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Above- and Below-Ground Part Growth in Chewings and Strong Creeping Red Fescue Grown for Seed Resulting from Retardants and N Fertilization

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Abstract: Generative tillers are a source of assimilates necessary for the seed formation. However, their excessive elongation, especially under high doses of nitrogen, increases the susceptibility to lodging. The growth of generative shoots depends, among others on the root biomass affecting nutrient uptake, and on the ability to form rhizomes, as well as on the competitiveness of parallel developing vegetative tillers. Two-replicate field experiments were performed in Poland (53°09′ N, 17°35′ E), to determine the effect of plant growth regulators (PGRs) (single application of chloromequat chloride (CCC) at BBCH 30-31 or sequential treatment CCC at BBCH 30-31 + ethephon (ET) or CCC at BBCH 30-31 + trinexapac-ethyl (TE) at BBCH 37-39, and N fertilization (40 and 70 kg ha^{-1}) on the length of generative tillers, the weight of generative and vegetative tillers, the canopy height, the weight of roots and rhizomes, and on N uptake in *Festuca rubra* L ssp. *rubra* (strong creeping red fescue) and *F. r.* L ssp. *commutata* (Chewings red fescue). Chewings red fescue turned to be more sensitive to the retardants. Generative tillers were shorter after single application of CCC as well as sequential treatment CCC + ET or TE. The tillers of strong creeping red fescue were shortened only after the application of CCC + TE. In every PGR treatments the canopy height at harvest was greater than in the control. Increasing the N rate from 40 to 70 kg ha^{-1} caused the reduction canopy height of strong creeping red fescue. Increased production of above-ground biomass, especially generative tillers, resulted in an increase in N accumulation in Chewings red fescue, as compared with strong creeping. Increasing the nitrogen rate from 40 to 70 kg ha^{-1}, despite the reduction of root dry matter weight, stimulated generative tiller dry matter accumulation but it did not affect the biomass of vegetative tillers.

Keywords: nitrogen uptake; plant growth regulators; rhizomes; tiller length

1. Introduction

Red fescue (*Festuca rubra* L.) is a species of great economic importance. Due to the variability of morphological and functional characteristics and good adaptation to nutrient-poor habitats, it can be widely used on grasslands and lawns [1,2]. Lawn cultivars of red fescue are useful for sodding of green areas of medium-intensive use, e.g., slopes, roadsides, parks. For this purpose, morphologically diverse cultivars are useful, belonging to subspecies *Festuca rubra* L ssp. *rubra* (strong creeping red fescue) and *F. r.* L ssp. *commutata* (Chewings red fescue) [3]. Strong creeping red fescue can spread through rhizomes, thanks to which it covers empty spaces after other, less durable components of mixtures. Strong creeping red fescue has lower turfgrass quality than Chewings [3], but its great advantage is high ability to have high yields when grown for seed [4], which promotes the availability of seed. In contrast, Chewings red fescue does not form rhizomes, but thanks to a thin leaf blade, blade density, uniformity, color, lower disease pressure, and weed suppression, it has high aesthetic qualities. However, seed yields are low, which limits their availability on the market and increases the price.

The productivity of grass seed crops depends not only on the genetic properties of species and cultivars, but also on habitat and cultivation factors. One of the most yield-forming agricultural treatments is nitrogen fertilization. Nitrogen stimulates the growth of generative tillers, and then assimilates accumulated there for the needs of developing seeds are used [5–7]. Seed yield increase linearly with increasing above-ground biomass [8]. Reduction in seed yield occurs when the total available C in the plant is limited [7]. Nitrogen availability may also have an impact on the development of the root system [9], which is the basis for proper nutrients and water supply of plants, especially during the period of intense growth in the stem elongation. In turn high nitrogen fertilization rates, especially in favorable soil moisture conditions may cause intensive growth of vegetative tillers from late spring propagation. These vegetative tillers constitute a competition for water, nutrients and light in relation to generative tillers. The biomass of vegetative and generative tillers is particularly high in strong creeping red fescue [10]. The high density of tillers and their excessive elongation may cause increased lodging.

