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Photosynthetic potential and productivity of annual mixed crops in Northern Kazakhstan

Aliya Baitelenova[1], Almas Kurbanbayev[2], Gani Stybayev[1], Hristina Yancheva[3*], Nurlan Serekpayev[1], Nurbolat Mukhanov[1] and Bekzat Amantaev[1]

[1] *"S. Seifullin" Kazakh Agrotechnical University, 010011 Nur – Sultan, Republic of Kazakhstan*
[2] *"I. Zhakhayev" Kazakh Research Institute of Rice Growing, 120000 Kyzylorda, Republic of Kazakhstan*
[3] *Agricultural University, 4000 Plovdiv, Bulgaria*
[*] *Corresponding author:* christina@au-plovdiv.bg

Abstract

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One of the serious shortcomings in modern forage production in Kazakhstan is the low nutritional value of forage. Cultivation of mixed crops of annual traditional forage crops with new high-protein annual forage crops Echinochloa *frumentacea* L. *and Pennisetum glaucum* (L.) R. Br. will help solve this problem. Mixtures are chosen to obtain high yields and feed quality; however, the photosynthetic and other properties of such mixtures are not well understood. This research evaluated the productivity and photosynthetic activity of annual grass mixtures over three growing seasons. *Sorghum* var. *eusorghum* Pers., *Echinochloa frumentacea* L, and *Pennisetum glaucum* (L.) R. Br. were grown as pure crops and in mixtures with *Hordeum vulgare* L. + *Sorghum* var. *eusorghum* Pers. + *Sorghum sudanense* hybrid P. + *Pisum sativum* L. Simultaneously, highly productive crops – *Echinochloa frumentacea* L. *and Pennisetum glaucum* (L.) R. Br., are newly introduced crops for the north of Kazakhstan. It was analyzed feed yield, quality, gas exchange, and chlorophyll fluorescence parameters. Mixed crops of annual forage crops improved forage yield, root-to-aerial ratio, and crude protein and lignin content. The results showed that the crops in the mixtures had higher net photosynthesis, water consumption, high water use efficiency, and nitrogen content in leaves (N) but a lower carbon ratio. *Pennisetum glaucum* (L.) R. Br. had a lower light compensation point and dark respiration rate, suggesting good shade tolerance. However, water scarcity reduced the biomass and photosynthetic capacity of *Pennisetum glaucum* (L.) R. Br. and the herbal mixture with its inclusion, respectively. Also, *Pennisetum glaucum* (L.) R. Br. was sensitive to soil moisture. The mixture with *Echinochloa frumentacea* L. had higher biomass and water use efficiency. *Echinochloa frumentacea* L. had a higher light saturation point in the mixture, indicating high light utilization efficiency. Based on the results, we could conclude that mixed crops improved feed production and photosynthetic capacity. The research provides a scientific basis for the creation of forage mixtures with high yields and quality.

Keywords: photosynthesis; annual crops; mixtures; yield; *Sorghum* var. *eusorghum* Pers.; *Echinochloa frumentacea* L.; *Pennisetum glaucum* (L.) R. Br.
Abbreviations: WUE (water use efficiency)

Introduction

The success of modern livestock breeding directly depends on the quality of the feed base. It is possible to expand the range of forage crops by using promising species of perennial and annual plants. (Postnikov, 2007) Pasture ecosystems occupy about 70% of the world's agricultural area and store a large amount of soil carbon; therefore, they play a decisive role in the global carbon cycle (Lorenz & Lal, 2018). Intensively managed pastures, usually containing several high-yielding species, play a crucial role in providing biomass feedstock for animal feed and bioenergy production (Nasiev, 2012). In the fodder production of Northern Kazakhstan, annual grasses are becoming increasingly important, which provide hay yields higher than perennial ones. Annual grasses are irreplaceable in the conveyor system for obtaining hay, haylage, vitamin-herbal flour, and green mass (Bakhralinova et al., 2016). Recently, due to the low productivity of the species composition of annual grasses, arable lands of annual grasses in the Republic of Kazakhstan are characterized by low productivity. Thus, both productivity and quality of grass on pastures have sharply decreased (Mukhanov et al., 2018; Stybaev et al., 2014). Mixed crops became the primary measure for solving these problems. It became necessary to analyze the yield and nutritional value of single-species and mixed crops of cereals and legumes, including introduced crops, in Kazakhstan's dry-steppe zone natural pastures.

The mixtures could support higher livestock intensities and increase the potential for sustainable development. Since the determining factor in the yield of annual forage crops is the indicator of photosynthetic activity of leaf surfaces, the study of *Echinochloa frumentacea* L. and *Pennisetum glaucum* (L.) R. Br. is relevant. They are distinguished by a high tillering coefficient, due to which up to 40-120 stems can be formed on one plant. Due to the leaves that start on each new branch, these plants are characterized by high foliage. One of the main features of introduced crops is that the leaves can fully maintain their green state until the seed is harvested. Because of the high content of nutrients in the leaves and not in the stems, their green and dry masses are distinguished not only by high yields but also by high quality (Nikitin, 2018).

