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Effect of Phytosanitarnary Products on Yield and Grain Quality of Winter Wheat in the Conditions of Central Non-Chernozem Region of Russia

Congera Alexandre[1,2,*], Barry Mamadou[2], Joseph Nyambose[2], Polityko PM, Basakin MP[3], Nazih Y Rebouh[4] and Vedenski VV[2]

[1]Burundi Institute of Agricultural Sciences (ISABU), Avenue de la Cathédrale,Bujumbura P.O. Box 795, Burundi

[2]Department of Crop Productions, Peoples' Friendship University of Russia (RUDN University), 117198 Moscow, Russia

[3]Federal Research Center Nemchinovka, 6 Agrochemists Street, village Novoivanovskoe, Odintsovo district, Moscow region, 143026, Russia

[4]Department of Environmental Management, Peoples' Friendship University of Russia (RUDN University), 117198 Moscow, Russia

[*]**Corresponding Author:** Congera Alexandre, Burundi Institute of Agricultural Sciences (ISABU), Avenue de la Cathédrale,Bujumbura P.O. Box 795, Burundi, Tel: +79778550030, E-mail: ac286448@gmail.com

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Abstract

The use of pesticides for ensuring high and stable winter wheat yields is one of the issues in winter wheat growing. Field experiments were conducted at the Federal Research Center Nemchinovka, in the Central Non-Black Earth region of Russia, over a period of 2 years (2021 to 2022). This study aimed at evaluating the effect of different phytosanitary products on the productivity and quality of winter wheat varieties with respect to intensity levels i. e. basic, intensive, and high intensity. Treatments included fertilizers, pesticides (fungicides, herbicides, insecticides) and growth regulators in different combinations and concentrations. Three varieties of winter wheat have been studied: Nemchinovskaya 85, Moskovskaya 40 and Moskovskaya 27. Insecticides (Picus 1.0 l/t, Danadim Power 0.6 l/ha, Picus 1.0 l/t + Danadim Power 0.6 l/ha, Picus 1.0 l/t + Vantex 60ml/ha, Picus 1.0 l/t + Vincite forte 1.5 l/t and Picus 0.7 l/t + Vantex 50ml/ha), fungicides (Impact Exclusive, 0.75 l/ha, Alto Super 0.5 l/ha, Consul, KS, 0.8 l/ha + Consul 1.0 l/ha and Consul, KS, 0.8 l/ha) and herbicides (Aton 0.06 kg/ha + Agroxon 0.5 l/ha + Foxtrot 1.0 l/ha, Accurate Extra 35g/ha + Foxtrot 1.0 l/ha + Agroxon 0.5 l/ha, Tandem 0.03kg/ha + Foxtrot 1.0 l/ha, Tandem 30g/ha + Foxtrot Extra 0.4 l/ha + Agroxon 0.5 l/ha and Lintur 180g/ha) confirmed their efficiency.

Nemchinovskaya 85 increased a yield of 1.14-3.10t/ha, Moskovskaya 27: 0.64-3.62t/ha and Moskovskaya 40: 0.71-3.21t/ha. Results may be useful in developing winter wheat cultivation practices aimed at increasing yields and improving grain quality.

Keywords: Winter wheat; grain yield; pesticides; wheat productivity; wheat varieties; nonchernozem Zone

Introduction

These last years, grain is the most important part of the world agricultural economy. The food security and well-being of countries are ensured by the level of cereal production as well as the capacity to increase the economic and political importance of the State in the world community [1]. Grain occupies the first place in the human diet and is essential for animal feed. According to the food and agricultural organization of the United Nations (http://www.fao.org/faostat/en/#data, accessed on 12 March 2023), world wheat production is about 770,87 million tons on a harvested area of 220,76 million ha. China, India, Russia and the United States occupy more than 50% of the total area of cereals cultivated in the world [2].

Research has shown that wheat is one of the oldest crops on the planet [3]; in Europe and Asia, it began to be cultivated in prehistoric times. More than 6.5 thousand years ago, wheat was known in Iraq, Egypt and Asia Minor, it was sown for 6000 years BC, for 3000 years BC, wheat was sown in China, Turkmenistan, Georgia, Armenia and Azerbaijan, and traces of its cultivation in the 4th millennium BC. [4,5].

