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# Ameliorating Forage Crop Resilience in Dry Steppe Zone Using Millet Growth Dynamics

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**Abstract:** Introducing new forage crops such as Japanese millet (*Echinochloa frumentacea*) and pearl millet (*Pennisetum glaucum*) is crucial for mitigating the impacts of climate change in the dry steppe zone, expanding forage crop options, and obtaining nutritious feed for the development of animal husbandry. The aim of this study was to assess the productivity and feed value of these crops. Field experiments were conducted in 2021 and 2022 to investigate the changes and variations in the yields and chemical compositions of Japanese millet and pearl millet when grown as sole crops or in mixed cropping in the dry steppe zone of northern Kazakhstan. Among the annual crops sown via sole cropping, the hay of the Japanese millet, sown in the third decade of May and harvested during full heading, was observed to have a higher content of raw protein and other nutrients than Sudanese grass hay, that is, the raw protein content was higher at 1.81%, the raw oil content at 0.12, and the raw ash content at 1.88%. In addition, among the mixtures of crops, the hay of the crop mixtures containing pearl millet, sown in the above period and harvested as hay during the milky stage, the full heading stage, and the formation of spikelets in the grain family stage, differed from the hay of Sudanese grass sown in the same period and collected during full heading in terms of the contents of raw protein and other nutrients and the low content of raw ash, that is, the content of raw protein was at 2.16%, raw oil at 0.39, raw ash at 0.95, without nitrogen extractives (WNEs) at 3.78, and starch at 0.11. The calcium content was higher by 0.08% and carotene by 0.11 mg/kg, and raw lentils were lower by 0.94%. The analysis of the results revealed that the variation in the crops' phenological phases depended on the moisture availability and the sowing time.

**Keywords:** Japanese millet; pearl millet; phenology; productivity; climate change



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## 1. Introduction

The impacts of climate change on agriculture are becoming more apparent worldwide [1]. Climate change negatively affects plants in low-latitude countries, which receive more short-wave radiation, while the effects in northern latitudes may be positive or negative [2]. There is a temperature range at which a plant produces seeds, and outside of this scope, the plant will not reproduce [3]. One reason for the low productivity of annual fodder crops in the Republic of Kazakhstan is the limited species composition [4,5]. The narrow species diversity of cultivated crops creates specific problems for global and domestic agriculture. As a result, there is a deficit of fodder on many farms. This has led to the deterioration of livestock quality in such farms.

The discrepancy between the need for feed and its availability, the unsatisfactory structure of the feed balance, and the high feed cost are the main reasons for the incomplete use of the productive capabilities of animals, low feeding efficiency, and the high cost of livestock products. Expanding the set of fodder crops with good feed quality traits is essential to reduce the cost of animal feed. Ideal fodder crops should have high and stable yields, lower energy consumption for cultivation, and high resilience to harsh agroclimatic conditions. This is one of the ways of creating a solid feed base for animal husbandry, leading to the production of high-quality livestock and improving an enterprise's profitability [6,7].

Pearl millet (*Pennisetum glaucum*) is the sixth most important cereal crop after rice, wheat, maize, barley, and sorghum [8]. It is widely grown on 30 million ha in Asia and Africa's arid and semi-arid tropical regions. It is also characterized by high-temperature resistance and low water requirements [9]. It can be cultivated on poor and depleted soils where 250–300 mm of precipitation falls per year, i.e., in conditions entirely unsuitable for other tropical crops. However, in this case, good harvests cannot be expected. It is better if the days are hot, the nights are cool, and the precipitation is 600–700 mm per year, but a smaller amount is acceptable with a favorable distribution [10]. Another new crop in the dry steppe zone of Kazakhstan, which has a high sugar content, is Japanese millet (*Echinochloa frumentacea*), known as a thermophilic crop. Seeds begin germinating at a soil temperature of 10–12 °C. Minor frosts are detrimental to seedlings. The optimal temperature for growth and development is 18–25 °C, and it is also a moisture-loving plant. To obtain a high yield, the annual precipitation should be at least 500 mm or cultivated with irrigation [11,12]. According to the fodder qualities, pearl millet can be equated to annual crops (Sudanese grass, sorghum, and corn). The green mass of pearl millet, in terms of protein content, can be equated to Sudanese grass and exceeds corn and sorghum in terms of fat and nitrogen-free substances. There are no significant differences compared with Sudanese grass, sorghum, and corn. Pearl millet contains sufficient ash elements in its green mass, especially calcium and phosphorus, which significantly increases its value in the feed diet of juvenile animals [13].

