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Crop Yield and the Quality of Sunflower Seeds in the Use of Fertilizers and Growth Regulation Substances

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Abstract: In the Russian Federation the most favorable area for high and stable yields of sunflower crop is the Northern zone of Krasnodar region. The research was conducted in multivariate experience of long-term stationary monitoring. We researched the effect of doses of mineral fertilizers and furolan on sunflower yield and seed quality. It was found that it is expedient and cost-effective to use small doses of nitrogen fertilizers for sunflower. The expediency of application of plant growth regulator (Furolan) during vegetation is shown. We found that the use of mineral fertilizers and the use of furolan contributed to the activation of growth processes of sunflower plants which led to the formation of optimal plant density. Improving the nutritional status of plants has provided an increase in the leaf area unit. The treatment of sunflower crops on the background of fertilizers $N_{20}P_{30}$ and the furolan has had a positive impact on the value of photosynthetic potential. Under the influence of mineral fertilizers there was an increase in the dissemination of the sunflower head, weight of seeds and weight of 1000 seeds, which has a positive impact on productivity. With the increase of fertilizer doses, the oil content of seeds increased when compared to the unfertilized variant. The treatment of plants with furolan has not violated the process of accumulation of protein and fat.

Keywords: Agro-environmental conditions, sunflower, dose of fertilizers, growth regulation substance, crop yield, quality of oilseeds

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Introduction

Yield (Kvashnin, 2008; Korobka *et al*., 2015; Malyuga *et al*., 2011; Neshchadim *et al*., 2015) and economic viability (Malyuga *et al*., 2011; Neshchadim *et al*., 2014b; Romanenko *et al*., 2010) are always a priority when growing crops. The quality of sunflower depends on several biological and morphological features (Penchukov *et al*., 2007; Zhuchenko *et al*., 2009), soil and climatic conditions of the region (Kvashnin *et al*., 2011; Sheudzhen *et al*., 2011; Stompel *et al*., 2009; Vasilko *et al*., 2010).

Sunflower is one of the most important oilseed crops. The sunflower oil contains substances with high nutritional value, including linoleic acid, phosphatides and fat-soluble vitamins A, D, E, and K. (Penchukov *et al*., 2007; Zhuchenko *et al*., 2009).

When yield formation is the preferred variety, its efficiency is determined by its genetic potential. (Goncharov, 2012; Kalaydzhyan *et al*., 2009; Prudnikov, 2013; Zhuchenko *et al*., 2009).

The feasibility and efficiency of cultivation of sunflower are also determined by agronomic techniques. In the technology of sunflower cultivation crop rotation, tillage system, application of chemical means of protection, (Goncharov, 2009; Neshchadim *et al*., 2014a; Neshchadim *et al*., 2014b; Neshchadim *et al*., 2015; Nenko *et al*., 2016; Nenko *et al*., 2017a; Dmitrieva *et al*., 2010; Yablonskaya *et al*., 2013; Yablonskaya *et al*., 2016a; Yablonskaya *et al*., 2016b; Yablonskaya, 2015) fertilizers (Baldini *et al*., 1996; Neshchadim *et al*., 2012; Sheudzhen *et al*., 2012; Romanenko *et al*., 2010) and sowing qualities of seeds are of great importance (Gaidukova *et al*., 2016; Goncharov and Zakharov, 2008; Goncharov, 2009; Prudnikov, 2013).

Proceeding from biological features of sunflower in the Krasnodar region, which is the most favorable region of the Russian Federation for obtaining high and stable yields of this crop. However, in the summer we can see the manifestation of drought that adversely affects productivity and quality of sunflower seeds.

The increased resistance to adverse weather conditions is possible only on the basis of detailed studying of physiological features of formation of productivity and the quality of seeds, which is a very important issue (Muromtsev *et al*., 1987; Neshchadim *et al*., 2012).

