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Festulolium seed production dependence on fertilizer application system

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Abstract. *Festulolium* (× *Festulolium* F. Aschers. et Graebn.) is a new perennial grass *Poaceae* family. The benefits of this culture are good regrow capacity, increased sugars content and higher winter hardiness. It can be used as a green feed when creating cultivated hayfields and pastures. Widespread application of this new culture for forage production is constrained by the shortage of seeds, due to the imperfection of their production technologies. There are still very few of studies on the biology and technology of *Festulolium* cultivation in the forest-steppe of the Central Chernozem Region of Russia (CCR). The experiments involved the VIC-90 *Festulolium* variety with the first crop being the vetch-oat mixture harvested for green fodder. The soil in the experimental plots was leached medium thick medium loamy chernozem. The humus content in the arable horizon was 4.56%, pH was 4.9, degree of base saturation was 74–86%, P_2O_5 content was 129 mg kg^{-1}, K_2O content was 115 mg kg^{-1} (according to Chirikov) and the hydrothermal index was 1.13. The experiment included the following variants: no fertilizer application (control) and application of mineral fertilizers (ammonium nitrate and ammonium nitrate phosphate fertilizer) at different doses. Soil preparation was conventional for seed swards of perennial grasses in the CCR. *Festulolium* was sown in broad drills by coverless sowing to the depth of 0.5–1.0 cm at the seeding rate of 6.0 kg ha^{-1}. Experiments, records, observations and determination of economic and bioenergetic efficiency were carried out according to conventional procedures. It was found that the climatic conditions in the forest steppe of the CCR were favorable for *Festulolium* seed cultivation. Application of mineral nitrogen fertilizers in autumn at a dose of 60 kg ha^{-1} of active ingredient (AI) ensures the formation of high yielding erect seed-producing sward, and can increase harvest energy efficiency an average by 1.45–1.82 times and obtain 591–620 kg ha^{-1} of certified seeds. The greatest profitability of production (179%) and the highest notional farm net income (RUB 43,000 per hectare) are provided by a single application of ammonium nitrate fertilizer at a dose of 60 kg ha^{-1} of active ingredient in autumn (after vegetative mass topping).

Key words: perennial grasses, non-lodged plant stand, overwintering, seasonal fertilizer application, different doses, seed productivity.

INTRODUCTION

One of the main factors for obtaining high yields of *Festulolium* seeds is a rational fertilizer application system. In contrast to cultivation for fodder purposes, when it is necessary to obtain the greatest yield of vegetative mass, fertilizer application system on seed producing plots should correspond to the production of non-lodged or slightly lodged plant stand with even flowering and seed ripening. A lot of researchers (Yansons, 1978; Mikhailichenko, 1987; Rogov, 1989; Meerovsky & Kovalets, 2008; Zolotarev et al., 2008; Perepravo et al., 2012) consider nitrogen to be the main element influencing seed growing potential in seed production of perennial grasses. Phosphate-potassium fertilizers are less important for obtaining high yields of grass seeds, but their lack in soil reduces the efficiency of additional nitrogen fertilizing.

Most Russian and foreign researchers think that the doses and timings of nitrogen fertilizer application are critical factors in seed production of perennial grasses (Griffiths et al., 1971; Mikhailichenko et al., 1999; Zolotarev et al., 2007; Perepravo et al., 2013; Cougnon et al., 2017; Mastalerczuk et al., 2017). According to S.P. Smelov (1966), perennial grasses absorb up to 50–80% of nitrogen from spring tillering to shooting stage. Spring application of nitrogen fertilizers stimulates the formation of reproductive organs, contributes to an increase in the number of seeds in the inflorescences. Nitrogen deficiency decelerates the developmental processes in plants, reduces formation of branching roots and rootlets, as well as chlorophyll content in leaves, CO_2 uptake and water use efficiency, which finely leads to a decrease in dry matter accumulation and seed productivity (Mastalerczuk et al., 2017). Excessive nitrogen nutrition, on the contrary, adversely affects plants development, especially in the seasons of sufficient and excessive depth of precipitation, causes lodging of generative shoots, which leads to a decrease in the potential seed productivity of plants, makes it difficult to harvest seeds mechanically and degrade their quality.

