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The effect of herbicides on seed productivity of *Festulolium*

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Abstract. An artificially developed intergeneric hybrid *Festulolium* (× *Festulolium* F. Aschers, et Graebn.) is the best forage crop with high energy and protein nutrition value which can be used for green fodder when creating cultural haylands and pastures. The advantages of this crop are high regrow capacity, high content of sugars and good winter hardiness. Wide use of this new crop in fodder production is constrained, firstly, because the crop is yet new and little known and, secondly, because there is a lack of seeds due to imperfections in the production technology. There are still very few scientific studies on the biology and technology of *Festulolium* cultivation in the forest-steppe of the Central Chernozem Region of Russia. In our works we were the first to study the biological features of *Festulolium* and develop the main technological methods of growing and harvesting its seeds. The work was carried out in long-term studies of the Department of Crop Science, Forage Production and Agricultural Technologies of Voronezh State Agrarian University in 2009–2011. The soil in the experimental plot was leached medium loamy chernozem. The experiments involved the VIK-90 *Festulolium* variety with the preceding crop being the vetch-oat mixture harvested for green fodder. The soil preparation was conventional for seed herbage of perennial grasses in the Central Chernozem Region. The associated records and observations were made according to conventional methods adopted in the seed production of perennial grasses. A high efficiency of the Aurorex (0.55 L ha^{-1}) and the Dicamba (0.15 L ha^{-1}) herbicides in the suppression of annual and perennial dicotyledonous weed plants has been identified. The application of these herbicides has significantly reduced (by 40–73%) the weed infestation of seed herbage in the first year of vegetation and, as a result, has improved its structure and crop quality. The use of the developed agricultural techniques allows reducing the energy costs and receiving an average of 433–496 kg ha^{-1} of certified seeds.

Key words: seed herbage, types of weed plants, shortfall in seed production, efficiency of herbicides, weed infestation.

INTRODUCTION

It is known that perennial grasses are the most efficient and least energy-demanding fodder crops. They allow obtaining fodders with well-balanced protein content, preserve the soil fertility, and increase the ecological safety and sustainability of fodder production (Lazarev et al., 2007; Perepravo, 2007; Shamsutdinov, 2010).

Grass species conventional for the Central Chernozem Region of Russia (*meadow fescue*, *cock's-foot*, *smooth bromegrass*, *timothy grass*, *etc.*) are characterized by insufficient content of water-soluble carbohydrates, extensive regrowth after regular disposal cycles, and growth depression in summer.

An important reserve for improving the level of fodder production industry in Russia is the creation of new species and varieties of non-conventional forage grasses on the basis of various selection methods, including distant hybridization. Such newly created species should have improved economic traits and should be introduced into production in order to increase the crop yield and the quality of produced fodders (Perepravo et al., 2011).

An intergeneric hybrid *Festulolium* (× *Festulolium* F. Aschers. et Graebn.) is a forage crop with high energy and protein nutrition value. It can be used for green fodder, hay, silage, and haylage, as well as in the creation of cultural haylands and pastures. The advantages of this crop over other Poaceae species are high content of sugars, good regrow capacity, winter hardiness, and drought resistance (Kocourkova et al., 2008; Barnes et al., 2014; Kvasnovsky et al., 2014; Schiavon et al., 2014; Kubota et al., 2015).

Festulolium shoots appear slowly and are heavily inhibited by strong stature weeds (Marchenko, 1996; Obraztsov & Fedotov, 2013). A high content of weed seeds in the crop harvest (more than 120 thousand pcs·per 1 kg, even with repeated cleaning on seed-cleaning machines) does not always allow obtaining a seed material of high grade by contamination, which leads to large crop losses (Zolotaryov, 1991). Therefore, it is impossible to obtain a stably high yield of seeds without applying efficient means of protection against weed plants.