One of the ways to solve this issue is the use of drugs possessing anti-stress activity, which contribute to the improvement of sowing qualities of seeds and the increase in productivity and resistance of plants to stressful environmental factors (Goncharov, 2014; Kvashnin *et al*., 2011; Nenko *et al*., 2016; Nenko *et al*.,

2017a; Nenko *et al*., 2017b; Chesnyuk *et al*., 2008; Sheudzhen *et al*., 2012; Yablonskaya *et al*., 2013; Yablonskaya *et al*., 2016a; Yablonskaya *et al*., 2016b; Yablonskaya, 2015).

In the experimental research of growth regulators, a formulation, legal in the Russian territory Furolan (2-(2-furyl)-1,3-dioxolan), was used. The effects of which are expressed in terms of anti-stress activity (Nenko *et al*., 2016; Nenko *et al*., 2017a; Nenko *et al*., 2017b; Yablonskaya *et al*., 2013; Yablonskaya *et al*., 2016a; Yablonskaya *et al*., 2016b; Yablonskaya, 2015). In its structure it contains a furan cycle, which accounts for its low toxicity. Furolan is synthesized in the Problem Research Laboratory (KubSTU), quality indicators conform TU 2449-006- 02067862-2000.

Economic efficiency of sunflower cultivation is due to the increased productivity and improvement of technological indicators of the quality of seeds (Goncharov, 2014; Nenko *et al*., 2016; Nenko *et al*., 2017a; Nenko *et al*., 2017b; Yablonskaya *et al*., 2013; Yablonskaya *et al*., 2016a; Yablonskaya *et al*., 2016b; Yablonskaya, 2015). The potential for improving yields of this crop are grade, science-based crop rotation, rational fertilization system and the use of growth regulators (Neshchadim *et al*., 2012; Nenko *et al*., 2016; Nenko *et al*., 2017a; Nenko *et al*., 2017b; Penchukov *et al*., 2007; Prudnikov, 2013; Yablonskaya *et al*., 2013; Yablonskaya *et al*., 2016a; Yablonskaya *et al*., 2016b; Yablonskaya, 2015).

Materials and methods

The study included an investigation into the influence of fertilizers and growth regulator furolan on productivity and technological quality of seeds of sunflower in the conditions of Krasnodar region.

The experiments were conducted in the Northern zone of the Krasnodar region on the North Kuban agricultural experimental station in grass seed row crop rotation (GSRCP). Crop rotation in the GSRCP: winter wheat – sugar beet – winter wheat – maize – pea – winter wheat – sunflower – spring barley sowing under cover sainfoin – sainfoin (seed) – winter wheat.

The soil at the trial plot, the common chernozem, has a low humus content of 4.5–5.5 % and it is characterized by a considerable capacity of the humus horizon. The amount of total nitrogen is in the range of 0.22–0.33 %, phosphorus 0.16–0.19 %. The potassium content in the ordinary chernozem is 8–10 times higher than the reserves of nitrogen and phosphorus.

The experimental plot was organized as follows:

(1) Without fertilizers (control);
(2) N_{40};
(3) P_{60};
(4) $N_{20}P_{30}$;
(5) $N_{40}K_{30}$;
(6) $N_{80}P_{60}$;
(7) $N_{80}P_{120}$;
(8) The treatment of sunflower plants with an aqueous solution of furolan, where the consumption of the drug is 5 g/ha and 300 dm^3/ha, was conducted in the early phase of budding, in the variant with fertilizer – $N_{20}P_{30}$.

Total area 190 m^2 plot, accounting and 108 m^2. Repeatability of the experiment is fourfold.

Results and discussion

Phenological observations and determination of density of standing of plants was performed according to the methodology of State variety testing of agricultural crops.

Photosynthetic capacity was determined using A.A.Nichiporovich's method (Nichiporovich, 1961), the harvest – by the method of the all-Russian research Institute of oilseed crops. Germination of sunflower seeds, which determines the initial plant density accounted for 77.6–82.5 %, while the determining factor for obtaining complete germination was rainfall during the after-sowing period. By the end of the growing season a decrease in the number of plants per unit area of 9.1 and 10.4 % was observed (Table 1). The differences between the safety of the plants before harvesting was mathematically accurate in some versions of the experiment.

