Original Research Paper

# Poly-Species Phytocenoses for Ecosystem Restoration of Degraded Soil Covers

**[1]Almabek B. Nugmanov, [2]Sergey V. Mamikhin, [1]Khusain Kh. Valiev, [1]Aliya U. Bugubaeva, [1]Asel S. Tokusheva, [3]Saniya A. Tulkubaeva and [4]Aleksandr G. Bulaev**

*[1]Kostanay Regional University named after A. Baitursynov, Kazakhstan*
*[2]Lomonosov Moscow State University, Russia*
*[3]Zarechnoye Agricultural Experimental Station LLP, Kazakhstan*
*[4]Winogradsky Institute of Microbiology, Research Center of Biotechnology of the Russian Academy of Sciences, Russia*

**Abstract:** Agroecological studies are based on the concept that, by understanding ecological processes, it is possible to manage agroecosystems for more sustainable production of more biomass and, thus, protection of natural resources. Many studies in the field of agroecology show that some farming methods can improve soil quality and restore agroecosystems by increasing plant biodiversity. Functional characteristics of plants for the assessment of ecosystem processes and services can be used for the sustainable management of agroecosystems. The paper discusses ways to restore pastures with low biological productivity in the arid steppe of Northern Kazakhstan (Kostanay region). Grass-and-legume mixtures were selected, according to the soil and climatic conditions of this region, to increase the productivity of pastures. The authors also describe the meteorological conditions in the region in question for 2021. The data of agrochemical analysis of the soil on which the grass mixture was grown differed slightly from the soils of other sites and often even was inferior to them in some indicators that affected plant productivity, namely, the humus, phosphorus, and potassium content. In the conditions of the experiment, the highest productivity was shown by the grass-and-legume mixture consisting of crested wheatgrass-*alfalfa*-awn less brome (27.8 c/ha of green mass and 12.6 c/ha of dry matter). Thus, according to the information obtained during the study, it can be concluded that to restore the productivity of pastures in Northern Kazakhstan, it is necessary to select the grass-and-legume mixtures that have the highest productivity and nutritional value and are adapted to the soil and climatic conditions of this region. The algorithm of the predictive simulation model of the dynamics of the graminoid community is also presented in a general form. Problems related to the remediation of soil covers are discussed.

**Keywords:** Pastures, Productivity, Grass-and-Legume Mixtures, Degradation, Fodder Crops

## Introduction

The Republic of Kazakhstan is an agrarian country and ranks sixth in the world in terms of pasture area. The total pasture area occupies 187 million ha. Currently, due to prolonged unsystematic use, 48.0 million ha have been degraded, among them, 26.5 million ha have been completely worn down (Torekhanov and Alimaev, 2007; Bakhralinova *et al.*, 2016).

For the development of animal husbandry in Kazakhstan, it is necessary to create a sustainable feed base, taking into account its potential, there are opportunities to introduce highly productive fodder crops and effective technologies into agricultural production. In Kazakhstan, the sources of providing plant feed for farm animals are pastures (187 million ha), hayfields (5.0 million ha), and fodder arable land (2.5 million ha) (BMAPA, 2009; Derpsch *et al.*, 2010; Popov *et al.*, 2017).

According to the Food and Agriculture Organization (FAO), the degradation of pastures leads to the loss of ecosystem functions caused by disturbances from which the system cannot fully recover (Agard *et al.,* 2007; Pereira *et al.*, 2018).

As a result of animal grazing, fodder grain crops and mixed herbs fall out of the herbage and low-value, weedy and poisonous plant species unsuitable for proper nutrition of livestock are introduced into its composition and begin to dominate. In addition, in previous studies (Liu *et al.*, 2019) it was noted that animal grazing led to a decrease in biomass, resulting in the long-term destruction of pastures. In Pakistan, vegetation degradation was mainly associated with an increase in livestock (Abbas *et al.*, 2017). In general, 21.29% of vegetation was degraded under the influence of climatic factors and anthropogenic actions, which was a serious problem (Zhao *et al.*, 2018). In the studies by several authors (Kubenkulov *et al.*, 2019; Oliveira *et al.*, 2022), criteria and indicators of the degree of degradation of vegetation cover were established, where the state of pasture vegetation was assessed by four degrees of degradation: 1: Weak, 2: Medium, 3: Severe, 4: Very severe. The limiting influence of abiotic factors on the productivity of degraded pastures and the manifestation of the influence of grazing as the most important deflationary process were determined (Edwards *et al.*, 2019; Leech *et al.*, 2019).

The main problems of the fodder industry are low yields of pasture feed; low levels of use of pastures and hayfields (Tokusheva and Nugmanov, 2016; Tokusheva *et al.*, 2017). To solve problems related to improving the state of pasture infrastructure, preventing the degradation of pasture lands, and preserving the ecological integrity of pasture ecosystems in the environment, as well as increase the production of environmentally friendly livestock products, so that Kazakhstan can become a global player in the production of milk and meat products (Nugmanov *et al.*, 2017).

In these works, sufficient attention was paid to the peculiarities and problems of growing perennial grasses, but they did not study the selection of legume components in the composition of pasture grass mixtures for the arid conditions of the Western Pre-Caucasian region (Bedilo, 2016).

The formation of grass-and-legume herbage on a pasture due to the replacement of technical nitrogen with a biological source helps to reduce average annual financial costs by 40% (Kutuzova, 2007). The positive effect of perennial legumes on the soil is also very great, as evidenced by numerous data obtained both in various regions of Kazakhstan and in Russia (Ganichev and Ryumin, 2018).

The relevance of our study is conditioned by the use of grass-and-legume mixtures to improve pastures without destroying the soil sod, which minimizes the degradation of pasture lands. In this aspect, this study is a popular and promising part of agricultural research,

especially in Kazakhstan.

