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Biotical cycle in single-crop sowing and mixed agrophytocenosis of forage crops

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Abstract. The biotic cycle is based on the assessment of chemical elements in the production, degradation processes, during the deposition and resynthesis of organic compounds. The biotic cycle of agrophytocenoses, in contrast to natural ecosystems, is characterized by a significant imbalance of macro- and microelements. One way of solving this problem is to approximate the composition and structure of agrophytocenoses to natural plant communities. The objective of the research was to investigate the biotic cycle of elements in single- and mixed-seeded crops of *Galega orientalis* Lam., *Inula helenium* L., *Symphytum asperum* Lepech., *urtica dioica* L. The research was conducted in the mountainous zone of the Kabardino-Balkarian Republic in 2015-2019 on grey forest soil. In mixed agrophytocenoses, the biotic balance becomes less negative compared to monoculture crops. The excess of consumption over the return of N, Ca, K, P to the soil averaged 3.96; 40.94; 334.02; 9.46 kg/ha, respectively, over 5 years. The inclusion of *Galega orientalis* in a mixture with nonlegurninous forage grasses increased the soil cultivation index from 0.87 to 0.90. The results show the high potential of a polyculture system based on the combined cultivation of legumes and non-legumes in increasing the sustainability of farming.

1 Introduction

The biotic cycle is based on the assessment of chemical elements in the production, degradation processes, during the deposition and resynthesis of organic compounds. The nitrogen cycle, being the most complex of the element cycles, has its own microbiological cycle of transfer from the atmosphere to the soil, transformation from organic to mineral forms, and release from the soil to the atmosphere. There are 3 sub-cycles of nitrogen in herbaceous biogeocenoses: microbial with a turnover of 5-6 cycles per year, vegetative with a turnover of 1 year, and humus with a turnover of 400-500 years. Common nitrogen stocks in herbal biogeocenoses range from 4000 to 17000 kg/ha, with 96% of this amount in slightly mineralized organic matter, the remaining part is accumulated in mortmass, phytomass and in mineral form. The balance of nutrients in natural plant communities in different years can be either positive, or negative. If the ecosystem is in a terminal state, a

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zero balance is usually established within 5-6 years. If the ecosystem is in slow succession, then a zero balance is established within one or two years [1].

The nature of the biotic cycle varies according to the cropping patterns (monoculture, mixed crop, narrow specialization crop rotations) and soil management strategies (tillage, no-till) [2]. In agrophytocenoses, the mineralization of organic matter is not compensated by the humification of plant residues, as their entry into the soil is reduced compared to their loss. Nitrogen, P, K and Ca losses are due to their removal with the crop. In addition, the release of these elements from the mineralizing plant residues exceeds their uptake by the plants. On grassland, the N value increases in mortmass and decreases in phytomass and soil organic matter. When grasslands are fertilized, the N value increases in green phytomass and in soil organic matter. Seeded grasslands with a high percentage of legumes receive about 50 kg/ha of nitrogen per year from the atmosphere through symbiotic nitrogen bonding and up to 2 kg/ha through non-symbiotic nitrogen bonding [1].

One possible way of solving the problem of the negative biotic balance of forage agrophytocenoses is to bring their composition and structure closer to natural plant communities. Formation of optimized mixed agrophytocenoses is based on the selection of species that complement each other fluctuationally, seasonally, successively, longitudinally and functionally [3, 4]. An important principle in the formation of sustainable, self-renewing agrophytocenoses is the differentiation of ecological niches and the ecological complementarity of plants of different adaptive strategies. Due to the fact that an important role in ensuring the stability of agrocenoses is played by the amount of return of substances removed out with the harvest of fodder mass, mixed agrophytocenoses should approach the natural systems and ecological equilibrium (sustaining) in the degree of closeness (balanceness) of circulation of substances [5, 6].

Information on biotic cycling and nutrient balance in mixed crops is scarce and mainly concerns grass-and-legume mixtures. In view of the above, the objective of the study was to investigate the biotic cycle of elements in single-species and mixed crops of non-conventional forage grasses of high nutritional, biological and energetic value.