Application of high doses of nitrogen reduces winter hardiness, the content of water-soluble carbohydrates and increases the nitrate content in feeding stuffs. In addition to the above, the efficiency of fertilizers largely depends on the biological properties of the cultivated crop. Therefore, it is of critical importance to determine correctly the doses and timings of the application of mineral fertilizers (Schuppenies, 1988; Mikhailichenko et al., 1999; Perepravo et al., 2003).

In the researches of I. Gutmane (2005; 2012) devoted to the effect of mineral nitrogen fertilizers on *Festulolium* seed productivity and carried out on sod gley soil in climatic conditions of Latvia, it was defined that N_{120} kg ha^{-1} nitrogen dose was the nearest to the optimal quantity of nitrogen fertilizers, that provides seed harvest from 0.6 to 1.0 t ha^{-1}.

Doses of nitrogen fertilizers and timings of their application before *Festulolium* sowing for seeds are not adequately investigated from the perspective of climatic conditions of the Central Chernozem Region. The objective of the presented research is revealing the influence of different types and doses of additional nitrogen fertilizing on the developmental biology of *Festulolium* of different planting period when the crop under study is growing for seed production.

MATERIALS AND METHODS

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

The soil in the experimental plot is leached middle thick middle loamy chernozem. The humus content in the arable horizon was from 4.56 to 5.50%, pH_{salt} was 4.9, and soil base saturation was 74–86%. The content of labile phosphorus (P_2O_5) and exchangeable potassium (K_2O) was 78–129 and 109–118 mg kg^{-1} of soil, the total absorbed bases was from 21.3 to 22.2 mg-eq. per 100 g of soil.

The variation of meteorological conditions during the period of experiments allowed to evaluate objectively the obtained results. In 2009 weather conditions were more favorable for *Festulolium* plantings although precipitation depth was below mean annual rainfall. In 2010 the weather was abnormally hot and dry, the air temperature on the soil surface in flaming summer days reached 60°C, average monthly temperatures of July and August were above 25 °C. In 2011 the conditions of vegetation season were relatively favorable.

The experiments involved the VIK–90 *Festulolium* variety. It was preceded by vetch-oat mixture harvested for green fodder.

The soil preparation to sowing was conventional for seed swards of perennial grasses in the Central Chernozem Region. After harvesting *Festulolium* preceding crop primary tillage was fulfilled to the depth of 8–10 cm, then in two weeks the soil was plowed using jointer shares to the depth of 27–30 cm. In spring, as far as the soil was ready, we performed early tandem disk harrowing, secondary tillage, soil packing before sowing, coverless wide-row (30 cm) sowing to the depth of 0.5–1.0 cm at the seeding rate of 8.0 kg ha^{-1}, and soil packing after sowing. Registration plot area was 20 sq. m., randomized experiments were carried out in fourfold replication.

Experiments, relevant records and observations were carried out according to standard Methodological Instructive Regulations (1986) for perennial grasses seed production.

RESULTS AND DISCUSSION

During the first year of life of *Festulolium* plantings the meteorological conditions of vegetation season, especially during seedling emergence, have a strong effect on the plant growth and development. Weather conditions during the period of research showed to be favorable for *Festulolium* seed sprouting, mean field germination rate reached 75.8%.

More favorable weather conditions for *Festulolium* seedling emergence were in 2009 and 2010: field germination rate average in all variants reached 76.1 –81.8%. In 2011 field germination rate decreased to 69.5% due to dry weather during sowing and seed sprouting stage.

In 2010 for the second part of summer hot and dry weather with air temperature above 25 °C continued during 24 days and thus negatively affected plants safety index during the first year of life. The mean crop failure during vegetation was the highest – 15.2%, whereas in other years it did not exceed 8.3–9.2%.