Weeds not only compete with perennial grasses for nutrition, light, and moisture, in many cases consuming more nutrients and water than cultivated plants, but also complicate the harvesting and post-harvest treatment of seeds. For instance, according to Vadopalas (1982), a shortfall in seed production of perennial grassland grasses with an average weed infestation is 10–20%, and with the basic seed cleaning the loss of seeds reaches another 12–20%. There are a number of weeds, the seeds of which are practically impossible to be removed from the seeds of the cultivated crop. Therefore, in addition to the agrotechnical and chemical means of weed control it is important to use herbicides in the preparation of soil for sowing perennial grasses, especially in their first year of vegetation, and also to improve the mechanical cleaning of seed material. According to Zolotaryov (2015), the agrotechnical and chemical treatments in the presowing period and in the year of sowing of herbs allow obtaining seeds of high grade by contamination and increasing the yield by 30% or more.

Herbicides allow eliminating the sprouted weeds, which ensures a better development of slowly growing plants of fodder crops. As a rule, the aftereffect of applying herbicides in the year of sowing persists on perennial grass seed plantings through all the years of their use. It is especially efficient for wide-row crops in combination with inter-row cultivation. This allows decreasing the contamination of seed herbages with vegetating weeds by 85–95% and reducing the amount of weed seeds in the crop harvest by 2–3 times (Mikhaylichenko, 1987).

At different times the Russian and foreign scientists were involved in the studies of harmfulness of weed plants in the herbages of perennial grasses and the development of measures of their suppression.

Bochkarev et al. (2012) recommended to treat perennial grasses against dandelion with the Agritox herbicide at the rate of 0.6–0.8 L ha^{-1} in the second year of use after the first mowing.

Chuvilina et al. (2014) established that the application of the Magnum herbicide in its pure form and in tank mixtures significantly reduced the contamination of old-aged perennial grass herbages. The greatest efficiency (91%) in the control of weed plants was obtained by applying a tank mixture of Magnum and Dialen Super. At the same time, the fresh yield of perennial grasses increased by 810 kg ha^{-1}. In the plantings treated with herbicides the feeding mass of perennial grasses exhibited a decrease in ash content (by 0.6–1.2%), sugars (by 1.1–1.8%), fiber (by 2.1–4.1%), and nitrates (by 31–54 mg kg^{-1}), and an increase in carotene content (by 2.1–6.3 mg kg^{-1}) compared to the control.

In the studies of Goliński et al. (2009) the treatment of plantings of the *Felopa* variety of *Festulolium* with herbicides in the first year of use resulted in the death of 41–71% of weeds. The largest increase (36.8%) in the seed yield was obtained when applying the tank mixture of the Lontrel 300 SL + the Chwastox Extra 300 SL herbicides. All the applied herbicides exerted a positive effect on the structure of seed herbage and the yield of seeds.

Due to the availability of a wide range of efficient and environmentally less harmful herbicides, a research on the selection and efficient use of new preparations now deserves special attention.

In our studies our objective was to consider the species composition of weed plants in the plantings of *Festulolium* and to develop a chemical method for combatting them having selected optimal doses of modern herbicides.

MATERIALS AND METHODS

Experimental part of the study was performed in 2009–2011 in field trials of the Department of Crop Science, Forage Production and Agricultural Technologies of Voronezh State Agrarian University named after Emperor Peter the Great on the fields of the Training, Research and Technological Center ‘Agrotechnology’ (N51.7140416 E39.21545371).

The soil in the experimental plot was leached medium loamy chernozem containing 4.56–5.50% of humus, 78–129 g kg^{-1} of labile phosphorus (P_2O_5), 109–118 mg kg^{-1} of exchangeable potassium (according to Chirikov), pH_{salt} was from 4.9 to 5.1, the total absorbed bases was from 21.3 to 22.2 mg-eq. per 100 g of soil, and the degree of base saturation was of 74–86%.