To improve the quality of the mixtures new crops were included. The studies showed that *Echinochloa frumentacea* L., *Pennisetum glaucum* (L.) R. Br. in the mixtures is more productive than pure crops (Kovalev et al., 2007). The crops selected in the composition of the grass mixtures must be cold-resistant and drought-resistant since northern Kazakhstan has a sharply continental climate. The selected crops must have a strong ability to adapt to a variety of conditions. The most common crops used in fodder production in Northern Kazakhstan are sorghum, barley, sorghum-sudan hybrids, and peas (Kashevarov et al., 2013). Usually, grass mixtures are formulated to increase feed production. Forage legumes fix atmospheric nitrogen (N_2) through their nodules, thereby increasing the availability of fixed N for various grasses (Savina et al., 2016). The amount of symbiotic fixation of N_2 by legumes can vary from 100 to 380 kg/ha per year in the northern regions (Sidorova et al., 2015).

Legumes in mixtures achieve a positive N balance by adding symbiotically fixed N_2 and increasing the soil N available to plants; this change, in particular, can increase grass production, with a lack of N in the soil (Shevchenko & Prosviryak, 2012). The use of highly productive mixed grass stands such a selection of grasses in which legumes components positively affect increasing productivity and feed quality (Subbotin et al., 2018). Therefore, both the yield and the nutritional value of grass mixtures are higher than pure crops (Dronova & Burtseva, 2014). These mixtures have become the preferred form in fodder production since the data on the chemical plant content confirm the dependence of the protein content on the species composition, cuttings, and the ratio of the components of the mixtures.

Unfortunately, the performance of various mixtures varies greatly, and the results vary from a decrease to an increase in yield. They sometimes do not change at all, which indicates that many factors affect the productivity of the grass mixture. Studies suggest that the highest yield of both green and dry matter was noted in the option of mixtures of barley, Sudan grass, and peas (Nasiev, 2014). The results support the possibility of improving the balance between available energy and protein by choosing species in complex mixtures consisting of one legume plant and three or four grass types (Da Silva et al., 2014). Productively necessary aggregate measures of the feed merits of a crop are collecting feed units, digestible protein, and feed protein units. Still, other mechanisms, including changes in photosynthetic capacity, remain poorly understood. Nitrogen plays an essential role in photosynthesis since proteins of the Calvin cycle, and thylakoid proteins make up most leaf reserves (Kulaeva, 1997). There is a strong positive causal relationship between leaf photosynthesis rate and the N content (Arya et al., 2010; Kiriziy, 2017). This means that the high N content provided by biological N_2 fixation can increase photosynthesis rates.

To take a closer look at these characteristics, we study the various adaptive mechanisms of several forage crops from released and promising varieties. We studied two mixtures and three pure crops.

Our objectives were to: (1) determine the effect of mixed crops on yield and feed quality; (2) to reveal the changes in the photosynthetic capacity of grasses caused by the transfer of N from the legumes included in the grass mixture; (3) compare changes in mixtures when *Echinochloa frumentacea* L. and *Pennisetum glaucum* (L.) R. Br. is included.

Material and Methods

Experimental Design

The study was carried out during three growing seasons 2017-2019, at the experimental station of the Department of Agriculture and Plant Growing of S. Seifullin Kazakh Agrotechnical University, Nur-Sultan, Kazakhstan (50°52′38.1″ N 71°21′33.7″ E). The average annual temperature in the region is 3°C (range from -41 °C to +38°C), the yearly sum of active temperatures is – 1100°C, the total annual precipitation ranges from 90 to 200 mm (of which 70% falls on June – September), and the frost-free period is 90-120 days (i.e., the growing season is only 3-4 months). The total precipitation in 2017 was only 90 mm, and in 2019 – 97.2 mm, compared with these two years, in 2018, 199.8 mm fell, which is 109.8 mm, and 102.6 mm higher compared to 2017 and 2019, respectively. The average monthly air temperature had a typical seasonal character for the study area, which peaked in July-August for three years (Figure 1).

The studies were carried out according to Dospekhov's field experiment methodology (Dospekhov 1985), the method of state variety testing of crops (SS (GOST) 12036-85. 2011).This article analyzes the results from 5 variants: 3 variants with pure crops – *Sorghum* var. *eusorghum* Pers.; *Echinochloa frumentacea* L.; *Pennisetum glaucum* (L.) R. Br. and two mixtures: Mixture 1 including *Hordeum vulgare* L.+*Sorghum* var. *eusorghum* Pers.+*Sorghum sudanense* hybrid P.+*Pisum sativum* L.+*Echinochloa frumentacea* L.,) and Mixture 2 including *Hordeum vulgare* L.+*Sorghum* var. *eusorghum* Pers.+*Sorghum sudanense* hybrid P.+*Pisum sativum* L.+*Pennisetum glaucum* (L.) R. Br. The randomized method was used, experimental plots of 5 by 5 m, four replicates, and 3-meter buffer zones between sites.