The purpose of this study was to determine the possibilities of poly–species agrophytocenoses and to develop software tools for the restoration and improvement of degraded pastures in the northern regions of Kazakhstan.

## Materials and Methods

### Design of the Study

During the study, the following goals were set:

– To study the current state and determine the main ways of increasing the productivity of degraded pastures
– To conduct agrochemical assessment of soils
– To determine the productivity of poly-species agrophytocenoses during field experiments
– To determine the level of plant nitrogen nutrition by the content of chlorophyll in the leaves by measuring with the N-tester device
– To develop software tools for studying pasture productivity by mathematical modeling in the conditions of climate change and anthropogenic load. The location of the study, Agricultural Experimental Station Zarechnoye LLP, is located in Northern Kazakhstan, between the Ural Ridge in the west and the Kazakh hillocky area in the east, in the basins of the Tobol and Ubagan rivers. The region occupies a vast territory, about 114 thousand km$^2$, which is divided into three natural and climatic zones. The study institute is located in the 2$^{nd}$ soil-climatic zone. The territory is characterized as an arid steppe mainly with southern low-humus chernozems

### Stages of the Study

To reach the goals set on the study topic, the following field experiments were conducted.

Experiment No. 1:

1. Degraded pastures (control)
2. Crested wheatgrass (Agropyron pectiniforme Roem. et Schult.)-*alfalfa* (*Medicago sativa* L.)-awnless brome (Bromus inermis Leyss.)
3. Russian wild rye (Elymus junceus Fisch.)-*alfalfa* (*Medicago sativa* L.)-awnless brome (Bromus inermis Leyss.)
4. Slender wheatgrass (Elymus trachycaulus Get.S.)-*alfalfa* (*Medicago sativa* L.)-crested wheatgrass (Agropyron pectiniforme Roem. et Schult.)

Experiment No. 2:

1. Crested wheatgrass (Agropyron pectiniforme Roem. et Schult.) -common sainfoin (*Onobrychis viciifolia* Scop. (O. *Sativa Lam.*)-awnless brome (*Bromus inermis Leyss.*)

2. Russian wild rye (Elymus junceus Fisch)-common sainfoin (Onobrychis viciifolia Scop). (O. Sativa Lam.)-awnless brome (Bromus inermis Leyss.)
3. Slender wheatgrass (Elymus trachycaulus Get.S.)-common sainfoin (Onobrychis viciifolia Scop). (O. Sativa Lam.)-crested wheatgrass (Agropyron pectiniforme Roem. et Schult.)

Experiment No. 3:

1. Crested wheatgrass (Agropyron pectiniforme Roem. et Schult.)-fodder Galega (Galega orientalis Lam.)-awnless brome (Bromus inermis Leyss.)
2. Russian wild rye (Elymus junceus Fisch.)-fodder Galega (Galega orientalis Lam.)-awnless brome (Bromus inermis Leyss.)
3. Slender wheatgrass (Elymus trachycaulus Get.S.)-fodder Galega (Galega orientalis Lam.)-crested wheatgrass (Agropyron pectiniforme Roem. et Schult.)

The area of the experiment is 0.75 ha. In the degraded area where the experiments were supposed to be set, a preliminary inspection of vegetation and soil cover was carried out in the spring. In the summer, after the vegetation regrowth, a second inspection was carried out and the species composition of the vegetation was determined (Fig. 1).

*Sampling*

Determination of the content of organic matter was carried out by the Tyurin method in the modification of the Central Research Institute of Agrochemical Services for Agriculture (TsINAO) (CSMM, 1992b), which is based on the oxidation of organic matter with a solution of potassium bicarbonate in sulfuric acid and subsequent determination of trivalent chromium equivalent to the content of organic matter on a photoelectric colorimeter. The content of nitrate nitrogen was determined using the ionomeric method (CSMM, 1986). The method involves the extraction of nitrates with an aluminum-potassic alum solution with a mass fraction of 1% or a solution of potassium sulfate with the concentration (½ K2SO4) = 1 moL/dm$^3$ (1 n) with the mass ratio of soil samples and the solution volume of 1:2.5 and subsequent determination of nitrates in the extract with the help of ion-selective electrode.

The content of mobile compounds of phosphorous and potassium was determined by the Chirikov method in the modification of TsINAO (CSMM, 1992a). The method is based on the extraction of mobile compounds of phosphorus and potassium from the soil with a solution of acetic acid concentration c ($CH_3COOH$) = 0.5 mol/dm$^3$ with a ratio of soil to a solution of 1:25 and subsequent determination of phosphorus in the form of a blue phosphorus-molybdenum complex on a photoelectric colorimeter and determination of potassium on a flame photometer.

The density of plant population was taken into account twice: After germination and before harvesting on specially designated sites in two repetitions. The density of plant population and the plant preservation were determined on test sites from adjacent rows of 0.5 m with subsequent counting.

The height of the plants was determined before taking into account the yield of the green mass by measuring 25 plants of each species (Fig. 2).

The botanical composition of the herbage was determined by analyzing plant samples weighing 1 kg with the release of legumes, grains, and mixed herbs, followed by weighing each component. To determine the botanical composition of the herbage, 100-250 g of air-dry mass or 500-1,000 g of green freshly harvested fodder mass were taken. During species analysis, each sample was disassembled into individual types of herbs included in it. The fractions were weighed and the botanical composition of the herbage was determined as a percentage of the sample weight. The botanical composition of the herbage was determined before each grazing on pastures (Novoselov, 1983).

The accounting of the green mass harvest in the pasture ripeness phase was determined by mowing and weighing the green mass on the accounting plots with analysis of the species composition of the grass mixture and by drying the sheaves to an air-dry state (Dospekhov, 1985).

The output of the air-dry mass was determined with trial sheaves weighing 1 kg. Determination of the dry matter content is associated with the establishment of its humidity. The samples are dried to a constant mass and the calculation is carried out according to the formula:

$$X_1 = (B_1 - C) x100 / B_1 \tag{1}$$

where, $X_1$ is the initial moisture content in the fodder, %; $B_1$ is the sample mass before drying, g; C is the sample mass after drying, *g*.