The preceding crop for *Festulolium* was the vetch-oat mixture harvested for green fodder. The preparation of soil for sowing was conventional for creating the seed herbages of perennial grasses in the Central Chernozem Region. The experimental design included the control variant (no herbicides applied) and the application of three herbicides at different concentrations in the first year of vegetation of seed herbage: Lontrel Grand (0.120; 0.125; 0.130 kg ha^{-1}), Dicamba (0.10; 0.15; 0.20 L ha^{-1}), and Aurorex (0.50; 0.55; 0.60 L ha^{-1}). The application of herbicides was performed once in the tillering phase using the 16-Litre Hozelock Professional 4816 knapsack sprayer. The efficiency of herbicides was determined by measuring weed infestation. Weed infestation was recorded using the quantitative weight method according to *The Guidelines for Evaluation of Herbicides Applied in Crop Farming* (Larina, 2009) prior to treatment, 30 and 45 days after treatment, and before wintering. The mass of weed plants per 1 m^2 was weighed in two replicates 30 and 45 days after the application of herbicides. Seed plantings of *Festulolium* were harvested by the Sampo-130 harvester at the seed moisture of 40–45% with split-plot yield accounting and its subsequent recalculation on the basis of 12% moisture and 100% seed purity. The experiment was laid in 4 replicates with the randomized location of the plots. The area of the registration plot was 20 m^2. Experiments, relevant records and observations were carried out according to standard *Methodological Instructive Regulations...* (1986) for seed production of perennial grasses.

RESULTS

The growth of *Festulolium* shoots is considerably suppressed by strong-stature weeds (Zolotaryov, 1991). However, there are still no herbicides allowed for application in *Festulolium* plantings.

The weed contamination of seed plantings of *Festulolium* was determined in the first and second years of vegetation. In the year of creation of *Festulolium* seed herbage there were more than 16 weed species in the plantings belonging to 7 different families: *Chenopodiaceae*, *Poaceae*, *Asteraceae*, *Brassicaceae*, *Convolvulaceae*, *Geraniaceae*, and *Euphorbiaceae*. In different years the following weeds were dominant: perennial weeds – *Convolvulus arvensis* L., *Cirsium arvense* L., *Sonchus arvensis* L., *Agropyron repens* L., *Taraxacum officinale* Wigg., *Barbarea vulgaris* R. Br., *Euphorbia virgata* Waldst. & Kit., *Artemisia absinthium* L.; spring weeds – *Chenopodium album* L., *Capsella bursa-pastoris* L., *Panicum crus galli* L., *Thlaspi arvense* L., *Galium aparine* L., *Setaria glauca* L.; annual and biennial wintering weeds – *Matricaria inodora* L., *Erodium cicutarium* L.

It was found that in 2009 the annual and biennial weeds represented 54.1% of weeds with the domination of wintering species (25.9%) (Table 1).

Table 1. Groups of weeds in the seed herbage of *Festulolium* in the first year of vegetation, %

Groups of weed species	2009	2010	2011
Annual and biennial, in total, including:	54.1	60.3	54.4
spring early	7.7	8.6	5.1
spring late	20.5	29.4	25.1
wintering	25.9	22.3	24.2
Perennial, in total, including:	45.9	39.7	45.6
soboliferous	36.2	30.6	34.5
rhizomatous	3.3	1.2	2.2
taproot	6.4	7.9	8.9

In 2010 the annual and biennial weed species were dominant (60.3%), mainly *Matricaria inodora* L., *Panicum crus galli* L., *Thlaspi arvense* L., and *Capsella bursa-pastoris* L. Among perennial species the *Sonchus arvensis* L. and *Convolvulus arvensis* L. were dominant. Their population varied throughout the vegetation season. The amount of annual and biennial weeds increased by 14.1%, whereas the amount of perennial weeds increased only by 4.1%. Such insignificant increase in the population of weeds in 2010 was due to the drought, especially in the 2^{nd} and 3^{rd} decades of May.

In the conditions of 2011 the weed contamination was represented by 45.6% of perennial and 54.4% of annual and biennial weed species. *Thlaspi arvense* L., *Setaria glauca* L., and *Matricaria inodora* L. were dominant among the annual and biennial weeds, while *Convolvulus arvensis* L., *Cirsium arvense* L. and *Taraxacum officinale* Wigg. were dominant among perennial weeds.