The protein in pearl millet ranges from 9 to 21%, which is higher than in sorghum (10.4%), rice (6.8%), and maize (4.7%) [14,15]. The grains of pearl millet are gluten-free and have a low glycemic index due to their high fiber content. The provitamin-A-enriched grains are also a rich source of fat (5–7 g/100 g) [16]. Pearl millet grain is encased in a tough fibrous seed that contains a variable amount of inhibitory plant compounds like phytic acid and polyphenols. However, these compounds can be reduced to a certain extent via various approaches like soaking, fermentation, blanching, and roasting [17,18]. Mixed cropping offers the significant benefit of improving yields and forage quality and increasing the efficiency of alternative new forage crops. Scientists have researched mixed crops and pure forms in climatic conditions with less than 400 mm annual precipitation in most of the lands similar to ours. The results showed that all mixtures had an advantage compared with pure stands (LER > 1 and ACYL-positive) in terms of hay and CP yields, ADF, and NDF ratios [19]. In addition, according to the results of Haruna et al. [20], using mixtures of different crops provided higher concentrations of soil organic carbon (SOC) (23.3 vs. 20.1 g/kg), soil organic nitrogen (SON) (2.4 vs. 2.0 g $kg^{-1}$), and particulate organic carbon (POC) (4.4 vs. 2.9 g $kg^{-1}$) at a 0–5 cm depth. The timings of sowing and harvesting crops have an important impact on yield, since an optimal sowing time can prevent weeds, and the timing of crop harvesting or the vegetative phase of the plant when mowing significantly affect the nutrient content in the green mass [21].

Moreover, anti-nutrient factors such as saponins, tannins, and phytic acid can reduce nutrient utilization and food uptake and hinder millet biofortification. All kinds of farm animals readily eat the green fodder and hay of pearl millet. The readily available sugars in the hay of pearl millet are no less than in sorghum, so the straw and green mass are well siloed and provide high-quality, succulent animal feed [22]. In this regard, the main objective of this study was to determine the adaptive phenology of annual fodder crops and their mixtures to obtain high productivity in the dry steppe zone of northern Kazakhstan and determine the best sowing dates. The authors hypothesize that evaluating forage cropping systems on different planting dates will significantly increase the feed value and yield under a mixed cropping system compared with the sole cropping approach. This kind of investigation would help to determine the best species composition of crops and planting dates to attain the optimum yield and yield compositions in the study region.

## 2. Materials and Methods

Site description and soil: This study was conducted during two growing seasons, 2021 and 2022, at a research farm at S. Seifullin Kazakh Agrotechnical Research University's "Goat Farm" in the Akmola region (51°26′1843″ N–71°09′8232″ E), located on the dark chestnut soils of the steppe zone of northern Kazakhstan. The experimental plot's soil was dark chestnut with a heavy mechanical composition. The depth of the arable layer was 20 cm. The humus content in the arable horizon ranged from 0 to 20 cm and was 2.09%, the nitrate nitrogen content was 7.15 mg/kg, the mobile phosphorus content was 12.51 mg/kg, the exchangeable potassium content was 583.50 mg/kg, and the pH was 6.91. In the 20–40 cm horizon, the humus content was 2.53%, the nitrate nitrogen content was 4.10 mg/kg, the mobile phosphorus content was 7.85 mg/kg, the exchangeable potassium content was 468.50 mg/kg, and the pH was 6.89.

Climatic conditions: In 2021, the average daily air temperature (Table 1) during the pearl millet growing season (May, June, July, and August) was at the level of the annual average, but some months exceeded it. In 2022, the average daily air temperature in the summer months, except August, was below the annual average by 1.0 °C. In the studied years, the precipitation (Table 2) during the growing season fell unevenly. At the beginning of the growing season in May, the precipitation was lower than the annual average by 21.7–22.0 mm.

