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Assessment of Vulnerability of Natural Grasslands That Are Used as Pastures: Russia's Example

I. P. Aidarov[1], A. A. Zavalin[1], Yu. N. Nikolskii[1], C. Landeros-Sanchez[2], V. V. Pchyolkin[3] & S. Montero-Aguirre[4]

[1] Russian Academy of Agricultural Sciences, Russia

[2] Colegio de Posgraduados, Campus Veracruz, Mexico

[3] Russian State Agrarian University, Moscow, Russia

[4] Colegio de Postgraduados, Campus Montecillo, Mexico

Correspondence: C. Landeros-Sanchez, Colegio de Posgraduados, Campus Veracruz, Km 88.5 Carretera Federal Xalapa-Veracruz, C.P. 91690, Apartado Postal 421, Veracruz, Mexico. Tel: E-mail: clandero@colpos.mx

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Abstract

Natural grasslands that are used as pastures have great importance for animal husbandry. Unfortunately, because of various reasons, the productivity of natural pastures can decline with time. The methodology to predict possible long-term change of the basic properties of natural pastures depending on the pasture load is considered in the present paper. The simulation models and the results of their application for the conditions of use of natural pastures in the steppe zone of Russia are presented. The models take into account the following aspects: biodiversity of plant species in the grassland, capacity of ecological niche, vegetation productivity of grassland, climatic conditions, soil fertility, pasture load, surface slope, intensity of water and wind soil erosion, projective surface coverage, and ecological sustainability of the grassland. The analysis resulted from the proposed models in the examples of practical application showed that the described methodology could be used to develop the necessary measures for sustainable and intensive use of natural grasslands.

Keywords: natural fodder lands, biodiversity, productivity, ecosystem sustainability, soil fertility, pasture rotation

1. Introduction

One of the basic reasons for low efficiency of the use of natural forage lands may be their unsatisfactory condition because of a number of reasons. For example, in Russia, from the total area 91 million hectares of fodder land, more than 65% are degraded resulting in overgrazing and as a consequence, development of pasture digression (Tishkov, 2006). The efficiency of the use of natural forage lands in the whole country does not exceed 13-15% of their potential productivity.

However, the problem is not only low productivity of forage lands. Pasture digression is accompanied by a decrease in the vegetation diversity and soil degradation of these lands, which in its intensity and scale represents a threat to the ecological safety of large regions. As it is known, the change of biodiversity of vegetation species in grasslands can affect landscape water balance, river flow, soil conservation and stability of ecosystem functioning (Budyko, 1981; Radkovich, 2003; Watson & Zakri, 2005).

The problem of conservation and the increase in productivity and biodiversity of natural pastures and hayfields is important for many countries. With the purpose of making a contribution to it, numerous studies are being carried out and some of them are oriented to improve the state of grass canopy. See, for example, the following publications (Campbell & Stafford Smith, 2000; Harpole & Tliman, 2007; Hooper & Dradey, 2012; Chen et al., 2018) which contain results (of such studies in) for Australia, New Zealand, Mongolia, China, India, USA, Canada, UK and some others.

At present, some types of land reclamation are used in Russia to increase the productivity of natural fodder lands, such as application of nitrogen fertilizers, irrigation, liming, agro-forestry measures, *etc.* (Kulik, Petrov, & Semenyukina, 2014; Kosolapov & Shamsutdinov, 2015). The use not of a complex, but of individual measures, increases the productivity of grasslands, but at the same time it reduces the vegetation diversity and consequently the stability of ecosystem functioning (Harpole & Tliman, 2007; Hooper, Adar, & Dradey, 2012).

Application of complex land reclamation, taking into account the environmental needs of vegetation, allows not only to increase the productivity of natural forage lands, but also to preserve the vegetation diversity at the level that insures the stability of pasture ecosystems functioning and their high fodder value (Harpole & Tliman, 2007). Such approach is now widely used in Russia, but, so far, it is limited by application of highly productive forage grasses on degraded pastures and conservation and planting of trees and shrubs. Such measures are considered as a method to manage the natural resources of fodder land. The studies confirm the effectiveness of this approach for increasing the productivity of fodder lands). However, these relatively short-term studies and a lack of a comprehensive assessment of the grassland ecosystems do not allow assessing the long-term change in the natural vegetation diversity by including artificially modified grasses.

