Downy Brome (Bromus tectorum L.) and Broadleaf Weed Control in Winter Wheat with Acetolactate Synthase-Inhibiting Herbicides / P. W.Stahlman, P. W. Geier // Agronomy. - 2013. - №3. - P. 340-348.

103. Rizwan, M. Increased Foliar Activity of Isoproturon+Tribenuron and Pyroxsulam Against Little Seed Canary Grass and Field Bindweed by Proper Adjuvant Selection in Wheat / A. Tanveer, A. Khaliq, T. Abbas, N.A. Ikram // Planta Daninha. -2018. - № 36. e018166733.

104. Sawicka, B. Biodiversity of weeds in fields of grain in ´South-Eastern Poland / B. Krochmal-Marczak, P. Barba´s, P. Pszczółkowski, M. Cwintal // Agriculture. - 2020. - № 10. - 589 P.

105. Scavo, A. Integrated Weed Management in Herbaceous Field Crops / G. Mauromicale // Agronomy. - 2020. - № 10. - P 466.

106. Schenck, F. J. Evaluation of the quick, easy, cheap, effective, rugged, and safe (QuEChERS) approach to pesticide residue analysis / J. E. Hobbs // Bulletin of Environmental Contamination and Toxicology. - 2004. - № 73(1). - P. 24–30. doi: 10.1007/s00128-004-0388-y.

107. Schonbeck, M. Principles of Sustainable Weed Management in Organic Cropping Systems / 3rd ed.; Workshop for Farmers and Agricultural Professionals on Sustainable Weed Management; Clemson University: Clemson, SC, USA, 2011.

108. Sharma, A. Seed presoaking with 24-epibrassinolide reduces the imidacloprid pesticide residues in green pods of Brassica juncea L. / V. Kumar, R. Bhardwaj, A. K. Thukral // Toxicol Environ Chem. - 2017. - № 99(1). - P. 95–103.

109. Sherwani, S. I. Modes of Action of Different Classes of Herbicides / I. A. Arif, H. A.Khan // Herbicides, Physiology of Action, and Safety. - 2015.-. doi: 10.5772/61779.

110. Sherwani, S.I. Modes of action of different classes of herbicides. In Herbicides, Physiology of Action, and Safety; Price / I.A. Arif, Khan, H.A., A., Kelton, J. Sarunaite, L. Eds / InTech: London, UK. - 2015. - № 131. - P. 165–186.

111. Shewry, P. R. Wheat / Journal of Experimental Botany. - 2009. - № 60(6). - P. 1537–1553. doi: 10.1093/jxb/erp058.

112. Shiferaw, B. Crops that feed the world 10. Past successes and future challenges to the role played by wheat in global food security / M. Smale, H.J. Braun, E. Duveiller, M. Reynolds, G. Muricho // Food Security. - 2013. - № 5(3). - P. 291–317. doi: 10.1007/s12571-013-0263-y.

113. Singh, D.K. Pesticides and Environment / Pestic. Chem. Toxicol. - 2012. - № 1. - P. 114–122.

114. Škrbic, B. Organochlorine pesticides and polychlorinated biphenyls in surface soils of Novi Sad and bank sediment of the Danube River. / J. Cvejanov, N. J. Duriši´c-Mladenovi´c // Environ. Sci. Health Part B.- 2007. - № 42. - P. 311–319.

115. Sleugh, B. B. Corteva Agriscience's perspective and commitment to managing herbicide resistance. / T. R. Wright, M. Salas, D. M. Simpson, P. R., Schmitzer, M. Morell, D. W. Saunders / Pest Manag Sci. - 2021. - № 77. - P. 1572-1577.

116. Sobiech, Ł. Effect of Adjuvants and pH Adjuster on the Efficacy of Sulcotrione Herbicide. / M. Grzanka, G. Skrzypczak, R. Idziak, S. Włodarczak, M. Ochowiak // Agronomy. - 2020. - №10(4).- P. 530.

117. Stankiewicz-Kosyl, M. Herbicide Resistance and Management Options of Papaver rhoeas L. and Centaurea cyanus L. in Europe: A Review. / A. Synowiec, M. Haliniarz, A. Wenda-Piesik, K. Domaradzki, D. Parylak, M. Wrochna, E. Pytlarz, D. Gala-Czekaj, K. Marczewska-Kolasa, K. Marcinkowska, T. Praczyk // Agronomy. -2020. - №10(6). - P. 874.

118. Sureshkumar, R. Weed characters and indices of transplanted rice as influenced by different weed management practices. / Durairaj // International Journal of Agriculture Sciences. - 2016.- № 8(51). - P. 2221-2223.

119. Taylor M.D. Pesticide residues in coastal tropical ecosystems: distribution, fate and efects / S.J. Klaine, F.P. Carvalho, D. Barcelo // CRC Press Boca Raton. 2002.

120. Tudi, M. Agriculture Development, Pesticide Application and Its Impact on the Environment / H. Daniel Ruan, L. Wang, J. Lyu, R. Sadler, D. Connell, C. Chu, D.T. Phung // Int. J. Environ. Res. Public Health. - 2021. - № 18. - P.1-23.

121. Urovic, R. Modern Extraction Techniques for Pesticide Residues Determination in Plant and Soil Samples/ T. Orevi // Pesticides in the Modern World Trends in Pesticides Analysis. -2011.- (January 2010). doi: 10.5772/17312.

122. Ustuner, T. Effect of herbicides on living organisms in the ecosystem and available alternative control methods / A. Sakran, K. Almhemed // Int. J. Sci. Res. Publ. – 2020. – №10 . – P. 633–641.

123 .Vats, S. Herbicides: History, Classification and Genetic Manipulation of Plants for Herbicide Resistance. -2015.- doi: 10.1007/978-3-319-09132-7_3.

124. Walorczyk S., Development of a multi-residue screening method for the

determination of pesticides in cereals and dry animal feed using gas chromatography–triple quadrupole tandem mass spectrometry // Journal of Chromatography A. - 2007. - № 1165 (1-2). - P. 200–212.

125. Weisenburger D. Human health effects of agrichemical use / Human Pathology. - 1993. - № 24. - P. 571-576.

126. Wilkowska A., Biziuk M., Determination of pesticide residues in food matrices using the QuEChERS methodology // Food Chemistry. - 2011. - № 125. - P. 803–812.

127. Xu, J. Mode of Action of a Novel Synthetic Auxin Herbicide Halauxifen-Methyl / X. Liu, R. Napier, L. Dong, J. Li // Agronomy.- 2022. - № 12. - P 1659.

128. Yang, C. Reproductive toxicity due to herbicide exposure in freshwater organisms / W. Lim, G. Song // Comp. Biochem. Physiol. Part C Toxicol. Pharmacol. - 2021. - № 248. - P. 109103.

129. Yazdani, M. Inducing novel resistance gene in wheat towards stem rust to improve food security to improve food security./ Swedish University of Agricultural Sciences. - 2022. - P. 1–44.