The survival rate of the plants during the growing season, primarily dependent on meteorological conditions, was confirmed by mathematical processing of the received data, the results obtained high correlation r = 0. 898.

Height is an important biometric indicator of the development of sunflower plants that characterize the variety or hybrid. The height and the habit of plants can be judged on their response to conditions of growth: mineral nutrition, weather conditions prevailing in the growing season of the crop and the density of plants per unit area. Improving nutrient status through fertilization contributed to the activation of plant growth. In the process of vegetation, from the

Table 1: The plant density of sunflower depending on the application of fertilizer and growth regulator (furolan), thousand pieces/ha.

Variant	The density of plants' standing, thousand pieces/ha		The decrease in plant density for harvest.	
	The beginning of vegetation	Before harvest	Thousand pieces/ha	%
Without fertilizers (control)	41.7	37.9	3.8	9.1
N_{40}	44.1	39.5	4.6	10.4
P_{60}	44.1	39.7	4.4	10.0
$N_{20}P_{30}$	44.4	40.3	4.1	9.2
N_{40} P_{60}	43.9	39.9	4.0	9.1
N_{40} P_{60} + N_{40} additional fertilizing	44.4	40.5	3.9	8.8
N_{40} P_{120} + N_{40} additional fertilizing	45.6	41.1	4.5	9.9
Cultivation with furolan, 5 g/ha	43.9	39.9	4.0	9.1
HCP_{05}	1.83	2.18	1.34	–

Table 2: Dynamics of linear growth of sunflower depending on the use of fertilizers and growth regulator (furolan) cm.

Variant	Period of determination			
	1–2 pair of current leaves	Composite flower's formation	Blooming	Yellow ripening
Without fertilizers (control)	4.9	114.7	169.5	171.7
N_{40}	5.0	114.6	173.2	174.7
P_{60}	4.9	114.5	171.8	173.4
N_{20} P_{30}	5.1	116.7	172.8	175.0
N_{40} P_{60}	5.1	117.9	174.5	176.5
N_{40} P_{60} + N_{40} additional fertilizing	5.3	119.2	175.7	177.9
$N_{40}P_{120}$ + N_{40} additional fertilizing	5.2	118.9	175.7	177.6
Cultivation with furolan, 5 g/ha	5.1	117.4	174.3	175.7
HCP_{05}	0.063	1.23	1.54	1.43

phase of formation of sunflower heads to flowering, the plant height increased. In the future, stem growth stops (Table 2).

In conditions of insufficient moistening of the Northern zone of the Krasnodar territory raising standards of fertilizer application had no significant effect on plant height in vegetation phases. It hardly had any impact on this figure and the treatment of crops with furolan.

Statistical analysis of the data showed the relationship between the height of sunflower plants and the applied doses of fertilizers. In this case there is a different dependence on the phases of growth and development. These differences resulted in the following regression equations: in the phase of 2–3 pairs of leaves $y = 0{,}0009\ x + 5{,}110$ ($R^2 = 0{,}397$), in the phase of formation of the sunflower head – $y = 0.011 \bullet x + 179$ ($R = 0.207$) in the phase of flowering – $y = 0.024 \bullet x + 177.1$ ($R^2 = 0.767$).

Close correlation between plant height and the applied doses of fertilizers was observed only in the flowering stage of plants with correlation coefficient $R^2 = 0.767$. Minimum value of leaf area index 1.186–1.193 and 1.185–1.328 was observed in the control variant and in the application of phosphorus (P_{60}). The results indicate the significance of the influence of all nutrients on the formation of photosynthetic capacity of sunflower plants (Table 3).