The Russian Federation is currently one of the largest producers and exporters of soft wheat [6]. The total area occupied by winter and spring wheat is constantly expanding and amounts to about 28,9 million ha area harvested (Federal State Statistics Service. Available online: https://rosstat.gov.ru/compendium/document/13276, accessed on 18 March 2023). There has been a significant increase in the yield of winter and spring wheat varieties over the past two decades, due to the introduction and development of new high-yielding wheat cultivars. Winter wheat occupies the main sowing areas in Europe and the United States, while spring wheat predominates in the Russian Federation and Canada. Wheat has been shown to be one of the most important, valuable, and productive grain crops [7]. The grain of wheat provides a major share of protein (20%), calorie intake (19%) from consumption [8] and carbohydrate (80%) content for the world's population, and the value and need to increase the production is recognized widely [9]. It is widely used with spring wheat, in the bakery, pasta, confectionery industry.

Several measures and methods of caring for winter wheat crops should be applied to achieve a higher grain yield. These maintenance measures and methods therefore aim to create conditions guaranteeing better plant safety during the autumn-winter and spring-summer periods. To achieve this, plant protection is mandatory for the cultivation of high-quality winter wheat to prevent crop losses due to pests, diseases, and weeds at minimal cost.

Crop protection has been an ancestral concern since the first agricultural peoples. In the eighth century BC, plant extracts were used to protect grain stocks and biological control methods were already in use in Chinese orchards. Protection strategies were then essentially based on mechanical and biological control. During the 19th century, pathogens carried by commercial expansion caused a succession of dramatic events for crops and populations, thus reinforcing the need for protection. At the end of the Second World War, the marketing of synthetic substances generated new hope for direct struggle and extermination [10].

Chemical control has remained the spearhead of crop protection since the middle of the 20th century. The global strategy for the development of agricultural production has contributed for more than 50 years to a considerable increase in the use of agricultural inputs, in particular synthetic pesticides, to reach today 2.5 million tons used each year [10] .

The use of comprehensive protection measures against pests, weeds and diseases ensures obtaining high yields and high-quality grain products [11–13]. By effectively using phytosanitary products, the production of food grain winter wheat can be increased by 1.5-2 times [14] (O.B et al., 2017).

The protection of winter wheat crops appears as a sustainable strategy for plant protection against crop pests, satisfying the economic, ecological and health requirements facing agriculture. The use of herbicides, fungicides and insecticides is one of the important factors in the intensification of cereal production [10].

The aim of this research is to substantiate the prospects of using plant protection products to improve grain yield and quality of grain and to mitigate the adverse effects of pathogens responsible for winter wheat disease, when grown in the Central Non-Chernozem region of Russia.

Materials and Methods

The research was conducted in 2021-2022 at the experimental field station of the Federal Research Center “Nemchinovskaya”. The experimental field station of the Federal Research Center "Nemchinovskaya" is in the usual conditions of the non-Chernozem zone for the central region of the Russian Federation.

Soil Characteristics

The soil is medium sodo-podzolic loam. To record the initial characteristics of this soil, samples were taken randomly from different locations at 0-15 cm. Field experiments were conducted on fields no 2 and 5 of a five-field rotation. A field survey conducted in 2020 and 2021 showed that the soil was characterized by a reaction that was within the limits of pHsalt. 4,3 – 5,7. Mobile phosphorus content was 155-316 mg/kg, mobile potassium availability was (125-181 mg/kg).

Climatic Conditions

Weather conditions for winter crops were generally described as favorable. The hydrothermal coefficient of the winter wheat growing season was 1,50-1,52 i.e. the year of water supply was optimal. In September-early November, an average daily air temperature of 5°C- 9,7°C. In winter, the plants remained in good condition, the spring conditions allowed the plants to develop normally. Snow cover established in the second decade of December with daily mean air temperature fluctuations ranging from -3.7°C to -5.3°C. The average annual temperature is +4.90°C. The average temperature of the hot season (May-August) is +15.98°C. The average temperature of the cool season (November-March) is -5.04°C. The average precipitation from May to September is 293.3 mm. The average annual rainfall is 623.75 mm: 56% in the spring-summer season and 26% in autumn.