**Table 1.** Average daily air temperature values for 2021 and 2022 in comparison with the long-term average for 2011–2020.

| Month | Temperature by Year, °C | | Long-Term Average, °C (2011–2020) |
|---|---|---|---|
| | 2021 | 2022 | |
| January | −14.5 | −12.3 | −15 |
| February | −7.6 | −14.2 | −15.2 |
| March | −0.6 | −8.8 | −8.8 |
| April | 9.9 | 5.9 | 5.1 |
| May | 14.2 | 14.8 | 13.3 |
| June | 18.3 | 21.5 | 19.3 |
| July | 19.8 | 20.3 | 20.9 |
| August | 20.1 | 19.9 | 18.1 |
| September | 15.5 | 12.4 | 17.1 |

**Table 2.** Amount of precipitation for 2021 and 2022 in comparison with the annual average.

| Month | Precipitation by Year, mm | | Long-Term Average 2011–2020 Precipitation, mm |
|---|---|---|---|
| | 2021 | 2022 | |
| January | 19.8 | 20.8 | 18.0 |
| February | 10.1 | 22.5 | 14.0 |
| March | 19.3 | 15.5 | 14.0 |
| April | 35.6 | 36.0 | 23.0 |
| May | 12.3 | 12.0 | 34.0 |
| June | 73.7 | 22.0 | 36.0 |
| July | 106.0 | 27.0 | 49.0 |
| August | 4.1 | 29.0 | 29.0 |
| September | 9.4 | 17.0 | 22.0 |

In June and July, the precipitation was 37.7 and 57.0 mm more than the average, whereas in August and September, there was 24.9 and 12.6 mm less precipitation than expected. In June and July 2021, the precipitation was below the long-term average by 14.0 and 22.0 mm, respectively, and in August, it remained at the level of the long-term average data. In September, there was 3.0 mm less precipitation than normal. During the research years, the change in productive moisture in the top-meter layer of soil was associated with the arrival of precipitation. In 2021, the antecedent in the soil was high, with the most considerable amount recorded in July, and ranged from 114.8 to 124.4 mm, depending on the month's segmented 10-day periods. This indicator was relatively high during the research period. From July 2022, the reserves of productive moisture in the soil in the first 10-day period amounted to 92.4 mm, decreasing to 91.3 mm by the end of the month. An absence of precipitation in 2022 was observed in all months except the third 10-day period of May, which contributed to decreased productive moisture in the top-meter layer of soil.

Site management and experimental design: Field experiments were conducted to study the effect of the species composition of crops and sowing dates on the yield of one-year fodder crops sown as sole crops and intercrops, and the quality of the fodder types obtained from them. The primary tillage was carried out in winter. In spring, with the onset of the physical preparation of the soil, discing with simultaneous rolling was conducted. Sowing was carried out using a selective manual seeder with simultaneous rolling. Weather data were computed by the "METOS" field agrometeorological station [23]. The experiments were repeated twice. The area of each experimental block was 120 $m^2$. The field experiments were carried out according to the methodology of field experiments [24].

The objects of research were spring barley, the Simbat variety; Sudanese grass, the Tugai variety; spring rapeseed, the Yubileiny variety; field peas, the Omsky neosipayushcheisya variety; a sorghum–Sudanese grass hybrid, the Solaris variety; Japanese millet, the Krasava variety; and pearl millet, the Sogur variety. The mixed crops from the cereal–legume grass mixtures in the study area served as the experimental crops. The monocultures were Sudanese grass (*Sorghum p.*), rapeseed (*Brassica napus*), Japanese millet (*E. frumentacea*), and pearl millet (*Pennisetum glaucum*). At the same time, the Japanese millet and pearl millet were new annual crops undergoing trials under the conditions of Kazakhstan's dry steppe zone. Varieties were obtained from Russia, as well as the following grain–legume crop mixtures: *Brassica napus* + *Hordeum vulgare* L. + *Pisum sativum* L. + Sorghum + *Sorghum saccharatum* × *S. Sudanense*, *Echinochloa frumentacea* L + *Hordeum vulgare* L. + *Pisum sativum* L. + Sorghum + *Sorghum saccharatum* × *S. Sudanense*, and *Pennisetum glaucum* + *Hordeum vulgare* L. + *Pisum sativum* L. + Sorghum + *Sorghum saccharatum* × *S. Sudanense*. The first four in each crop mixture were local annual plants (Table 3).