130 . Young, S. L. Automation: The future of weed control in cropping systems / F. J. Pierce, P. Nowak // ResharchGate. - 2014. - P. 1–265. doi: 10.1007/978-94-007-7512-1.

131. Varanasi, A. Impact of climate change factors on weeds and herbicide efficacy / P.V. Prasad, M. Jugulam // Adv. Agron. - 2016. - № 135. - P. 107–146.

132. Zargar, M. Study of postemergence-directed herbicides for redroot pigweed (*Amaranthus retroflexus* L.) control in winter wheat in southern Russia / M. Bayat, T. Astarkhanova // Journal of Plant Protection Research. - 2020. - № 60 (1). - P. 7-13.

133. Zimdahl, R. L. Fundamentals of Weed Science, Fundamentals of Weed Science. // Book Fifth Edition. - 2018. doi: 10.1016/c2015-0-04331-3.

134. Al-Maliki, A.A., Dolzhenko, V.I., Dolzhenko O.V. Effectiveness of a new domestic herbicide for the protection of winter wheat // Izvestiya St. Petersburg State Agrarian University. – 2023. – №2 (71). – Pp. 47-56. doi:10.24412/2078-1318-2023-2-47-56. (in Russian)

135. Alekseev E.Yu., Dolzhenko V.I. Study of pesticide residues: methodology and methods // Plant protection from harmful organisms: materials of the International Scientific and Practical Conference. – Krasnodar, 2023. – P.12-14. (in Russian)

136. Aminopyralide, handbook of Pesticides. [electronic resource]. – Access mode: https://www.pesticidy.ru/active_substance . free. – (date of application: 08/21/2022). (in Russian)

137. Zelensky, N.A. The influence of elements of cultivation technology on the yield and quality of grain varieties of winter wheat/ M.I. Tekieva // Scientific journal of KubGAU.- 2012.- № 78(04).- Pp. 1-11. (in Russian)

138.Bankina, T.A. Chromatography in agroecology / M.Yu. Petrov, T.M. Petrova, T.M. Bankin. St. Petersburg, 2000. - 587c. (in Russian)

139. Baibekov, R.F. Behavior of the herbicide aminopyralide in the soil of a field column experiment/ A.V. Kalinin // Agrochemical products and technologies. -2009. - No. 6. - pp. 16-17. (in Russian)

140. Boyko, E.S., Vasilko V.P., Nazarenko L.V. Improving the system of weed control measures for winter wheat cultivation in the central zone of the Krasnodar Territory // Plant protection from harmful organisms: materials of the International Scientific and practical Conference. – Krasnodar, 2023. – pp.60-63. (in Russian)

141. Vlasova, O. I. Weeds and their control in agrophytocenoses of field crops/ V.M. Perederieva, G.R. Dorozhko, I.A. Volters // Stavropol: Stavropol State Agrarian University. - 2018. - C. 80. (in Russian)

142. Voishchutskaya N.P., Sources of economically valuable traits for breeding winter soft wheat in the steppe zone of the Krasnodar Territory / Legumes and cereals. - 2020. - №. 4(36). - Pp. 106-116. (in Russian)

143. Matveev, A. G. Productivity of winter wheat depending on cultivation technology and fertilizers on leached chernozem of the Central Caucasus / Thesis. ... candidate of Agricultural Sciences: 06.01.01. - 2015. - 149 p. (in Russian)

144. GlavAgronom - TOP 20 wintering annual dicotyledonous weeds in grain crops/

December 1, 2022 Source: https://glavagronom.ru /articles. (in Russian)

145. Golubev, A. S. The effectiveness of a new domestic herbicide based on flumetsulam and florasulam in the form of an oil dispersion for the protection of grain crops / Plant protection and quarantine. - 2022. - No. 5. - P.43–46. (in Russian)

146. Goryanin, O.I. The influence of soil treatment systems, fertilizers, herbicides and growth regulators on the weed component in winter wheat crops / V.I. Turusov, V.M. Gamashov, I.M. Kornilov, N.A. Necessary // Methods and Means. - 2014. - pp. 26–28. (in Russian)

147. State catalog of pesticides and agrochemicals approved for use on the territory of the Russian Federation. - Moscow, 2022. - 877 p. (in Russian)

148.Dospekhov, B.A. Methodology of field experience / B.A. Dospekhov. – Moscow: Kolos, 1985. – 336 p. (in Russian)

149. Dolzhenko, V.I. Plant protection: state, problems and prospects of their solution in grain production / V.I. Dolzhenko, A.I. Silaev // Agro XXI. – 2010. – No. 7-9. – pp. 3-5. (in Russian)

150. Dolzhenko, V.I. Principles of creating environmentally friendly plant protection systems / V.I. Dolzhenko, T.V. Dolzhenko // Chemical method of plant protection. Proceedings of the international scientific and practical conference December 6-10, 2004 - 2004. - pp. 91-93. (in Russian).

151. Flumetsulam / reference book Pesticides. [Electronic resource]. – Access mode: https://www.pesticidy.ru/active_substance. free. – (access date: 08/21/2022). (in Russian)

152. Zhidkova, A.Yu. The average annual precipitation of Rostov-on-Don in the period from 1970 to 2019 / Kovrova, V. A./ - 2019. - pp. 124-128. (in Russian)

153. Zakota T.Yu., Luneva N.N. Species composition of weeds in field crops in the steppe zone of the Krasnodar Territory as the basis of agrotechnical methods of plant protection // Protection of plants from harmful organisms: materials of the International Scientific and Practical Conference. – Krasnodar, 2023. – P.156-159. (in Russian)

154. Zakharenko, V. A. Trends and prospects for chemical and biological plant

protection / ON THE TOPIC OF THE DAY. - 2005. - P. 6–10. (in Russian)

155. Zayats M. F. Development and validation of a methodology for the joint determination of pesticide residues in winter wheat grain by gas chromatography with mass spectral detection // Proceedings of the National Academy of Sciences of Belarus. Chemical series. - 2017. - № 2. - P. 51–60. (in Russian)

156. Zvereva, G.K. Agrocenoses (concepts, structure, features of functioning): textbook / G.K. Zvereva // Novosibirsk: Publishing House NGPU. - 2006.- 118 p. (in Russian)

157 Zinchenko, V.A. Chemical plant protection: means, technology and environmental safety / V.A. Zinchenko. - Moscow: KolosS. - 2012. - 247 pp. (in Russian)

158. Illarionov, A. Modern methods and means of winter wheat against weeds / Bulletin of the Voronezh State Agrarian University. – 2019. – No. 3(62). - pp. 79–94. (in Russian)

159. Kovtun, V.I. High-yielding variety of soft winter wheat of universal type Status // Agronomy and Forestry. - 2017- No. 32. - P. 2013–2016. (in Russian)

160. Kulikova, N. Herbicides and environmental aspects of their use / Lebedeva G. // Moscow. – 2010. - 78 p. (in Russian)