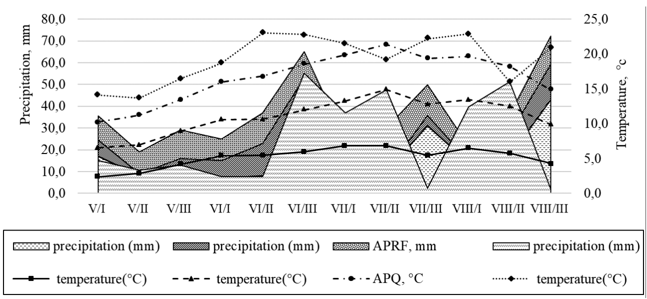

Fig. 1. Monthly precipitation (by decades) and average temperature in the studied areas in 2017–2019

Before the study, plots had shallow vegetation cover. Before sowing the seeds, the plots were treated to a 30 cm depth with a BDT-9 and a dominator to eliminate all remaining vegetation. Sowing was carried out in three different periods – the second and third decades of May, and the first decade of June, to determine the most optimal sowing time for the proposed pure crops and grass mixtures in this climatic region.

However, as the researchers note, in mixtures with approximately equal proportions of cereals and legumes, legumes over time, as a rule, exclude cereal grasses (Stybaev et al., 2020). To balance feed yield and nutritional value and ensure the species composition's relative stability, a 1: 4 ratio was chosen (i.e., 20% legumes based on seed weight) in mixtures. Previous research showed that the productivity and efficiency of using the resources of agricultural pasture systems were maximum in grass mixtures with 30-40% of legumes (Serekpaev et al., 2020). Pure crops of *Sorghum* var. *eusorghum* Pers.; *Echinochloa frumentacea* L. and *Pennisetum glaucum* (L.) R. Br. was sown at 12 and 14 kg of seeds per hectare, respectively. No fertilization or irrigation was applied either during sowing or during the maintenance of the crops using cultivation agrotechnical, adopted for the dry steppe zone.

Biomass measurements

During all three years of research, the peak in the production of aboveground plant biomass was determined in mid-August. It was randomly identified three test plots (1 m by 1 m) within each study plot at different sowing dates. It obtained aboveground biomass at each plot, leaving stubble about 3 cm above the soil level. In grass mixtures, the measurement of green biomass refers to the mass of mixed crops. After harvesting the green mass, it was taken soil samples to a depth of 0-20 and 20-40 cm using a soil drill with a core diameter of 5 cm, cleaned the root residues through a sieve to determine the underground biomass. In the variants of the grass mixture, root residues were also not divided between cereals and legumes. Following previous studies on specific sites of the northern region of Kazakhstan, most of the underground biomass is located in the upper 20 cm of the soil (Stybaev et al., 2020; Lin et al., 2004). Green biomass of plants was dried in a drying oven to constant weight at a temperature of 105°C.

Feed quality

The dried samples were ground to pass through a 0.5 mm mesh using a grinding mill (Retsch GmbH, made in

Germany) before determining the quality of feed nutrients. The biomass of grass mixtures from cereals and legumes were combined (not separated) when analyzing the quality of feed; thus, the quality values represent the correct (net) result for both types of mixtures. We have determined the chemical content according to Official Methods of Analysis, 2019 as follows: crude protein by Kjeldahl; cellulose and lignin-method, crude fat-Soxhlet extraction method, raw ash – loss on ignition method. The total carbon content (C) and N in the leaves were measured by the wet oxidation method and the Kjeldahl method. Based on these values, we calculated the C: N ratio of the feed.

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Chlorophyll gas exchange and fluorescence parameters

It was measured gas exchange in mature, fully expanded leaves of individual plants of each species on clear, cloudless days in mid-July 2017, 2018, and 2019 from 07:00 to 18:00 using a portable photosynthesis system (MIMI-PAM-II, Photosynthesis Yield Analyzer, Germany). It was measured pure crops and grass in mixtures. For these individual plants, the net photosynthesis rate (P_n) and transpiration (T_r) were calculated, and then the water use efficiency (WUE) of each species was obtained using the following equation:

$$WUE = P_n / T_r \qquad (1)$$

Variable chlorophyll fluorescence was measured using a portable pulse amplitude modulation fluorometer (MIMI-PAM-II). For these measurements, mature, fully unfolded leaves were kept in the dark overnight, still attached to the plant. Before measurements, samples were kept in the dark adaptation clamping cuvettes for > 30 min at ambient temperature. Maximum fluorescence (F_m) and minimum fluorescence (F_0) were measured simultaneously in the dark. Then the leaves were exposed to a photosynthetic photon flux with a density of 1000 μmol photons m^{-2} s^{-1} for> 3 min to measure maximum fluorescence (F_m'), minimum fluorescence (F_0'), and stationary fluorescence (Fs) in a light-adapted state after stabilization P_n. These measurements were carried out every 2 hours from 08:00 to 20:00 on sunny days. The efficiency of photochemical quenching was evaluated by comparing the stable fluorescence yield in light and the fluorescence yield in the absence of photosynthetic light.