To counteract lodging and subsequent seed loss, plant growth regulators (PGRs) are used in agricultural crops [11–13]. They reduce elongation and lead to dwarfing by inhibiting production of gibberellins (GA) or promoting biosynthesis of ethylene. Most growth retardants act by inhibiting gibberellin (GA) biosynthesis, e.g., chlormequat chloride (CCC), which blocks the cyclases copalyl-diphosphate synthase and ent-kaurene synthase involved in the early steps of GA metabolism. In turn trinexapac-ethyl (TE) blocks 3ss-hydroxylation, thereby inhibiting the formation of highly active GAs from inactive precursors [14]. Ethephon unlike other PGRs, does not inhibit GA production, but results in the release the gaseous plant hormone ethylene. The increased ethylene causes cells to limit elongation and increase in width instead [15,16]. In grass seed production PGRs (retardants) are used to shorten and strengthen generative tillers, but high shoots biomass is needed to increase seed yields because stems contributed assimilates are essential to seed filling [6,7].

In our study we want to determine whether the use of PGRs affects the amount of biomass of generative and vegetative tillers of red fescue before the stage of outflow of assimilates into growing seeds (anthesis stage) and the effect of retardants on the biomass of rhizomes and roots two morphotypes of red fescue under different nitrogen availability.

The hypothesis was that retardants and nitrogen have an effect not only on the length, but also on the amount of biomass of generative tillers capable of forming the yield, as well as on the development of vegetative tillers competing with them, interdependent on the weight of rhizomes. In addition, growth regulators may also have an effect on the weight of the root system, whereby the response to these factors will be different in Chewings and strong creeping red fescue.

The aim of this study was to determine *Festuca rubra* ssp. multiple biometric characteristics response on application of plant growth regulators (retardants) and low (40 kg ha^{-1}) and average (70 kg ha^{-1}) dose of nitrogen fertilization.

2. Materials and Methods

2.1. Study Site

The study was based on two replicate experiments performed in two fields 500 m apart and located in Poland, in the Kuyavian-Pomeranian region (17°35′ E; 53°09′ N). According to USDA Soil Taxonomy the soil in the experimental site is classified as mesic Typic Hapludalfs [17]. The soil at experimental site was characterized by high content of available P (65.0 mg kg^{-1}), medium content of K

(145.2 mg kg^{-1}) (both determined with Egner-Riehm method) and a very low content of Mg (69 mg g^{-1}) (determined with Schachtschabel method). The soil at experimental fields was characterized by a low content of organic carbon 7.5–7.8 g kg^{-1}, and low content of the inorganic nitrogen (0.69–0.75 g kg^{-1} NH_4–N and NO_3–N). This soil was characterized by a slight acidic reaction (pH in 1 mol KCL 5.7–6.1).

The total yearly precipitation at experimental site in the long-term period in on average 515 mm, and the mean air temperature is 8.5 °C. Mostly the growing period starts early spring (late March or the beginning of April), and ends late in fall (October). The mean air temperature from the starting of growing period to final assessment of canopy height made just before the harvest (March–June) was 8.9 °C in 2013; 11.2 °C in 2014, and 10.1 °C in 2015. The total rainfall in the same period was 169 mm, 201 mm, and 106 mm, respectively.

2.2. Experimental Design

The first field experiment was established in 2012, and the second in 2013. The first and second seed production years were: in the first experiment, 2013 and 2014, and in the second, 2014 and 2015. A split-split-plot design was used with four replications. The plot area was 15 m^2. In both experiments of red fescue (*Festuca rubra* L) grown for seed depending on the nitrogen fertilization and retardants was examined. Treatments with plant growth regulators (retardants) (main plot, 60 m^2) were as follows: untreated control; chloromequat chloride (CCC) 1350 a.i. g ha^{-1} at beginning of stem elongation stage (BBCH 30-31) [18]; chloromequat chloride 625 a.i. g ha^{-1} at BBCH 30-31 + ethephon (ET) 240 a.i. g ha^{-1} at flag leaf stage (BBCH 37-39); chloromequat chloride 625 a.i. g ha^{-1}, at BBCH 30-31 + trinexapac-ethyl (TE) 75 a.i.g ha^{-1} at BBCH 37-39 (Table 1). Two lawn cultivars: 'Nista' (*Festuca rubra* L ssp. *rubra*, strong creeping red fescue) and cv. 'Dorosa' (*F. r.* L ssp. *commutata*, Chewings red fescue) were cultivated (subplots, 30 m^2). Both varieties are the result of breeding work carried out in the same period and Dorosa was registered in 2004 and Nista in 2005. They are characterized by high aesthetic value in lawn use and relatively high yields compared to other cultivars in growing for seeds. Two nitrogen rates: 40 and 70 kg ha^{-1} were applied (sub-sub-plot, 15 m^2) in the early spring, during starting growth, which in the region where the experiment was established occurs in the last ten days of March.