A randomized complete block design with four blocks was carried out in both experiments. The blocks comprised plots measuring 4 m by 30 m (120 $m^2$) with six crop rows (with a row width of 15 cm). The two central crop rows were used to evaluate and analyze the crop yield differences influenced by the treatments.

Data recording: Phenological observations were made and records taken according to the All-Russian Scientific Research Institute of Feeds methodology [25]. During the onset of each vegetative phase of plant development, with the onset of the phase in 70% of the plants, the plant density was calculated upon the onset of complete germination, and the safety of the plants was carried out before mowing. Yield records were taken using the quantitative and weight method, and the determination of the crop structure was carried out in the laboratory after cutting the grass. Weed data from two 0.25 $m^2$ quadrats in each plot were randomly taken from two sampling areas (2 rows by 1 m) in each experimental plot [24].

According to the phenological phases, the average growth of phytomass was determined by taking plant samples during each crop's growing season. From each plot, samples were taken to determine the dynamics of crop accumulation. For pure-sown crops, samples from two 0.25 $m^2$ quadrats in each plot were randomly taken. Weighing was carried out in the field and the laboratory, and the samples were transported in thick plastic bags to prevent moisture loss and the drying out of the plants. The roots of the plants were cut off, and the wet weight of the plants per unit area (1 $m^2$/$ha^{-1}$) was determined.

**Table 3.** Schemes of the conducted experiments.

| Factor A<br>Crops and Grass Mixtures | Factor B<br>Sowing Time | Factor C<br>Mowing Term |
|---|---|---|
| *Sorghum p.* | II/V; III/V; I/VI | 1. In the phase of exiting from the tubes of cereals<br>2. In the phase of heading of the grain |
| *Brassica napus* | II/V; III/V; I/VI | 1. Flowering<br>2. Pod formation |
| *Brassica napus* + *Hordeum vulgare* L. + *Pisum sativum* L. + *Sorghum* + *Sorghum saccharatum* × *S. Sudanense* | II/V; III/V; I/VI | 1. In the phases of stemming and earing of cereal crops, flowering of legumes, and rape<br>2. In the phases of milky ripeness and heading of cereal crops, the formation of beans of legumes, the formation of pods of rape |
| *E. frumentacea* | II/V; III/V; I/VI | 1. In the phase of exiting from the tubes of cereals<br>2. In the phase of heading of the grain |
| *Echinochloa frumentacea* L. + *Hordeum vulgare* L. + *Pisum sativum* L. + *Sorghum* + *Sorghum saccharatum* × *S. Sudanense* | II/V; III/V; I/VI | 1. In the phases of stemming and earing of cereal crops, flowering of legumes, and rape<br>2. In the phases of milky ripeness and heading of cereal crops, the formation of beans of legumes, the formation of pods of rape |
| *Pennisetum glaucum* | II/V; III/V; I/VI | 1. In the phase of exiting from the tube of cereals<br>2. In the phase of heading of the grain |
| *Pennisetum glaucum* + *Hordeum vulgare* L. + *Pisum sativum* L. + *Sorghum* + *Sorghum saccharatum* × *S. Sudanense* | II/V; III/V; I/VI | 1. In the phases of stemming and earing of cereal crops, flowering of legumes, and rape<br>2. In the phases of milky ripeness and heading of cereal crops, the formation of beans of legumes, the formation of pods of rape |

Note: II/V; III/V; I/VI: 20 May; 30 May; 10 June.