To determine the level of nitrogen nutrition of plants was determined by the content of chlorophyll in the leaves, directly in the field, using an N-tester portable device.

Various numbers appear on the display after 30 taps. The range of these numbers is sometimes higher or lower. The higher the nitrogen content in plants, the more intense and brighter the color of the leaves. This intensity is measured by the device and shows how much nitrogen is enough or not enough in plants.

*Statistical Analysis*

The data were statistically processed using variance analysis. The significance of the differences between the variants was estimated at a probability level of 0.05. Statistical analysis was carried out using Microsoft Excel 2003 and AGROS 2.11 software.

**Fig. 1:** Grass-and-legume mixtures



**Fig. 2:** Determination of the height of legume crops

## Results

The climate in the study area is sharply continental with hot and dry summers and cold winters with little snow. The annual amplitude of the air temperature averages 75°C and in some years reaches 88°C. In winter, the minimum air temperature often drops to-35-40°C and in rare cases, the temperature drops to-45-50°C. In summer, the absolute temperature equals + 41-43°C. The warm period with an average daily temperature above 0°C lasts 195 to 200 days (from the first decade of April to the third decade of October). The duration of the frost-free period ranges from 108 to 130 days. The average annual air temperature is 0.3-2.3°C and in some years it rises to 4.5-5°C or drops to 0-1.2°C. The duration of the growing season increases from north to south and equals 166 to 174 days. A characteristic feature of the continental climate is the predominance of precipitation during the warm period (May to October) when 60-80% of the annual precipitation falls. The maximum precipitation falls in the second half of summer, most often in July. The humidification index (Hydrothermal Index, HTI) in the region varies from 0.9 in the north to 0.5 in the south. Prolonged cold in spring, earlier temperature fall in autumn, and late summer precipitation are typical for the climate of the region and distinguish it from other arid regions.

Meteorological data obtained for the growing season of 2021 in the Kostanay region were characterized by the following indicators: Precipitation in May was 5.5 mm with an average annual norm of 36 mm and the air temperature was 20.0°C, which is higher than the average long-term norm by +6.3°C. In June, 13.7 mm of precipitation fell, which was 21.3 mm less than the average annual value, and the air temperature corresponded to the average annual value of 20.8°C, which favorably affected the germination and development of plants (Table 1). In July, 103.5 mm of precipitation fell, which was 47.5 mm more than the long-term norm and the air temperature was 21.3°C, i.e., slightly higher than the average long-term norm. In August, precipitation totaled 5.4 mm, which was a low indicator compared to the average annual norm of 35.0 mm and the air temperature showed a slight increase in temperature by 3.3°C. The results of the agrochemical analysis of the soil are shown in Table 2, where the humus content in the degraded pasture (control) was 3.99%, and in the other variants, it varied from 3.63 to 4.69%.

The provision of the soil with mobile forms of nitrate-nitrogen (N-NO$_3$) was ≤2.8, the phosphorus content (P$_2$O$_5$ according to Chirikov) was 23-68 and

potassium content ($K_2O$ according to Chirikov) was 155 and more than 200 (high).

The primary indicators of vegetation productivity in herbaceous communities are the density and height of the herbage.

Figure 3 shows a diagram of the average density of grass-and-legume mixtures for three experiments. At the control plot, there were such types of herbs as milfoil, milkweed, crested wheatgrass, sow thistle, sheep fescue, and cinquefoil. The average density of plants on the control plot was 67 plants/m$^2$. The greatest density of legumes was noted on the variant of the crested wheatgrass-*alfalfa*-awnless brome, equaling 214 plants/m$^2$. The greatest density of grain crops was noted on the variant of Russian wild rye-*alfalfa*-awnless brome with 109 plants/m$^2$.

As can be seen in Fig. 4, the average height of grains and legumes in three experiments varied from 45 to 70 cm. In the variants, the average height of plants was higher compared to the control plot, where it ranged from 20 to 32 cm.

According to the primary productivity indicators, some of the proposed grass mixtures are significantly higher, up to 4 times, than the mixed herbs of the degraded pasture that served as a control variant. This is confirmed by direct data on phytomass reserves.

As can be seen in Table 3, the conducted studies have shown that poly-species agrophytocenoses demonstrate the highest productivity in the variant of the grass mixture of crested wheatgrass-*alfalfa*-awnless brome (80.3 c/ha). Besides, compatibility is observed between grain perennial grasses and *alfalfa*, apparently due to their biological characteristics. There is a good combination of species and a lack of competition between them in the herbage. In the 2$^{nd}$ experiment, the highest productivity was noted for the variant crested wheatgrass-common sainfoin-awnless brome. In the 3rd experiment, the productivity of all variants was lower than compared with other variants of the experiment. However, in all the experiments of the study, the productivity indicators were higher than in the control variant.

One of the most important indicators of the value of fodder crops is their nitrogen content in them, which is necessary for the proper nutrition of farm animals (Arlauskienė *et al*., 2021). In this regard, we conducted a study of the nitrogen content in plants proposed as structural components of experimental grass mixtures. Figure 5 shows that in experiment 1, the nitrogen content in the studied species is higher than in the other experiments. The highest nitrogen content was noted in *alfalfa* (553), which makes this crop and the grass

mixtures in which it is included the most preferable ones from the point of view of nutritional value.

When considering the issue of restoration of degraded pastures, the issue of developing mathematical tools for predicting the dynamics of biomass in grassland communities was also considered. We propose an algorithm for describing the behavior of the hourly dynamics of organic matter carbon in grass communities of various types of Eco Grass, which is an upgraded version of the algorithm described in S.V. Mamikhin's monograph (Mamikhin, 2003). The algorithm was tested when constructing a model of carbon dynamics in the soil and vegetation cover of a particular graminoid community.