For an objective assessment of the environmental and economic effectiveness of the proposed approaches, further research is needed, including the following:

- Determination of necessary growth conditions of introduced highly productive fodder crops and their ecological niches;
- Assessment of the necessity and composition of measures that ensure not only realization of the biological capabilities of highly productive species, but also the maintenance of the necessary vegetation diversity;
- Determination of optimal of grassland vegetation diversity ensuring not only the sustainability of ecosystem functioning, but also preservation of its economic value depending on the ratio of edible; and
- Inedible plants, which deteriorates with increasing pasture load.

The present paper contains a methodology for long-term prediction of the state of grassland ecosystems in case of their use as pastures. Such predictions are necessary for the development of measures that ensure a high productivity, conservation of necessary vegetation biodiversity and stability of grassland ecosystem functioning.

2. Method

The methodology is based on modeling of functioning of grassland ecosystems, taking into account the dynamics of possible changes in grass species diversity, climate, soil fertility, productivity and sustainability of grassland ecosystem, as well as other natural and anthropogenic factors.

The Budyko's dimensionless radiative index of dryness (I) was applied to characterize climatic conditions of individual years and mean annual conditions (Budyko, 1977; Koster & Suarez, 1999):

$$I = Rn/(L \times Pr) \tag{1}$$

where, Pr and Rn are annual o mean annual values of precipitation (in mm) and net radiation (in KJ m^{-2}), L is the latent heat of evaporation equal to 2.51 KJ m^{-2} mm^{-1}.

Values of $I < 1$ approximately correspond to humid climatic conditions, $1 \le I < 2.5$ to semi-humid and semi-arid and $I \ge 2.5$ to arid conditions.

The following model was used to describe the dynamics of vegetation biodiversity of natural pastures during one year (Odum, 1983; Riznichenko, 2010):

$$B_{fin} = B_{in}\exp\left[\left(\frac{1}{1-r}\right)\left(1 - \frac{B_{in}}{B_{pot}}\right)\right] \tag{2}$$

where, B_{in} and B_{fin} represent the biodiversity of plant species in the natural pasture at the beginning and end of each year, respectively; B_{in} and B_{fin} are dimensionless, as a fraction of the productivity of natural grasslands in the region without their use, and varying from 0 to 1; r: pasture load as a fraction of annual grass biomass growth consuming or trampling annually by animals (dimensionless); $0 \le r < 1$, considering that animals consume not all grass species of natural pastures; B_{pot} is the capacity of the ecological niche or potential biodiversity corresponding to annual climatic condition and soil fertility; it is dimensionless, as a fraction of maximum productivity of natural grasslands, and varying from 0 to 1; B_{in} in a particular year may be greater or less than the B_{pot} value.

From Equation 2, when the climatic conditions of the year are favorable $B_{pot} > B_{in}$ and $B_{fin} > B_{in}$. The difference between B_{fin} and B_{in} is greater, the larger r. When climatic conditions are unfavorable $B_{pot} < B_{in}$ and $B_{fin} < B_{in}$. The difference between B_{fin} and B_{in} is greater again, the larger r value is. When $B_{pot} > B_{in}$, $B_{fin} = B_{in}$ independently from r.

According to data from Aidarov (2012) and Barmin, Iolin and Grigorenkova (2012), B_{pot} can be assessed as follows:

$$B_{pot} = f\ B(I) \tag{3}$$

where, f is the mean annual soil fertility level as a fraction of regional natural, dimensionless, changing between 0 and 1:

$$f = f_1\ S \tag{4}$$

where, f_1 and S are dimensionless coefficients considering content of nutrients and soil salinity, respectively; both coefficients vary between 0 and 1. Coefficient S is a reduction factor for the soil fertility level (f). Therefore, in the absence of soil salinity $S = 1$.

The dependence of B_{pot} annual values on the annual climatic index I is presented in the Table 1.

Table 1. Relationship $B_{pot}(I)$ in case $f_1 = S = 1$ (Tishkov, 2006; Aidarov, 2012)

I	0.8	1.2	1.6	2.0	2.4	2.8	3.2	3.6	4.0	4.4
B	0.70	0.82	0.90	0.96	1.00	0.94	0.84	0.66	0.56	0.50

As it should be expected, in very dry years, when $I > 3.5$, or in very humid years, when $I < 1.2$, the capacity of the ecological niche or potential biodiversity of plant species B_{max} is reduced.