Chemical analyses: The determination of the obtained feed’s nutritional value and chemical composition was carried out with a DS 2500 “Foss” device in the Plovdiv Agrarian University (Republic of Bulgaria) laboratory. For the chemical analysis of African millet, samples were taken during three phases: the phase of emergence into the tube, heading, and flowering. The plant dry matter was determined by drying to a constant weight at 100–105 °C [26]. The chemical analysis of the samples was conducted at 25 °C and at a relative humidity of 45%. The chemical analyses were carried out according to the Russian Standards and Regulations [27], and the determination of dry matter was conducted according to GOST 31640-2012 [28]. Bottles of appropriate sizes were dried at 105 °C for one hour. A test sample of feed weighing 5–70 g was placed in a weighed bottle. The bottle with the sample was placed in a drying cabinet. Drying was carried out at a temperature of 105 °C for six hours. After drying, the bottle was closed with a lid and cooled in a desiccator to room temperature. The weighing of an empty bottle, a sample, and a bottle with a dried sample was carried out with an accuracy of ±0.01 g. The determination of the crude fat content according to GOST 13496.15-97 was carried out as follows [29]: a 5–10 g sample was weighed onto a sheet of filter paper, depending on the expected fat content, with an error of no more than 0.001 g. A piece of fat-free cotton wool was placed on top. The mortar was wiped with cotton wool soaked in ether, which was attached to a dry sample. The bottle was wiped 2–3 times with fat-free cotton wool soaked in ether and placed on the filter paper. The Soxhlet flask was dried at a temperature of 105 °C for 30 min and weighed after cooling. The flask was filled to approximately 2/3 of the volume with ether and connected to the extractor. Water was placed in the refrigerator, and the flask of ether was heated in a water bath. When the extractor was filled with ether to the upper bend of the siphon tube, the ether was poured into the flask, taking the fat with it. After filling the extractor to the upper bend of the siphon tube, pure ether was drained from the extractor, which was then reconnected to the Soxhlet apparatus, and the remaining ether in the flask was distilled off. Once the ether had been distilled off, the extractor was disconnected, and the flask was kept in a bath until the solvent evaporated. After the solvent evaporated, the flask was placed in an oven, dried at 105 °C for one hour, cooled in a desiccator, and weighed. Subsequent weighing was carried out after repeated drying for 30 min. The drying and weighing were repeated until the difference between two successive weights was no more than 0.001 g. The determination of the crude ash content according to GOST 26226-95 was carried out as follows [30]: the sample was placed in a crucible without compaction so that air oxygen entered its lower layers. The crucible with the sample was weighed to the nearest 0.001 g, placed in a cold oven, and the temperature was raised to 200–250 °C. After the emission of smoke stopped, the furnace temperature was brought up to 525 ± 25 °C, and the crucible with the sample was calcined for 4–5 h. The absence of coal particles and the ash's uniform grey color indicated the material's complete ashing. After calcination was complete, the crucible with ash was cooled in a switched-off furnace and then placed in a desiccator and weighed. The determination of the crude protein content according to GOST 13496.4-93 was carried out as follows [31]: the test sample was quantitatively transferred to a Kjeldahl flask of an appropriate capacity, potassium sulfate was added, and then 25 $cm^3$ of sulfuric acid was added for the first gram of dry matter of the sample and 6–12 $cm^3$ for each additional gram of dry matter. After the clarification of the liquid, heating was continued for one hour, and then the ammonia was distilled off, after which it was titrated and the nitrogen content was calculated using the formula. The determination of the water-soluble carbohydrates (sugars) content according to GOST 26176-91 was carried out as follows [32]: in volumetric flasks with a capacity of 100 $cm^3$, depending on the carbohydrate content in the analyzed sample, 5–10 $cm^3$ was taken from the extract of concentrates, succulent, or roughage. Then, 2 $cm^3$ of zinc sulfate or acetate solution and potassium ferric sulfate were added to the identical flasks. Solutions with a formed amorphous precipitate were brought to the mark with distilled water, mixed thoroughly, and left for 20 min with periodic stirring. The solutions were filtered through filter paper into dry conical flasks with a capacity of 100 $cm^3$, discarding the first portions of the filtrate. The carbohydrate content in a test sample was determined using a calibration graph constructed by measuring the optical density of glucose reference solutions.