161. Kulikova, N.A. Herbicides and environmental aspects of their use / N.A. Kulikova, G.F. Lebedeva // Textbook. Ed. stereotype. – M.: Book house “LIBROKOM”, 2015. – pp. 125–127. (in Russian)

162. Ksykin, I.V. Harmfulness of weeds and measures to combat them in crops of grain crops on light chestnut soils of the Volga-Don interfluve.: Thesis. ... Candidate of Agricultural Sciences: 01/06/01. - 2015. - 181 p. (in Russian)

163. Luneva N.N. Methodology of phytosanitary zoning of weeds as the basis for the development of zonal systems for the protection of cultivated plants // Protection of plants from harmful organisms: materials of the International Scientific and Practical Conference. – Krasnodar, 2023. – P.240-243. (in Russian)

164. Lunev M.I. Pesticides and protection of agrophytocenoses. Guidelines for using

the bioindication method to assess residual quantities of herbicides in soil and their phytotoxicity. M.: Gosagroprom RSFSR. - M.: Kolos. - 1992.- 268 p. (in Russian)

165. Matveev, A. G. Productivity of winter wheat depending on cultivation technology and fertilizers on leached chernozem of the Central Ciscaucasia / dis. ...cand. agricultural Sciences: 06.01.01. - 2015. - 149 p. (in Russian)

166. Guidelines for registration testing of herbicides in agriculture. – St. Petersburg, 2013. – 280 p. (in Russian)

167. Methodological recommendations for conducting registration tests of herbicides. - St. Petersburg, 2020. – 80 p. (in Russian)

168. MCPA (2M-4X)/ reference book Pesticides. [Electronic resource]. – Access mode: https://www.pesticidy.ru/active_substance. free. – (access date: 08/21/2022). (in Russian)

169. MUK 4.1.2054-06. Guidelines for determining residual amounts of prochloraz in water, soil, grain and straw of cereal crops using high-performance liquid chromatography: approved. Rospotrebnadzor 04/10/2006. – M.: Ros. state agrarian University - MSHA. (in Russian)

170. MUK 4.1.2172-07. Determination of residual amounts of tau-fluvalinate in grain and straw of cereal crops, in berries and grape juice, green mass of pasture grasses, rapeseed seeds and oil, soybeans using capillary gas-liquid chromatography. Guidelines: approved. Rospotrebnadzor 02/15/2007. – M.: Ros. state agrarian university - Moscow Agricultural Academy named after. K. A. Timiryazeva; Educational-scientific consulting Center “Agroecology of Pesticides and Agrochemicals”, 2007. – 12 p. (in Russian)

171. Nekrasov E.I., Marchenko D.M., Ivanisov M.M. Ecological plasticity of winter soft wheat varieties // Grain Economy of Russia. - 2022 - T. 14. - No. 2. - P. 54–58. (in Russian)

172. Osipova A.G., Logoyda T.V. Application of various agricultural technologies in the cultivation of winter wheat in the central zone of Kuban // Plant protection from harmful organisms: materials of the International Scientific and Practical Conference. – Krasnodar,

2023. – P.301-302. (in Russian)

173. Okazova, Z. P. Harmfulness of the weed component for sowing winter wheat / International agricultural journal. - 2022. - No. 5. P.10. (in Russian)

174.Piroxsulam, reference book Pesticides. [Electronic resource]. https://www.pesticidy.ru/active_substance, [date of access: 21.9.2022]. (in Russian)

175. Wheat production in Russia in 2021 will decrease by 7 million tons - FAO [Electronic resource]. – Access mode:: https://zerno.ru/node/14070 (date of access: November 29, 2022).URL. (in Russian)

176. Agriculture and agro-industrial complex - Government of the Rostov region (undated). Available at: http://old.donland.ru/economy/APK/?pageid=75915 (Viewed: December 26, 2022). (in Russian)

177. Directory of pesticides and agrochemicals approved for use on the territory of the Russian Federation - AgroXXI [Electronic resource]. – URL://www.agroxxi.ru/goshandbook, [access date: 10/25/2022]. (in Russian)

178. Stolyarov, B.V. Practical gas and liquid chromatography./ I.M. Savinov, A.G. Vitenberg, L.A. Kartsova, I.G. Kalmanovsky, Yu.A. Kalambet // St. Petersburg, 1998. - 612 p. (in Russian)

179. Tansky, V.I. Protection of grain crops from pests, diseases and weeds in the Non-Chernozem zone of Russia / V.I. Tansky, V.I. Dolzhenko, N.R. Goncharov, T.I. Ishkova. - Saint Petersburg. - 2004. - 48 p. (in Russian)

180. Tribenuron-methyl, reference book Pesticides. [Electronic resource]. – Access mode: https://www.pesticidy.ru/active_substance. free. – (date of access: 8.9.2022). (in Russian)

181. Tifensulfuron-methyl, reference book Pesticides. [Electronic resource]. – Access mode: https://www.pesticidy.ru/active_substance. free. – (date of access: 8.9.2022). (in Russian)

182. Fadeev, Yu.N. Assessment of sanitary and environmental safety of pesticides // Yu.N. Fadeev / Plant protection. - 1988. - No. 7. - pp. 20-21. (in Russian)

183. Filenko, G. A. Sown area and yield of winter wheat / Agrarian Bulletin of the Urals - Biology and Biotechnology // - 2016. - No. 06 (148). - pp. 61–69. (in Russian)

184. Flumetsulam, reference book Pesticides. [Electronic resource]. – Access mode: https://www.pesticidy.ru/active_substance. free. – (access date: 12/12/2022). (in Russian)

185. Florasulam, reference book Pesticides. [Electronic resource]. – Access mode: https://www.pesticidy.ru/active_substance. free. – (access date: 12/12/2022). (in Russian)

186. Kharkovsky, A., Gorbacheva, A. V. Recommendations for growing winter wheat on farms in the Voronezh region. - 2019. - P. 36. (in Russian)

187. Chulkina, V.A. Phytosanitary diagnostics of agroecosystems / V.A. Chulkina, E.Yu. Toropova, G.Ya. Stetsov, A.A. Kirichenko, E.Yu. Marmuleva, V.M. Grishin, O.A. Kazakova, M.P. Selyuk // ed. Professor Toropova E.Yu. – Barnaul, 2017. – 210 p. (in Russian)

188. Chichvarin, A.V. Technology of weed control in grain crops using modern domestic herbicides: dis. ...cand. agricultural Sciences: 06. 01. 11. - 2008. - 210 p.

189. 2,4 D (2-ethylhexyl ether), reference book Pesticides. [Electronic resource]. – Access mode: https://www.pesticidy.ru/active_substance. free. – (access date: 10/19/2022). (in Russian).