The model is deterministic with elements of stochasticity and point, i.e., the values of state variables depend only on time. The time step *t* in this version of the model is 1 h. The basic version of the model consists of six blocks: "Climate", "Meteo", "Hydrological", "Temperature", "Phytomass", and "Soil carbon". Figure 6 shows a diagram of the interaction of the model blocks, including an additional "Grazing" block.

In the "Meteo" block, the values of solar radiation and air temperature are calculated for each hour. The "phenological" time is also calculated here. The variable of the "phenological" time tph shows at what stage of the annual phenological cycle, characterized by the number of phenocenoses since the beginning of the year, the phytocenosis is located, which is necessary to take into account the influence of the phenological stages of the state of plants on the distribution of assimilates and other life processes. For all stages, it is accepted that in the first half of the year, the increased air temperature in comparison with the average monthly long-term accelerates the passage of the plant phenological cycle and in the second one it slows down (with a coefficient of 0.05).

In the "Hydrological" and "Temperature" blocks, the humidity and temperature of the soil horizons are calculated for each hour. Besides, the dynamics of stocks of mortmass and humus are calculated along the soil horizons. We consider the dynamics of two parts of the humus, which we can call the labile and stable parts. The first part includes non-specific compounds and newly formed humic acids and the second one includes the mature humic acids, humin.

To assess the impact of grazing of farm animals on the productivity of a graminoid community, an additional "Grazing" block of the model can be connected, the input variables for which are the stocks of green phytomass and the number of heads of grazed animals per unit area regulated by a human, Cattle Grazing (CG). The block calculates the functions of grazing on phytomass, as well as the amount of excrement excreted by animals daily, to account for the

intake of organic matter into the soil. It is logical to assume that in the absence of natural fodder, for example in winter, livestock is provided with compound fodders.

Next, we will consider in more detail the structure of the "Phytomass" block of the model, which reproduces the seasonal dynamics of organic matter carbon in phytocenosis components. Table 4 shows the variables describing the dynamics of carbon stocks in the components of the phytomass of the graminoid community and Table 5 and 6 show the input and auxiliary variables necessary for the operation of the model.

The formulas used in the calculations in the listed blocks of the model are described in the aforementioned monograph (Mamikhin, 2003).

The Eco Grass model is implemented in a modern freely distributed cross-platform programming environment Qb 64 (https://www.qb64.org/portal /), which allows using it in any version of Microsoft Windows (starting with Microsoft Windows XP and later versions), Linux, or Mac OS. The simulation results are displayed on the screen in text-digital and graphical form (Fig. 7), as well as in a separate text file data_gr.dat with data in a format convenient for further processing, for example statistical, in other programs.
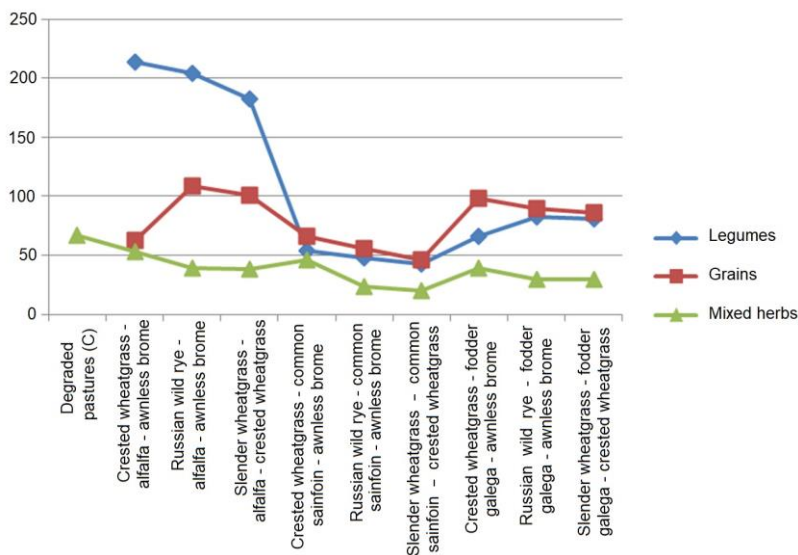


**Fig. 3:** The average density of grass-and-legume mixtures, plants/m$^2$ Note: L: Legumes; G: Grains; M: Mixed herbs (sheep fescue, sow thistle, milkweed, milfoil)



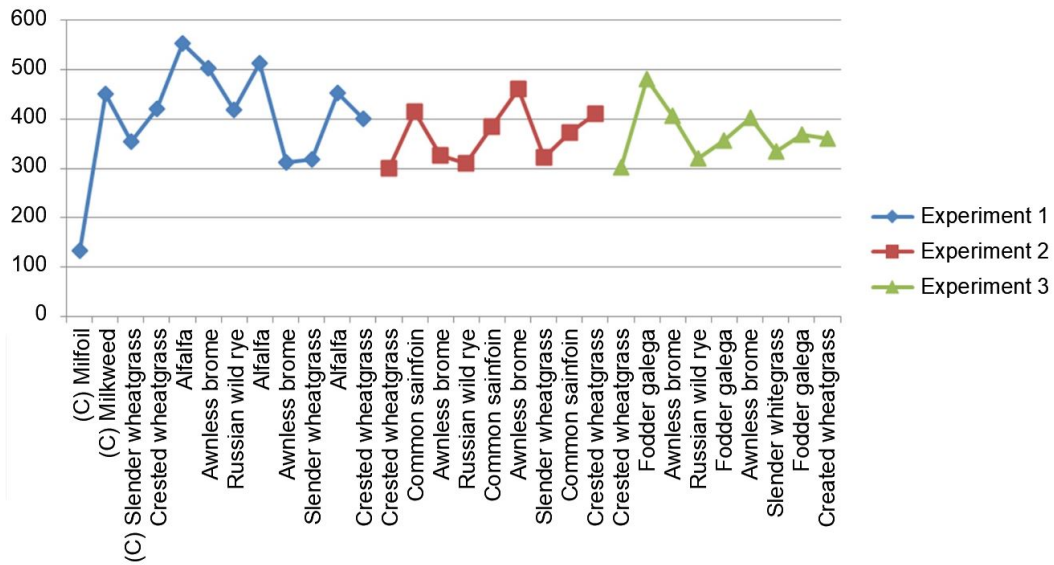**Fig. 4:** The average height of grains and legumes