Table 1. Experimental treatments.

Plant Growth Regulator	Morphotype/Cultivar of Red Fescue	Spring Nitrogen Rate
Control-without treatment		
chloromequat chloride (CCC) 1350 a.i. g ha^{-1} at BBCH 30-31	strong creeping red fescue *Festuca rubra* L ssp. *rubra* cv. 'Nista'	40 kg ha^{-1}
chloromequat chloride (CCC) 625 a.i. g ha^{-1} at BBCH 30-31 + ethephon (ET) 240 a.i. g ha^{-1} at BBCH 37-39		
chloromequat chloride (CCC) 625 a.i. g ha^{-1} at BBCH 30-3 + trinexapac-ethyl (TE) 75 a.i. g ha^{-1} at BBCH 37-39	Chewings red fescue *Festuca rubra* L ssp. *commutate* cv. 'Dorosa'	70 kg ha^{-1}

2.3. Crop Management

Red fescue was sown between 8th and 10th of April in an amount of 10 kg ha^{-1}, as an undersown crop into spring barley (*Hodreum vulgare* L. cv. 'Nagradowicki'), at the density of 300 grain per m^2. The row spacing of red fescue amounted to 24 cm, and sowing depth was between 1 and 2 cm. After the harvest of the cover crop (spring barley) in the establishment year or the harvest of red fescue seeds in the first production year, the rates of mineral fertilization were: N 20 kg ha^{-1}, P 26 kg ha^{-1}, and K 66 kg ha^{-1}. In the autumn in the establishment year and in the first production year mecoprop [2-(2-Methyl-4-chlorophenoxy)propionic acid] 0.225 a.i. kg ha^{-1}, [4-chloro-2methylphenoxy]acetic acid [MCPA] 0.300 a.i. kg ha^{-1}, dicamba [3.6-dichloro-o-anisic acid] 0.06 a.i. kg ha^{-1}, fluroxypyr [4-amino-3.5-dichloro-6-fluoro-2-pyridyloxyacetic acid] 0.20 a.i. kg ha^{-1} and fluaiyfop-P butyl [butyl (R)-2-{4-[5-(trifluoromethyl)-2-pyridyloxy]phenoxy}propionate] 0.375 a.i. kg ha^{-1} for weed control were applied. During the start of red fescue growth in the first and second production years (in the middle of March), nitrogen (ammonium nitrate) was applied at rates consistent with the factor levels (40 or 70 kg ha^{-1}).

2.4. Measurement

Most plant biometric features measurement (except lodging) were performed at the end of anthesis stage (BBCH 69) because we wanted to determine the amount of above-ground and below-ground biomass before the seed developing stage. The length of generative tillers was measured from the ground level to the top of the panicle on 30 randomly selected tillers on each plot. To assess generative and vegetative tiller weight, the above-ground part of red fescue was cut at the ground level on the area of 0.5 m^2 on each plot. After cutting, generative and vegetative tillers were separated and oven-dried at 60 °C until constantly dry-weight, and weighted. After the determination of dry matter weight, generative and vegetative tillers were combined, ground, and mineral nitrogen content was determined separately from each plot with the Kjeldahl method. At the same growing stage, the samples of roots and rhizomes (if any) were gathered. Soil and root samples were collected at four points on each plot (two in rows and two in inter-rows) with an Eijkelkamp ring probe with the area 0.002 m^2 and depth 0.09 m. The roots and rhizomes (horizontal underground plant stem) were separated from the soil with a stream of water. The material thus obtained was separated into individual components and dried at 60 °C to obtain air-dry weight. The biomass of below-ground parts was presented in the soil volume of 0.09 m^{-3}, after converting the results to a surface of 1 m^2 to a depth of 0.09 m. The lodging assessment was based on red fescue canopy height. Measurements were taken at the ripening stage, at the end of June (BBCH 85-87) using a meter stick at eight points on each plot (one for every 2 m^2).