Treatments

The experiments were carried out during 2021-2022 according to a two-factor scheme. Field area - 1.5 ha, under experiment - 1.2 ha. The total size of the plot for each technology is 40 m^2, the accounting area is 10 m^2, the repetition is four times. After harvesting the predecessor, the soil was twice disked by the Katros tillage unit. Then fertilizers were applied, the soil was cultivated and after 14 days it was produced with the Amazone seeder. The seeding rate for winter wheat varieties was 5 million germinating grains per ha.

Varieties of winter wheat (factor A) were placed in experimental variants differing in the level of application of plant protection products - basic technology (1), intensive (2), high-intensity (3) (factor B). Sowing was carried out according to the following norms: winter wheat – 5 million germinating grains per hectare.

Characteristics of winter wheat varieties (factor A)

Variety Nemchinovskaya 85 has the following qualities: mid-season, winter-hardy, resistant to waterlogging, resistant to lodging. Resistant to major types of diseases, such as snow mold, brown rust, powdery mildew, Septoria. The average yield for 3 years of testing was 8.27 t/ha, the maximum yield was 11.63 t/ha. The content of protein in grain is 14.4%, gluten in flour is 33.8%.

Cultivar Moskovskaya 27 has high winter hardiness, field resistance to powdery mildew, brown and stem rust, and Septoria. The variety is resistant to lodging, forms a larger grain and a greater number of productive shoots per unit area. The average yield for 3 years was 8.64 t/ha. Plant height - 90 - 95 cm. Protein content in grain - 15.5%, gluten content up to 27.2%. The nature of the grain is 816 g /l, the weight of 1000 grains was 44-47 g.

Cultivar Moskovskaya 40 is highly adaptive, short--stemmed, winter-hardy, resistant to lodging, resistant to leaf rust, powdery mildew, and common smut. The protein content in grain is 15%, raw gluten in flour is 33.7%. The average yield for 5 years was 6.74 t/ha, the maximum - 7.36 t/ha. Weight of 1000 grains - 45 - 48 g.

Technologies (factor B)

The following drugs FMS limited liability company (LLC) Vincit, KS (0.25 g/l flutriafol + 25 g/l thiabendazole), Vincit Forte, UK (37.5 g/l flutriafol + 25 g/l thiabendazole + 15 g/l imazalil), Pikus, UK (600 g/l imidacloprid), Tandem, VDH (200 g/l l florasulam + 600 g/gatribenuron-methyl), Foxtrot, VE (phenoxaprop-p-ethyl 69 g/l + 34.5 g/lcloquinoset-mexil), Aton, VDH (tifensulfuron-methyl 750 g/ha), Sapress, EC (250 g/l trinexapak-ethyl), Impact Super, SC (75 g/l flutriafol + 225 g/l tebuconazole), Impact Exclusive, SC (117.5 g/l flutriafol + 250 g/l carbendazim), Alto Super EC (250 g/l propiconazole + 80 g/l cyproconazole), Consul, CS (125 g / l flutriafol + 125 g / l azoxystrobin), Vantex, ISS (60 g / l gamma-cyhalothrin), Danadim Power, EC (6.4 g / l gamma-cyhalothrin + 400 g / l dimethoate) in field conditions on varieties of winter wheat were used to provide a biological efficiency.

Basic technology - designed for a planned yield of 5 - 6 t/ha. The plant protection system is represented by a tank mixture of herbicide, insecticide, and fungicide (Lintur 180 g/ha + Danadim 1 l/ha + Impact SC 0.5 l/ha), which were applied only in autumn. In the spring protection according to the forecast.

Intensive technology - the planned yield is 6 - 8 t/ha. Since autumn - plant protection products - Lintur 180 g / ha + Vantex 0.06 l / ha + Impact SK 0.5 kg / ha, in spring - insecticide Danadim 1 l / ha + Alto super fungicide 0.5 l/ha + Sapress retardants 0.4 l/ha (phase GS 21 - 22). In the spring, in the presence of bluegrass weeds, Foxtrot 1.0 l/ha + Agroxon 0.5 l/ha, Sapress 0.3 l/ha (phase GS 31-32) were used. Fungicides Impact Super 0.75 l/ha + Danadim Power 0.6 l/ha. Ear protection according to the forecast.

