Productivity of perennial herbage with the participation of *Trifolium pratense* L. on sod-podzolic soils of the Republic of Karelia

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Abstract. In the conditions of northern arable farming, the productivity and nutritional value of the dry mass of pure stand of *Tr. pratense* and three-component agrophytocenoses with the participation of meadow clover, as well as legume and cereal representatives (*Galega orientalis* Lam., *Medicago varia* Mart., *Bromus inermis* Leys., *Phlum pratense* L.) were studied. Against the background of spring fertilizing with $N_{45}P_{60}K_{90}$ and two-time mowing, the yield of dry biomass of grass mixtures averaged 8.3-8.8 t/ha over four years compared to single-species sowing of meadow clover (7.8 t/ha). In terms of energy and protein productivity, the maximum indicators of one hectare were provided by agrophytocenoses of clover (7.54 thousand feed units, 84.8 GJ of exchange energy, 1.22 tons of crude protein) and clover-timothy with the addition of galega or alfalfa (up to 7.19 thousand, 87.7 GJ, and 1.09 tons, respectively). The highest nutritional value of the feed mass (up to 16.71% of crude protein and 138 g of digestible protein/feed units) was allocated to a single-species clover herbage.

1 Introduction

In Karelia, the production of plant feeds for farm animals is mainly based on the use of perennial grasses. The conditions of their cultivation, the mowing multiplicity, the composition and productivity of aboveground biomass determine the quality of raw materials. Economic entities of the republic, when creating seed legume-cereal agrophytocenoses, prefer meadow clover. Poly-species crops with the participation of *Tr. pratense* contribute to solving the problem of the production of energy-saturated, high-protein bulky feeds [1, 2].

The cultivation of clover in the northern territories of Russia is limited by specific climatic and edaphic conditions: sharp temperature changes in winter, variability in the timing of stable snow cover occurrence, slow warming and spring waterlogging of the arable layer, uneven moisture and heat supply of plants during the field season, mainly low fertility rates of sod-podzolic soils, etc. Here, clover is prone to thinning during

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overwintering, differs in longer rates of regrowth at the beginning of the growing season, often suffers from a lack of moisture in the intercostal period, a deficiency of nutrients and increased soil acidity [3]. The manifestation of the above negative features of *Tr. pratense* is smoothed out by its use in mixed crops of perennial legumes and cereals. The formation of highly productive agrophytocenoses involves the selection of species composition considering their morphobiological features and the improvement of nitrogen nutrition of cereal components due to symbiotic nitrogen fixation of legumes, which contributes to an increase in yield, the balance of the feed mass in terms of sugar-protein ratio and energy [4, 5]. Allelopathic properties of plants, specifics of their relations with each other and with the environment, stability of the plant community, etc. are also considered when designing long-term mowing grass stands. It is known that the meadow clover of the second year of life in grass stands is coenotically very active and displaces other types of grasses [6] due to its high competitiveness associated with more developed root system and functioning of legume-rhizobial symbiosis [7, 8]. According to Liu, Quan, & Xu et all [9], the phytotoxic activity of *Tr. pratense* against other plants is associated with the synthesis of allelochemical substances. Therefore, it is promising to organize artificial perennial herbage in certain agroecological conditions according to the principles of optimal complementation of phytocenosis components for the fullness of living space and the gradual change of some species by others with more productive longevity.

The purpose of the work is to study the yield and nutritional value of the dry mass of single- and poly-species perennial agrophytocenoses with the inclusion of meadow clover on sod-podzolic soils in the conditions of northern agriculture.

2 Materials and Methods

The objects for the formation of productive grass stands of the mowing type were the single-species sowing of meadow clover (*Tr. pratense*) variety Dobryak and three-species agrophytocenoses with its participation, as well as legume and cereal components - Eastern galega (*G. orientalis*) variety Jubilyar, variegated alfalfa (*M. varia*) variety Blagodat, common timothy (*Ph. pratense*) variety Olonetskaya mestnaya, awnless brome (*Br. inermis*) variety Voronezhsky 17.