Appendix

Table 1. **Efficacy of the herbicide Pinta, OD herbicide on overall crop infestation Winter wheat (tillering stage, Rostov region, 2020)**

Experimental Options	Dates accounts	Number of weeds		Mass of weeds			
		ind./m^2	Reduction, % to control	g/m^2		Reduction, % to control	
				Annual	Perennial	Annual	Perennial
1. Pinta, OD – 0,1 l/h	30th	12	85,2	11,4	6,8	92,1	76,1
	45th	8	89,2	7,0	5,8	96,8	91,7
	90th	2	88,2	–	–	–	–
2. Pinta, OD – 0,15 l/h	30th	6	92,6	4,3	3,1	97,0	89,1
	45th	3	95,9	1,4	2,0	99,4	97,1
	90th	0	100	–	–	–	–
3. Derby 175, SC – 0,05 l/h	30th	14	82,7	13,4	7,6	90,8	73,2
	45th	11	85,1	7,8	6,3	96,4	91,0
	90th	3	82,4	–	–	–	–
4. Derby 175, SC – 0,07 l/h	30th	7	91,4	5,1	5,3	96,5	81,3
	45th	5	93,2	2,4	3,0	98,9	95,7
	90th	1	94,1	–	–	–	–
5. Control	30th	81	–	145,2	28,4	–	–
	45th	74	–	219,0	69,8	–	–
	90th	17	–	–	–	–	–

Table 2. **Efficacy of the herbicide Pinta, OD herbicide on overall crop infestation Winter wheat (at the exit stage into the tube, Rostov region, 2020)**

Experimental Options	Dates accounts	Number of weeds		Mass of weeds			
		ind./m^2	Reduction, % to control	g/m^2		Reduction, % to control	
				Annual	Perennial	Annual	Perennial
1. Pinta, OD – 0,1 l/h	30th	19	75,9	25,7	24,3	89,5	67,0
	45th	11	80,7	16,2	15,1	94,0	83,5
	90th	3	84,2	–	–	–	–
2. Pinta, OD – 0,15 l/h	30th	11	86,1	10,2	9,5	95,8	87,1
	45th	5	91,2	4,5	6,6	98,3	92,8
	90th	1	94,7	–	–	–	–
3. Derby 175, SC – 0,05 l/h	30th	20	74,7	24,2	27,0	90,1	63,4
	45th	12	78,9	18,1	16,4	93,3	82,1
	90th	3	84,2	–	–	–	–
4. Derby 175, SC – 0,07 l/h	30th	13	83,5	12,2	11,8	95,0	84,0
	45th	7	87,7	8,0	8,4	97,0	90,8
	90th	2	89,5	–	–	–	–
5. Control	30th	79	–	245,5	73,7	–	–
	45th	57	–	270,7	91,7	–	–
	90th	19	–	–	–	–	–

Table 3. **Efficacy of the herbicide Pinta, OD herbicide on overall crop infestation Winter wheat (tillering stage, Rostov region, 2021)**

Experimental Options	Dates accounts	Number of weeds		Mass of weeds			
		ind./m^2	Reduction, % to control	g/m^2		Reduction, % to control	
				Annual	Perennial	Annual	Perennial
1. Pinta, OD – 0,1 l/h	30th	17	81,1	21,4	54,2	86,0	55,5
	45th	10	84,1	10,0	38,3	96,0	75,7
	90th	3	88,5	–	–	–	–
2. Pinta, OD – 0,15 l/h	30th	9	90,0	8,8	24,7	94,3	79,7
	45th	5	92,1	2,3	16,9	99,1	89,3
	90th	1	96,2	–	–	–	–
3. Derby 175, SC – 0,05 l/h	30th	17	81,1	19,1	46,3	87,5	62,0
	45th	11	82,5	11,4	34,3	95,5	78,2
	90th	4	84,6	–	–	–	–
4. Derby 175, SC – 0,07 l/h	30th	7	92,2	5,3	18,9	96,5	84,5
	45th	5	92,1	3,9	15,0	98,5	90,5
	90th	1	96,2	–	–	–	–
5. Control	30th	90	–	153,1	121,7	–	–
	45th	63	–	253,1	157,7	–	–
	90th	26	–	–	–	–	–

Table 4. **Efficacy of the herbicide Pinta, OD herbicide on overall crop infestation Winter wheat (at the exit stage into the tube, Rostov region, 2021)**

Experimental Options	Dates accounts	Number of weeds		Mass of weeds			
		ind./m²	Reduction, % to control	g/m²		Reduction, % to control	
				Annual	Perennial	Annual	Perennial
1. Pinta, OD – 0,1 l/h	30th	25	73,7	28,4	78,1	84,1	48,2
	45th	14	77,0	17,9	51,5	93,4	66,9
	90th	5	82,1	–	–	–	–
2. Pinta, OD – 0,15 l/h	30th	15	84,2	16,0	48,2	91,0	68,1
	45th	7	88,5	7,1	32,0	97,4	79,4
	90th	2	92,9	–	–	–	–
3. Derby 175, SC – 0,05 l/h	30th	26	72,6	35,9	66,7	79,9	55,8
	45th	15	75,4	22,5	45,5	91,7	70,8
	90th	6	78,6	–	–	–	–
4. Derby 175, SC – 0,07 l/h	30th	13	86,3	13,8	37,5	92,3	75,1
	45th	8	86,9	5,8	21,0	97,8	86,5
	90th	3	89,3	–	–	–	–
5. Control	30th	95	–	178,3	150,9	–	–
	45th	61	–	269,5	155,6	–	–
	90th	28	–	–	–	–	–

Table 5. **Efficacy of the herbicide Fortissimo, OD herbicide on overall crop infestation Winter wheat at tillering stage (Rostov Region, 2021)**

Experimental Options	Dates accounts	Number of weeds		Mass of weeds			
		ind./m^2	Reduction, % to control	g/m^2		Reduction, % to control	
				Annual	Perennial	Annual	Perennial
1. Fortissimo, OD – 0,4 l/h	30th	16	82,8	14,4	31,2	89,9	76,6
	45th	10	84,4	7,6	18,5	97,1	89,5
	90th	3	88,5	–	–	–	–
2. Fortissimo, OD – 0,5 l/h	30th	9	90,3	8,3	19,5	94,2	85,4
	45th	5	92,2	3,5	7,2	98,7	95,9
	90th	2	92,3	–	–	–	–
3. Fortissimo, OD – 0,7 l/h	30th	5	94,6	1,4	7,9	99,0	94,1
	45th	1	98,4	0,0	4,0	100	97,7
	90th	0	100	–	–	–	–
4. Prima Forte 195, SE – 0,5 l/h	30th	14	84,9	9,6	36,5	93,3	72,6
	45th	8	87,5	2,7	19,6	99,0	88,9
	90th	3	88,5	–	–	–	–
5. Prima Forte 195, SE – 0,7 l/h	30th	7	92,5	3,8	15,6	97,3	88,3
	45th	3	95,3	1,5	5,7	99,4	96,8
	90th	1	96,2	–	–	–	–
6. Control	30th	93	–	142,9	133,4	–	–
	45th	64	–	262,3	175,8	–	–
	90th	26	–	–	–	–	–