It was calculated the fraction of light absorbed by PSII antennas and used in PSII photochemistry. It was used this data to determine photosynthetic electron transport (P), the fraction of light absorbed by PSII antennas that were thermally scattered (D), and the component of absorbed light, neglected by either P or D, which is “excess” energy (E) using the following formulas (Genty et al., 1989):

$$P = (F_m' - F_s) / F_m' \qquad (2)$$

$$D = 1 - (F_v'/ F_m') \qquad (3)$$

$$E = (F_v'/ F_m') * (1 - qP) \qquad (4)$$

The light energy absorbed by the chlorophyll molecules is released through these three mechanisms, and their total is equal to the total captured energy:

$$P + D + E = 1 \qquad (5)$$

Photosynthetic light output curves were obtained from data recorded from 09:00 to 11:00 in the light intensity range (0-2600 mmol m^{-2} s^{-1}) using a portable photosynthetic system (MIMI-PAM-II). The irradiation reaction was measured at a temperature of 25^{0}C and relative humidity of 50%. The CO_2 concentration was 400 μmol per second, and the light output curve of plants was determined at intensities of photosynthetically active radiation in the range from 0 to 2600 mmol m^{-2} s^{-1}. Photosynthesis parameters were obtained after fitting the photosensitivity data to the following equation:

$$A = (A_{max} (I - I_c) \alpha_c) / (Amax + (I - I_c) \alpha_c) \qquad (6)$$

A is the net rate of photosynthesis, A_{max} is the maximum net rate of photosynthesis, I_c is the light compensation point, I is the light intensity, and αc is the quantum yield. The dark respiration rate (R_d) was calculated from the light-limited part of the photosynthesis light output curve:

$$A = \alpha_c I - R_d$$

For $I = I_c$, $A = 0$ and $R_d = \alpha_c I$

Data and statistical analysis

To determine the significance of differences we used analysis of variance (ANOVA). The value of the little significant difference was defined as $P_{0.05}$. All analyzes were performed using the software (Stepanov et al., 2016).

Results and Discussion

Aboveground and underground biomass

In 2017, the aboveground biomass of grass mixtures was higher than pure crops, except for *Echinochloa frumentacea* L. The yield of which had a slight difference (-094 t/ha) in comparison with the grass mixture *H. vulgare* L. + *S.* var. *eusorghum* Pers. + *S. sudanense* hybrid P. + *P. sativum* L. + *E. frumentacea* L. In 2018, the aboveground biomass of the mixtures was significantly higher than that of pure crops, especially in *H. vulgare* L. + *S.* var. *eusorghum* Pers. + *S. sudanense* hybrid P. + *P. sativum* L. + *E. frumentacea* L., which had a higher biomass yield of the *Echinochloa frumentacea* L. (Figure 2a).

The biomass of *H. vulgare* L. + *S.* var. *eusorghum* Pers. + *S. sudanense* hybrid P. + *P. sativum* L. + *E. frumentacea* L. is 26.88 t/ha, which is more than *Echinochloa frumentacea* L. (20.65 t/ha) by 0.76%, and the grass mixture *H. vulgare* L. + *S.* var. *eusorghum* Pers. + *S. sudanense* hybrid P. + *P. sativum* L. + *P. glaucum* (L.) R. Br. was 25.4 t/ha, which is 4.16% higher than in the *Pennisetum glaucum* (L.) R. Br. (Figure 2b).

In 2019 the yield of pure crops and grass mixtures was lower than the previous year, but higher than in 2017 by 0.82%, while the yield dynamics remained the same, except for *Pennisetum glaucum*, in the aboveground biomass – 17.07 t/ha, however, the grass mixture with the inclusion of *Pennisetum glaucum* (L.) R. Br. showed an insignificant difference (+0.41 t/ha) compared to the herbal mixture, including *Echinochloa frumentacea L.* (Figure 2c). Along with this, the biomass of the *Echinochloa frumentacea* L. in 2018 sharply increased in comparison with the value of 2017. It became much higher in the mixture *H. vulgare* L. + *S.* var. *eusorghum* Pers. + *S. sudanense* hybrid P. + *P. sativum* L. + *E. frumentacea* L., a positive dynamics of aboveground biomass was observed. These dynamics continued in 2019 (Figure 2).

Underground biomass and root: shoot ratio varied significantly between pure crops and grass mixtures in 2019 (Figure 3). Among the crops in pure sowing, *Sorghum* var. *eusorghum* Pers. had the highest underground biomass (Figure 3a) and compared to *Echinochloa frumentacea* L. and *Pennisetum glaucum* (L.) R. Br., it was higher by 43.4 and 41.8%, respectively. However, the underground biomass of mixed crops of annual crops was significantly higher than the corresponding value in their monocultures (Figure 3a). The root: shoot ratio showed the same tendencies (Figure 3b).