The experiment was laid on July 11, 2018, open, drill sowing. The seeding rate of meadow clover in single-species sowing (control) is 14 kg/ ha. Legume-cereal three-species grass mixtures included 50% of the cereal component (timothy – 5 or brome – 10 kg/ha) and 25% of legumes (clover – 3.5 kg/ha, galega - 3.5, or alfalfa – 3.75 kg/ha). On the day of sowing, legume seeds were pretreated with rhizotorphin strains specific to each species.

Experimental studies with perennial herbs were carried out using techniques [10, 11]. The accounting plot area is 10 m^2, the repetition is 4-fold, the method of placing options is randomized. At the beginning of the spring regrowth of plants, mineral fertilizers were applied at a dose of $N_{45}P_{60}K_{90}$. Mowing of grasses was carried out twice during the season. Before mowing, the length of plant stems was measured and the density of the agrophytocenoses created was determined. In the phase of grass earing and the beginning of budding of legumes, the yield of aboveground biomass was considered in a continuous way, energy productivity, raw protein harvesting, and the protein value of feed were evaluated.

The analysis of soil and plant samples was carried out on the scientific equipment of the Center for Collective Use of the Federal Research Center "Karelian Scientific Center of the Russian Academy of Sciences" (spectrophotometer SF-2000, atomic absorption spectrophotometer AA-7000, potentiometer Anion 4100).

The presence of reliable deviations in the indicators of dry mass yield of the control and experimental variants was established using single-factor variance analysis [10]. In mixed

crops, the principal component analysis (PCA) method was used to determine the relationships between variables (length of shoots, their number per unit area – density, dry matter yield) [12]. Statistical processing of experimental data was carried out using computer programs Microsoft Excel 10 and StatGraphics Centurion XV.

During the research years 2018-2022, fluctuations in the average monthly air temperature and the amount of precipitation by month were noted [13]. The growth processes of perennial grasses and the accumulation of their biomass in 2018 occurred against the background of elevated temperatures and moisture deficiency (35.4-72.7% below normal) from May to July. The heat and moisture availability of plants close to the long-term norm in the first half of the growing season, as well as moderate temperature and excessive precipitation in July 2019 were optimal for forage crops. In 2020, a sufficient amount of heat and moisture had a positive effect on the photosynthetic activity of plants and the accumulation of the harvest of the green mass of perennial grasses. In 2021, the harvest of the first mowing was formed in relatively favorable weather conditions. The lack of moisture in July, which was the cause of water stress of plants, and excessive precipitation (1.9 times higher than normal) in August, caused a decrease in the level of grass productivity. During the 2022 field season, linear growth, plant development, and leaf-stem mass formation took place under conditions close to the biological optimum of the studied varieties.

The soil of the site on which the experiment was laid is sod-podzolic, well cultivated, in granulometric composition – light loamy. According to the agrochemical analysis of soil samples, the humus content in terms of carbon in soil organic matter is average (3.53%), mobile forms of phosphorus (250 mg/kg) and potassium (280 mg/kg) are very high, the acidity of the soil solution (pH 5.3) is slightly acidic. Cultivated sod-podzolic soils differ from their natural fertility. Soils of the sod-podzolic type on the territory of Karelia were formed as a result of the eluvial-illuvial process of soil formation in the conditions of the leaching regime. Their essential feature is the low saturation with bases, the presence of exchange ions of hydrogen and aluminum in the composition of absorbed cations. These soils are mostly characterized by the low power of the humus-accumulative horizon, depletion of organic and mineral compounds, insufficient aeration, fragile structure [14], as a result of which they are able to swim when moistened, form a soil cap when drying and compact.

3 Results and Discussion

A comparative analysis of the dry mass yield of the studied herbages by years of use showed that the single-species sowing of meadow clover was mainly inferior to poly-species agrophytocenoses (Table 1). In the control option, the yield decreased by the third year, and subsequently its growth occurred due to the introduced cereal species and various grasses. The productivity of mixed legume-cereal grass stands was characterized by relative stability over the years. No significant differences from the control have been established, with the exception of most options of the first mowing of the third year of use.