Table 6. **Efficacy of the herbicide Fortissimo, OD herbicide on overall crop infestation Winter wheat at the exit stage into the tube (Rostov Region, 2021)**

Experimental Options	Dates accounts	Number of weeds		Mass of weeds			
		ind./m^2	Reduction, % to control	g/m^2		Reduction, % to control	
				Annual	Perennial	Annual	Perennial
1. Fortissimo, OD – 0,4 l/h	30th	23	74,2	25,6	65,2	84,3	59,5
	45th	14	76,3	20,9	48,5	80,8	72,1
	90th	6	76,9	–	–	–	–
2. Fortissimo, OD – 0,5 l/h	30th	18	79,8	18,8	45,9	88,5	71,5
	45th	9	84,7	11,5	35,2	89,5	79,7
	90th	4	84,6	–	–	–	–
3. Fortissimo, OD – 0,7 l/h	30th	13	85,4	5,8	21,5	96,4	86,6
	45th	6	89,8	2,9	15,3	97,3	91,2
	90th	2	92,3	–	–	–	–
4. Lancelot 450, WDG – 0,03 kg/h	30th	17	80,9	13,9	29,5	91,5	81,7
	45th	10	83,1	15,0	20,2	86,3	88,4
	90th	5	80,8	–	–	–	–
5. Lancelot 450, WDG – 0,033 kg/h	30th	14	84,3	10,7	19,6	93,4	87,8
	45th	7	88,1	9,2	12,9	91,6	92,6
	90th	3	88,5	–	–	–	–
6. Control	30th	89	–	163,2	160,8	–	–
	45th	59	–	109,1	173,6	–	–
	90th	26	–	–	–	–	–

Table 7. **Efficacy of the herbicide Fortissimo, OD herbicide on overall crop infestation Winter wheat at tillering stage (Rostov Region, 2022)**

Experimental Options	Dates accounts	Number of weeds		Mass of weeds			
		ind./m²	Reduction, % to control	g/m²		Reduction, % to control	
				Annual	Perennial	Annual	Perennial
1. Fortissimo, OD – 0,4 l/h	30th	12	83,1	35,8	17,7	85,6	74,9
	45th	8	85,7	23,2	14,3	93,5	83,4
	90th	2	90,5	–	–	–	–
2. Fortissimo, OD – 0,5 l/h	30th	8	88,7	22,8	12,2	90,8	82,7
	45th	3	94,6	6,4	8,0	98,2	90,7
	90th	2	90,5	–	–	–	–
3. Fortissimo, OD – 0,7 l/h	30th	3	95,8	0,0	7,8	100	88,9
	45th	1	98,2	0,0	3,3	100	96,2
	90th	0	100	–	–	–	–
4. Prima Forte 195, SE – 0,5 l/h	30th	10	85,9	25,7	14,8	89,6	79,0
	45th	5	91,1	7,5	8,9	97,9	89,7
	90th	2	90,5	–	–	–	–
5. Prima Forte 195, SE – 0,7 l/h	30th	5	93,0	5,8	9,8	97,7	86,1
	45th	2	96,4	0,0	4,6	100	94,7
	90th	1	95,2	–	–	–	–
6. Control	30th	71	–	248,0	70,5	–	–
	45th	56	–	359,4	86,1	–	–
	90th	21	–	–	–	–	–

Table 8. **Efficacy of the herbicide Fortissimo, OD herbicide on overall crop infestation Winter wheat at the exit stage into the tube (Rostov Region, 2022)**

Experimental Options	Dates accounts	Number of weeds		Mass of weeds			
		ind./m²	Reduction, % to control	g/m²		Reduction, % to control	
				Annual	Perennial	Annual	Perennial
1. Fortissimo, OD – 0,4 l/h	30th	17	77,0	45,4	25,8	83,1	69,3
	45th	13	77,6	39,6	27,2	89,6	72,0
	90th	5	78,3	–	–	–	–
2. Fortissimo, OD – 0,5 l/h	30th	14	81,1	33,5	20,2	87,5	76,0
	45th	8	86,2	25,7	18,5	93,2	81,0
	90th	4	82,6	–	–	–	–
3. Fortissimo, OD – 0,7 l/h	30th	8	89,2	15,4	11,3	94,3	86,5
	45th	4	93,1	8,2	9,6	97,8	90,1
	90th	1	95,7	–	–	–	–
4. Lancelot 450, WDG – 0,03 kg/h	30th	12	83,8	29,0	16,6	89,2	80,2
	45th	9	84,5	21,9	16,0	94,2	83,5
	90th	3	87,0	–	–	–	–
5. Lancelot 450, WDG – 0,033 kg/h	30th	9	87,8	18,1	10,5	93,3	87,5
	45th	5	91,4	10,7	10,5	97,2	89,2
	90th	2	91,3	–	–	–	–
6. Control	30th	74	–	268,3	84,0	–	–
	45th	58	–	380,6	97,2	–	–
	90th	23	–	–	–	–	–

Table 9. **Efficacy of the herbicide Cayenne Turbo, OD herbicide on overall crop infestation**

Winter wheat at tillering stage (Rostov Region, 2021)

Experimental Options	Dates accounts	Number of weeds		Mass of weeds			
		ind./m^2	Reduction, % to control	g/m^2		Reduction, % to control	
				Annual	Perennial	Annual	Perennial
1. Cayenne Turbo, OD – 0,15 l/ha	30th	17	82,7	15,9	61,1	89,9	51,9
	45th	11	84,5	9,2	75,1	97,0	58,8
	90th	5	82,8	–	–	–	–
2. Cayenne Turbo, OD – 0,25 l/ha	30th	13	86,7	9,3	46,9	94,1	63,0
	45th	7	90,1	3,7	41,1	98,8	77,4
	90th	3	89,7	–	–	–	–
3. Cayenne Turbo, OD – 0,35 l/ha	30th	9	90,8	3,8	24,7	97,6	80,5
	45th	5	93,0	1,1	18,7	99,6	89,7
	90th	2	93,1	–	–	–	–
4. Cayenne Turbo, OD + SURFACTANT Bit-90, L – 0,15 l/ha + 0,2 l/ha	30th	14	85,7	10,4	49,3	93,4	61,2
	45th	9	87,3	4,9	40,2	98,4	77,9
	90th	3	89,7	–	–	–	–
5 Cayenne Turbo, OD + SURFACTANT Bit-90, L – 0,25 l/ha + 0,2 l/ha	30th	10	89,8	5,8	27,7	96,3	78,2
	45th	4	94,4	0,8	20,0	99,7	89,0
	90th	2	93,1	–	–	–	–
6. Cayenne Turbo, OD + SURFACTANT Bit-90, L – 0,35 l/ha+ 0,2l/ha	30th	6	93,9	2,6	11,9	98,3	90,6
	45th	2	97,2	0,0	6,2	100	96,6
	90th	1	96,6	–	–	–	–
7. Status Max, WDG – 0,03 kg/ha	30th	17	82,7	12,8	38,3	91,8	69,8
	45th	11	84,5	8,2	33,0	97,3	81,9
	90th	5	82,8	–	–	–	–
8. Status Max, WDG – 0,05 kg/ha	30th	8	91,8	7,4	8,4	95,3	93,4
	45th	3	95,8	1,6	7,6	99,5	95,8
	90th	1	96,6	–	–	–	–
9. Control	30th	98	–	156,8	126,9	–	–
	45th	71	–	304,6	182,2	–	–
	90th	29	–	–	–	–	–