The value of f_1 is calculated as follows (Pegov & Khomyakov, 1991; Nikolskii-Gavrilov et al., 2014):

$$f_1 = 0.32\frac{OM}{OM_{max}} + 0.42\sqrt[3]{\frac{N}{N_{max}}\cdot\frac{P}{P_{max}}\cdot\frac{K}{K_{max}}} + 0.26e^{-\left(\frac{\text{pH-6}}{2}\right)^2} \tag{5}$$

where, $f_1 = 0$ in the case of completely degraded soil, $f_1 = 1$ in case of maximum possible level of soil fertility in the region of study); OM: organic matter content, N and P: nitrogen and phosphorus available for crops, K: exchangeable potassium; OM_{max}, N_{max}, P_{max} and K_{max} are maximum values of these properties in the region of study (in the same units as OM, N, P and K).

The f_1 value is related also to the intensity of water and wind soil erosion (Er) (Kiryushin, 2001). In accordance with the universal soil loss equation (Wischmeier & Smith, 1978), the Er value depends on a number of factors, including slope of the surface and the projective surface coverage as a fraction of soil surface covered with vegetation.

The values of S depending on the content of toxic water-soluble salts in the 0-50 cm layer of the soil profile are obtained using the data obtained by Aidarov (2012), Aidarov and Zavalin (2015), and Averianov (2015), which are presented in Table 2.

Table 2. The values of S depending on the content of toxic water-soluble salts in the 0-50 cm layer of the soil profile (Aidarov, 2012; Aidarov & Zavalin, 2015; Averianov, 2015)

Salt content (% of dry soil mass)	0.30	0.40	0.50	0.55	0.60	0.65
Biodiversity of plant species (dimensionless)	1.0	0.8	0.6	0.4	0.2	0.0

Equation 2 corresponds to a simplified situation and, nevertheless, it allows quantifying the dynamics of the vegetation biodiversity in the grasslands. The state of the vegetation biodiversity in each year is temporal and it varies in accordance with the annual natural and anthropogenic factors.

In order to predict possible long-term change of the basic properties of natural pastures depending on the pasture load, the Equation 2 should be used successively over a number of years considering B_{fin} value for previous year as B_{in} value for the next year.

In general, for any T successive years the biodiversity $B_{fin}{}^T$ at the end of the year with number T can be determined as follows:

$$B_{fin}^T = B_{in}^1\beta_1\beta_2\beta_3 \dots \beta_T = B_{fin}^0\beta_1\beta_2\beta_3 \cdots \beta_T \tag{6}$$

where, $\beta_1 = \exp\left[\left(\frac{1}{1-r}\right)_1\left(1-\frac{B_{fin}^0}{B_{pot}^1}\right)\right]$; $\beta_2 = \exp\left[\left(\frac{1}{1-r}\right)_2\left(1-\frac{B_{fin}^1}{B_{pot}^2}\right)\right]$; and … ;

$$\beta_T = \exp\left[\left(\frac{1}{1-r}\right)_T\left(1-\frac{B_{fin}^{T-1}}{B_{pot}}\right)\right] \tag{7}$$

and digits 0, 1, 2, etc., correspond to a number of year.

The dependence of the projective surface coverage (λ) on the biodiversity (B), obtained by generalization of the available published data by Chernikov and Chekes (2000); Gilyarov (2003); Harpole and Tliman (2007); and Kazantseva and Svanidze (2014) has the following form:

$$\lambda = 1 - exp(-4B) \tag{8}$$

The regression coefficient of the dependence (8) is 0.81±0.10.

The productivity of natural grasslands (Y), as annual grass species biomass growth, depending on their biodiversity (B) was assessed in the following form based on the data reported by Foster and Dickson (2004); Kazantseva and Svanidze (2014) and Chen et al. (2018):

$$Y = \frac{1.05}{1 + 75.62e^{-7.33B}} \tag{9}$$

where, Y is dimensionless grassland productivity as a fraction of its potential value; Y varies from 0 to 1; B is dimensionless biodiversity varying also from 0 to 1. The correlation coefficient of the dependence (9) is 0.97±0.03.

As it is known the grassland ecosystems during their evolution have developed ways to protect themselves from excessive pasture load from wild herd animals (Odum, 1983; Hooper et al., 2012; Kosolapov & Shamsutdinov, 2015).

Natural grassland ecosystems are protected from overgrazing by mean of inedible plants. The density of such plants increases with the growth of pasture load and a decrease in biodiversity. The economic efficiency of pasture use depends on the edible plants productivity.