2 Materials and Methods

The objects of the research were the parameters of the biotic cycle of single-species crops and mixed agrophytocenosis of fodder galega (*Galega orientalis* Lam.), alant (*Inula helenium* L.), prickly comfrey (*Symphytum asperum* Lepech.), stinging nettle (*Urtica dioica* L.). The research was carried out in the mountainous area of the Kabardino-Balkarian Republic (950 m above sea level). Seeding was performed in 2013. The wide-row seeding method was used with row spacing of 70 cm and seed application rate of 1 mln. pcs./Ha (*Galega orientalis*, *urtica dioica*), 0.25 mln. pcs./Ha (*Inula helenium*), 0.1 mln. pcs./Ha (*Symphytum asperum*). Plot area of 20 m^2. For the purpose of creation of a mixed agrophytocoenosis in 2013, segments of roots and rootstock of the studied species were planted with a plant spacing of 70 cm and a row spacing of 70 cm. Systematic arrangement. Planting was done in alternating strips of 5 m in length. No agro-technical activities were carried out on the sites, standing grass crop was used for haymaking (2 times during the growing season). The biotic cycle parameters in the monoculture and in the mixture were recorded in 2015-2019. The green phytomass was cut at soil level, then litter was collected from the site. Underground phytomass was counted using the 1 dm^3 monolith method to a depth of 40 cm. Replication: 4-times. The plant matter samples were dried to air-dry weight and weighed. The rate of mineralization of root and crop residues was analyzed by embedding a mixed sample in the soil and periodically checking the mass loss of the sample. The content of mobile P and K compounds (according to Chirikov), exchangeable Ca (by complexometric method) and pH were determined in the soil samples. The soil cultivation index (Ic) was determined as the arithmetic mean of the relative indices of agrochemical properties (pH, phosphorus, potassium, humus) [7]. The contents of N (Kjeldahl), Ca (complexometric method), P (photometric method), K (flame emission spectroscopy) were determined in the above-ground and below-ground phytomass. The uptake of elements from the soil was estimated based on their content in the above-ground and below-ground mass. The return of elements to the soil was assessed by symbiotic nitrogen fixation, the amount of elements leached by precipitation from above-ground organs (N, P), released by decomposition of underground organs and litter, released by lifetime from underground organs (Ca, P, K).

3 Results and Discussion

The study area is moderately humid. There is 500-800 mm of rainfall during the growing season, with 50% of all precipitation occurring between May and July. The amount of temperature does not exceed 1800°C. The grey forest soil of the experimental site is medium-deep (humus layer thickness 25-28 cm), medium loamy, slightly rocky. The physical clay content in the soil is 50-60%, with a coarse dust fraction (34%) predominating and silty fraction of 10-15%. The density of the plowing soil horizon is 1.26 g/cm^3 and there is significant compaction of the soil horizon at a depth of 35-45 cm. The content of humus in the soil is average, the reaction of the soil solution is slightly acidic (pH_{KCl}=6.7) the content of mobile forms of phosphorus and potassium is elevated, Ic=0.87 (Table 1).

Table 1. Agrochemical indexes of the experimental plot soil.

Sampling depth (cm)	Humus (%)	P_2O_5 (mg/kg of soil)	K_2O (mg/kg of soil)	Ca exchangeable (mg/100 g of soil)
0-10	4.2	82.0	105.0	360.0
19-28	2.3	63.0	98.0	332.0
30-40	1.5	47.0	82.0	304.0

The starting point for the calculation of the biotic balance was the estimation of the main withdrawal of nutrients – accumulation of dry matter in above-ground (2 cuttings per season) and below-ground phytomass (Figure 1).

The general trend for all variants is an annual increase in below-ground phytomass. Compared to the original value, the weight of roots and rootstock has increased in the crops of *Galega orientalis*, *Inula helenium*, *Symphytum asperum*, *Urtica dioica* and mixture by 1,97; 2,43; 2,12; 3,70 and 2,25 times respectively. The average annual specific weight of underground phytomass in total biomass of dry matter was 55.86% for *Galega orientalis*, 37.0% for *Inula helenium*, 56.06% for *Symphytum asperum*, 27.57% for *Urtica dioica*, and 46.21% for mixed agrophytocoenosis.