High-intensity technology - planned yield is 8 - 10 t/ha. From autumn - use of plant protection products - Accurate Extra 35 g/ha + Danadim Power 0.6 l/ha, Impact Exclusive 0.5 l/ha, in spring - Aton 60 g/ha + Tandem 30 g/ha, Vanteks 60 ml / ha + Capress 0.3 l/ha (phase GS 21 - 22) + Impact Exclusive 0.5 l/ha; Impact Super 0.75 l/ha + Sapress 0.3 l/ha (phase GS 31 - 32) + Foxtrot 1.0 l/ha + Consul 1.0 l/ha + Danadim Power 0.6 l/ha; to protect the flag leaf and ear - Consul 1.0 l /ha + Vantex 60 ml / ha.

For all technology options, the seeds were treated with Vincite forte 1.25 l/t and Picus 1 l/t. Spraying of crops was carried out with Amazone US-605 machine. Varieties of winter crops were sown on the predecessor of annual grasses on September 07, 2020 (field no 5) and 13, 2021 (field no 2). Field area - 2.0 ha, under experiment - 1.0 ha. The total size of the plot is 160 m2, the accounting area for varieties is 30 m2, the repetition is four times, the agricultural technique for cultivating winter crops is generally accepted for the Central region of the non- Chernozem zone. Preparation of the field for sowing included plowing green manure and harrowing. Cultivation to a depth of 10-12 cm. Mineral fertilizers were applied at the planned level of yield (basic 4-5 t, intensive 6-8 t, high-intensity 8-10 t/ha), cultivation to a depth of 4-5 cm with rolling (unit "Katros). Winter wheat was sown with Amazone D 9 seeder. Harvesting was carried out by direct combining with a Sampo-500 combine.

During the years of research, observations were made of the water regime, agrophysical properties, the content of nutrients in the soil, phytometric and photosynthetic parameters of plants (according to generally accepted state standards). The structure of the crop, the yield of varieties, the quality of grain, protein and the nature of grain were determined according to existing methods and GOSTs.

The experiments were carried out according to the following methods: "Experimental work in field farming." The team of authors of the Scientific Research Institute of

Agriculture of the TsRNZ. Rosselkhozizdat. 1982. - 190 p.; "Methodology of state variety testing of agricultural crops". Cereals, cereals, legumes, and fodder crops. Issue 1., M., 1985, 269 p.; Issue 2 M., 1989, 194 p. and considering the appropriate adapters. Statistical processing of the research results was performed according to B.A. Armor (1985) in the computer version of "AGROS" 2.07.

Results and Discussion

Biological effectiveness of insecticides on winter wheat

Analysis of the results of overwintering showed that the intensification of protective measures and the enrichment of the soil with nutrients make it possible to create optimal conditions for plants in the initial period of life and development. The prevailing weather conditions were favorable for the development of snow mold, powdery mildew, brown rust, Septoria blight, and wireworms, bedbugs, ground beetles, leafhoppers, aphids (especially on the ear) prevailed among pests. When treating seeds, Picus 0.7 l/t was used and when treating vegetative plants Vantex 0.06 l/ha. When seeds were treated with Pikus 1.0 l/t, damage to winter and spring wheat crops by leafhoppers, Swedish fly, wireworm, grain striped flea beetle and other pests decreased (Table 1).

Table 1: Biological effectiveness of insecticides on winter wheat, %

Options	Biological efficiency, %				
	Wireworm	Bugharmfulturtle	Swedishfly	Leafhoppers	Others
Picus 1.0 l/t	92,5	77	78,5	84,5	95,5
Danadim Power 0.6 l/ha	98	98	70	75	99
Picus 1.0 l/t + Danadim Power 0.6 l/ha	98	99	78	84	99
Picus 1.0 l/t + Vantex 60 ml/ha	95	94	82	96	99
Picus 1.0 l/t + Vincite forte 1.5 l/t	90	78	73	75	95
Picus 0.7 l/t + Vantex 50 ml/ha	91	90	77	91	94
Control (plant damage, %)	19,25	4,15	0,45	21,30	1,70