Table 3 presents the dependence of productivity of edible plants (η), as a fraction of total grassland productivity (Y), on the biodiversity (B).

Table 3. Dependence of productivity of edible plants (η), as a fraction of total grassland productivity (Y), on the biodiversity (B) of natural pastures (Myrzakhmetov, 2017)

B	1.00	0.80	0.60	0.40	0.20	0.10	0.05
η	1.00	0.97	0.88	0.62	0.21	0.07	0.03

The ecosystem sustainability of natural pastures (K_S) can be assessed using the following expression (Chernikov & Cherekes, 2000; Aidarov et al., 2018):

$$K_S = \sum_{i=1}^{n} \frac{A_i}{A_0} K_0 \cdot K_i \tag{10}$$

where, K_S is a dimensionless parameter of the pasture ecosystem sustainability varying between 0 and 1; n is the number of biotic and abiotic components of the ecosystem; A_i is the area of each biotic and abiotic component of the ecosystem as a fraction of total area of the ecosystem (A_0); K_0 is a dimensionless factor of geological and geomorphological stability of the relief, depending on water and wind soil erosion (Table 4) as a fraction of available level of soil erosion and varying between 0 and 1; K_i is a dimensionless factor of relative ecological significance of each component of the ecosystem. K_i basically depends on the biodiversity (B) and productivity (Y) of grassland and varies between 0 and 1. The methodology of determination of K_i depending on B and Y is described in the publication (Aidarov, 2012). When $K_S < 0.33$, it means the ecosystem is unstable; if K_S varies from 0.34-0.50 the ecosystem is weak-stable; 0.51-0.66, mid-stable; and 0.67-1.0, stable.

Thus, the natural pastures of the steppe zone of the European part of Russia were considered as an object of study (Figure 1). The total area of the study is 67×10^3 ha.

Figure 1. Location of the studied natural pastures of the European part of Russia

The climate of this region is continental with large variation of temperature in the year: from -5 °C to -25 °C in the coldest month during winter time and from 15 °C to 25 °C in the warmest month during summer time. Mean annual temperature is about 9 °C. The mean annual precipitation is 260 mm and annual precipitation varies from 150 to 450 mm. Annual net radiation varies inside interval (1.6-1.7)10^6 KJ m^{-2}. During the year, the wind speed is mostly 4-8 m s^{-1}, however, it is not uncommon for wind speed to reach 15-20 m s^{-1} (Narodetskaya, 1976). Mean annual climatic index I value varies between years in the studied region from 1.5 to 4.3, which means that the climatic conditions vary from semi-humid to arid.

The soils are mainly Kastanozems with organic matter stock of 150 t ha^{-1} in 0-30 cm layer of the soil profile. The content of water-soluble salts at a depth of 1 m is about 0.5% of the dry soil mass. The water table depth is more than 5 m. Therefore, groundwater practically does not affect soil formation processes.

The data on *Pr* and *Rn* for period of 1935-1975 years with a large variation in precipitation (from dry to wet years) were used to carry out a long-term prediction of dynamics of basic properties of the grassland ecosystems.

The long-term prediction of the state of pasture ecosystem was made for the following values of pasture load: r = 0.1, 0.2, 0.3, 0.4, 0.5 and 0.6.

The effect of soil salinity on pasture productivity was estimated from the data of Aidarov (2012), Aidarov and Zavalin (2015).

Annual data on climate, soil, pasture load and vegetation biodiversity were obtained from 1935 to 1975 in specific plots of the studied region (Narodetskaya, 1976; Chernikov & Chekes, 2000). Afterwards, they were generalized for their practical use in long-term prediction, in order to know a possible change of the state of pasture ecosystem over consecutive years for the whole region (Aidarov, 2012; Aidarov & Zavalin, 2015).

The grassland ecosystem in this region is rather homogeneous and geologically and geomorphologically stable. Therefore, it was possible consider $n = 1$, $K_i = K_0 = 1$. The content of content of toxic water-soluble salts in soils is less than 0.3%. According to Chernikov and Chekes (2000), and Aidarov and Zavalin (2015), the parameter of the natural grassland ecological sustainability in the absence of grassland use is $K_S = 0.8$.

According to the publications of Kirkby and Morgan (1980) and Narodetskaya (1976), the dependence of water and wind soil erosion (Er) on the projective surface coverage (β) and surface slope at mean wind speed equal to 10 m s^{-1} for this region is presented in Table 4.