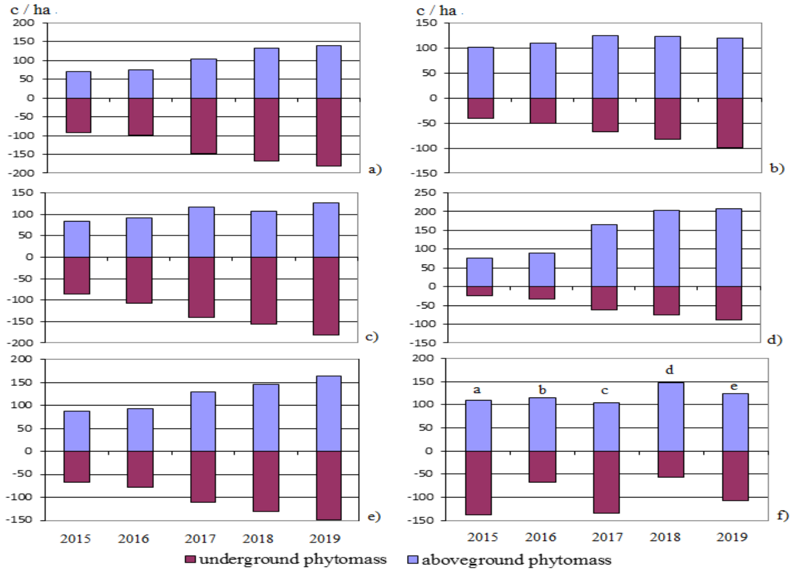

Fig. 1. Dynamics of above-ground and below-ground phytomass, dry weight, cwt/ha, in single-species crops.

Galega orientalis (a), *Inula helenium* (b), *Symphytum asperum* (c), *Urtica dioica* (d), mixtures (e) and the annual average of the variants (f).

The nitrogen balance in single-species crops of *Galega orientalis* is positive, due to symbiotic nitrogen bonding. In the remaining grasses, the difference between N intake and consumption was negative in all years of the study (Table 2).

Table 2. N value of crops.

Years	Yield, kg/ha				Input, kg/ha			
	Galega orientalis	Inula helenium	Symphytum asperum	Urtica dioica	Galega orientalis	Inula helenium	Symphytum asperum	Urtica dioica
2015	214.6	209.2	200.5	225.2	260.2	171.3	164.6	183.8
2016	277.8	290.3	246.3	256.9	384.1	234.6	200.3	208.6
2017	416.4	344.6	318.6	371.2	453.2	266.9	256.7	297.8
2018	463.1	358.4	310.9	382.0	480.0	287.9	250.7	306.1
2019	514.8	362.1	366.5	405.3	545.4	290.6	294.0	324.3
∑	1886.7	1564.6	1442.8	1640.6	2122.9	1251.3	1166.3	1320.6

Ca balance is positive only in the *Galega orientalis crop.* The greatest difference between the input and yield of Ca was observed for *Urtica dioica* (Table 3).

Table 3. Ca balance in crops.

Years	Yield, kg/ha				Input, kg/ha			
	Galega orientalis	Inula helenium	Symphytum asperum	Urtica dioica	Galega orientalis	Inula helenium	Symphytum asperum	Urtica dioica
2015	46.4	45.4	35.2	450.3	34.5	31.9	29.2	387.1
2016	60.2	50.6	41.0	518.6	47.0	38.1	33.8	443.4
2017	71.9	52.4	40.6	611.8	64.6	40.3	33.4	520.2
2018	86.1	55.3	48.4	760.0	75.4	43.7	39.8	642.4
2019	97.0	56.5	50.7	812.2	81.6	45.2	41.8	685.4
∑	361.6	260.2	215.9	3152.9	303.1	199.2	178.0	2678.5

K and P in all crops are characterized by a negative balance due to their significant accumulation in the underground mass and their removal with the hay crop (Tables 4, 5).

Table 4. K balance in crops.

Years	Yield, kg/ha				Input, kg/ha			
	Galega orientalis	Inula helenium	Symphytum asperum	Urtica dioica	Galega orientalis	Inula helenium	Symphytum asperum	Urtica dioica
2015	106.8	654.4	620.8	434.2	82.6	312.9	298.7	220.2
2016	134.0	771.1	719.7	490.2	94.0	361.9	340.3	243.8
2017	162.7	795.6	802.1	521.5	106.1	372.1	374.9	256.9
2018	185.9	826.5	909.3	645.2	115.9	385.2	419.8	308.9
2019	189.1	840.0	926.2	679.1	117.2	390.8	427.0	323.1
∑	778.5	3887.6	3978.1	2770.2	515.8	1822.9	1860.7	1352.9

Table 5. P balance in crops.