273
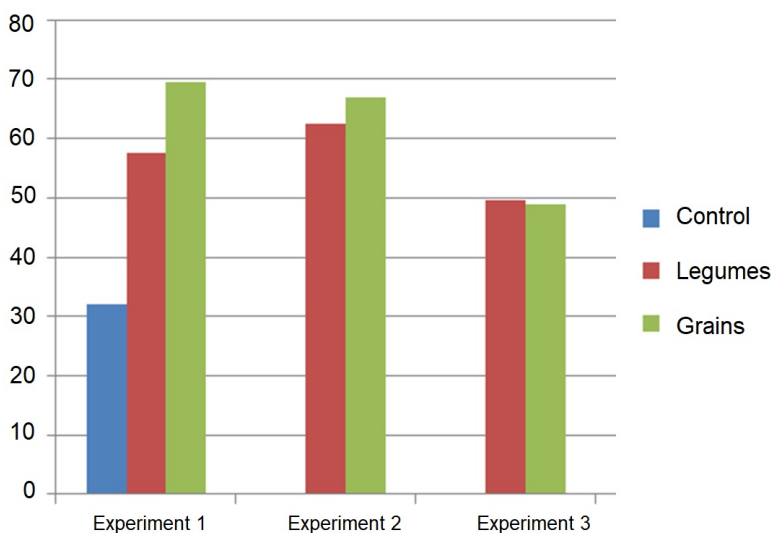
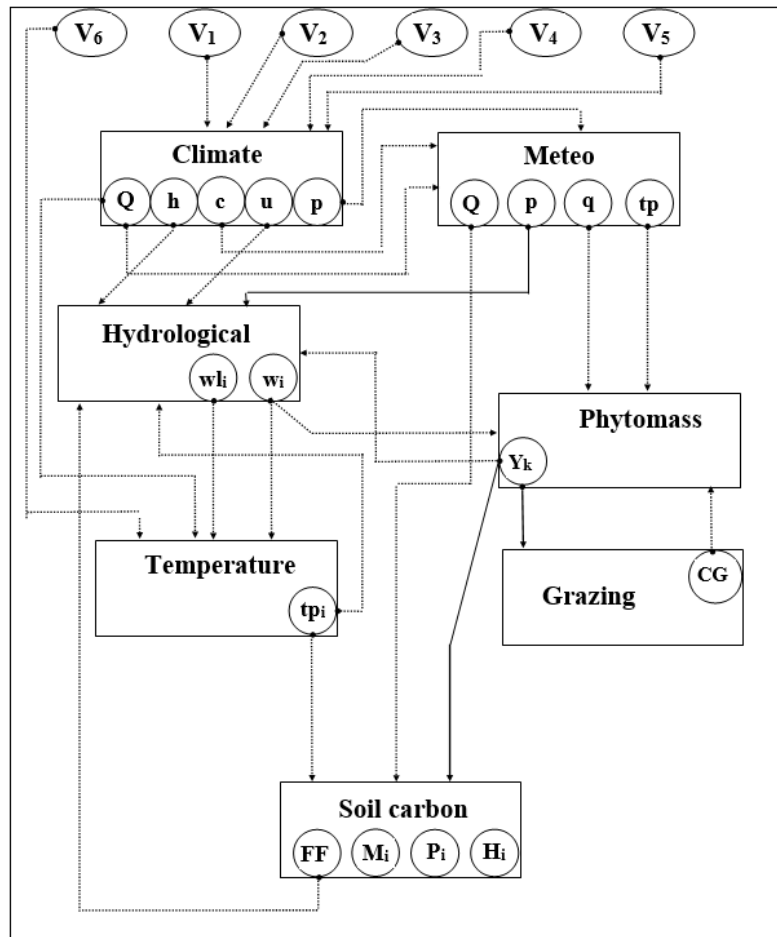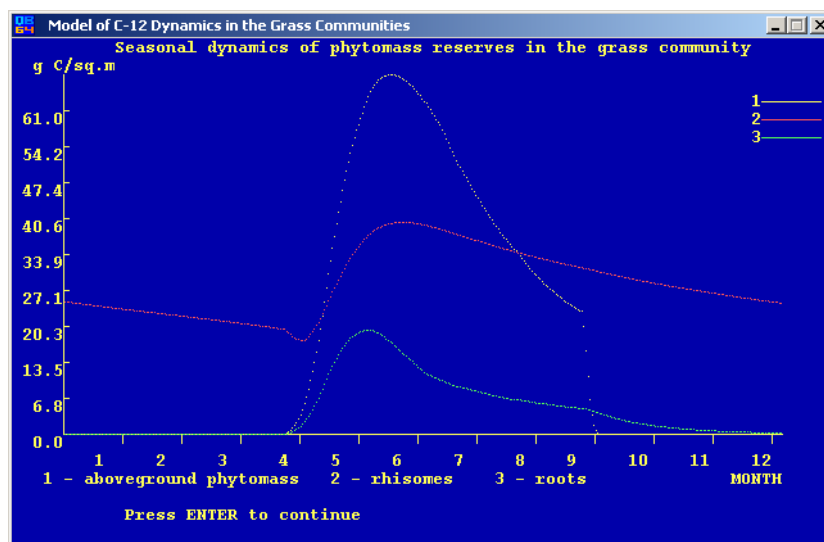**Fig. 5:** Nitrogen content in the plants of grass mixtures