Our research showed that the application of the Aurorex herbicide in a dose of 0.50 L ha^{-1} ensured a decrease in the total amount of weeds by 56.2% (including a decrease in the amount of perennial species 57.6%) already in 30 days. The efficiency of this herbicide against annual and biennial weeds during the first post-treatment period was not very high (61.2%) due to the presence of resistant grass weeds in *Festulolium* plantings (namely *Panicum crus galli* L., *Setaria glauca* L. and *Agropyron repens* L.). After 45 days the density of annual and biennial weeds decreased from 75.4 to 30.8 plants per 1 m^2, i.e. by 59.2%, and by the end of vegetation the total weed count in this variant was 49 plants per 1 m^2, which was 63.4% lower compared to the control variant (Table 2).

The Aurorex herbicide in a dose of 0.55 L ha^{-1} decreased the total weed count to 60.5 plants per 1 m^2 after 30 days and to 36.1 plants per 1 m^2 by wintering. The total weed count decreased by 64.3% after 30 days, and by 73% by the end of vegetation season compared to control. The highest mortality (64.7%) was observed in perennial weeds after 30 days and reached 70% by wintering. The mortality of annual and biennial weeds was slightly lower compared to perennial, but it was also rather high: 64.1% after 30 days and 71.1% by wintering. The total weed mortality was 64.3–70.6%. The application of the Aurorex herbicide in a dose of 0.60 L ha^{-1} yielded the highest herbicidal effect. The total decrease in the annual, biennial and perennial weed count in the plantings reached 69.0–77.5%. The maximum herbicidal efficiency against perennial weed species was 75.3%.

The Dicamba herbicide in a dose of 0.10 L ha^{-1} decreased the total count of all weed species by 50% 30 days after its application. Throughout the vegetation period the weed mortality increased and reached 57.5% by wintering. A higher decrease was observed in perennial weed count: by 46.9% in the first recorded period and by 52.4% by the end of vegetation season. Thirty days after the treatment of plantings with the Dicamba herbicide in a dose of 0.15 L ha^{-1} the annual and perennial weed count decreased by 66.8% and 61.1%, which was significantly more efficient than the dose of 0.1 L ha^{-1}.

Increasing the dose of the Dicamba herbicide up to 0.20 L ha^{-1} increased the total weed mortality that reached 68.9% 30 days after the application and 74% by the end of vegetation season. This was much more efficient compared to the dose of 0.15 L ha^{-1}. The highest decrease in weed count was observed for annual and biennial weeds, i.e. by 72.2% 30 days after treatment and by 77.1% by wintering.

An increase in the dose of the Dicamba herbicide up to 0.20 L ha^{-1} led to a further decrease in the weed count of *Sonchus arvensis* L., *Taraxacum officinale* Wigg., and *Cirsium arvense* L. At the end of vegetation season a complete death of *Convolvulus arvensis* L. was observed.

Table 2. The effect of herbicides on weed count and mass of weeds in *Festulolium* plantings in the first y
the 2009–2011 period)