The main goal of the long-term prediction of the state of pasture ecosystem is to assess the dynamics of change of its components: vegetation biodiversity, productivity, soil fertility, ecosystem sustainability and economic value of the forage, as well as assessment of the possibility of the proposed models use for development of measures ensuring the effective use and conservation of natural fodder lands.

Table 4. Intensity of total water and wind soil erosion (t ha^{-1} $year^{-1}$) of natural pastures in the steppe zone of the European part of Russia, which depends on projective surface coverage and surface slope (Narodetskaya, 1976; Kirkby & Morgan, 1980)

Surface slope	Projective Surface Coverage (Dimensionless)					
	0	0.2	0.4	0.6	0.8	1.0
0.01	20	16	11	7	3	2
0.02	25	21	14	10	7	3
0.03	32	27	18	14	11	7
0.04	42	36	27	13	17	8

3. Results and Discussion

The graphs of annual precipitation (*Pr*), radiative index of dryness (*I*) and the results of calculation on change of the vegetation biodiversity (*B*), grassland productivity (*Y*), coefficient of variation of productivity (C_V), soil fertility (*f*) and grassland ecosystem sustainability (K_S) during 40 years (from 1935 to 1975) in the Russian region of study depending on the pasture load (*r*) and climatic conditions are shown in Figure 2. This period includes years with different air temperature and precipitation. The change in the biodiversity is shown by years, and the values of *Y*, C_V, *f* and K_S for decades.

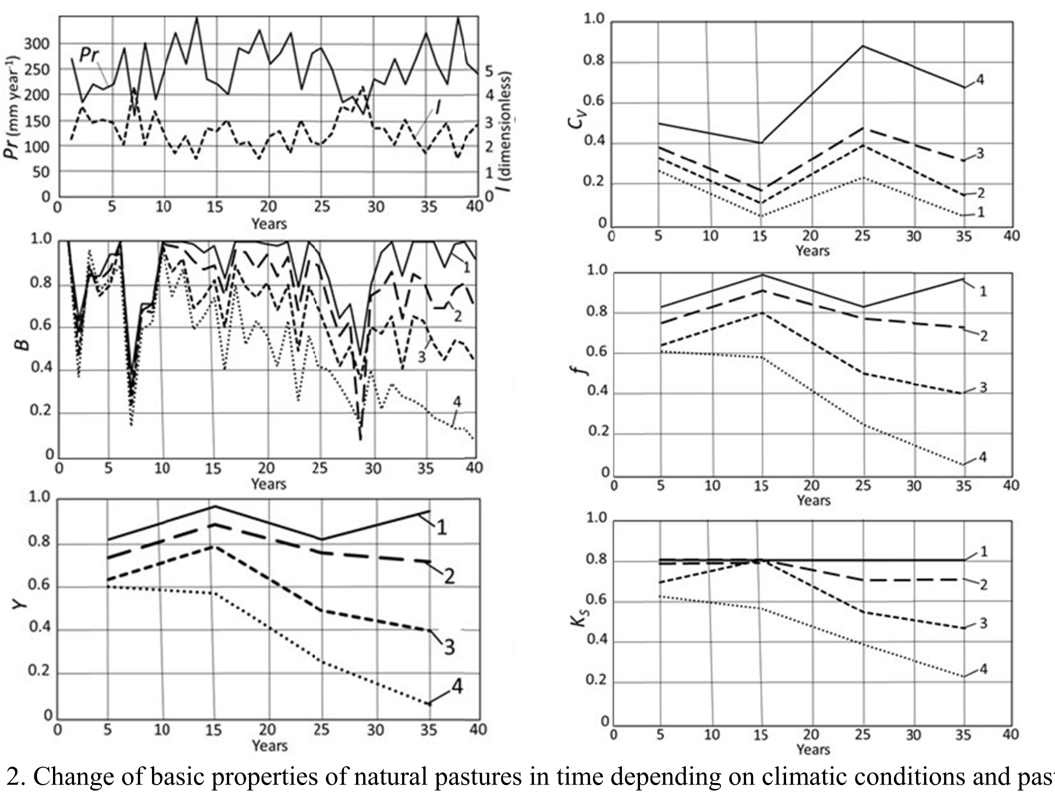

Figure 2. Change of basic properties of natural pastures in time depending on climatic conditions and pasture load: 1. $r = 0$; 2. $r = 0.2$; 3. $r = 0.4$; 4. $r = 0.6$. *Pr*: precipitation; *I*: radiative index of dryness; *B*: vegetation biodiversity; *Y*: productivity of natural grassland; C_V: coefficient of interannual productivity of natural grassland; *f*: soil fertility; K_S: ecosystem sustainability of grassland; *I*, *B*, *Y*, C_V, *f* and K_S values are dimensionless