Nitrogen plays an important role in plant growth and development. One of the important advantages of grass mixtures is the biological fixation of N_2 by legumes, which can vary depending on N's productivity by legumes (Ignatov, 1998; Herridge et al., 1993). Legumes included in the mixture can promote plant growth through biological N_2 fixation. This can be especially important in regions such as our area of study, according to previous studies, in the soils of which there is an excess of potassium and a deficiency of nitrogen, which limits plant growth (Arystangulov & Zhambakin, 1985). The obtained data on the chemical composition of plants confirm the dependence of the content of protein on the species composition, mowing, and the ratio of the mixture components. In this study, we found that the proportion of biomass of grass mixtures that included a single legume remained relatively stable over the years. The N content and biomass of grass mixtures of annual forage crops increased significantly compared to the corresponding pure crops. Transferring N between legumes and grasses can explain the biomass in the mixtures (Arkhipenko, 2000; Artemiev et al., 2010). When planning the production of forage, it is necessary to take into account soil conditions, harvesting time, and place annual forage crops in such a way as to obtain the most extensive collection of forage from 1 hectare.

In contrast, stable production of forage is possible over the years. Different species have different effects on the productivity of mixed crops (Istranin & Zinovenko, 2016). In

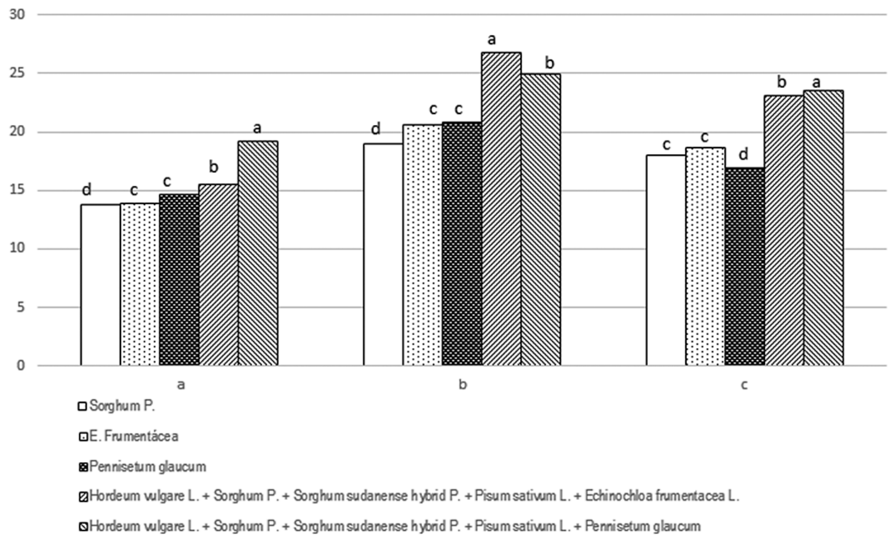

Fig. 2. Aboveground biomass (t/ha) of forage crops in monocultures and mixed crops in 2017 (a), 2018 (b) and 2019 (c). For each year, the mean in the columns, with the different letters least significant difference (P < 0.05)

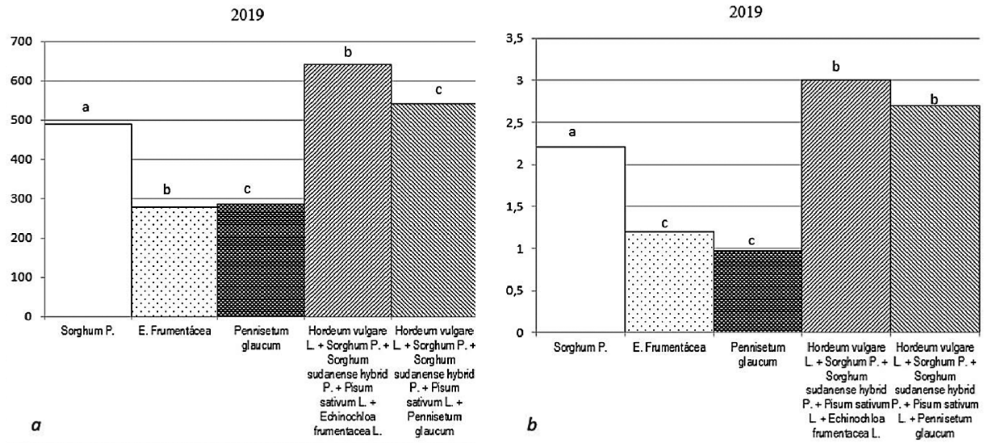

Fig. 3. Underground biomass and ratio of roots and shoots of forage crops in monocultures and grass mixtures in 2019. For each average value in the columns, with different letters the least significant difference (P < 0.05)

this study, the aboveground biomass of grass mixtures of annual crops was higher than that of grasses sown neatly in 2018 (wet year). The same dynamics continued in 2017, 2019 (dry years), but the overall yield was relatively low. The reason for this is probably the differences in the intensity of competition between crops for water (Mukhanov et al., 2018). Thus, the development of more compatible mixtures, as in a mixture of *H. vulgare* L. + *S.* var. *eusorghum* Pers. + *S. sudanense* hybrid P. + *P.sativum* L. + *E. frumentacea* L. could significantly increase the yield of feed and their stability (Waldron et al., 2017).

Feed quality

Different sowing methods had different effects on the feed quality. The results are shown in (Table 1).