There is a decrease in plant damage by pests with varied use of insecticides. When vegetative plants were treated with Danadim Power 0.6 l/ha, damage to plants by wireworms decreased by 98%, by leafhoppers by 75%, by Swedish fly by 70%, by bug 98% and other pests by 99%. The biological efficiency of using Vantex 60 ml/ha against the background of seed dressing Picus 1.0 l/t was from 82 to 99% for the above pests. Thus, the use of the drug Pikus as a seed disinfectant and the treatment of crops during the growing season with insecticides Danadim Power or Vantex provides a reduction in plant damage by pests and helps to preserve the crop. This was reflected in the structure of the crop and the yield of winter wheat varieties. Protection of plants from damage contributes to the better development of cultivated plants, the formation of high-quality grain. These findings support research by Peng Zhang [15] which suggests that imidacloprid and clothianidin seed treatments may prevent yield loss and wheat aphid infestations throughout the winter wheat growing season. Protection of plants from damage contributes to the better development of cultivated plants and the formation of high-quality grain. The drug is most effective at a dose of 1.0 l/t. Plants leave in the winter period developed, with a supply of nutrients, which ensures their successful overwintering.

Biological effectiveness of fungicides for winter wheat

The development of snow mold in the spring after the snow melted was 14,75%. Further in the growing season, powdery mildew was noted about 14,8%, leaf rust 8%, Septoria – 5,85%, Fusarium head blight – 1,6% and root rot – 5,85%. The use of new generation fungicides Impact Exclusive, Alto Super, Consul effectively suppressed the development of epitaphs of fungal diseases. The best efficiency was obtained with the double application of Consul 0.8 l/ha (booting phase) and Consul 1.0 l/ha (earing phase). Biological efficiency varied by disease from 91 to 99%. Efficiency Impact Exclusive 0.75 l/ha to a greater extent contributed to the reduction of the phytosanitary state of Fusarium 90,5% and Septoria 92,5%. Good indicators in terms of biological efficiency were also obtained in the variant with the use of Alto Super fungicide 0.5 l/ha. The development of diseases was reduced by 82,5-94,5% (Table 2).

Table 2: Biological effectiveness of fungicides for winter wheat, %

Options	Rootrot	Snowmold	Powderymildew	Septoria	Leaf rust	Fusariumhead blight
Impact Exclusive, 0.75 l/ha	64,5	81,5	78	92,5	85,5	90,5
Alto Super 0.5 l/ha	82,5	91	87	94,5	94,5	93
Consul, KS, 0.8 l/ha + Consul 1.0 l/ha	91	95	98,5	98	99	97,5
Consul, KS, 0.8 l/ha	87,5	90	92	93	95,5	93,5
Control	5,85	14,75	14,8	5,85	8	1,6

The development of snow mold in the control on winter wheat reached 14,75%, powdery mildew 14,8%, leaf rust 8%, Septoria and root rot 5,85%. The biological effectiveness varied depending on the disease and the applied fungicide. The best efficiency was obtained when using Consul 0.8 (phase exit into the tube) and Consul 1 l/ha (heading phase). Biological efficiency varied depending on the disease and amounted to 91 - 99%.

Yield loss of genotypes susceptible to leaf rust varied from 30% to 60% and genotypes resistant responded positively to fungicide protection, with 10–30% average yield range increases [16]. The findings of Sharma [17] revealed that stripe rust reduced grain yield from 24 to 39% and 1000-kernel weight and from 16 to 24%. Septoria leaf blotch can cause up to 60% wheat yield loss and preventative application of Pyraclostrobin and Fluxapyroxad can increase approximately 20% wheat yield [18]. Among Caramba, Stratego YLD, Priaxor, Prosaro, and Trivapro fungicide products applied curatively to treat Powdery mildew (Blumeria graminis) of wheat, Kleczewski et al. [19] revealed that Priaxor provided 11 to 18% less activity than other fungicides. Powdery mildew challenges Bacillus amyloliquefaciens strain QST 713 suspension concentrate (Serenade®ASO) as a standalone control measure [20].