Years	Yield, kg/ha				Input, kg/ha			
	Galega orientalis	Inula helenium	Symphytum asperum	Urtica dioica	Galega orientalis	Inula helenium	Symphytum asperum	Urtica dioica
2015	60.4	80.0	68.1	84.5	53.6	69.8	69.0	73.5
2016	78.5	86.3	74.5	90.1	68.7	75.0	65.3	78.2
2017	98.0	95.5	83.3	114.3	84.5	82.7	72.5	98.2
2018	118.0	102.0	80.6	130.0	101.3	88.1	70.3	111.3
2019	132.7	110.8	95.2	140.2	113.5	95.3	82.4	119.7
∑	487.6	474.6	401.7	559.1	421.6	410.9	359.5	480.9

In mixed agrophytocenoses, the biotic balance becomes less negative compared to monoculture crops (Table 6). On average, the excess of yield over input for N, Ca, K and P over 5 years of the study was 3.96, 40.94, 334.02 and 9.46 kg/ha, respectively (Figure 2).

The results show an increase in the biotic cycling of chemical elements in mixed agrophytocenoses compared to single-species crops of *Galega orientalis*, *Inula helenium*, *Symphytum asperum* and *Urtica dioica.* In our opinion, the principle of chemical element imbalance compensation should be considered when optimizing the placement of grasses in a polyculture. The reduction of element imbalances in *Inula helenium*, *Symphytum asperum*, *Urtica dioica* crops is ensured by their co-growth with a legume component (*Galega orientalis*).

Table 6. N, Ca, K, P balance in a mixed agrophytocenosis.

Years	Yield, kg/ha				Input, kg/ha			
	N	Ca	K	P.	N	Ca	K	P.
2015	310.2	272.5	537.9	75.1	288.3	256.6	301.5	69.4
2016	331.9	380.4	610.5	86.3	295.2	347.8	332.0	78.6
2017	365.5	433.8	691.9	99.5	391.4	392.1	366.3	89.5
2018	464.5	474.2	800.0	109.9	488.6	425.7	411.6	98.2
2019	513.0	577.0	891.3	112.7	501.8	511.0	450.1	100.5
∑	1985.1	2137.9	3531.6	483.5	1965.3	1933.2	1861.5	436.2

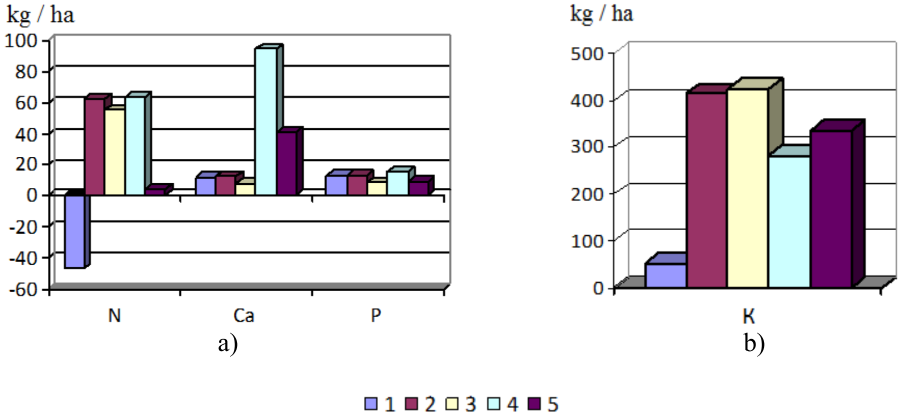

Fig. 2. Excess consumption of N, Ca, P (a), K (b) by *Galega orientalis* (1), *Inula helenium* (2), *Symphytum asperum* (3), *Urtica dioica* (4) and mixture (5) over the return of elements to soil. Average over the 5 years of the study, kg/ha.

In the mixed agrophytocenosis, *Galega orientalis*, *Inula helenium*, *Symphytum asperum* and *Urtica dioica* differ significantly in the requirements for individual of mineral elements, more effective use of resources by reducing the inter-species competition and regional differentiation of ecological niches, which leads to increased productivity and stability of the system.