2.5. Statistical Analysis

Analysis of variance (ANOVA) was carried out using a mixed procedure of Analysis of Variance for Orthogonal Experiments, developed by the UTP University of Science and Technology in Bydgoszcz, Poland. The means were verified with the Tukey's test at significance level α = 0.05. The paper presents the means for two seed production years for two "replicate" experiments.

3. Results

3.1. Length of Generative Tillers and Canopy Height

Chewings red fescue (cv. 'Dorosa') had significantly longer generative tillers (by 2.7 cm) than strong creeping red fescue (cv. 'Nista') (Table 2). The use of growth regulators, regardless of their type, caused, on average for the cultivars as well as for the Chewings red fescue cv. 'Dorosa', shortening of generative tillers relative to the control. Moreover, the application of CCC alone at BBCH 30-31 had a similar effect on the shortening of generative tillers as the use of CCC at BBCH 30-31 + ET at BBCH 37-39. Generative tillers of red fescue, on average for the cultivars, were the shortest if CCC was applied at BBCH 30-31 + TE at BBCH 37-39. The response of strong creeping red fescue cv. 'Nista' to the type and date of the applied growth regulators was weaker. The shortening of generative tillers in this cultivar as compared to the control was noted only after the application of CCC (at BBCH 30-31) and TE (at BBCH 37-39).

Table 2. Length of generative tiller of *Festuca rubra* ssp. *rubra* cv. 'Nista' and *F. r.* ssp. *commutata* cv. 'Dorosa' depending on plant growth regulator, and nitrogen fertilization rate, means for two production years, and two field experiments (cm).

Treatment	Plant Growth Regulator (PGR): Control	Chlormequat Chloride	Chlormequat Chloride + Ethephon	Chlormequat Chloride + Trinexapac-ethyl	Mean	LSD $_{\alpha = 0.05}$
Generative tiller length (cm)						
Cultivar						
Nista	72.7	71.0	71.5	69.8	71.3	PGR—1.75; cultivar—1.33; N rate—0.75; PGR × cultivar—2.54; PGR × N rate—ns; cultivar × N rate—ns
Dorosa	74.0	67.5	68.2	64.6	68.6	
N rate [kg ha^{-1}]						
40	73.5	68.4	69.0	66.1	69.3	
70	73.2	70.1	70.7	68.3	70.6	
Mean	73.4	69.3	69.9	67.2	69.9	

Note: ns—not significant.

Progressive bending over of the tillers near ground level was observed from anthesis to ripening stage of red fescue. The canopy height was influenced by PGRs, cultivars and nitrogen fertilization rates (Table 3). In all PGR treatments, on average for nitrogen rate and cultivars, the canopy height at harvest was significantly higher than in the control. Cultivar 'Dorosa' was more resistant to lodging. Its canopy height, an average for PGRs, was similar after application of N in rates 40 and 70 kg ha^{-1}. The increasing the N fertilization rate from 40 to 70 kg ha^{-1} caused the significant reduction (by 4.4 cm) canopy height of strong creeping red fescue cv. 'Nista'.

Table 3. Canopy height at harvest of *Festuca rubra* ssp. *rubra* cv. 'Nista' and *F. r.* ssp. *commutata* cv. 'Dorosa' before seed harvest depending on plant growth regulator, and nitrogen fertilization rate, means for two production years, and two field experiments (cm).