Types of weeds	Term after treatment	Control, pcs per 1 m^2 or g per 1 m^2	Aurorex, L ha^{-1}						Dicamba, L ha^{-1}					
			0.5		0.55		0.6		0.1		0.15		0.2	
			a	b	a	b	a	b	a	b	a	b	a	b
Weed count														
Annual and biennial	after 30 days	89	40	55	32	66	25	73	41	53	29	69	24	74
	after 45 days	75	31	59	24	70	20	75	28	62	22	73	17	78
	before wintering	72	28	61	19	74	16	79	25	65	20	74	16	79
Perennial	after 30 days	81	34	58	29	63	22	71	43	47	32	59	28	63
	after 45 days	70	27	62	20	69	20	70	33	52	26	60	20	68
	before wintering	62	21	66	15	73	14	75	29	52	22	62	18	69
Total	after 30 days	170	74	56	60	65	47	72	84	50	61	65	53	69
	after 45 days	145	57	60	44	70	39	73	62	58	48	67	38	74
	before wintering	134	49	63	35	74	30	77	54	59	41	69	34	75
Mass of weeds														
Annual and biennial	after 30 days	39	19	52	15	61	14	66	16	75	13	81	10	85
	after 45 days	32	14	56	11	67	9	71	13	82	11	85	8	88
Perennial	after 30 days	43	20	52	15	64	13	69	24	65	16	77	13	81
	after 45 days	40	17	58	13	68	12	69	18	74	12	82	11	84
Total	after 30 days	82	39	52	31	63	27	67	40	40	29	58	24	65
	after 45 days	72	31	57	24	67	22	70	31	56	23	67	19	73

a – weed count, pcs per 1 m^2; mass of weeds, g per 1 m^2; b – decrease in weed count in % compared to control.

The Lontrel Grand herbicide in a dose of 0.120 kg ha^{-1} decreased the contamination of *Festulolium* plantings by 26% for annual and biennial weeds and by 39.9% for perennial weeds 30 days after treatment. This herbicide was highly efficient against *Sonchus arvensis* L., *Taraxacum officinale* Wigg., *Convolvulus arvensis* L., and *Cirsium arvense* L. In the dose of 0.125 kg ha^{-1} its efficiency increased significantly. The total mortality of weeds 30 days after treatment and at the end of vegetation season reached 38.1% and 47.1%, respectively. The highest efficiency of the Lontrel Grand herbicide was registered in a dose of 0.13 kg ha^{-1}.

The Aurorex herbicide appeared to be more efficient in *Festulolium* plantings. In the variants where it was applied in the year of seed harvesting the structure of yield components of seed herbage was considerably improved (Table 3).

Table 2. The effect of herbicides on the structure of deed herbage and seed yield of *Festulolium* the second year of vegetation (averaged for the 2010–2011 period)

Herbicide	Dose, L·ha^{-1}, kg·ha^{-1}	Count generative shoots, pcs per 1 m^2	Ear length, cm	Number of seeds per 1 ear, pcs	Seed yield, kg ha^{-1}
Control	0.00	739	15.7	60.0	432.7
Aurorex	0.50	798	16.0	59.5	480.5
(a.i. 21 g L^{-1} carfentrazone-ethyl	0.55	810	16.1	57.0	496.4
+ 500 g L^{-1} complex 2-ethylhexanol ester 2,4-D)	0.60	785	15.8	59.0	472.0
Dicamba	0.10	766	16.1	57.5	459.5
(a.i. 480 g L^{-1}dicamba acid)	0.15	774	15.8	60.0	464.8
	0.20	756	15.7	56.5	449.6
Lontrel Grand	0.120	741	15.9	59.5	433.3
(a.i. clopyralid 750 g kg^{-1}	0.125	729	15.8	55.5	428.8
	0.130	716	15.4	56.5	419.5
LSD_{05}		27.1	0.14	3.3	19.5

For instance, the average generative shoot count over three years in the variant with Aurorex application was 785–810 pcs per 1 m^2 compared to 739 pcs per 1 m^2 in the control. This herbicide was characterized by a broad spectrum of activity and eliminated the weeds in the herbage when applied in a dose of 0.55 L ha^{-1}.

The number of vegetating weeds decreased to 45%, which resulted in the highest yield of *Festulolium* seeds in the experiment (496.4 kg ha^{-1}). The Dicamba herbicide was efficient against weeds in a dose of 0.15 L ha^{-1}. Having provided the mortality of 67.2% of weeds, it increased the yield of *Festulolium*, which reached 464.8 kg ha^{-1}.