Table 3: The effect of fertilizer application and growth regulator (furolan) on the photosynthetic capacity of sunflower plants, million m^2/ha per day.

Variant	Period of determination			
	Seedlings – 2–3 pairs of current leaves	2–3 pairs of leaves – the formation of sunflower heads	Flowering formation	Flowering – yellow-brown ripeness
Without fertilizers (control)	0.104	0.400	0.245	–0.157
N_{40}	0.104	0.403	0.262	–0.181
P_{60}	0.137	0.452	0.284	–0.181
N_{20} P_{30}	0.144	0.477	0.282	–0.181
N_{40} P_{60}	0.170	0.561	0.381	–0.195
N_{40} P_{60} + N_{40} additional fertilizing	0.162	0.585	0.366	–0.188
N_{40} P_{120} + N_{40} additional fertilizing	0.164	0.575	0.380	–0.191
Cultivation with furolan, 5 g/ha	1.484	0.555	0.381	–0.190
HCP_{05}	0.053	0.029	0.027	–

Analysis of the data showed that the value of FSP is least affected by nitrogen fertilizers only (N_{40}). The increase in photosynthetic capacity of sunflower crops was observed from a phase of 2–3 pairs of true leaves to the complete education of the sunflower heads (Table 3). The magnitude of photosynthetic capacity according to variants of experience has made 0.400–0.585 million m^2/ha per day.

The greatest effect is observed with the joint use of nitrogen and phosphorus in the two fertilizers ($N_{40}P_{60}$ + N_{40} fertilizer.)

The processing of sunflower crops with furolan has a positive impact on the amount of photosynthetic potential. In interphase, the period of the formation of the sunflower head-flowering capacity of the photosynthetic capacity of sunflower sowing ranged 0.245–0.381 million m^2/ha per day. The high photosynthetic potential of crops is due to the duration of the interphase periods of 26 and 23 days and the significant area of leaf surface per unit area.

From complete flowering to yellow ripeness of sunflower the growth of leaf area was suspended until the first phase of yellowing of the sunflower head, and then, as the withering away of the leaves decreased gradually, and the early phase of the Browning of sunflower heads made 0.749–1.119 million m^2/ha per day. This is due to the intensive growth of the vegetative organs of plants until the end of flowering, and in the period from flowering to yellow ripeness an enhanced formation of reproductive organs occurs. Furthermore, in the phase of browning, the aging of plants, there is an outflow of plastic substances from leaves to reproductive organs, the loss of leaves reduces the photosynthetic surface of leaves.

Between the magnitude of photosynthetic capacity and the doses of fertilization a close correlation with the coefficient 0.796–0.821 was noted.

The determining factor in the evaluation of technological methods of cultivation of sunflower is productivity, which, like any other culture is formed from the individual elements of the structure inherent in a given culture. The basic elements of structure of yield of sunflower: plant density per unit area, number of seeds in a sunflower head, their implementations and weight, as well as the mass of 1000 seeds.

One of the fundamental elements is the plant density per unit area. As it was established, by the end of the growing season, stand density ranged from 37.9 to 41.1 thousand units/ha (Table 4).

Along with the plant density of a certain value are such factors as the diameter of the sunflower head, empty part of the sunflower head, and the number of full achenes in a sunflower head and their weight.

The dimension indicators of the inflorescence of a sunflower change under the influence of agronomical and environmental factors, such indicators are the number of seeds and weight of seeds from sunflower heads. The aggregate of these indicators is the value of the crop.

The empty part of the sunflower head in contrast to its diameter was more expressly pronounced on the applied fertilization systems. The highest percentage of the empty part of the sunflower head was observed in the unfertilized variants (22.1–22.4 %). The exclusion from the composition of the nutrients nitrogen and phosphorus (P_{60}, N_{40}) had a negative impact on the pollination

Table 4: The effect of fertilizer application and growth regulator (furolan) on the yield structure elements of sunflower.