## 3. Statistical Analysis

Data analysis was conducted using the statistical software SPSS 23.0. A one-way analysis of variance (ANOVA) was used to determine statistically significant differences between the yields of the studied crops and the influence of the sowing time on their yield. The distributions were first checked for the normality of the samples using the Shapiro–Wilk test, and the homogeneity of variance was determined using the Levene test. For multiple comparisons, Duncan's test was applied.

## 4. Results

### *4.1. Phenological Observations*

Depending on the sowing dates of Sudanese grass in its pure state, the life span from sowing to the exit from the tube ranged from 51 to 55 days (Table 4). The duration from sowing to the complete sprouting stage was 61 to 71 days. In addition, the life span of the spring rapeseed, Japanese millet, and pearl millet in monoculture was from 50 to 56 and 61 to 69, 50 to 57, and 61 to 70, respectively. Depending on the sowing dates of the mixture of spring rapeseed with barley, peas, Sudanese grass, and the sorghum–Sudanese grass hybrid, the vegetative period varied from 49 to 60 days from sowing to the stages of germination and flowering, and from 61 to 70 days from sowing to the stages of sprouting/germination and the formation of legumes. The vegetative period of the mixture of Japanese millet with barley, peas, Sudanese grass, and the sorghum–Sudanese grass hybrid was from 51 to 58 days from sowing to the stages of exit from the tube and flowering, and the duration from sowing to the stage of complete spikelet formation and the formation of pods was from 61 to 68 days. When sowing pearl millet mixed with barley, peas, Sudanese grass, and the sorghum–Sudanese grass hybrid, depending on the timing of sowing, the vegetative periods of the crops ranged from 47 to 59 days from sowing to flowering, and from 61 to 69 days from sowing to the stages of complete spikelet formation and pea formation. Thus, the duration of the growth stages of the annual forage crops using sole cropping and mixed cropping, from sowing to ripening, was shorter for later sowing periods.

**Table 4.** Phenological observations depending on the sowing time (average 2021–2022) in days.

| Sowing Period | Stages of Crop Development (for Crops of Grain/Bean/Rape), Number of Days | | | | | | Periods after Germination, Number of Days | |
|---|---|---|---|---|---|---|---|---|
| | From Sowing to Full Shoots | From Full Shoots to Binding/Branching | From Binding/Branching to Tube Exit/Branching | From Tube Exit/Branching to Spike/Collapse | For Legumes and Rape | | From Full Shoots to Tube Exit/Spike/Flowering | From Full Shoots to Milkweed Ripeness/Fringing/ Formation of Legumes |
| | | | | | Flowering | Pea Formation | | |
| **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** |
| Sudanese (st) | | | | | | | | |
| II/V | 12 | 26 | 29 | 16 | - | - | 55 | 71 |
| III/V | 26 | 33 | 18 | 10 | - | - | 51 | 61 |
| I/VI | 22 | 31 | 24 | 7 | - | - | 55 | 62 |
| Spring rapeseed | | | | | | | | |
| II/V | 16 | 10 | 28 | 14 | 4 | 13 | 56 | 69 |
| III/V | 26 | 4 | 25 | 12 | 9 | 11 | 50 | 61 |
| I/VI | 20 | 4 | 29 | 11 | 11 | 8 | 55 | 63 |
| Japanese millet | | | | | | | | |
| II/V | 13 | 23 | 34 | 13 | - | - | 57 | 70 |
| III/V | 27 | 33 | 17 | 11 | - | - | 50 | 61 |
| I/VI | 21 | 32 | 24 | 8 | - | - | 56 | 64 |
| Pearl millet | | | | | | | | |
| II/V | 12 | 25 | 32 | 16 | - | - | 57 | 73 |
| III/V | 26 | 34 | 16 | 12 | - | - | 50 | 62 |
| I/VI | 22 | 32 | 24 | 7 | - | - | 56 | 63 |
| Spring rapeseed + barley + peas + Sudanese + sorghum–Sudanese hybrid | | | | | | | | |
| II/V | 14 | 22 | 38 | 10 | - | - | 60 | 70 |
| III/V | 27 | 33 | 16 | 12 | - | - | 49 | 61 |
| I/VI | 19 | 35 | 23 | 9 | - | - | 58 | 67 |
| Japanese millet + barley + peas + Sudanese + sorghum–Sudanese hybrid | | | | | | | | |
| II/V | 16 | 21 | 37 | 10 | - | - | 58 | 68 |
| III/V | 26 | 36 | 15 | 10 | - | - | 51 | 61 |
| I/VI | 22 | 32 | 24 | 6 | - | - | 56 | 62 |
| Pearl millet + barley + peas + Sudanese + sorghum–Sudanese hybrid | | | | | | | | |
| II/V | 15 | 21 | 38 | 10 | - | - | 59 | 69 |
| III/V | 26 | 34 | 13 | 15 | - | - | 47 | 62 |
| I/VI | 23 | 32 | 22 | 7 | - | - | 54 | 61 |