Table 10. **Efficacy of the herbicide Cayenne Turbo, OD herbicide on overall crop infestation Winter wheat at the exit stage into the tube (Rostov Region, 2021)**

Experimental Options	Dates accounts	Number of weeds		Mass of weeds			
		ind./m^2	Reduction, % to control	g/m^2		Reduction, % to control	
				Annual	Perennial	Annual	Perennial
1. Cayenne Turbo, OD – 0,15 l/ha	30th	24	72,1	25,9	89,5	85,8	46,6
	45th	14	77,4	20,1	94,5	94,0	50,3
	90th	7	75,0	–	–	–	–
2. Cayenne Turbo, OD – 0,25 l/ha	30th	19	77,9	21,2	69,3	88,4	58,7
	45th	10	83,9	12,9	59,8	96,1	68,6
	90th	4	85,7	–	–	–	–
3. Cayenne Turbo, OD – 0,35 l/ha	30th	15	82,6	18,1	45,1	90,1	73,1
	45th	7	88,7	5,5	38,2	98,3	79,9
	90th	3	89,3	–	–	–	–
4. Cayenne Turbo, OD + SURFACTANT Bit-90, L – 0,15 l/ha + 0,2 l/ha	30th	21	75,6	19,6	73,6	89,3	56,1
	45th	10	83,9	10,2	58,8	96,9	69,1
	90th	5	82,1	–	–	–	–
5 Cayenne Turbo, OD + SURFACTANT Bit-90, L – 0,25 l/ha + 0,2 l/ha	30th	15	82,6	14,7	44,7	91,9	73,3
	45th	6	90,3	6,0	28,5	98,2	85,0
	90th	3	89,3	–	–	–	–
6. Cayenne Turbo, OD + SURFACTANT Bit-90, L – 0,35 l/ha+ 0,2l/ha	30th	10	88,4	11,1	30,7	93,9	81,7
	45th	4	93,5	1,3	18,3	99,6	90,4
	90th	2	92,9	–	–	–	–
7. Status Max, WDG – 0,03 kg/ha	30th	25	70,9	27,3	64,0	85,0	61,8
	45th	16	74,2	24,0	54,1	92,8	71,6
	90th	8	71,4	–	–	–	–
8. Status Max, WDG – 0,05 kg/ha	30th	12	86,0	14,1	17,0	92,3	89,9
	45th	7	88,7	8,7	13,6	97,4	92,8
	90th	2	92,9	–	–	–	–
9. Control	30th	86	–	182,6	167,7	–	–
	45th	62	–	332,7	190,2	–	–
	90th	28	–	–	–	–	–

Table 11. **Efficacy of the herbicide Cayenne Turbo, OD herbicide on overall crop infestation Winter wheat at tillering stage (Rostov Region, 2022)**

Experimental Options	Dates accounts	Number of weeds		Mass of weeds			
		ind./m^2	Reduction, % to control	g/m^2		Reduction, % to control	
				Annual	Perennial	Annual	Perennial
1. Cayenne Turbo, OD – 0,15 l/ha	30th	14	82,1	36,4	28,2	86,2	65,8
	45th	11	83,8	28,4	30,5	92,5	70,5
	90th	4	85,2	–	–	–	–
2. Cayenne Turbo, OD – 0,25 l/ha	30th	10	87,2	22,6	16,8	91,4	79,6
	45th	6	91,2	13,0	15,5	96,6	85,0
	90th	3	88,9	–	–	–	–
3. Cayenne Turbo, OD – 0,35 l/ha	30th	5	93,6	8,9	7,4	96,6	91,0
	45th	4	94,1	3,2	6,1	99,2	94,1
	90th	1	96,3	–	–	–	–
4. Cayenne Turbo, OD + SURFACTANT Bit-90, L – 0,15 l/ha + 0,2 l/ha	30th	12	84,6	25,9	22,3	90,2	73,0
	45th	9	86,8	16,9	18,5	95,5	82,1
	90th	3	88,9	–	–	–	–
5 Cayenne Turbo, OD + SURFACTANT Bit-90, L – 0,25 l/ha + 0,2 l/ha	30th	7	91,0	12,7	11,2	95,2	86,4
	45th	3	95,6	0,0	7,9	100	92,4
	90th	2	92,6	–	–	–	–
6. Cayenne Turbo, OD + SURFACTANT Bit-90, L – 0,35 l/ha+ 0,2l/ha	30th	4	94,9	5,1	4,3	98,1	94,8
	45th	2	97,1	0,0	2,8	100	97,3
	90th	0	100	–	–	–	–
7. Status Max, WDG – 0,03 kg/ha	30th	13	83,3	31,1	26,0	88,2	68,5
	45th	10	85,3	17,8	24,4	95,3	76,4
	90th	4	85,2	–	–	–	–
8. Status Max, WDG – 0,05 kg/ha	30th	6	92,3	8,0	9,5	97,0	88,5
	45th	5	92,6	4,1	6,6	98,9	93,6
	90th	1	96,3	–	–	–	–
9. Control	30th	78	–	263,5	82,5	–	–
	45th	68	–	378,2	103,5	–	–
	90th	27	–	–	–	–	–

Table 12. **Efficacy of the herbicide Cayenne Turbo, OD herbicide on overall crop infestation Winter wheat at the exit stage into the tube (Rostov Region, 2022)**