Variant	The plant density, thousand pieces/ha	Blind-seed disease, %	The number of seeds in a sunflower head, piece	Weight of seeds with one sunflower head, g	The mass of 1000 seeds, g
Without fertilizers (control)	37.9	22.4	1090	67.1	61.3
N_{40}	39.5	21.5	1216	74.6	61.6
P_{60}	39.7	20.0	1207	75.5	62.7
$N_{20}P_{30}$	40.3	18.4	1246	77.5	62.8
$N_{40}P_{60}$	39.9	17.7	1247	79.6	63.3
$N_{40}P_{60} + N_{40}$ additional fertilizing	40.5	17.9	1271	78.8	62.7
$N_{40}P_{120} + N_{40}$ additional fertilizing	41.1	17.9	1222	79.4	64.6
Cultivation with furolan, 5 g/ha	39.9	17.9	1247	78.7	63.0
HCP_{05}	1.04	1.53	24	1.15	0.86

of the Central part of the sunflower head and the execution of the achenes. A positive result was obtained in fertilizer in combination $N_{20}P_{30}$ and $N_{40}P_{60}$. Further increase of doses of fertilizers to $N_{40}P_{60}$ and $N_{40}P_{120}$ practically did not change the value of this indicator. The empty part of the sunflower head has decreased in comparison with the control at 4.5–4.9 %.

Other important components of the magnitude of the harvest of sunflower seeds are the number of achenes formed in the sunflower head and their weight, the value of which is based on variants of experience which changed from 1090–1247, and their bulk from 67.1 to 79.6 g.

When analyzing the interaction of each element of the structure of crops with the largest collection of seeds per hectare a close correlation between the number of seeds and their weight was noted ($r = 0.648$), the weight between the weight of seeds and the yield of sunflower ($r = 0.621–0.624$). A clear dependence with mass of 1000 seeds ($r = 0.349–0.370$) was not observed.

Consequently, the fertilizer in combination with the application of a preparation furolan has a positive impact on the formation of productivity of the sunflower head, defining the value of the yield of sunflower.

Mineral fertilizers had a positive effect on the yield structure elements, which led to the increase in productivity of the culture. Under equal weather conditions, low productivity of sunflower was determined by a natural folding of the agrochemical supply control variants, where the average for the study years, the average yield of sunflower with fertilizer was made up of 2.69 t/ha (Table 5).

Table 5: Effect of fertilizer application and growth regulator (furolan) on sunflower yield, t/ha.

Variant	Output yield, t/ha	Augmentation to control
Without fertilizers (control)	2.69	–
N_{40}	2.94	0.25
P_{60}	2.98	0.29
$N_{20}P_{30}$	3.01	0.32
N_{40} P_{60}	3.10	0.41
N_{40} P_{60} + N_{40} additional fertilizing	3.11	0.42
N_{40} P_{120} + N_{40} additional fertilizing	3.09	0.40
Cultivation with furolan, 5 g/ha	3.08	0.39
HCP_{05}	0.24	–

Increasing the level of mineral nutrition through application of fertilizers, with different combination and ratio of nutrients, increased the seed productivity of sunflower on 0.25–0.42 t/ha.

The responsiveness of the sunflower plants to fertilizers, above all, depended on the availability of soil nutrients, so the reaction of culture on the same dose on different backgrounds of fertility has been uneven. The introduction of some phosphate fertilizers on the background of the systematic application of only phosphorus-potash and phosphate fertilizers, to the exclusion of the composition of the fertilizer of nitrogen, led to the increase in yield by 9–12%.