Treatment	Plant Growth Regulator (PGR): Control	Chlormequat Chloride	Chlormequat Chloride + Ethephon	Chlormequat Chloride + Trinexapac-ethyl	Mean	LSD $_{\alpha = 0.05}$
Canopy height [cm]						
Cultivar						
Nista $_{40}$	47.2	54.4	53.7	54.7	52.5	PGR—5.63; cultivar—2.09; N rate—1.03; PGR × cultivar—ns; PGR × N rate—ns; cultivar × N rate—1.45
Nista $_{70}$	41.2	51.4	49.7	50.2	48.1	
Mean	44.2	52.9	51.7	52.5	50.3	
Dorosa $_{40}$	44.5	57.9	56.4	56.2	53.7	
Dorosa $_{70}$	42.9	54.4	54.6	54.6	51.6	
Mean	43.7	56.1	55.5	55.4	52.7	
N rate [kg ha^{-1}]						
40	45.8	56.2	55.0	55.5	53.1	
70	42.0	52.9	52.2	52.4	49.9	
Mean	43.9	54.5	53.6	53.9	51.5	

Note: ns—not significant.

3.2. Biomass Production of Aboveground Part

Red fescue, on average for the cultivars, plant growth regulators treatment and N rates, produced 0.680 kg m^{-2} (6.8 t ha^{-1}) of above-ground dry weight (e.g., vegetative and generative tillers) of which 72.4% were generative tillers and 27.6% vegetative ones (Table 4).

Table 4. Dry matter of vegetative and generative tillers of *Festuca rubra* ssp. *rubra* cv. 'Nista' and *F. r.* ssp. *commutata* cv. 'Dorosa' depending on plant growth regulator, and nitrogen fertilization rate, means for two production years, and two field experiments [kg m^{-2}].

Treatment	Plant Growth Regulator (PGR)				Mean	LSD $_{\alpha = 0.05}$
	Control	Chlormequat Chloride	Chlormequat Chloride + Ethephon	Chlormequat Chloride + Trinexapac-ethyl		
Vegetative tillers DM (kg m^{-2})						
Cultivar						
Nista	0.247	0.199	0.224	0.213	0.221	PGR—ns; cultivar—0.022; N rate—ns; PGR × cultivar—ns; PGR × N rate—ns; cultivar × N rate —ns
Dorosa	0.150	0.192	0.164	0.149	0.164	
N rate [kg ha^{-1}]						
40	0.178	0.170	0.191	0.190	0.182	
70	0.220	0.187	0.197	0.172	0.194	
Mean	0.199	0.179	0.194	0.181	0.188	
Generative tiller DM (kg m^{-2})						
Cultivar						
Nista	0.452	0.448	0.364	0.448	0.428	PGR—ns; cultivar—0.042; N rate—0.023; PGR × cultivar—ns; PGR × N rate—ns; cultivar × N rate —ns
Dorosa	0.564	0.516	0.568	0.560	0.552	
N rate [kg ha^{-1}]						
40	0.492	0.428	0.432	0.464	0.452	
70	0.520	0.572	0.500	0.544	0.532	
Mean	0.508	0.500	0.464	0.504	0.492	

Note: ns—not significant.

3.3. Biomass Production of Below-Ground Part

Averaged over all treatments, biomass of red fescue generative tillers was 2.6 times higher than of the vegetative ones. Cultivars differed in terms of the weight of vegetative and generative tillers produced. 'Nista' produced a significantly higher weight of vegetative tillers than cv. 'Dorosa'. The percentage of vegetative tiller weight in the total above-ground biomass was relatively height and amount to 34% and 23% for cv. 'Nista' and 'Dorosa', respectively. In contrast, the weight of generative tillers was significantly higher in Chewings red fescue (cv. 'Dorosa'). The use of growth regulators had no significant effect on the production of dry weight of either vegetative or generative tillers. Similarly, increasing the N fertilization rate from 40 to 70 kg ha^{-1} did not have a significant effect on the amount of dry weight of vegetative tillers but caused a significant increase in the amount of dry weight of generative tillers.