In order to assess the quality of these calculations, a comparison was made between the calculated values of *Y*, depending on *B*, and published data on the pasture productivity measured in the region of study for some years with a known pasture load (Voronina, 2009). The comparison showed that the correlation coefficient between the calculated and observed values of the annual pasture productivity is 0.85±0.10. It means that the graphs in Figure 2 of *B*, *Y*, C_V, *f* and K_S, apparently reflect their real change in time, depending on climatic conditions and pasture load.

As it can be seen in Figure 2, a grassland ecosystem under natural conditions periodically experiences impacts associated with extreme arid years (second, seventh and twenty-ninth years). During these years, the grass species biodiversity (B) temporary reduces, but does not cause permanent long-term disturbance of the sustainability and functioning of ecosystem (K_S), since the historically developed vegetation is well adapted to the natural conditions. Therefore, the biodiversity (B) and productivity (Y), reduced in dry years, are restored within 3 years to the initial level. The grassland ecosystem, despite repeated dry years, strives for equilibrium. The coefficient of variation in productivity decreases after last increase. This feature of the behavior of the natural grassland ecosystem is due to the fact that the long coexistence of competing grass species is not accompanied by an increase in the difference between their ecological niches. Natural selection is aimed at achieving one "goal" *i.e.* to increase grass biomass and soil fertility (Gilyarov, 2003).

During the use of grassland as natural pasture, there are two differently directed processes in its ecosystem: on one side, the ecosystem tends to establish equilibrium and, on the other, the capacity of the ecological niche is reduced because of biomass alienation, development of degradation processes and reduction of soil fertility. As a result, the impact of climatic conditions on the biodiversity and productivity is sharply increased, and the stability of fodder production is reduced. The coefficient of variation of pasture productivity increases. The situation is further complicated by the fact that livestock eats edible plants, due to which the dominance of weed plants increases and, consequently, the feed value of pastures decreases.

At the pasture load $r = 0.2$, the ecosystem after the second extremely dry year (the 7th in the count) is not restored and it passes to a level with a lower ecological stability. The biodiversity (B) and grassland productivity (Y) by the end of the 40th year are reduced by 20%, the coefficient of variation in productivity (C_V) increases from 0.05 to 0.15, the coefficient of ecosystem stability (K_S) decreases from 0.8 to 0.7. The reduction in grassland productivity is associated primarily with a decrease in soil fertility (f) by about 20% because of deterioration of balance of soil organic matter.

An increase in pasture load up to 0.4 causes even more disruption of the grassland ecosystem. Coefficient of ecosystem sustainability at the end of the 40th year is 0.46, and biodiversity, productivity and fertility of soils are reduced to 0.42, 0.39 and 0.41 respectively. Further exploitation of the pasture at such pasture load will inevitably lead to the destruction of the ecosystem and the loss of its economic value.

The increase in the pasture load up to 0.6 removes the grassland ecosystem from equilibrium already in the second decade. Changes in the biodiversity and productivity are becoming chaotic. By the end of the 40th year, the ecosystem is practically destroyed: $K_S = 0.22$.

The influence of pasture load on the possible change of biodiversity, productivity and its variability over the years, soil fertility, ecological sustainability and utility of grass cover of the natural pastures after 40 years of their use is shown in the Table 5.

Table 5. Possible change of basic properties of the pasture ecosystem after 40 years of its use

Properties of pasture ecosystem	Pasture load (r)						
	0	0.1	0.2	0.3	0.4	0.5	0.6
Biodiversity (B_{fin})	0.90	0.82	0.75	0.59	0.42	0.27	0.10
Pasture productivity (Y)	0.95	0.89	0.82	0.61	0.39	0.22	0.07
Coefficient of variation of the productivity over the years (C_V)	0.04	0.10	0.17	0.25	0.34	0.50	0.67
Soil fertility (f)	0.95	0.85	0.76	0.52	0.41	0.22	0.06
Pasture ecosystem sustainability (K_S)	0.80	0.75	0.70	0.59	0.46	0.35	0.22
Utility of grass cover (η)	0.98	0.97	0.95	0.81	0.48	0.17	0.02

The data presented in Table 5 show that an increase in the pasture load r with time leads to a reduction in the following properties of the pasture ecosystem:

- Vegetation biodiversity,
- Stability of fodder production, and
- Soil fertility, which is usually ignored.