Experimental Options	Dates accounts	Number of weeds		Mass of weeds			
		ind./m^2	Reduction, % to control	g/m^2		Reduction, % to control	
				Annual	Perennial	Annual	Perennial
1. Cayenne Turbo, OD – 0,15 l/ha	30th	19	74,3	50,2	39,6	82,8	58,6
	45th	14	76,3	41,8	43,6	89,3	62,0
	90th	7	77,4	–	–	–	–
2. Cayenne Turbo, OD – 0,25 l/ha	30th	14	81,1	36,4	27,5	87,5	71,2
	45th	10	83,1	25,4	29,0	93,5	74,7
	90th	5	83,9	–	–	–	–
3. Cayenne Turbo, OD – 0,35 l/ha	30th	10	86,5	19,3	13,0	93,4	86,4
	45th	6	89,8	9,5	11,3	97,6	90,1
	90th	3	90,3	–	–	–	–
4. Cayenne Turbo, OD + SURFACTANT Bit-90, L – 0,15 l/ha + 0,2 l/ha	30th	17	77,0	39,8	30,8	86,4	67,8
	45th	12	79,7	32,8	35,9	91,6	68,7
	90th	6	80,6	–	–	–	–
5 Cayenne Turbo, OD + SURFACTANT Bit-90, L – 0,25 l/ha + 0,2 l/ha	30th	12	83,8	23,8	21,6	91,8	77,4
	45th	7	88,1	14,7	22,3	96,2	80,5
	90th	4	87,1	–	–	–	–
6. Cayenne Turbo, OD + SURFACTANT Bit-90, L – 0,35 l/ha+ 0,2l/ha	30th	7	90,5	10,5	7,4	96,4	92,3
	45th	4	93,2	4,2	8,1	98,9	92,9
	90th	2	93,5	–	–	–	–
7. Status Max, WDG – 0,03 kg/ha	30th	18	75,7	44,2	34,3	84,8	64,1
	45th	13	78,0	33,4	35,3	91,4	69,2
	90th	6	80,6	–	–	–	–
8. Status Max, WDG – 0,05 kg/ha	30th	9	87,8	17,2	14,8	94,1	84,5
	45th	5	91,5	7,2	13,6	98,2	88,1
	90th	3	90,3	–	–	–	–
9. Control	30th	74	–	291,7	95,6	–	–
	45th	59	–	389,2	114,6	–	–
	90th	31	–	–	–	–	–

Table 13. **Effect of the herbicide Polian, OD on the overall infestation of winter wheat crops in the tillering phase (Rostov region, 2021)**

Experimental Options	Dates accounts	Number of weeds		Mass of weeds			
		ind./m^2	Reduction, % to control	g/m^2		Reduction, % to control	
				Annual	Perennial	Annual	Perennial
1. Polian, OD - 0,05 l/ha	30th	25	72,5	18,4	67,5	87,2	44,2
	45th	18	73,1	14,6	78,0	94,9	55,3
	90th	7	76,7	–	–	–	–
2. Polian, OD - 0,075 l/ha	30th	18	80,2	13,0	53,8	90,9	55,5
	45th	12	82,1	8,2	50,9	97,1	70,8
	90th	4	86,7	–	–	–	–
3. Polian, OD – 0,1 l/ha	30th	14	84,6	7,6	34,2	94,7	71,7
	45th	8	88,1	5,1	27,8	98,2	84,1
	90th	3	90,0	–	–	–	–
4. Polian, OD + surfactant Bit-90, L – 0,05 l/ha + 0,2 l/ha	30th	21	76,9	15,5	63,3	89,2	47,6
	45th	16	76,1	11,7	46,5	95,9	73,4
	90th	6	80,0	–	–	–	–
5. Polian, OD + surfactant Bit-90, L – 0,075 l/ha + 0,2 l/ha	30th	15	83,5	10,2	44,6	92,9	63,1
	45th	11	83,6	7,0	30,4	97,5	82,6
	90th	3	90,0	–	–	–	–
6. Polian, OD + surfactant Bit-90, L – 0,1 l/ha + 0,2 l/ha	30th	9	90,1	6,1	26,7	95,8	77,9
	45th	4	94,0	0,0	20,7	100	88,1
	90th	2	93,3	–	–	–	–
7. Caliber Gold, WDG + surfactant Trend 90, L – 0,03 kg/ha + 0,2 l/ha	30th	23	74,7	15,4	54,5	89,3	54,9
	45th	14	79,1	9,2	49,1	96,8	71,9
	90th	6	80,0	–	–	–	–
8. Caliber Gold, WDG – 0,05 kg/ha	30th	10	89,0	7,8	30,5	94,6	74,8
	45th	5	92,5	2,8	19,2	99,0	89,0
	90th	3	90,0	–	–	–	–
9. Control	30th	91	–	143,6	120,9	–	–
	45th	67	–	283,5	174,5	–	–
	90th	30	–	–	–	–	–

Table 14. **Effect of the herbicide Polian, OD on the overall infestation of winter wheat crops in at the exit stage into the tube (Rostov region, 2021)**

Experimental Options	Dates accounts	Number of weeds		Mass of weeds			
		ind./m²	Reduction, % to control	g/m²		Reduction, % to control	
				Annual	Perennial	Annual	Perennial
1. Polian, OD - 0,05 l/ha	30th	29	64,2	33,2	86,8	79,1	40,9
	45th	20	66,1	37,7	96,4	89,4	44,4
	90th	9	65,4	–	–	–	–
2. Polian, OD - 0,075 l/ha	30th	24	70,4	29,7	71,4	81,3	51,4
	45th	15	74,6	28,6	68,4	92,0	60,5
	90th	5	80,8	–	–	–	–
3. Polian, OD – 0,1 l/ha	30th	18	77,8	17,4	48,8	89,0	66,8
	45th	11	81,4	15,8	51,0	95,6	70,6
	90th	4	84,6	–	–	–	–
4. Polian, OD + surfactant Bit-90, L – 0,05 l/ha + 0,2 l/ha	30th	26	67,9	31,2	78,8	80,3	46,3
	45th	17	71,2	32,0	88,2	91,0	49,1
	90th	6	76,9	–	–	–	–
5. Polian, OD + surfactant Bit-90, L – 0,075 l/ha + 0,2 l/ha	30th	21	74,1	24,1	56,2	84,8	61,7
	45th	12	79,7	21,4	54,0	94,0	68,8
	90th	4	84,6	–	–	–	–
6. Polian, OD + surfactant Bit-90, L – 0,1 l/ha + 0,2 l/ha	30th	14	82,7	12,5	42,7	92,1	70,9
	45th	8	86,4	8,3	36,2	97,7	79,1
	90th	3	88,5	–	–	–	–
7. Caliber Gold, WDG + surfactant Trend 90, L – 0,03 kg/ha + 0,2 l/ha	30th	26	67,9	26,3	73,1	83,4	50,2
	45th	16	72,9	34,7	71,2	90,2	58,9
	90th	7	73,1	–	–	–	–
8. Caliber Gold, WDG – 0,05 kg/ha	30th	14	82,7	16,1	45,3	89,8	69,1
	45th	8	86,4	11,3	31,1	96,8	82,1
	90th	4	84,6	–	–	–	–
9. Control	30th	81	–	158,5	146,8	–	–
	45th	59	–	355,5	173,3	–	–
	90th	26	–	–	–	–	–

Table 15. **Effect of the herbicide Polian, OD on the overall infestation of winter wheat crops in the tillering phase (Rostov region, 2022)**