**Fig. 6:** The interaction scheme of blocks of the model of seasonal dynamics of organic matter carbon in the graminoid community

**Fig. 7:** The output of simulation results in graphical form

**Table 1:** The average monthly amount of precipitation and air temperature during the growing season for 2021

| Months | Precipitation amount, mm | | Air temperature, °C | |
| --- | --- | --- | --- | --- |
| | 2021 | Long-term norms | 2021 | Long-term norms |
| May | 5.5 | 36.0 | 20.0 | 13.7 |
| June | 13.7 | 35.0 | 20.8 | 20.0 |
| July | 103.5 | 56.0 | 21.3 | 20.9 |
| August | 5.4 | 35.0 | 22.2 | 18.9 |

**Table 2:** Results of agrochemical soil analysis

| No. | Name of the sample | Organic matter, % GOST 26213-91 | Nitrate nitrogen (N-NO$_3$), million$^{-1}$ GOST 26951-86 | Mobile phosphorus compounds, million$^{-1}$ GOST 26204-91 | Mobile potassium compounds, million$^{-1}$ |
| --- | --- | --- | --- | --- | --- |
| 1 | Degraded pasture (control) | 3.99 | ≤2.8 | 68 | 215 |
| 2 | Crested wheatgrass-*alfalfa*-awnless brome | 4.42 | ≤2.8 | 36 | 197 |
| 3 | Russian wild rye-*alfalfa*-awnless brome | 4.29 | ≤2.8 | 25 | 192 |
| 4 | Slender wheatgrass-*alfalfa*-crested wheatgrass | 4.10 | ≤2.8 | 62 | 199 |
| 5 | Crested wheatgrass-common sainfoin-awnless brome | 3.63 | ≤2.8 | 29 | 155 |
| 6 | Russian wild rye-common sainfoin-awnless brome | 4.62 | 3.5 | 55 | 195 |
| 7 | Slender wheatgrass-common sainfoin-crested wheatgrass | 4.69 | ≤2.8 | 47 | 218 |
| 8 | Crested wheatgrass-fodder Galega-awnless brome | 4.69 | ≤2.8 | 35 | 214 |
| 9 | Russian wild rye-fodder Galega-awnless brome | 4.42 | ≤2.8 | 23 | 193 |
| 10 | Slender wheatgrass-fodder Galega-crested wheatgrass | 4.31 | ≤2.8 | 35 | 233 |

**Table 3:** Productivity of poly-species agrophytocenoses

| No. | Variants | Green mass, c/ha | Air-dry weight, c/ha | Air-dry weight output, % |
| --- | --- | --- | --- | --- |
| No. 1 | | | | |
| 1 | Control | 27.8 | 12.6 | 54.7 |
| 2 | Crested wheatgrass-*alfalfa*-awnless brome | 80.3 | 31.9 | 60.0 |
| 3 | Russian wild rye-*alfalfa*-awnless brome | 78.0 | 31.8 | 59.0 |
| 4 | Slender wheatgrass-*alfalfa*-crested wheatgrass | 70.8 | 25.7 | 64.0 |
| No. 2 | | | | |
| 1 | Crested wheatgrass-common sainfoin-awnless brome | 71.5 | 26.5 | 63.0 |
| 2 | Russian wild rye-common sainfoin-awnless brome | 70.2 | 21.7 | 69.0 |
| 3 | Slender wheatgrass-common sainfoin-crested wheatgrass | 63.5 | 24.6 | 61.0 |
| No. 3 | | | | |
| 1 | Crested wheatgrass-fodder galega-awnless brome | 32.3 | 11.2 | 65.0 |
| 2 | Russian wild rye-fodder galega-awnless brome | 31.8 | 10.9 | 65.0 |
| 3 | Slender wheatgrass-fodder galega-crested wheatgrass | 34.0 | 12.8 | 62.0 |
| | A Least Significant Difference (LSD) $_{05}$ | 7.2 | | |

**Table 4:** Variable states of carbon dynamics (all in g S/m$^2$)

| Symbol | Variable name |
|---|---|
| $Y_1$ | Distribution pool of assimilates |
| $Y_2$ | Aboveground (green) phytomass |
| $Y_3$ | Rhizomes |
| $Y_4$ | Roots |

**Table 5:** Model input variables

| Symbol | Variable name | Units of measurement |
|---|---|---|
| Average monthly: | | |
| $V_1$ | Air temperature | ℃ |
| $V_2$ | Relative air humidity | % |
| $V_3$ | Cloud cover | Scores |
| $V_4$ | Wind speed | m/sec |
| $V_6$ | Soil temperature at a depth of 2 m | ℃ |
| $V_5$ | Monthly precipitation amount | cm/month |

**Table 6:** Model auxiliary variables

| Symbol | Variable name | Units of measurement |
|---|---|---|
| $tph$ | Phenological time | 24 h |
| $w_i$ | Volume humidity of soil horizons | cm$^3$ H$_2$O/cm$^3$ soil |
| $w_0$ | Moisture storage in a 2-meter layer | cm |
| $tp_i$ | The temperature of soil horizons | ℃ |
| $Q'$ | Average daily air temperature | ℃ |
| $h$ | Average daily relative air humidity | % |
| $c$ | Average daily cloud cover | Scores |
| $u$ | Average daily wind speed | m/sec |
| $p'$ | Daily precipitation amount | cm/day |
| $Q$ | Air temperature for a given hour | ℃ |
| $q$ | Solar radiation intensity | cal/cm$^2$/hour |
| $p$ | Precipitation amount per hour | cm/hour |

## Discussion

For the practical application of the model, its localization is necessary, such as obtaining information about the dynamics of soil moisture, the intensity of photosynthesis and respiration in plants included in the grass mixture, plant phenology, animal grazing intensity, etc.