We did not find of plant growth regulator effect on the amount of root dry weight of red fescue cultivars (Table 5). Chewings red fescue cv. 'Dorosa' was characterized by a higher root weight as compared with strong creeping red fescue cv. 'Nista'. Increasing the nitrogen fertilization rate from 40 to 70 kg ha^{-1} caused, on average for cultivars and growth regulators, a significant reduction in the amount of root dry weight produced.

No effect of plant growth regulators treatment on the amount of rhizome biomass of strong creeping red fescue cv. 'Nista' was found. However, the effect of the nitrogen fertilization rate was significant. Rhizome weight after the application of 70 kg N ha^{-1} was significantly lower than after the application of 40 kg N ha^{-1}.

Table 5. Dry matter of roots and rhizomes of *Festuca rubra* ssp. *rubra* cv. 'Nista' and *F. r.* ssp. *commutata* cv. 'Dorosa' depending on plant growth regulator, and nitrogen fertilization rate, means for two production years, and two field experiments [kg 0.09 m^{-3}].

Treatment	**Plant Growth Regulator (PGR)**				**Mean**	**LSD** $_{\alpha = 0.05}$
	Control	**Chlormequat Chloride**	**Chlormequat Chloride + Ethephon**	**Chlormequat Chloride + Trinexapac-ethyl**		
	Roots DM (kg 0.09 m^{-3})					
Cultivar						
Nista	0.460	0.467	0.476	0.463	0.467	PGR—ns; cultivar—0.024; N rate—0.023; PGR × cultivar—ns; PGR × N rate—ns; cultivar × N rate—ns
Dorosa	0.533	0.549	0.573	0.568	0.556	
N rate [kg ha^{-1}]						
40	0.510	0.511	0.543	0.522	0.522	
70	0.483	0.505	0.507	0.509	0.501	
Mean	0.497	0.508	0.525	0.515	0.511	
	Rhizomes DM (kg 0.09 m^{-3})					
N rate [kg ha^{-1}]						
40	0.116	0.120	0.107	0.113	0.114	PGR—ns; N rate—0.012; PGR × N rate—ns
70	0.103	0.089	0.092	0.097	0.095	
Mean	0.109	0.104	0.100	0.105	0.105	

Note: ns—not significant.

3.4. Nitrogen Concentration and Accumulation

The nitrogen content in the above-ground part of red fescue at the flowering stage was on average 0.115 g kg^{-1} dry weight (Table 6). There was no significant effect of the retardant type or cultivar on the nitrogen content in the above-ground biomass, whereas the effect of the applied nitrogen rate was significant. After the application of 70 kg N ha^{-1}, the N concentration in the above-ground part of fescue was significantly higher than after the application of 40 kg ha^{-1}.

Table 6. The N content [%] and N uptake [kg ha^{-1}] in above ground part (vegetative and generative shoots) of *Festuca rubra* ssp. *rubra* cv. 'Nista' and *F. r.* ssp. *commutata* cv. 'Dorosa' depending on plant growth regulator, and nitrogen fertilization rate, means for two production years, and two field experiments.

Treatment	**Plant growth regulator (PGR)**				**Mean**	**LSD** $_{\alpha = 0.05}$
	Control	**Chlormequat Chloride**	**Chlormequat Chloride + Ethephon**	**Chlormequat Chloride + Trinexapac-ethyl**		
	N content (%)					
Cultivar						
Nista	1.13	1.12	1.15	1.18	1.15	PGR—ns; cultivar—ns; N rate—0.037; PGR × cultivar—ns; PGR × N rate—ns; cultivar × N rate—ns
Dorosa	1.11	1.15	1.17	1.16	1.15	
N rate [kg ha^{-1}]						
40	1.07	1.07	1.12	1.10	1.09	
70	1.17	1.20	1.20	1.24	1.20	
Mean	1.12	1.14	1.16	1.17	1.15	
	N uptake (kg ha^{-1})					
Cultivar						
Nista	79.2	71.1	67.0	76,1	73.3	PGR—ns; cultivar—6.29; N rate—5.00; PGR × cultivar—ns; PGR × N rate—ns; cultivar × N rate—ns
Dorosa	78.7	82.2	83.9	81.5	81.6	
N rate [kg ha^{-1}]						
40	71.3	63.1	68.8	70.5	68.3	
70	86.6	90.2	82.0	87,2	86.3	
Mean	78.9	76.6	75.4	78.8	77.5	

Note: ns—not significant.