Experimental Options	Dates accounts	Number of weeds		Mass of weeds			
		ind./m^2	Reduction, % to control	g/m^2		Reduction, % to control	
				Annual	Perennial	Annual	Perennial
1. Polian, OD - 0,05 l/ha	30th	19	75,0	39,4	34,7	84,3	60,6
	45th	14	78,5	30,8	32,1	91,3	69,7
	90th	6	79,3	–	–	–	–
2. Polian, OD - 0,075 l/ha	30th	13	82,9	25,5	23,5	89,8	73,3
	45th	10	84,6	16,8	19,2	95,2	81,9
	90th	4	86,2	–	–	–	–
3. Polian, OD – 0,1 l/ha	30th	8	89,5	16,1	9,6	93,6	89,1
	45th	5	92,3	10,8	5,8	96,9	94,5
	90th	2	93,1	–	–	–	–
4. Polian, OD + surfactant Bit-90, L – 0,05 l/ha + 0,2 l/ha	30th	16	78,9	35,9	28,0	85,7	68,2
	45th	12	81,5	22,4	27,5	93,6	74,0
	90th	5	82,8	–	–	–	–
5. Polian, OD + surfactant Bit-90, L – 0,075 l/ha + 0,2 l/ha	30th	10	86,8	20,3	16,2	91,9	81,6
	45th	7	89,2	11,4	15,9	96,8	85,0
	90th	3	89,7	–	–	–	–
6. Polian, OD + surfactant Bit-90, L – 0,1 l/ha + 0,2 l/ha	30th	4	94,7	6,4	5,1	97,4	94,2
	45th	3	95,4	3,3	4,1	99,1	96,1
	90th	1	96,6	–	–	–	–
7. Caliber Gold, WDG + surfactant Trend 90, L – 0,03 kg/ha + 0,2 l/ha	30th	17	77,6	34,0	21,1	86,4	76,0
	45th	11	83,1	18,2	20,6	94,8	80,5
	90th	5	82,8	–	–	–	–
8. Caliber Gold, WDG – 0,05 kg/ha	30th	7	90,8	10,3	7,9	95,9	91,0
	45th	4	93,8	4,8	6,4	98,6	94,0
	90th	2	93,1	–	–	–	–
9. Control	30th	76	–	250,4	88,0	–	–
	45th	65	–	352,2	105,8	–	–
	90th	29	–	–	–	–	–

Table 16. **Effect of the herbicide Polian, OD on the overall infestation of winter wheat crops in at the exit stage into the tube (Rostov region, 2022)**

Experimental Options	Dates accounts	Number of weeds		Mass of weeds			
		ind./m^2	Reduction, % to control	g/m^2		Reduction, % to control	
				Annual	Perennial	Annual	Perennial
1. Polian, OD - 0,05 l/ha	30th	29	64,2	33,2	86,8	79,1	40,9
	45th	20	66,1	37,7	96,4	89,4	44,4
	90th	9	65,4	–	–	–	–
2. Polian, OD - 0,075 l/ha	30th	24	70,4	29,7	71,4	81,3	51,4
	45th	15	74,6	28,6	68,4	92,0	60,5
	90th	5	80,8	–	–	–	–
3. Polian, OD – 0,1 l/ha	30th	18	77,8	17,4	48,8	89,0	66,8
	45th	11	81,4	15,8	51,0	95,6	70,6
	90th	4	84,6	–	–	–	–
4. Polian, OD + surfactant Bit-90, L – 0,05 l/ha + 0,2 l/ha	30th	26	67,9	31,2	78,8	80,3	46,3
	45th	17	71,2	32,0	88,2	91,0	49,1
	90th	6	76,9	–	–	–	–
5. Polian, OD + surfactant Bit-90, L – 0,075 l/ha + 0,2 l/ha	30th	21	74,1	24,1	56,2	84,8	61,7
	45th	12	79,7	21,4	54,0	94,0	68,8
	90th	4	84,6	–	–	–	–
6. Polian, OD + surfactant Bit-90, L – 0,1 l/ha + 0,2 l/ha	30th	14	82,7	12,5	42,7	92,1	70,9
	45th	8	86,4	8,3	36,2	97,7	79,1
	90th	3	88,5	–	–	–	–
7. Caliber Gold, WDG + surfactant Trend 90, L – 0,03 kg/ha + 0,2 l/ha	30th	26	67,9	26,3	73,1	83,4	50,2
	45th	16	72,9	34,7	71,2	90,2	58,9
	90th	7	73,1	–	–	–	–
8. Caliber Gold, WDG – 0,05 kg/ha	30th	14	82,7	16,1	45,3	89,8	69,1
	45th	8	86,4	11,3	31,1	96,8	82,1
	90th	4	84,6	–	–	–	–
9. Control	30th	81	–	158,5	146,8	–	–
	45th	59	–	355,5	173,3	–	–
	90th	26	–	–	–	–	–

Table 17. Effect of the herbicide Tarzek, WG, against Weed Species, (2019, 2020)

Treatments	*Galium aparine*			*Papaver rhoeas*			*Cerastium nemorale*			*Avena fatua*			*Alopecurus myosuroides*		
	14 Day*	28 Day	56 Day	14 Day	28 Day	56 Day	14 Day	28 Day	56 Day	14 Day	28 Day	56 Day	14 Day	28 Day	56 Day
2019															
1.Tarzek, WG+ Surfer SL 0.075 kg/ha + 1.0 l/ha	91.3	100	100	91.8	100	100	92.5	100	100	87.5	95.5	93.3	85.5	93.5	92.5
2. Tarzek, WG+ Surfer SL - 0.09 kg/ha + 1.0 l/ha	93.5	100	100	94.0	100	100	95.0	100	100	90.5	97.5	96.5	88.5	96.5	95.5
3. Pallas 45, OD - 0.5 l/ha	82.0	90.3	87.3	24.0	19.0	5.5	93.8	100	100	92.3	97.3	96.3	90.3	96.3	94.0
4. Verdict, WDG+ adjuvant BioPower, SL - 0.3 kg/ha + 0.5 l/ha	72.8	81.5	76.8	87.8	96.0	93.0	87.5	96.5	94.3	80.5	87.5	85.0	78.3	85.5	83.5
LSD$_{0.05}$	3.3	1.6	1.9	3.3	2.7	2.1	2.5	1.0	1.3	1.9	1.9	2.1	2.3	1.9	1.8
2020															
1.Tarzek, WG+ Surfer SL 0.075 kg/ha + 1.0 l/ha	84.3	94.3	92.0	85.5	94.5	93.0	86.5	95.5	93.5	82.5	93.5	91.5	81.3	92.3	90.3
2. Tarzek, WG+ Surfer SL - 0.09 kg/ha + 1.0 l/ha	88.3	97.3	96.3	89.3	96.5	95.5	90.3	97.5	96.5	85.5	96.5	95.5	84.5	95.5	94.5
3. Pallas 45, OD - 0.5 l/ha	82.5	92.3	90.3	0	0	0	84.5	93.5	92.0	80.5	93.0	89.5	79.3	90.3	88.3
4. Verdict, WDG+ adjuvant BioPower, SL - 0.3 kg/ha + 0.5 l/ha	83.5	93.0	91.0	84.5	93.5	91.5	85.5	94.5	92.5	81.5	92.5	90.5	79.5	90.5	88.5
LSD$_{0.05}$	1.8	1.4	2.1	1.6	1.7	2.0	1.9	2.0	2.4	2.0	3.6	2.0	1.8	1.8	1.8

* Day - days after treatment.