*4.2. Weed Infestation*

The highest weed density among the crops sown in the sole cropping system in the second 10-day period of May was found in the fields of pearl millet, spring rapeseed, and Japanese millet (Table 5). The total number of weeds per meter square was 41, 38, and 35, respectively, of which 37, 36, and 31 were annual weeds, and 4, 2, and 3 were perennial weeds. In addition, the most common annual weeds found in the mentioned fields were *Amaranthus albus*, *Chenopodium album*, *Setariaviridis*, and *Avena fatua*, with *Convolvulus arvensis* as a perennial weed. When the sowing of crops and crop mixtures was performed in the third 10-day period of May, the most significant numbers of annual and perennial weeds were established in the fields of sole-cropped Japanese millet (34/m$^2$, including 30 annual weeds and 4 perennial weeds), spring rapeseed (31/m$^2$, including 28 annual weeds and 3 perennial weeds), and pearl millet (25/m$^2$, including 22 annual weeds and 3 perennial weeds) (Table 6).

**Table 5.** Weed infestation of sole crops and mixed crops sown in the second 10-day period of May (number of weeds/m$^2$ (2021–2022)).

| Crops/Crop Mixes | Weeds | | | | | Total |
|---|---|---|---|---|---|---|
| | Annual | | | | Perennial | |
| | *Amaranthus albus* | *Chenopodium album* | *Setaria viridis* | *Avena fatua* | *Convolvulus arvensis* | |
| Sudanese (st) | 5 | 1 | 3 | 1 | 1 | 11 |
| Spring rapeseed | 8 | 10 | 5 | 13 | 2 | 38 |
| Japanese millet | 8 | 6 | 5 | 12 | 3 | 35 |
| Pearl millet | 8 | 7 | 6 | 15 | 4 | 41 |
| Spring rapeseed + barley + peas + Sudanese + sorghum–Sudanese hybrid | 1 | 2 | 1 | 2 | - | 6 |
| Japanese millet + barley + peas + Sudanese + sorghum–Sudanese hybrid | 15 | 2 | 1 | - | 1 | 19 |
| Pearl millet + barley + peas + Sudanese + sorghum–Sudanese hybrid | - | - | 2 | 1 | 3 | 6 |

**Table 6.** Weed infestation of sole crops and their mixtures sown in the third 10-day period of May (number of weeds/m$^2$ (2021–2022)).

| Crops/Crop Mixes | Weeds | | | | | Total |
|---|---|---|---|---|---|---|
| | Annual | | | | Perennial | |
| | *Amaranthus albus* | *Chenopodium album* | *Setaria viridis* | *Avena fatua* | *Convolvulus arvensis* | |
| Sudanese (st) | 4 | 1 | 2 | 3 | 4 | 14 |
| Spring rapeseed | 10 | 9 | - | 9 | 3 | 31 |
| Japanese millet | 10 | 9 | 5 | 6 | 4 | 34 |
| Pearl millet | 6 | 6 | 3 | 7 | 3 | 25 |
| Spring rapeseed + barley + peas + Sudanese + sorghum–Sudanese hybrid | - | 1 | 1 | - | 1 | 3 |
| Japanese millet + barley + peas + Sudanese + sorghum–Sudanese hybrid | 9 | 3 | 4 | - | 2 | 17 |
| Pearl millet + barley + peas + Sudanese + sorghum–Sudanese hybrid | - | - | 1 | - | 5 | 6 |