Numerous studies showed the different effects of fungicides application on Fusarium spp. reduction; but in field experiments, the efficacy of fungicides is often examined exclusively without herbicidal protection. Buśko et al. [21] and Masiello et al. [22] respectively noticed that 250 mg L−1 of propiconazole and metconazole (1 l/ha), tebuconazole (1 kg/ha), prochloraz (1.1 l/ha) and prothioconazole (0.8 l/ha) singly applied are effective fungicides against Fusarium spp. Under field conditions, Lozowicka et al. [23] indicated that the use of a sulfonylurea herbicide (26.5 g/ha) combined with propiconazole and cyproconazole (a total of 200 ml/ha) and spiroxamine, tebuconazole, and triadimenol (a total of 600 ml/ ha) fungicides is the best strategy to reduce Fusarium spp. in wheat. Xia [24] indicated that combination of moderately resistant cultivars and fungicides reduced total deoxynivalenol by 67%, Fusarium-damaged kernels by 49%, Fusarium head blight index by 86%, and increased yield by 21-32%. Bolanos-Carriel et al. [25] suggested that application of Prosaro (prothioconazole + tebuconazole) at early anthesis is the most effective fungicide treatment in reducing Fusarium head blight and yield loss. Scarpino et al. [26] reported azole fungicides (prothioconazole) to be the most effective active substances in the control of Fusarium head blight and in the reduction of prevalence of mycotoxins that occur in cereal grain such as deoxynivalenol. Application of foliar Prosaro (prothioconazole + tebuconazole) reduced disease severity up to 84% [27].

The fungistatic activity against pathogens realized by (Нuу et al., 2016) in vitro against Fusarium spp. demonstrated that the treatment of winter wheat grains with seed disinfectants (Dividend Extreme 0.75 l/t (92 g/l difenokonazol + 23 g/l mefenoksam), Lamador 0.2 l/t (250 g /l protiokonazole + 150 g/l tebuconazole), 0.6 l/t Benefis limited the development of Fusarium disease etiology with an efficiency of 66.8 - 83.5%.

The effectiveness of herbicides in winter wheat crops

The fight against weeds in modern technologies for the cultivation of new crops is relevant not only at the present time, but also in the future. We have determined the species composition of weeds on winter crops. The following types of weeds were noted: chicken millet (33.2%), marshwort (11.6%), medium chickweed (10.3%), field violet (7.3%), white gauze (6.5 %), odorless chamomile (5.6%), field bluegrass (4.3%), broomstick (3.0%), pikulnik and gray bristles (2.2%), field yaruka, tenacious bedstraw and pharmacy fumes (1.7%), shepherd's purse (1.3%), roofing skerda, sow thistle species, medicinal dandelion, etc. from 0.4 to 1.3% (Table 3).

Table 3: The effectiveness of herbicides in winter wheat crops

Options	Number of weeds, pcs/m2			Biological efficiency, %	
	Beforeprocessing	Afterprocessing	Beforecleaning	Afterprocessing	Beforecleaning
Aton 0.06 kg/ha + Agroxon 0.5 l/ha+ Foxtrot 1.0 l/ha	229	4	2	98	99
Accurate Extra 35 g/ha + Foxtrot 1.0 l/ha + Agroxon 0.5 l/ha	236	11	3	95	98
Tandem 0.03 kg/ha + Foxtrot 1.0 l/ha	232	10	5	96	98
Tandem 30 g/ha + Foxtrot Extra 0.4 l/ha + Agroxon 0.5 l/ha	241	5	2	98	99
Lintur 180 g/ha	231,5	18	13	92	94
Control	238	238,5	206	–	–

In experiments to study the responsiveness of new and promising varieties of winter wheat to herbicides with different cultivation technologies, Aton 60 g/ha, Accurate Extra at a dose of 35 g/ha, Tandem 30 g/ha, Agroxon 0.5 l/ha - high-intensity and intensive technologies, and Lintur 180 g/ha were used with basic technology. The biological efficiency of Tandem 0.03 kg/ha + Foxtrot 1.0 l/ha was 96-98%, Tandem 30 g/ha + Foxtrot Extra 0.4 l/ha + Agroxon 0.5 l/ha - 98- 99%, Accurate Extra 35 g/ha + Foxtrot 1.0 l/ha + Agroxon 0.5 l/ha -95-98%, Aton 0.06 kg/ha + Foxtrot 1.0 l/ha - 98 - 99%, Lintur 180 g / ha - 92 - 94% (Table 3). The applied herbicides at the time of the beginning of earing and until full ripening suppressed the development of weeds well and ensured high biological efficiency. This, of course, affected the yield. According to many years of research, it is known that when using highly effective herbicides, yield increases reach 0.7 - 1.5 t/ha.