Among the pure crops, *Sorghum* var. *eusorghum* Pers. had a significantly higher crude protein and crude fat content than other species. They had significantly lower cellulose content and significantly lower crude ash content than *Echinochloa frumentacea* L. and *Pennisetum glaucum* (L.) R. Br. The content of crude proteins in mixed crops with *Echinochloa frumentacea* L. was significantly higher than in *Echinochloa frumentacea* L., and crude protein content in *Pennisetum glaucum* (L.) R. Br. did not differ from the level in mixed crops. The cellulose content in the grass mixture *H. vulgare* L. + *S.* var. *eusorghum* Pers. + *S. sudanense* hybrid P. + *P. sativum* L. + *E. frumentacea* L. was significantly lower than in *Echinochloa frumentacea* L. Mixture with *H. vulgare* L. + *S.* var. *eusorghum* Pers. + *S. sudanense* hybrid P. + *P. sativum* L. + *P. glaucum* (L.) R. Br. did not differ significantly from the corresponding pure crop. In general, the lignin content did not differ significantly between sowing species, although in the mixture *H. vugare* L. + *S.* var. *eusorghum* Pers. + *S. sudanense* hybrid P. + *P. sativum* L. + *P. glaucum* (L.) R. Br. it was significantly higher than in *Pennisetum glaucum* (L.)R. Br. The content of C and N and the ratio of C: N in crops significantly differed between species (P < 0.05 (Table 2). *Sorghum* var. *eusorghum* Pers. had significantly lower carbon content and C:N ratio. The C: N ratio in mixtures was higher than in pure crops.

Chlorophyll fluorescence and gas exchange

Pure crops and grass mixtures had different gas exchange characteristics depending on the year (Table 3). The cereal-legume mixtures had much higher net photosynthesis (P_n) than the corresponding pure crops. In 2017 and 2018, the dif-

Table 1. Feed quality parameters (%) for various forage crops and grass mixtures

Grass /grass mixtures	Crude protein	Cellulose	Lignin	Crude ash	Crude fat
S. eusorghum Pers.	21.9±0.89a	17.2±0.03b	3.8±0.55ab	12.8±0.53b	2.61±0.48c
E.frumentácea L.	17.7±0.12c	18.4±0.15b	3.5±0.18a	18.6±0.89a	4.1±0.27b
P. glaucum (L.) R. Br.	18.3±0.41b	20.0±0.09bc	2.8±0.15b	15.2±*0.*65b	4.1±0.33b
Mixture 1	20.1±*0.15*a	21.7±0.19c	3.2±*0.0*8ab	13.5±0.13b	8.1±0.20a
Mixture 2	18.5±*0.61b*	20.3±0.20a	3.3±0.20ab	15.1±0.10b	3.71±0.18b

Within a column, means followed by the same letter are not significantly different at P = 0.05 (ANOVA followed by l.s.d. test) ference was approximately two times. Still, in 2019 the difference (~50%) and this indicator were marked by the highest in the mixture *H. vulgare* L. + *S.* var. *eusorghum* Pers. + *S. sudanense* hybrid P. + *P. sativum* L. + *E. frumentacea* L. In 2018, forage crops in mixtures had significantly higher transpiration (T_r) than in corresponding monocultures, as the year was characterized by high humidity. Still, in 2017 and 2019, there was no significant difference when the amount of precipitation was much lower. Gas exchange characteristics varied over the years. In 2017, P_n decreased for all types of crops, except for *Echinochloa frumentacea* L., respectively, WUE decreased for all types of crops. The indicator T_r increased for all pure crops and decreased for grass mixtures.

The curves of photosensitivity made it possible to calculate changes in the photosynthetic and physiological characteristics of plants (Table 4). Light compensation point (I_c) and dark respiration (R_d) of *Sorghum* var. *eusorghum* Pers. were significantly higher than *Echinochloa frumentacea* L. and *Pennisetum glaucum*. Light compensation point (Ic) and respiration rate in the dark (R_d) increased in the mixture *H. vulgare* L. + *S.* var. *eusorghum* Pers. + *S. sudanense* hybrid P. + *P. sativum* L. + *E. frumentacea* L. this mixture, on the contrary, decreased. Similarly, the light saturation point of the grass mixture *H. L.* + *S.* var. *eusorghum* Pers. + *S. sudanense* hybrid P. + *P. sativum* L. + *P. glaucum* (L.) R. Br. was higher than that of *Pennisetum glaucum* (L.) R. Br. sown in its pure form.

Also, the research results indicate that energy consumption and its distribution differed between crops in pure form and grass mixtures. However, over three years, aboveground biomass was positively correlated with photosynthetic ability (Figure 4).