Compared to non-legume grasses, the *Galega orientalis* agrophytocenosis is characterized by the greatest balanceness of chemical elements, which contributes to improved soil fertility. In 2019, the Ic for humus increased by 0.05 due to a 0.23% increase in humus content. The pH shift towards alcalinity (from 6.7 to 6.9) is due to the release of nitrogen in the form of ammonium during the decomposition of the dead plant mass of *Galega orientalis.* After 5 years, an increase in the content of mobile forms of phosphorus (from 82 to 112 mg/kg) and potassium (from 105 to 135 mg/kg of soil) was noted. As a result, soil Ic increased by 0.05 (Table 7).

The inclusion of *Galega orientalis* in mixtures with non-legume fodder grasses improves soil agrochemical parameters (increasing humus content by 0.02%, pH by 0.08) and increases Ic to 0.90. Improving the balanceness of the biotic cycle brings the mixed agrophytocenosis closer to natural ecosystems.

Table 7. Changes in soil agrochemical parameters in *Galega orientalis* agrophytocenosis.

Indicator	Indicator value					Ic	
	2015	2016	2017	2018	2019	2015	2019
Humus, %	4.20	4.20	4.23	4.30	4.43	0.62	0.67
pH_{KCl}	6.7	6.7	6.8	6.8	6.9	1.00	1.00
P_2O_5	82.0	92.0	100	110.0	112.0	0.87	1.00
K_2O	105.0	112.0	120	128.0	135.0	1.00	1.00
Ic						0.87	0.92

The compulsory inclusion of legume grasses in mixtures with other crops has been confirmed by numerous studies. The main advantages of legume cultivation are saving energy by reducing the need for nitrogen fertilizers, release of organic matter to the soil with an optimum C:N ratio (20-40:1), facilitating nutrient circulation in the soil, restoring inaccessible forms of soil phosphorus, retaining and ensuring the availability of soil water

[8-12]. The deep root systems of a number of legume species facilitate the exchange of nutrients by root exudates and their absorption/recirculation, as well as the infiltration of water into deeper soil layers. The impact of legumes on soil carbon sequestration is more pronounced for forage, green manure and cover crops, which return organic C and N to the soil and release hydrogen gas, which promotes the development of nodules of symbiotic nitrogen-bonding bacteria in the rhizosphere [13-21]. Some legume crops are able to mobilize the bonded forms of soil phosphorus by secreting organic acids (citrate and malate) and other P-mobilizing compounds from their roots [22].

A multicultural system based on the co-cropping of legumes and non-legumes is one aspect of sustainable farming. The main advantage of the polyculture system is the ecologisation of crop production, based on nitrogen bonding and nitrogen transportation from the legumes to non-legumes, soil protection from water and wind erosion, stabilization of soil temperature, water accumulation in the soil profile, improved physical characteristics, increased soil fertility and biological activity [23, 24].

4 Conclusion

The biotic cycle is based on the assessment of chemical elements in the production, degradation processes, during the deposition and resynthesis of organic compounds. Natural ecosystems are characterized by a zero balance of inputs and removal of chemical elements. In the biotic cycle of agrophytocenoses there is a significant imbalance of macro- and microelements. One way of solving this problem is to approximate the composition and structure of agrophytocenoses to natural plant communities. As a result of evaluation of biotic cycle of elements in single-species and mixed crops of *Galega orientalis* Lam., *Inula helenium* L., *Symphytum asperum* Lepech., *Urtica dioica* L., the relatively high balanceness of biotic cycles of nitrogen, phosphorus, potassium, calcium and improved soil agrochemical parameters in *Galega orientalis* agrophytocenosis was established. The biotic balance in the mixed agrophytocenosis was less negative compared to the single-species crop. The excess of consumption over the return of N, Ca, K, P to the soil over 5 years averaged 3.96; 40.94; 334.02; 9.46 kg/ha, respectively. The inclusion of *Galega orientalis* in mixture with non-legume fodder grasses improved soil agrochemical parameters (increasing humus content by 0.02%, pH by 0.08) and increase of soil cultivation index to from 0.87 to 0.90. Improving the balanceness of the biotic cycle brings the mixed agrophytocenosis closer to natural ecosystems. The results show the high potential of a polyculture system based on the combined cultivation of legumes and non-legumes in increasing the sustainability of farming.

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