There was no significant effect of plant growth regulators on the amount of accumulated nitrogen in the biomass of generative and vegetative tillers (Table 6). However, the total nitrogen uptake in the above-ground part of red fescue was dependent on the rate of mineral nitrogen applied and on the cultivar. The nitrogen uptake by red fescue fertilized with nitrogen at a rate of 70 kg ha^{-1} was significantly higher (by 18 kg ha^{-1}) than after the use of a rate of 40 kg ha^{-1}. Chewings red fescue cv. 'Dorosa' accumulated significantly more nitrogen in the above-ground part compared with strong creeping red fescue 'Nista'.

4. Discussion

Our results showed a varied response of cultivars to the applied combinations of retardants (Table 2). In the Chewings cultivar, the use of CCC alone or its application with ET or TE resulted in a significant shortening of generative tillers. In the strong creeping cultivar, only the CCC + TE application had an effect on the shortening of generative tillers. The beneficial effect of TE on tiller shortening is also described by Chastain et al. [19] based on research on perennial ryegrass. In creeping red fescue (*Festuca rubra* L.), paclobutrazol applied alone reduced the tiller height of red fescue by 32% and caused reduction in their tiller weights [20]. In the present study, despite the shortening of generative tillers under the influence of retardants, the amount of above-ground biomass (vegetative and generative tillers) of fescue treated with retardants and untreated was similar (Table 4). This could have been due to thickening of the tillers or increased leaf weight. Tilhou and Nave [21] showed an increase in leaf proportion on fall native worm season grasses forage after the application of TE. Rademacher [14] claims that TE is inhibiting the activity of enzyme 3-β hydroxylase that the transforms inactive gibberellins form GA20 on highly active forms GA1 and GA3, which causes growth reduction and stem wall thickening. The study results available in the literature showed that the above-ground dry weight response depends on the type of retardant, grass species, cultivation and habitat factors. Chastain et al. report [19] that application of TE in perennial ryegrass did not reduce of above-ground biomass. Chynoweth and Moot [6], in turn, showed a decrease in the individual stem weight of this species after the application of TE, but only at delayed sowing. In a study of red fescue, a total dry weigh reduction was indicated after TE application, but only in one in four years of the study [22].

Chynoweth and Moot [6] claim that stems contributed assimilates to increase seed yield but are still a net sink with assimilates in the stem at harvest, and suggested the use of chemical stem shorteners that produce shorter stems with less storage capacity are expected to increase the rate of seed filling and increase seed yield of perennial ryegrass. Griffith [7], in turn, based on research of three grass species (perennial ryegrass, Italian ryegrass and tall fescue), claimed that the assimilates accumulated in tillers are the source of the supply of developing seeds and there was no evidence that stem growth or stem assimilate accumulation processes compete with developing seeds for available assimilates. Pre- and post-anthesis assimilate reserves play an important role in seed filling when current photoassimilate supply is reduced [7]. In our study, after application of retardants, red fescue seed yield increased from 9% to 13% compared to the control (data not shown), which indicates a favorable distribution of assimilates in plants treated with PGRs.

In the present study, the use of retardants did not affect the amount of the root dry weight of the studied cultivars or the amount of the amount of rhizome biomass in strong creeping red fescue (Table 5). Few studies of the root system response to the use of retardants (CCC and TE) indicate the beneficial effect of such preparations on the growth of cereal roots, but the effect of their action depends on the species and dose [15]. In a study of Kentucky bluegrass (*Poa pratensis*), flurprimidol (a gibberellic acid (GA)-biosynthesis inhibitor) had no effect on the root weight or root depth [23]. In creeping red fescue (*Festuca rubra* L.), grown a turf under container culture mefluidide applied alone or in combination with paclobutrazol caused significant reduction in root growth. Paclobutrazol applied alone did not affect the root length of red fescue [20].