It is well known that the area of the leaf surface of crops in the grass mixture depends on agrometeorological conditions and the applied agrotechnical measures, etc. Thus, we observe the influence of the types of sowing and agrometeo-

Table 2. Leaf carbon (C) and nitrogen (N) contents and C:N ratios for the for forage crops and grass mixtures with their inclusion

Grass and grass mixtures	C, %	N, %	C:N
S. eushorghum Pers.	22.3±0.11b	2.5±0.07a	8.92±0.24c
E. frumentácea L.	22.6±0.11*a*	0.8±*0.02d*	20.2±0.55a
P. glaucum (L.) R. Br.	23.2±0.10a	0,9±0.12d	18.9±1,22a
Mixture 1	24.4±0.06d	1.1±0.10a	23.2±0.35b
Mixture 2	25.7±*0.08c*	1.2±0.04b	22.7±0.23c

Table 3. Gas exchange characteristics in forage crops in grass mixtures

Grass / grass mixtures	P_n (*µ*mol mml^{-1})			T_r (µmol mml^{-1})			WUE (µmol mml^{-1})		
	2017	2018	2019	2017	2018	2019	2017	2018	2019
S.eusorghum Pers.	3.2±0.58 b	3.5±1.10 *a*b	3.2±0.66 b	1.5±*0.21* b	1.7±*0.25* a	1.5±0.19 *a*	2.1±*0.82* a	2.3±0.33 ab	2.0±*0.83* a
E.frumentacea L.	3.7±0.65 *c*	4.8+0.75 c	4.1±0.59 b	1.2±0.18 b	1.9±0.25 a	1.3±0.17 b	2.3±*0.65* ab	2.1±0.31 b	2.4±0.55 ab
P. glaucum (L.) R. Br.	2,9±0.78 a	3.9+0.68 c	3,8±0.75 a	1.3±0.07 b	1.8±*0.35* a	1.4±0.12 b	2,4±0.22 b	2.0±0.29 b	2.1±0.21 b
Mixture 1	6.5±1.11 a	8.2+2.11 *a*	7.2±1.25 a	2.4±0.15 a	3.3±0.34 a	2.1±0.13 a	2.8±*0.72* ab	3.2±0.46 a	2.3±*0.77* ab
Mixture 2	4.9±*0.77* ab	7.6+1.12 b	5.8±*0.78* ab	2.8±0.19 a	3.5±*0.35* a	2.2±0.12 a	2.1±0.52 b	2.5±*0.28* b	2.0±0.41 b

Table 4. Photosynthetic parameters of forage crops in crops sown in pure form and grass mixtures according to light curves

Grass and grass mixtures	Light saturation point, *µmolm*$^{-2}$s^{-1}	Light compensation point (I_c), µmolm^{-2}s^{-1}	Respiration in the dark (R_d), µmolm^{-2}s^{-1}	Obvious quantum yield, µmol CO_2 µmol^{-1}
Sorghum eusorghum Pers.	1401.0	111.2	2.8	0.013
E. frumentacea L.	1301.4	108.1	0.9	0.026
P. glaucum (L.) R. Br.	1305.7	100.7	2.1	0.014
Mixture 1	1700.4	123.5	1.8	0.015
Mixture 2	1500.0	118.6	1.6	0.013

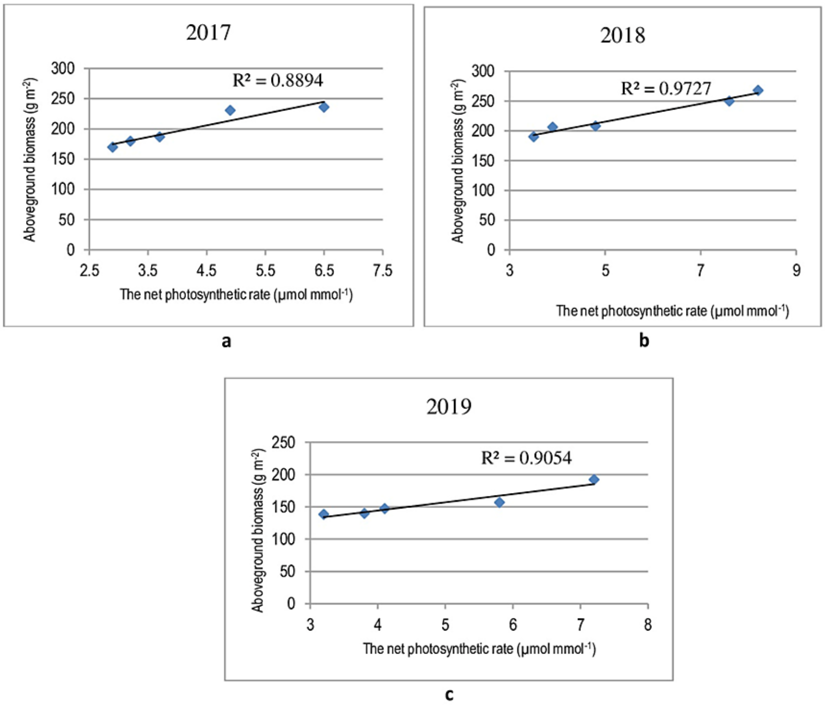

Fig. 4. Relationship between the net photosynthetic rate and the aboveground biomass in: (a) 2017, (b) 2018 and (c) 2019