In addition, we are conducting a study on soil reclamation of spent ore deposits of the mining and metallurgical complex of Kazakhstan and adjacent territories, where soil covers require restoration for their subsequent use for economic purposes. Experiments are being conducted to study the agrochemical properties of the soil areas of the spent deposits on which these grass mixtures are grown.

Bioremediation is used, that is, plants affect the environment in different ways and three main approaches to bioremediation of soils with the help of microorganisms are being tested: Biostimulation, i.e., stimulating the development of native microflora in the contaminated area; bioadditioning, i.e. introducing biological preparations of microorganisms capable of degrading the pollutant into the soil and phytostimulation, i.e., using plants to stimulate the development of rhizosphere microorganisms. The main ones are rhizofiltration (roots absorb water and chemical elements necessary for the vital activity of plants); phytoextraction (accumulation of dangerous pollutants in the plant body (for example, heavy metals)); phytovolatilization (evaporation of water and volatile chemical elements (As, Se) by plant leaves); Phyto stabilization (conversion of chemical compounds into a less mobile and active form (which reduces the risks of contamination spread)); phytodegradation (degradation by plants and symbiotic microorganisms of the organic part of pollutants) and Phyto stimulation (stimulation of the development of symbiotic microorganisms involved in the process of cleaning soil). The results of the study are presented in subsequent papers (Valiyev *et al.*, 2018; Bulaev *et al.*, 2019; Kalybekov *et al.*, 2020).

## Conclusion

It was found that the highest productivity under experimental conditions was formed by a grass-and-legume mixture of crested wheatgrass-*alfalfa*-awnless brome (27.8 c/ha of green mass and 12.6 c/ha of dry matter). The highest nitrogen content was noted in *alfalfa*, which was part of the same grass mixture of crested wheatgrass-*alfalfa*-awnless brome. The conducted study has also revealed several issues that should be addressed for the successful implementation of new technologies for

the remediation of degraded pastures. It is necessary to find out how well and for how long the introduced species of fodder crops will be reproduced in conditions of natural growth, without additional human intervention. The issue related to the adaptive capabilities of artificial poly-species phytocenoses, their ability to withstand adverse climatic conditions, such as drought, an increase in average annual temperature, etc., has not been fully clarified. This requires additional research.

The proposed predictive simulation model Eco Grass is built on the block principle, which allows embedding additional modules, expanding the functionality of the model. The algorithm can be modified. For example, if there is a lack of information on the dynamics of the water regime of the corresponding soils, regression equations or even tabular data can be used. A necessary condition for the possibility of using the model in the presented version is the availability of information on the dynamics of soil moisture and physiological parameters of plant vital activity.

## Data Availability

The data used to support the findings of this study are included in the article.

## Funding Statement

## Author's Contributions

All authors equally contributed to this study.

## Ethics

This article is original and contains unpublished material. The corresponding author confirms that all of the other authors have read and approved the manuscript and that no ethical issues are involved.

## References

Abbas, G., Ahmad, S., Ahmad, A., Nasim, W., Fatima, Z., Hussain, S., & Hoogenboom, G. (2017). Quantification of the impacts of climate change and crop management on the phenology of maize-based cropping system in Punjab, Pakistan. Agricultural and Forest Meteorology, 247, 42-55. doi.org/10.1016/j.agrformet.2017.07.012

Agard, J., Alcamo, J., Ash, N., Arthurton, R., Barker, S., Barr, J., & Zommers, Z. (2007). Global Environment Outlook GEO4 Environment for Development. UNEP, ISBN, 978-992.

Arlauskienė, A., Gecaitė, V., Toleikienė, M., Šarūnaitė, L., & Kadžiulienė, Ž. (2021). Soil nitrate-nitrogen content and grain yields of organically grown cereals as affected by strip tillage and forage legume intercropping. Plants, 10(7), 1453. doi.org/10.3390/plants10071453

Bakhralinova, A. S., Kurishbayev, A. K., Serekpaev, N. A., Stybayev, G. Z., & Nogayev, A. A. (2016). Condition of pastures neighboring the villages in Enbekshilder district of Akmola region and the effectiveness of some surface improvement techniques. Biosciences Biotechnology Research Asia, 13(2), 733.

Bedilo, N. A. (2016). Productivity, feed value and symbiotic activity of legume species and their mixtures on leached Chernozem of the Western Caucasus. Dissertation for the degree of candidate of agricultural sciences, Kuban State Agrarian University, Krasnodar, Russia. https://kubsau.ru/upload/iblock/eb9/eb9186cf94840e26 184ee644de37185c.pdf

BMAPA. (2009). Secretaria de Defesa Agropecuária. (2009). Regras para análise de sementes.

Bulaev, A., Valiev, K., Bugubayeva, A., Amandikova, A., & Melamud, V. (2019). Effect of organic nutrients on biooxidation of gold-bearing refractory concentrate. International Multidisciplinary Scientific GeoConference: SGEM, 19(1.3), 793-798. doi.org/10.5593/sgem2019/1.3/S04.101

CSMM. (1986) Instruments under the USSR Council of Ministers, 1986. GOST 26951-86. Pochvy. Opredelenie nitratov ionometricheskim metodom [Soils. Determination of nitrate byionometric method]. Izdatelstvo standartov, Moscow. https://internet-law.ru/gosts/gost/12344/

CSMM. (1992a). Instruments under the USSR Council of Ministers, 1992a. GOST 26204-91. Pochvy. Opredelenie podvizhnykh soedinenii fosfora i kaliya po metodu Chirikova v modifikatsii CINAO [Soils. Determination of mobile compounds of phosphorus and potassium by Chiricov method modified by CINAO]. Izdatelstvo standartov, Moscow. https://internet-law.ru/gosts/gost/28250/

CSMM. (1992b). Instruments under the USSR Council of Ministers, 1992b. GOST 26213-91. Pochvy. Metody opredeleniya organicheskogo veshchestva [Soils. Methods for determination of organic matter]. Izdatelstvo standartov, Moscow. https://internet-law.ru/gosts/gost/10564/

Derpsch, R., Friedrich, T., Kassam, A., & Li, H. (2010). Current status of adoption of no-till farming in the world and some of its main benefits. International Journal of Agricultural and Biological Engineering, 3(1), 1-25. doi.org/10.3965/j.issn.1934-6344.2010.01.001-025

Dospekhov, B. A. (1985). Metodika polevogo opyta (s osnovami statisticheskoy obrabotki rezul'tatov issledovaniy) [Field experience methodology (with the basics of statistical processing of research results)]. Moskva: Agropromizdat, 351.