Table 1. Yield of dry mass of perennial herbage by mowing (2019-2022), t/ha

Experiment option	Year of use							
	first		second		third		fourth	
	1st* / 2nd	total	1st / 2nd	total	1st / 2nd	total	1st / 2nd	total
1. Meadow clover (K)	5.54 / 2.86	8.40	4.92 / 3.69	8.61	4.20 / 2.10	6.30	5.04 / 3.01	8.05
2. Clover +	5.45	8.42	6.09	8.87	6.90**	9.00	5.73	8.71

galega + timothy	2.97		2.78		2.10		2.98	
3. Clover + galega + brome	5.35 / 2.11	7.46	4.46 / 3.29	7.75	5.60** / 2.50	8.10	6.30 / 3.59	9.89
4. Clover + alfalfa + timothy	6.71 / 2.69	9.40	5.58 / 3.62	9.20	5.90** / 2.40	8.30	5.70 / 2.60	8.30
5. Clover + alfalfa + brome	5.43 / 3.19	8.62	5.21 / 3.53	8.74	5.20 / 2.80	8.00	6.52 / 2.92	9.44
F_f	0.78 / 1.20	0.94	4.34 / 1.58	2.18	5.05 / 0.88	2.17	1.14 / 1.70	1.48
LSD_{05}	–	–	1.18 / –	–	1.36 / –	–	–	–

Note: * – numerator - yield of the first, denominator – second mowing; F_f, F_t – actual and tabular values of the Fisher criterion; LSD_{05} – less significant difference; ** – significant deviation from the control (K) at the 5% significance level ($F_t = 3.26$).

The method of main components carried out for polyspecies agrophytocenoses established two main components for each of the mowing (Fig. 1). In the first mowing, the positive loads of component 1 indicate that the yield of dry weight (0.37) was determined mainly by the number of shoots of the cereal species (0.49). Reverse signs of loads with indicators of the number of shoots probably indicate a competitive relationship between clover (-0.30) and one of the cereal representatives (0.49) in the herbage. Unidirectional change in the length of shoots of *Tr. pratense* (-0.50) and *Ph. pratense* or *Br. inermis* (-0.49) indicates the same type of reaction of growth processes of plants of these species to growing conditions. According to the reverse signs of loads of component 2 suggested the presence of competition between *Tr. pratense* (-0.58) and *G. orientalis* or *M. varia* (0.42) in the struggle for living conditions. In addition, the latter differed in individual growth characteristics (0.67).

In the second mowing component 1 also indicates a negative mutual effect of clover and timothy or brome, which manifested in unequal signs of loads with number (0.50 and -0.32) and length (0.46 and -0.36, respectively) variables of shoots. Differences in linear indicators of clover (0.46) and other legume species (-0.51) were revealed. According to component 2, the yield of dry mass (0.50) was determined mainly by the length (0.47) and the number (0.52) of shoots of cereal grasses.