In the year of sowing *Festulolium* plantings grow slowly and do not form generative shoots. They are formed during the second and the following years, both from overwintered shoots as well as from shoots newly appeared in spring.

The first leaf expansion occurs 4–6 days after seedling emergence, 5–6 days after unfolds the second one. In the phase of 3–4 leaves the first side tillering-branching shoot appears. *Festulolium* plantings of the first year of life vigorously put out side shoots during the whole summer period. The amount of well-developed shoots in the first year of life directly affects overwintering and the amount of yield.

Festulolium is a cross-pollinated plant. Flowering period of a single plant continues from 2 to 4 days, whereas flowering period of the population is extended up to 8–11 days. During the second year of life the period from spring aftergrowing till complete seed ripeness continued 99–107 days.

Nitrogen fertilizers increase the vegetation period of plants, especially spring tillering and shooting stages. In the second year of life the vegetation period of plants as compared to control increased in the variants with additional ammonium nitrate (N) and nitroammophoska (ammonium nitrate phosphate fertilizer) fertilizing by 3–7 days and 3–8 days, respectively (Table 1).

Table 1. The Influence of Fertilizers on the Duration of Stages of *Festulolium* Plantings of the Second Year of Life from the Vegetative Renewal to Shooting, Earing, Flowering and Complete Seed Ripeness (2009–2011 period average)

Fertilizer type	Dosage of fertilizer, kg ha^{-1} of active ingredient (AI)	Duration of stages from spring vegetative renewal to the beginning of the stage			
		Shooting	Earing	Flowering	Complete seed ripeness
	Control (no fertilizers)	32	46	63	99
Ammonium nitrate	N_{45} – in autumn	34	49	66	100
	N_{60} – in autumn	34	51	68	103
	N_{75} – in autumn	35	51	69	104
	N_{90} – in autumn	36	52	71	105
	N_{30} – in autumn + N_{30} – in spring	36	53	71	106
	N_{45} – in autumn + N_{45} – in spring	37	54	72	107
Nitroammophoska 16:16:16	$(NPK)_{45}$ – in autumn	35	50	69	101
	$(NPK)_{60}$ – in autumn	35	51	70	104
	$(NPK)_{75}$ – in autumn	36	52	71	105
	$(NPK)_{90}$ – in autumn	37	53	73	106
	$(NPK)_{30}$ – in autumn + $(NPK)_{30}$ – in spring	37	52	72	107
	$(NPK)_{30}$ – in autumn + $(NPK)_{45}$ – in spring	38	53	74	107

Additional nitrogen fertilization increases the height of plants. In the second year of life in the control variant average height of generative shoots reached 41.8 cm, and when applying additional N_{45} and N_{90} fertilization it increased by 7.3 and 18.0 cm, respectively.

An increase of fertilization doses from 75 to 90 kg ha^{-1} of active ingredient (AI) contributed to the intensification of plant growth at early stages of vegetation leading to high lodging of plants, which negatively affected cross-pollination of flowers, seed formation and ripening, and also worsened the conditions of their harvesting. E.g. in wet weather conditions of 2009 in the variants with N_{45} and N_{60} application the degree of lodging reached 16.8 and 35.2%, and in the variants with N_{75} and N_{90} application it reached 39.0 and 46.8%, respectively.

In 2010 characterized by low amount of precipitation in the second half of vegetation season low degree of grass lodging was observed. It was found that in the lodged plantings the beginning of complete ripeness stage was delayed by 2–4 days as compared to control, and the amount of imperfect (shrunken) weevils in inflorescences increased.

The lowest degree of lodging of *Festulolium* seed crops (14.9%) was observed in the variant with $(NPK)_{45}$. In the variants with N_{90} and $(NPK)_{90}$ application the degree of grass lodging reached on average 33.6 and 34.8%.

It was found that *Festulolium* had high winter hardiness. During all years of study in the variants with mineral fertilizers application the amount of overwintered plants reached 84.9–88.9%.