Edwards, T., Howieson, J., Nutt, B., Yates, R., O'hara, G., & Van Wyk, B. E. (2019). A ley-farming system for marginal lands based upon a self-regenerating perennial pasture legume. Agronomy for Sustainable Development, 39(1), 1-19. doi.org/10.1007/s13593-019-0558-2

Ganichev, I. A., & Ryumin, A. G. (2018). Diagnostika obespechennosti rastenii azotom I zhelezom s pomoshchyu metoda impulsnoi fluoriemetrii khlorofilla [Diagnostics of the supply of plants with nitrogen and iron using the method of pulse fluorimetry of chlorophyll]. In: Materials of the International Scientific Conference XXI Dokuchaev Youth Readings, Publishing House of St. Petersburg State University, St. Petersburg, pp, 308–309. http://www.dokuchaevskie.ru/wp-content/uploads/2017/11/DMH-2018_cut.pdf

Kalybekov, T., Rysbekov, K., Sandibekov, M., Bi, Y. L., & Toktarov, A. (2020). Substantiation of the intensified dump reclamation in the process of field development. Mining of Mineral Deposits, 14(2), 59-65. doi.org/10.33271/mining14.02.059

Kubenkulov, K., Naushabaev, A., Abdirahymov, N., Rustemov, B., & Bazarbaev, S. (2019). particularities of forming desert pastures near settlements of southern Balkhash (Kazakhstan). Journal of Ecological Engineering, 20(8). doi.org/10.12911/22998993/110768

Kutuzova, A. A. (2007). Forecast of the role of meadow ecosystems in forage production and biosphere processes. Feed Production, 10, 2–4.

Leech, F. J., Richardson, A. E., Kertesz, M. A., Orchard, B. A., Banerjee, S., & Graham, P. (2019). Comparative effect of alternative fertilizers on pasture production, soil properties and soil microbial community structure. Crop and Pasture Science, 70(12), 1110-1127. doi.org/10.1071/CP19018

Liu, Q., Wang, X., Zhang, Y., Zhang, H., & Li, L. (2019). Vegetation degradation and its driving factors in the farming–pastoral ecotone over the countries along belt and road initiative. Sustainability, 11(6), 1590. doi.org/10.3390/su11061590

Mamikhin, S. V. (2003). Dinamika ugleroda organicheskogo veshchestva i radionuklidov v nazemnykh ekosistemakh (imitatsionnoe modelirovanie i primenenie informatsionnykh tekhnologii). Dynamics of organic carbon and radionuclides in terrestrial ecosystems (imitation simulation and information technologies), Moscow.

Novoselov, Y. U. (1983). K. Metodycheskye ukazanyya po provedenyyu polevykh opytov s kormovymy kul′turamy/YU. K. Novoselov, HD Khar′kov, YS Shekhovtseva. Vsesoyuznyy nauch.-yssled. ynstyt. Kormov ym. VR Vyl′yamsa.

Nugmanov, A. B., Tulayev, Y. V., Tulkubayeva, S. A., Somova, S. V., & Vodopyanov, E. M. (2017). Updating of sowing terms of spring wheat in the conditions of northern Kazakhstan in conservation agriculture. Ecology, Environment and Conservation, 23(1), 292-295.

Oliveira, E. R. D., Silva, J. R., Baumann, L. R. F., Miziara, F., Ferreira, L. G., & Merelles, L. R. D. O. (2022). Technology and degradation of pastures in livestock in the brazilian Cerrado. Sociedade and Natureza, 32, 585-596. doi.org/10.14393/SN-v32-2020-55795

Pereira, O. J. R., Ferreira, L. G., Pinto, F., & Baumgarten, L. (2018). Assessing pasture degradation in the Brazilian Cerrado based on the analysis of MODIS NDVI time-series. Remote Sensing, 10(11), 1761. doi.org/10.3390/rs10111761

Popov, V., Serekpaev, N., Zharlygasov, Z., Stybaev, G., & Ansabaeva, A. (2017). Adaptive technology for environmentally-friendly production of legumes in the dry steppe zones. Journal of Central European Agriculture. doi.org/10.5513/JCEA01/18.1.1869

Tokusheva, A. S., & Nugmanov, A. B. (2016). The Problem of feed production development. Izvestiya NAS RK. Almaty, 4, 41-43.

Tokusheva, A. S., Nugmanov, A. B., & Melnikov, V. A. (2017). Degraded pastures improvement using no-till technology in Northern Kazakhstan. Ecology, Environment and Conservation, 23(2), 1242-1248.

Torekhanov, A. A., & Alimaev, A. A. (2007). Nauchno-prakticheskoe posobie po lugopastbishchnomu hozyajstvu. Almaty: Bastau, 105-107.

Valiyev, K. K., Kanayev, A.T., & Bugubayeva, A. U. (2018). Granulometric analyzing fractional composition of the ore in the section of heap leaving after long-term-mothballing the enterprise. Proceedings of the Tula States University. Sciences of Earth, 4, 147–160.

Zhao, L., Dai, A., & Dong, B. (2018). Changes in global vegetation activity and its driving factors during 1982–2013. Agricultural and Forest Meteorology, 249, 198-209. doi.org/10.1016/j.agrformet.2017.11.013