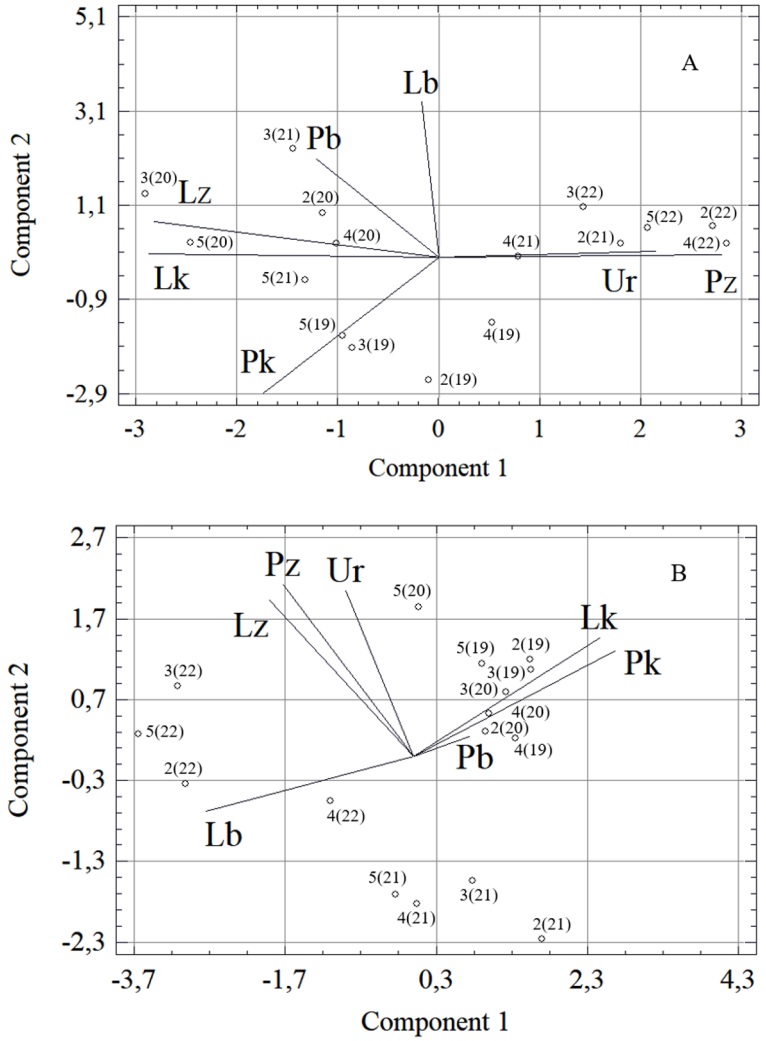

Fig. 1. Bi-plot analysis of dry matter yield indicators, length and number of shoots according to the results of the first (A) and second (B) mowing: Ur – dry matter yield; shoot length: Lk – clover; Lb – legume species; Lz – cereal species; number of shoots: Pk – clover; Pb – legume species; Pz – cereal species; the designation of points is the number of the experiment option (year).

On average, during the study period (Table 2), despite the higher yield of dry weight of polyspecies agrophytocenoses (8.3-8.8 t/ha) relative to single-species sowing (7.8 t/ha), *Tr. pratense* provided the largest collection of fodder units (7.54 thousand feed units) and crude protein (1.22 t) per hectare. Among the mixed crops, herbage with the participation of clover, timothy, galega or alfalfa stood out – energy and protein productivity indicators reached 7.19 thousand feed units, 87.7 GJ, and 1.09 tons of crude protein.

Table 2. Productivity of aboveground biomass of perennial herbage with the participation of meadow clover (on average for 2019-2022)

Experiment option	Received from 1 ha			
	of dry mass, t	feed units, thous.	exchange energy, GJ	crude protein, t
1. Meadow clover	7.84	7.54	84.8	1.22
2. Clover + galega + timothy	8.73	7.19	87.7	1.08
3. Clover + galega + brome	8.33	6.25	79.9	0.96
4. Clover + alfalfa + timothy	8.81	7.07	87.5	1.09
5. Clover + alfalfa + brome	8.70	6.45	83.1	0.91

According to the protein nutrition of the feed mass obtained from various grass stands, the maximum content of crude protein, regardless of the mowing, was characterized by a single-species phytocenosis of meadow clover. The indicators of crude protein in the dry mass reached 16.71%, and the provision of a feed unit with digestible protein was 138 g. Among the three-component herbages, clover-timothy agrophytocenoses with the addition of galega or alfalfa were noted. The content of crude protein in the dry mass was 13.58 and 14.51%, respectively, and the provision of feed unit with digestible protein was 133 and 129 g.

4 Conclusion

In the agroecological conditions of Karelia, three-species legume-cereal perennial grass stands based on meadow clover are more productive (1.1 times) compared to monospecies *Tr. pratense*. With the age of agrophytocenosis, against the background of a decrease in the participation of meadow clover, the yield of aboveground biomass of mixed crops, regardless of their species composition, is relatively stable over the years. The maximum values of one hectare (8.73-8.81 tons of dry mass, 7.07- 7.19 thousand feed units, 87.5-87.7 GJ of exchange energy, and 1.08-1.09 tons of crude protein) are provided by clover-timothy herbage with the addition of Eastern galega or variegated alfalfa relative to the control – meadow clover (7.8 tons, 7.54 thousand feed units., 84.8 GJ, 1.22 t, respectively). The nutritional value of the feed mass of *Tr. pratense* (up to 16.71% of crude protein and 138 g of digestible protein/feed units) exceeds the indicators of the studied three-component herbage. In the first three years of use of perennial legume-cereal agrophytocenoses, the greatest energy and nutritional value of the dry mass is provided by meadow clover, and in the future – eastern galega or variegated alfalfa, characterized by more productive longevity.

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