In the present author's research, there was no significant effect of retardants on nitrogen content in the above-ground biomass of red fescue (Table 6). This fact, in the absence of response of the generative and vegetative tiller dry weight, determined the similar uptake of nitrogen in the above-ground biomass of red fescue treated with retardants and untreated.

The weight of vegetative tillers was higher in strong creeping red fescue compared with Chewings (Table 4). Fairey and Lefkovitch [10] report that the natural growth habit of creeping red fescue (*Festuca rubra* ssp. *rubra*) involves a steady proliferation of tillers which eventually become too dense to form seedheads. According to other researchers, *Festuca rubra* ssp. *rubra*, due to the formation of numerous rhizomes, tends to produce numerous tillers in the spring which remain vegetative if are non-induced. According to Heide [24], red fescue must go through the stage of flowering induction in autumn, below condition of short day (12 h) and low temperatures (6–15 °C for 12–20 wk). Furthermore, in contrast to other species, it should be considered that overwintering tillers in red fescue have no or little ability to transfer the induction stimulus to the tillers emerging in spring [25].

Chewings red fescue produced a greater weight of roots compared to strong creeping cultivars (Table 5). Other researchers also point to the differences in the root weight of Chewings and strong creeping lawn cultivars of red fescue [9,26]. Chewings red fescue 'Dorosa' accumulated significantly more nitrogen in the above-ground part compared with strong creeping red fescue 'Nista' (Table 6). In the absence of the effect of the cultivar on nitrogen content in the above-ground biomass, this increase in accumulation resulted only from a greater amount of this biomass. The beneficiaries of this nitrogen were mainly generative tillers whose percentage in cv. 'Dorosa' in the total above-ground biomass was higher than in 'Nista' and accounted for 77% (Table 4).

Increasing the N fertilization rate from 40 to 70 kg ha^{-1} did not affect the length of generative tillers (Table 2) or the amount of dry weight of vegetative tillers, but caused, on average for the cultivars, a significant increase in the production of dry weight of generative tillers (Table 4). The total above-ground mass of fescue after the application of 70 kg N ha^{-1} was by 14.5% higher than after applying 40 kg N ha^{-1}. Similarly, Young et al. [27] did not show a plant height response of Chewings red fescue at maturity to nitrogen fertilization doses but unlike our results, the total dry weight did not change under the influence of N rates, probably due to the very high level of fertilization (90–210 kg N ha^{-1}). Red fescue, irrespective of the cultivar and retardants, had a similar percentage of the vegetative tiller biomass in the total above-ground biomass after the application of 40 and 70 kg N ha^{-1}, 28.7% and 26.7%, respectively (Table 4). Thus, the 70 N ha^{-1} turned out to be "safe" due to the lack of extra stimulation of the development of vegetative tillers competing with generative tillers and hindering harvesting. In our study increasing the nitrogen rate also stimulated seed yields. The use of 70 kg N ha^{-1}, on average for other experimental factors, resulted in a 10% increase in yield compared to the dose of 40 kg ha^{-1} (data not shown).

Red fescue is a grass that has a shallow root. In the study by Brown et al. [28], in the top 7.6 cm of the soil it was from 61.1 to 84.3% of root weight. In the present study, it was shown that increasing the nitrogen fertilization rate from 40 to 70 kg ha^{-1} limited the amount of produced root and rhizome biomass (Table 5). It can reduce the drought resistance of plant. Previous studies show the sensitivity of the red fescue root system to the subsoil abundance in nutrients. It was shown that the root weight of lawn cultivars was smaller with a reduced proportion of fertile compost soil in the subsoil [9].

5. Conclusions

These results suggest that the use of retardants may have a beneficial effect on the shortening of generative tillers and reducing lodging in Chewings and strong creeping red fescue and, at the same time, not have a negative effect on the amount of produced above-ground biomass of generative tillers. Increasing the nitrogen fertilization rate from 40 to 70 kg ha^{-1} stimulates the growth of generative tiller biomass and at the same time does not pose a threat of excessive stimulation of the growth of non-productive vegetative tillers. The increase in the applied nitrogen rate, despite a negative effect on the root weight, does not limit the N content or accumulation in the above-ground part of red fescue.

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