Based on the harvest, data suggest that the cultivation of sunflower in the crop rotations, with the use of different fertilization systems influencing the level of soil fertility, the norm of fertilizers should be reduced, because the increasing doses of fertilizers from medium to high do not provide a significant increase, showing a weak responsiveness of sunflowers to increase. The use of minimal doses $N_{20}P_{30}$ and treatment of plants by furolan has a positive impact on the yield of sunflower. Statistical processing of the data by the method of step-by-step multiple regression showed an average correlation between yield and content of major nutrients in the soil, expressed through the following regression coefficients: in the early phase of the vegetation period of the culture with mineral nitrogen $r = 0.83$, with mobile phosphates – 0.771–0.724, exchange potassium – 0.788–0.702. In the flowering phase, this dependence was lower 0.074; 0.590 and 0.209. This mathematical analysis suggests that under weak responsiveness, the increase of standards of fertilizer to the level of mineral nutrition of sunflower is needed in the early stages of development.

Our data show that in conditions of insufficient moistening of the North of Krasnodar region on common chernozem of the Western Ciscaucasia, subject to science-based crop rotations and the implementation of technological discipline,

sufficiently high yields of this crop at minimum cost of fertilizers can be obtained, $N_{20}P_{30}$. In the cultivation of sunflower it is advisable to use the average dose $N_{40}P_{60}$ providing a sufficiently high harvest of oilseeds – the 3.3–3.5 t/ha, and the preservation of soil fertility.

Sunflower is the culture for high-quality food and technical vegetable oils, besides there is a high-protein concentrated feed. Along with the value of the yield, important indicators of productivity of culture are the oil yield and protein productivity.

Analysis of plant samples has allowed establishing the equivalence of the studied doses of fertilizers on protein content in sunflower seeds (Table 6).

Table 6: Protein content in sunflower seeds and protein productivity depending on application of fertilizers and growth regulator (furolan).

Variant	Protein content	Gathering protein	The fat content in the seeds	Gathering oil
	%	%	%	t/ha
Without fertilizers (control)	16.51	4.37	43.7	47.1
N_{40}	18.35	5.36	47.1	49.9
P_{60}	17.63	5.21	46.2	47.0
$N_{20}P_{30}$	18.42	5.48	47.0	48.1
$N_{40}P_{60}$	19.05	5.80	46.6	47.6
$N_{40}P_{60} + N_{40}$ additional fertilizing	19.27	6.03	46.3	46.5
$N_{40}P_{120} + N_{40}$ additional fertilizing	19.26	5.98	45.4	47.4
Cultivation with furolan, 5 g/ha	18.55	5.74	47.6	48.0
HCP_{05}	1.33	0.21	2.64	0.97

The role of nitrogen fertilizers is evident. By increasing this element in the fertilizer the percentage of protein increased. It was the lowest in unfertilized variants, making only phosphate fertilizers in a dose of 60 kg/ha of active substance, which contributed to the mobilization of soil nitrogen and the increase of protein in seeds. Under the influence of some nitrogen fertilizers (N_{40}) protein levels were increased in comparison to the control variant.

Maximum values of protein content obtained at high ($N_{40}P_{60}$) and high ($N_{80}P_{120}$) doses of fertilizer.

The high fat content marked in sunflower seeds has already grown when making only phosphate (P_{60}) and nitrogen (N_{40}) fertilizers. Making azotobacteria of fertilizers promotes the increase of oil content in seeds compared with control. The treatment of plants by furolan does not violate the process of accumulation of protein and fat in the seeds.

Conclusion

Based on the experimental data in our research, we came to the conclusion that using Furolane together with common mineral fertilizers, additional activation of the sunflower growth process and the formation of the optimal leaf surface, and plant density per unit area, occurred.

The improvement of the sunflower nutritional status directly contributed to the increase of the total leaf surface of plants, so the Furolan treatment of sunflower, together with the basic dose of mineral fertilizers $N_{20}P_{30}$, had a very positive influence on the overall photosynthetic potential of sunflower.

The influence of the use of mineral fertilizers is evident in the increase of the sunflower head diameter, seed weight, and 1000 seeds weight, and directly affects sunflower productivity. Increasing sunflower treatment with mineral fertilizers increases the oil content of the seed, in a significant degree, than in non-fertilized variants. The use of Furolan did not lead to the deterioration of protein and oil accumulation in the seed.

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