Several studies have been carried out by many researchers to control weeds in winter wheat crops. For effective weed control in early planting of winter wheat, wheat seeds should be treated prior to planting with a growth promoter at a rate of 50 ml/t, autumn herbicide Caliber 75 pg application, consumption rate of 50 g/ha + Trend 90 surfactant consumption rate of 0.2 l/ha in the 3rd leaf phase of wheat and a foliar application of Quantum-Grain microfertilizer at the consumption rate of 1.0 l /ha in the spring period will reduce weeds by up to 91.9% [28]. The findings of Bayat and Zargar [29] revealed that application of Pyroxasulfone at the wheat tillering stage affected the control of field bindweed ranging from 69 to 90%. Autumn applications of herbicide mixtures of trifloxysulfuron, simazine, Smetolachlor, or mesotrione controlled resistant annual bluegrass phenotype 84 to 98% in spring [30]. Barua et al. [31] found that amicarbazone and terbuthylazine were most Poa annua control effective for spring and autumn application whereas pyroxasulfone and s-metolachlor only provided moderate control in both the autumn and spring, reducing P. annua occurrence by 50%. Flumioxazin at 0.43 kg ha−1 controlled ≥ 95% of annual bluegrass up to two tillers [32]. Patton et al. [33] suggested that the availability of methiozolin and bispyribac-sodium would provide needed options in Poa annua control system. The results of studies conducted by Bobrovsky et al. [34] showed that the use of a mixture of Lastik Top, MKE + Magnum Super, VDG allowed a yield increase of 1.06 t/ha or 39.6% while a mixture of Lastik Extra, KE + Ballerina Super, SE – 1.08 t/ha or 40.0% relativeto control. The findings of Mitkov et al. [35] reported that combine application of Pallas 75 WG (75 g/kg pyroxsulam) + Derby Super (150.2 g/kg florasulam + 300.5 g/kg aminopyralid-potassium) recorded the highest herbicide efficacy and the highest yield (5.78 t. ha^{-1}).

When considering the results of the action of herbicides, we confirmed that winter wheat, as a highly competitive crop, enhances the effect of herbicides on weeds, especially if wheat plants have favorable conditions for growth and development. Here, a kind of synergistic effect arises, in which the competitiveness of wheat plants in relation to weeds and the action of herbicides are mutually enhanced. Therefore, the use of herbicides in the applied cultivation technologies ensured their high biological efficiency in relation to weeds and increased with higher technology. In particular, therefore, the use of herbicides ensured their high biological efficiency in relation to weeds and increased with higher technology. According to our long-term observations, when using highly effective herbicides, yield increases reach 0.8 - 1.3 t/ha.

Yields of winter wheat varieties in technologies of varying degrees of intensity

The use of timely sowing treatments with phytosanitary products and mineral fertilizers ensured an increase in the yield of the studied varieties of winter wheat. In the 2021 year, the best response to phytosanitary products and mineral nutrition was observed in the Moskovskaya 27 variety (Table 4).

Table 4: Yields of winter wheat varieties in technologies of varying degrees of intensity, (2021 and 2022)

Variety (Factor A)	Technology (Factor B)	2021			2022		
		Average Yield	**Supplement to base T/ha %**		**Average Yield**	**Supplement to base T/ha %**	
Nemchinovskaya 85	1	6,44	-	-	4,52	-	-
	2	9,15	2,71	42	5,66	1,14	25,2
	3	9,54	3,10	48	6,43	1,91	42,2
Average by variety		7,65	-		5,53	-	
Moskovskaya 27	1	7,21	-	-	5,91	-	-
	2	9,96	2,75	38	6,55	0,64	10,8
	3	10,83	3,62	50	7,15	1,24	20,9
Average by variety		8,56	-		6,53	-	
Moskovskaya 40	1	6,13	-	-	4,62	-	-
	2	8,81	2,68	44	5,33	0,71	15,3
	3	9,34	3,21	52	6,24	1,62	35,0
Average by variety		7,44	-		5,39	-	
Average Factor B		1	2	3	1	2	3
		6,59	9,31	9,90	5,02	5,85	6,61
Supplement to base							
T/ha		–	2,27	3,31	–	0,83	1,59
%		–	41,33	50,0	–	16,53	31,67