The treatment of plantings with the Lontrel Grand herbicide resulted in a noticeable depression of *Festulolium* plants, especially in the first days, and the level of their depression increased with the dose of the herbicide. However, in the subsequent period the plants developed normally. Nevertheless, when this herbicide was applied in the doses of 0.125 and 0.130 kg ha^{-1} there was a certain trend towards the decrease in *Festulolium* yield compared to control, although it was insignificant.

The cost of the obtained seeds per 1 hectare was determined using data on sales prices of *Festulolium* seeds (as of the end of 2011) and the crop yield. The cost of the obtained seeds was RUB'000 51.90 on the control variant, and ranged from RUB'000 50.34 to 59.52 on other variants (Table 4).

Table 4. Economic efficiency of producing *Festulolium* seeds depending on the application of herbicides (averaged for the 2010–2011 period)

Herbicide	Dose, L ha^{-1}, kg ha^{-1}	Value of production, RUB'000 per 1 hectare	Costs, RUB'000 per 1 hectare	Cost of 100 kg of seeds, RUB'000 per 1 hectare	Net income, RUB'000 per 1 hectare	Level of profitability, %
Control	0.00	51.90	29.18	6.74	22.71	78
Aurorex	0.50	57.66	30.19	6.28	27.46	91
(a.i. 21 g L^{-1}	0.55	59.52	30.29	6.10	29.22	97
carfentrazone-ethyl +	0.60	56.64	30.39	6.44	26.24	86
500 g L^{-1}complex						
2-ethylhexanol ester						
2,4-D)						
Dicamba	0.10	55.14	30.29	6.59	24.84	82
(a.i. 480 g L^{-1}	0.15	55.74	30.19	6.54	25.34	83
dicamba acid)	0.20	53.88	29.55	6.58	24.32	82
Lontrel Grand	0.120	52.02	30.09	6.85	22.05	75
(a.i. clopyralid	0.125	51.42	29.36	7.01	21.62	71
750 g kg^{-1})	0.130	50.34	29.92	7.13	20.14	68

Total costs per 1 hectare of planted area depended on the doses of applied herbicides and their cost. For instance, the lowest costs were observed on the control variant (RUB'000 29.18). The maximal costs (RUB'000 30.39) were observed on the plantings treated with the Aurorex herbicide in a dose of 0.60 L ha^{-1}.

The cost of the obtained seeds on the control variant was RUB'000 6.74 per 100 kg. The maximal cost (RUB'000 7.13) was noted on the plantings treated with the Lontrel Grand herbicide in the dose of 0.13 kg ha^{-1}, while the minimal cost (RUB'000 6.10) was observed on the plantings treated with the Aurorex herbicide in a dose of 0.55 L ha^{-1}.

The highest net income (RUB'000 29.22) and the maximal level of profitability (97%) were obtained with the application of the Aurorex herbicide in a dose of 0.55 L ha^{-1}.

Thus, in order to create a highly productive seed herbage of *Festulolium* it is necessary to apply herbicides in the year of sowing in order to eliminate the dicotyledonous weeds. The application of Aurorex in a dose of 0.55 L ha^{-1} or Dicamba in a dose of 0.15 L ha^{-1} proved to be the most efficient. It ensured the mortality of 69.5–73.0% of weeds and the yield of 464.8–496.4 kg ha^{-1} of high-quality *Festulolium* seeds.

CONCLUSIONS

The following conclusions can be derived on the basis of our studies conducted in 2009–2011 during seed harvesting in the conditions of the forest-steppe of the Central Chernozem Region and devoted to winter hardiness, growth, development and seed productivity of *Festulolium* depending on application of herbicides.

The application of the Aurorex herbicide in a dose of 0.55 L ha^{-1} in *Festulolium* plantings ensures the elimination of 73% of weeds. The mass of weed plants decreases by 67.3%. The yield of *Festulolium* seeds exceeded the control variant by 63.7 kg ha^{-1} and provided the highest economic efficiency (the net operating profit amounted to

RUB'000 29.22 per hectare, the prime cost of 100 kg of seeds did not exceed RUB'000 6.10, and the profitability reached 97%).

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