Unfortunately, the restoration of soil fertility requires large financial costs and long time.

Similar observations were also made in the studies reported by Campbell and Stafford Smith (2000), Harpole and Tliman (2007), and Hooper and Dradey (2012).

It is also known that restoration of soil fertility to the initial level in the near future is almost impossible. This is confirmed by the experience of soil restoration of the Great Plains of the USA. It took about 30 years to turn degraded prairie soils into low-grass and low-productive pastures (Mikha et al., 2008). Therefore, when studying the problem of conservation and rational use of natural fodder lands, it is necessary to consider the whole complex of grassland ecosystem properties, but not only its productivity.

The results of present studies provide a basis for using the proposed simulation models for prediction of long-term state of natural grasslands. Calculations shows that natural fodder lands can be used for a long time as pastures without changing their state under pasture load less than 15%. This is also confirmed by centuries of experience in the grasslands use as natural pastures. The increase in pasture load is inevitably accompanied by deterioration in the state of grassland ecosystems until their complete destruction.

The unsatisfactory state of natural fodder lands requires the solution of two problems:

- An increase in the efficiency of use and conservation of natural fodder lands, which are in a satisfactory condition, and
- Restoration of medium and heavily degraded fodder lands.

Among the various types of measures that have been used to improve the state of natural pastures, the introduction of pasture rotation is the simplest and most acceptable from an ecological and economic point of view. It is based on the pasture load management in order to maintain vegetation biodiversity, productivity and sustainability of pasture ecosystems.

Pasture rotation is a flexible system for the use of natural fodder lands, which allows combining various types of their economic use. The proposed simulation models permit to evaluate the efficiency of pasture rotation. One of the simple schemes of pasture rotation is alternate shift in pasture use and break in order to improve grass formation.

Preliminary calculations of the change of the pasture ecosystems state allow formulating the following rules for pasture rotation:

- The duration of the break in the economic use of pastures should not be less than the duration of restoration of vegetation biodiversity after extreme climatic impacts in natural conditions, which in this case is 3 years;
- Soil fertility conservation should be at the level of 80-90% of the regional natural;
- It is necessary to consider an increase in the vegetation productivity of pastures and annual fodder production stability; and
- It is necessary to maintain the sustainability of pasture ecosystems, which is important in conditions of present global warming.

The graphs of variation of grass vegetation biodiversity (B) and productivity of grasslands (Y) during the same 40 years (from 1935 to 1975), depending on the pasture load (r) calculated with the proposed model (9) and (11), for cases with and without pasture rotation are shown in Figure 3. The following conditions of pasture rotation were considered: at the pasture load $r = 0.2$ it was considered 5 years of pasture use and 3 years of interruption in the pasture use; at $r = 0.3$, 5 years of pasture use and 4 years of interruption in pasture use; at $r = 0.4$, 5 years of pasture use and 5 years of interruption of pasture use; at $r = 0.5$, 5 years of pasture use and 10 years of interruption in the pasture use. Therefore, the B and Y values were calculated on average for every 10 years at $r \leq 0.4$ and on average for every 20 years at $r = 0.5$.