With the basic technology, it was 6.59 t/ha; 9.9 t/ha with an increase of 3.31 t/ha (50%) at high intensity. The grain harvest per hectare of Moskovskaya 27 increased with an increase in the level of cultivation intensification from 7.21 t/ha to 10.83 t/ha. yield was 6.59 t/ha for the basic technology. The increase in yield was 2.27 t/ha (41.33%) for the intensive and 3.31 t/ha (50%) for the high intensity. On average, the Moskovskaya 27 and Nemchinovskaya 85 varieties gave more than 9 tons of cereals per hectare, or more than 2 t/ha more. In comparison between varieties, there is a significant increase in grain yield. The yield of the Moskovskaya 40 variety by technology ranged from 6.13 to

9.34 t/ha. With an increase in cultivation intensity of the Moskovskaya 40 variety, its yield increased from 8.81 t/ha to 9.34 t/ha, and the yield increase was 2.8–3.21 t/ha (44-52%) compared to basic technology.

The yield of winter wheat varieties in 2022 increased with an increase in the level of intensification of their cultivation (Table 4). The climatic conditions of the year had a decisive influence on the level of crop yields. Years characterized by a lack of precipitation, especially in summer, as a rule, there is a shortage of grain harvest. However, the implementation of measures for the use of fertilizers and phytosanitary products made it possible to ensure the average yield of winter wheat for varieties up to 5.85-6.61 t/ha of grain respectively in technology intensive and high intensity. The increase in yield was 0.83 t/ha (16.53%) for the intensive and 1.59 t/ha (31.67%) for the high intensity.

The findings of Yuan et al. [36] identified application of 2% imidacloprid controlled-release granule and 0.2% imidacloprid pesticide-fertilizer controlled-release granule on winter wheat as an effective way to enhance the pesticide utilization rate and ensure adequate yield. Average yield of wheat crops increased by more than 98% worldwide and part of this dramatic yield increase is due to the increasing use of pesticides [37]. Yields from low fertilized or unfertilized fields do not show an increase progress in yield significantly [38]. The results of Sokólski et al. [39] corroborate our study when he suggests that high-input production technologies were more profitable because the resulting increase in wheat seed yield. The findings of Loyce et al. [40] indicated that a decrease in input level of N fertilizer, fungicides, growth regulator resulted in loss of productivity. Wheat yield increase has generally been accompanied by an increased input of external resources such as mineral fertilizers and pesticides [41]. Rempelos et al. [42] found that the use of herbicides, fungicides, and growth regulators reduces foliar disease severity.

In contrast, Gaba et al. [43] suggested that that reducing the use of herbicides by up to 50% could maintain crop production. The results of Bezuglova et al. [44] showed that the application of sulfonylurea herbicide induced a chemical stress on winter wheat plants. Guo et al. [45] suggested that if pesticides are used in a timely fashion and at the appropriate stage, their use may be greatly reduced with the help of an insect-trapping lamp.

Conclusion

The adoption of high-yielding cultivars and a greater use of external inputs, such as pesticides and nitrogen fertilizer, have resulted in higher yields for winter wheat. This study has shown that a system of integrated phytosanitary treatments using several active molecules, in particular fertilizers, fungicides, herbicides, insecticides, and growth regulators, at the different concentrations mentioned in this article, therefore ensured optimal protection. against winter wheat plant diseases and increased yield performance and grain quality. The results obtained in this experiment showed that when setting up a protection system, the normative method must consider the varietal characteristics, the nutritional conditions of the plants, the agrochemical characteristics of the soil and meteorological factors. Farmers' practices in winter wheat crops mostly focus on combining high-yielding cultivars with an intensive crop management system (such as intensive or high intensity technology). The results of this study open up real opportunities for large-scale implementation of the treatments tested in different regions of the Russian Federation.

Author Contributions

Conceptualization, Congera Alexandre; methodology, Congera Alexandre and Basakin MP, software, Rebouh Nazih Yacer, validation, Polityko PM, Nazih Y Rebouh and Vedeski VV, formal analysis, Basakin MP, investigation, Congera Alexandre, resources, Congera Alexandre and Joseph Nyambose, data curation, Vedenski VV and Basakin MP, writing-original draft preparation, Congera Alexandre, writing-review and editing, Barry Mamadou, visualization, Polityko PM, supervision, Vedenski VV and Basakin MP, project administration, Basakin MP. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest.

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