Favorable conditions for *Festulolium* wintering occurred in the winter of 2010/2011 due to high snowing. In all the variants crop failure was low (4–8%). Better plant safety index (97.8–95.9%) was registered in the variants with higher doses of fertilizers, less plants (92%) survived in the control variant without fertilizers.

Winter weather conditions in 2009/2010 were the most unfavorable. Strong frosts and long-term absence of snow cover led to the considerable crop failure. In the control variant before wintering the density of plantings was 1,030 pcs m^{-2}, after wintering it was only 734 pcs m^{-2}, crop failure reached 28.7%. The application of ammonium nitrate and nitroammophoska increased the amount of overwintered plants to 77.0–81.8%, which is by 5.7–10.5% higher than in the control variant.

Table 2. The Influence of Fertilizers on the Elements of Crop Structure of *Festulolium* of the Second Year of Life (2009–2011 period average)

Fertilizer type	Dosage of fertilizer, kg ha^{-1} of AI	Ear length, cm	Number of generative shoots, pcs m^{-2}	Number of spikelets in a ear	Number of seeds in a ear
	Control (no fertilizers)	16.0	639.3	14.4	48.7
Ammonium nitrate	N_{45} – in autumn	17.1	762.2	15.8	57.8
	N_{60} – in autumn	18.3	853.6	16.7	65.2
	N_{75} – in autumn	18.4	813.1	17.9	66.7
	N_{90} – in autumn	19.7	793.6	18.3	67.1
	N_{30} – in autumn + N_{30} – in spring	17.2	834.0	15.9	63.7
	N_{45} – in autumn + N_{45} – in spring	18.0	815.1	16.6	64.9
Nitroammophoska 16:16:16	$(NPK)_{45}$ – in autumn	18.0	775.1	16.0	61.3
	$(NPK)_{60}$ – in autumn	18.9	868.0	17.2	67.1
	$(NPK)_{75}$ – in autumn	20.0	827.2	18.6	67.1
	$(NPK)_{90}$ – in autumn	21.0	805.8	19.2	66.9
	$(NPK)_{30}$ – in autumn + $(NPK)_{30}$ – in spring	17.8	844.7	17.1	62.8
	$(NPK)_{45}$ – in autumn + $(NPK)_{45}$ – in spring	18.5	822.2	17.6	64.0
LSD_{05} for fertilizer type		0.8	37.2	0.3	1.8
LSD_{05} for fertilizer dose		1.5	24.3	0.5	2.2

The density of generative shoots of *Festulolium* of the second year of life was higher in the variants with fertilization – in the variants with ammonium nitrate and nitroammophoska application it reached 762–853 and 775–868 pcs m^{-2}, respectively; in the control variant this index was by 16–26% lower. However, the increase of doses of both nitrogen and compound fertilizer above 60 kg ha^{-1} of AI did not increase the amount of generative shoots (Table 2).

Mineral fertilizers application increased the size of ears. Their length in the control variant was 16 cm, whereas in the variants with ammonium nitrate and nitroammophoska application it reached 17.1–19.7 cm and 18–21 cm, respectively, i.e. the length of ears were by 11.4–13.2% longer as compared to control variant without fertilizers application. This trend was registered throughout four years of *Festulolium* seed crop life.

Mineral fertilizers application increased the amount of spikelets in a ear by 1.4–4.8 pcs due to more intensive nutrition of generative organs during the period of their growth, flowering and seed formation.

It has been found experimentally that in order to obtain high yielding non-lodged or slightly lodged *Festulolium* grass sward nitrogen fertilizers should be applied in autumn period during sowing or after harvesting of *Festulolium* vegetative mass (i.e. in mid-September) at a dose of 60 kg ha^{-1} of AI.

In our experiments *Festulolium* seed harvest directly depended on the amount of generative shoots per crop area unit and on inflorescence seed content (Table 3).