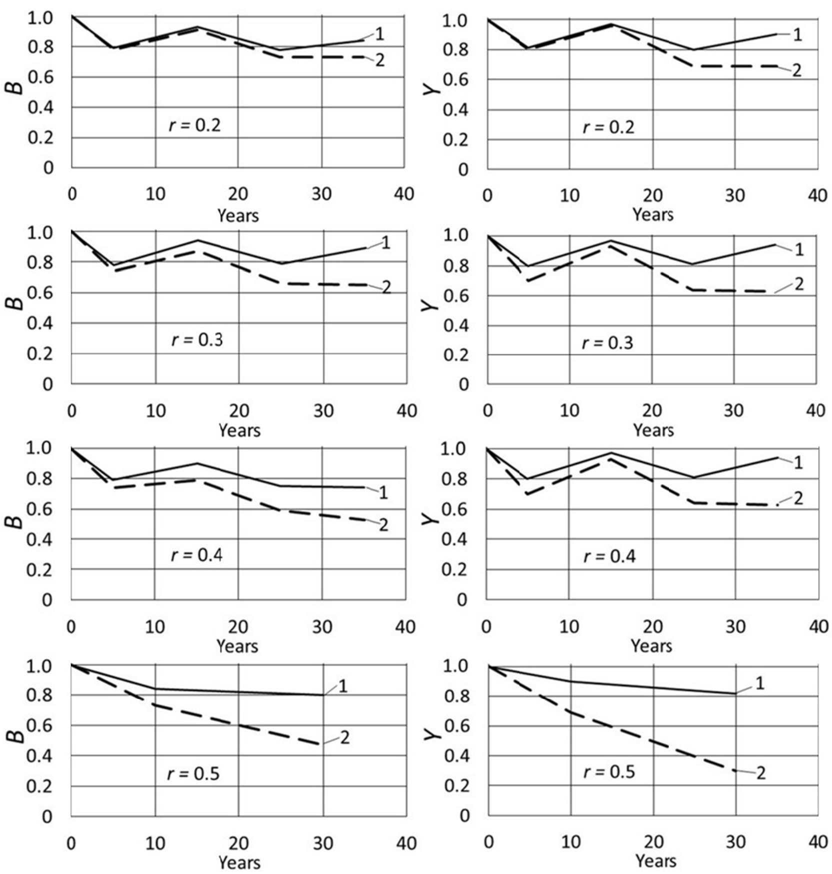

Figure 3. Comparative graphs of variation in the grass vegetation biodiversity of (*B*) and productivity of grasslands (*Y*) during 40 years, which depends on pasture load (*r*) with (1) and without (2) pasture rotation. *B* and *Y* are shown in fractions of the natural level without use of the grassland

As it is seen in Figure 3, the pasture rotation permits to maintain a high level of vegetation biodiversity and productivity of grasslands and long-term their use as pastures without destruction of the basic properties of pasture ecosystem.

Table 6 presents the comparative results of calculation of the B, Y, C_V, f and K_S values on average for the period of 40 years, with and without pasture rotation.

Table 6. Parameters B, Y, C_V, f, K_S and η of natural pastures for an average period of 40 years, with (1) and without (2) pasture rotation

Pasture properties	Pasture load (*r*)							
	0.2		0.3		0.4		0.5	
	1	2	1	2	1	2	1	2
Biodiversity (*B*)	0.84	0.79	0.82	0.73	0.77	0.66	0.82	0.60
Productivity (*Y*)	0.88	0.84	0.87	0.74	0.78	0.63	0.86	0.54
Soil pfertility (*f*)	0.93	0.79	0.95	0.66	0.78	0.51	0.95	0.49
Coefficient of variation of fodder production (C_V)	0.18	0.28	0.17	0.24	0.21	0.30	0.25	0.55
Pasture ecosystem sustainability (K_S)	0.67	0.63	0.67	0.58	0.62	0.53	0.66	0.48
Utility of grass cover (η)	0.98	0.97	0.98	0.92	0.95	0.85	0.98	0.74

As it is seen, on average over the entire period of 40 years the vegetation biodiversity can be maintained at the level of 0.77-0.84 and productivity 0.80-0.86 from the natural level due to pasture rotation at the pasture load $r \leq 0.5$. Soil fertility can be conserved at the level of 0.78-0.93 from its natural level. The variation of annual fodder production at pasture rotation decreases by more than 1.5-2 times, that is, it becomes more stable, and the pasture ecosystem sustainability increases up to 0.62. It is important to note that these results correspond to the case of intensive and long-term pasture use.

It is possible to reduce the duration of the breaks in the pasture use by means of the use of such periods for haymaking in order to increase fodder production. But this can lead to a deterioration of the ecological state of pasture ecosystems.

Therefore, at the final selection of the pasture rotation scheme, it is necessary to take into account not only the improvement of the properties and productivity of pastures, but also stability of fodder production.

4. Conclusions

The proposed methodology can help to solve the following important problems:

- Determination of limited pasture load, ensuring conservation of biodiversity, productivity and pasture ecosystem sustainability;
- Assessment of long-term possible changes in the ecological state of natural grasslands using as pastures;
- Assessment of the economic value of natural pastures depending on the level of pasture load and biodiversity; and

The development of measures to increase the productivity of natural grasslands at long-term used as pastures.

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