rological conditions on the phytometric parameters of *E. frumentacea* in the grass mixture. (Arinov et al., 2011). Due to atmospheric precipitation, good formation of photosynthetic potential, an increase in the leaf surface of plants is observed in the second half of summer. A good harvest of green mass was obtained. (Serekpayev et al., 2018). *Echinochloa frumentacea* L. in the composition of the grass mixture due to the formation of the largest leaf area allows you to get a high yield of green mass. The leaf area of this crop in 2017 and 2019 was 1.5-2.0 times lower than in 2018. This is because 2017 and 2019 were dry years, which led to a decrease in moisture reserves in the soil, which led to an insignificant harvest of green mass. In 2018, a sufficient level of moisture reserves and an optimal soil temperature for the *E. frumentácea* L. crop in the composition of the grass mixture contributed to good tillering, abundant foliage, and an increase in the yield of green mass. This is evidenced by the results of studies carried out in the Akmola region by N. K. Mukhanov and other works of foreign scientists. (Mukhanov et.al., 2017; Korzun et al., 2012). Cellulose is a major component of plant cell walls and comprises glucose polysaccharides (Vermerris & Abril, 2015). The cellulose content in *Sorghum* var. *eusorghum* Pers. was significantly lower than in other crops. The cellulose content in the mixtures either did not change *(H. vulgare* L. + *S.* var. *eusorghum* Pers. + *S. sudanense* hybrid P. + *P. sativum* L. + *P. glaucum* (L). R. Br. or slightly increased *(H. vulgare* L. + *S.* var. *eusorghum* Pers. + *S. sudanense* hybrid P. + *P. sativum* L. + *E. frumentacea* L.) compared to crops in pure sowing. Thus, the mixtures most likely increased the synthesis of sugars related to C substrates (Curilel et al., 2004). In general, the mixtures of grass with introduced forage crops had better performance than crops in pure sowing.

According to the average data for three years, one of the main factors of the high chemical composition of crops in the grass mixture is the presence of precipitation in June in the phases of stalking, going into the tube, which contributes to an increase in protein in the composition of plants (Simeanu et al., 2019; Vasin et al. 2018; Vetharaniam et al., 2018).

Compatibility leading to stable coexistence between species depends on the morphology and physiological characteristics of the species depending on climate, soil, and biotic conditions (Laidlaw & Teuber, 2001). In the present study, all species were annuals, with varying nutrient ratios. For example, the introduced culture *Echinochloa frumentacea* L. has a high sugar content, which provides a high nutritional value to the entire mixture. *Echinochloa frumentacea* L. has high productivity – with early mowing, it grows well and gives a higher yield of green mass than in the first mowing. Under favorable conditions for the growing season, it can form several cuttings per growing season (2-4 cuttings), providing a high yield of green mass and hay, readily eaten by all types of farm animals. *E. frumentacea* L. is used as a fodder plant in the USA and can produce 8 mows of green mass per year. This is important when animal husbandry is experiencing a particularly acute shortage of green fodder. Therefore, *Echinochloa frumentacea* L. is a valuable fodder crop for a green conveyor (Lifer, 1988). The hypothesis of optimal distribution assumes that plants respond to changes in environmental conditions by optimal distribution of biomass between different organs to capture nutrients, water, and light to maximize their growth rate or survival (Kiriziy, 2017). The mixtures offered by us improved the growth of annual forage crops. However, water is a limiting factor in the dry steppe zone, particularly in our research conditions. During the research period, 2017 and 2019 became arid, while the introduced cultures of *Echinochloa frumentacea* L. and *Pennisetum glaucum* (L.) R. Br.in their pure form showed lower results than the adapted *Sorghum* var. *eusorghum* Pers. However, grass mixtures, including new crops, showed promising results, regardless of the year of research.

Conclusion

Based on the results of the studies, the following conclusions can be drawn: the productivity indicators of the introduced crops of *Echinochloa frumentacea* L. and *Pennisetum glaucum* (L.) R. Br. was lower than *Sorghum* var. *eusorghum* Pers. that is adapted to the region. However, these crops in the grass mixture showed high results, depending on weather conditions. The grass mixtures improved the yield of forage crops. They increased the ratio of roots and aboveground parts of grasses, which made it possible to release more biomass to the roots to increase the ability to absorb nutrients and water, thus increasing the plant's growth rate. There was a transfer of N from leguminous peas to cereal grasses in our proposed mixtures, which allowed more energy to be absorbed by natural pigments to support photosynthesis. In this regard, the photosynthetic ability and productivity of forage grasses improved in the grass mixtures. As seen from the data obtained, water is an important limiting factor for sowing forage crops. Compared to crops in clean sowing, grass mixtures had a higher WUE in a wet year (2018). Still, in dry years such dynamics were observed only in mixture with *E. frumentacea* L. The *Pennisetum glaucum* (L.) R. Br. was more sensitive to drought, while *Echinochloa frumentacea* L. had more biomass and higher WUE. Both mixtures can improve feed production compared to pure crops. Mixture with *H. vulgare* L. + *S.* var. *eusorghum* Pers. + *S. sudanense* hybrid P. + *P. sativum* L. + *E. frumentacea* L. showed better results than a mixture with *H. vulgare* L. + *S.* var. *eusorghum* Pers. + *S. sudanense* hybrid P. + *P. sativum* L. + *P. glaucum* (L.) R. Br., especially in dry years. Because the proposed mixtures include introduced crops, additional research is needed to determine the effectiveness of yield in different year conditions. It will be necessary to continue monitoring the mixtures for a more extended period to determine if the current results remain valid.

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