Table 3. The Influence of Fertilizers on *Festulolium* Seed Harvest in Plantings of Different Year of Life (2009–2011 period average)

Fertilizer type	Dosage of fertilizer, kg ha^{-1} of AI	Year of life		
		Year 2	Year 3	Year 4
	Control (without fertilizers)	410.7	192.0	154.6
Ammonium nitrate	N_{45} – in autumn	489.4	206.4	180.5
	N_{60} – in autumn	591.4	253.3	223.4
	N_{75} – in autumn	540.3	224.5	207.9
	N_{90} – in autumn	514.3	212.6	200.8
	N_{30} – in autumn + N_{30} – in spring	559.7	241.5	208.8
	N_{45} – in autumn + N_{45} – in spring	568.3	246.9	213.8
Nitroammophoska 16:16:16	$(NPK)_{45}$ – in autumn	513.4	247.0	197.9
	$(NPK)_{60}$ – in autumn	620.5	272.5	240.9
	$(NPK)_{75}$ – in autumn	565.8	244.0	227.5
	$(NPK)_{90}$ – in autumn	538.5	230.1	222.6
	$(NPK)_{30}$ – in autumn + $(NPK)_{30}$ – in spring	586.1	260.0	228.0
	$(NPK)_{45}$ – in autumn + $(NPK)_{45}$ – in spring	591.7	271.9	230.8
LSD_{05} for fertilizer type		27.9	14.3	15.7
LSD_{05} for fertilizer dose		24.1	12.1	12.9

Seed harvest in the control variant (without fertilizers) was 410.7 kg ha^{-1}. In the variants with autumn application of nitrogen fertilizers (N_{30}–N_{90}) seed harvest of *Festulolium* plantings of the second year of life increased as compared to control by 16.1–30.6% and totaled from 489.4 to 591.4 kg ha^{-1}. In the variants with nitroammophoska application seed harvest was even higher (by 19.9–35.5% as compared to control) and totaled from 513.4 to 620.5 kg ha^{-1}.

The applied fertilizers practically did not affect sowing qualities of *Festulolium* seeds. Laboratory germination varied from 93 to 95% and the mass of 1,000 seeds was 2.91–2.99 g.

Production cost of 100 kg of *Festulolium* seeds was the lowest (43,000 rubles) and the level of profitability of their production was the highest (179%) in the variants with N_{60} application. It was also rather high (145%) in the variants with $(NPK)_{60}$ application.

CONCLUSIONS

The authors draw following conclusions from the results of research of winter hardiness, growth and seed productivity of *Festulolium* in dependence on fertilizer application system in climatic conditions of the forest-steppe of the Central Chernozem Region conducted in 2009–2011.

1. Agroclimatic conditions of the forest-steppe of the Central Chernozem Region are favorable for seed production of VIK–90 *Festulolium* variety. During all years of study in the variants with mineral fertilizers application the amount of overwintered plants reached 84.9–88.9%. Mineral fertilizers application, including nitrogen ones, improved winter hardiness of *Festulolium* plantings by 3.2–7.2%.

2. In the year of sowing *Festulolium* plantings are characterized by slow growth and development without generative shoots forming. Nitrogen and compound fertilizers increase the duration of vegetation period of plantings in the second year of life by 3–8 days, especially in spring tillering and shooting stages. Generally the period from spring regeneration to complete ripeness in the second year of life amounted 99–107 days, in the third and fourth years of life it continued 95–103 days.

3. Autumn application of ammonium nitrate (N_{60}) or nitroammophoska (NPK_{60}) provides the formation of higher seed harvest of *Festulolium* plantings of the second year of life from 591.4 to 620.5 kg ha^{-1}. In the following years *Festulolium* seed productivity decreases by 2.3–2.7 times. Mineral nitrogen application at a dose of 30 kg ha^{-1} of AI before autumn and spring grass tillering increases seed harvest by 31.4–37.2%.

4. In economic terms it is advisable to apply ammonium nitrate at a dose of 60 kg ha^{-1} of AI once a year in the fall. In this variant the highest notional farm net income of RUB 43,000 per hectare and profitability level of 179% can be obtained.

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