Among the fields of sole crops and crop mixtures sown during this sowing time, the fields were infested with weeds at the lowest level for crops of spring rapeseed and pearl millet, which were sown in a mixture state, that is, the total number of weeds per meter square was three in a mixture field containing spring rapeseed and six in a mixture field with pearl millet. When sowing sole crops and crop mixtures in the first 10-day period of June, the most significant numbers of annual and perennial weeds were established in the fields of mono-cropped pearl millet (46 plants/m$^2$), spring rapeseed (43 plants/m$^2$), and Japanese millet (40 plants/m$^2$) (Tables 7 and 8). Among the fields of sole crops and crop mixes sown during this sowing period, the fields with the lowest weed numbers were those of a mixture of crops with the addition of pearl millet (7/m$^2$) and spring rapeseed (9/m$^2$). In the fields of annual sole crops and their mixtures, the number of weeds per meter square in the first sowing period (the second 10-day period of May) was 22 weeds; in the second sowing period (the second 10-day period of May), it was 21; and in the third sowing period (the first 10-day period of June), it was 30.

**Table 7.** Weed infestation of sole crops and their mixtures sown in the first 10-day period of June (number of weeds/m$^2$ (2021–2022)).

| Crops/Crop Mixes | Weeds | | | | | Total |
|---|---|---|---|---|---|---|
| | Annual | | | | Perennial | |
| | *Amaranthus albus* | *Chenopodium album* | *Setaria viridis* | *Avena fatua* | *Convolvulus arvensis* | |
| Sudanese (st) | 12 | 2 | 1 | 5 | 4 | 23 |
| Spring rapeseed | 9 | 11 | 6 | 14 | 3 | 43 |
| Japanese millet | 9 | 7 | 6 | 13 | 4 | 40 |
| Pearl millet | 9 | 8 | 7 | 16 | 5 | 46 |
| Spring rapeseed + barley + peas + Sudanese + sorghum–Sudanese hybrid | 3 | 2 | 1 | 2 | 1 | 9 |
| Japanese millet + barley + peas + Sudanese + sorghum–Sudanese hybrid | 11 | 2 | 1 | 1 | 2 | 18 |
| Pearl millet + barley + peas + Sudanese + sorghum–Sudanese hybrid | - | - | 2 | 2 | 3 | 7 |

**Table 8.** Total weed infestation of sole crops and their mixtures depending on the sowing dates in the years of study (2021–2022) (number of weeds/m$^2$).

| Sowing Date | Weeds | | | | | Total |
|---|---|---|---|---|---|---|
| | Annual | | | | Perennial | |
| | *Amaranthus albus* | *Chenopodium album* | *Setaria Viridis* | *Avena fatua* | *Convolvulus arvensis* | |
| II/V | 6.0 | 4.0 | 3.0 | 7.0 | 2.0 | 22.0 |
| III/V | 7.0 | 5.0 | 2.0 | 5.0 | 3.0 | 21.0 |
| I/VI | 10.0 | 5.0 | 3.0 | 9.0 | 3.0 | 30.0 |

Weed infestation in the experimental fields of sole and mixed crops was observed at all sowing times (average 21–30 weeds/m$^2$). However, due to the convenience of the soil temperature for the germination of weed seeds, the fields sown in the third sowing period (the first ten days of June) were more infested than those in the first sowing period. In addition, due to the higher density of planted crops per unit area in the mixed cropping system, the weed population was significantly lower for the sole-cropped fields.

### *4.3. Growth Dynamics of Annual Sole Crops and Their Mixtures Affected by Sowing Times*

Soil moisture, air, temperature, and light are the main environmental factors that are important for the growth of plants in farming systems. The importance of moisture is especially evident in places where moisture is a limiting factor for plant growth and development. During this study, the average daily growth of sole-cropped Sudanese grass at the stages of binding and tube exit varied from 3.2 to 3.4 cm; in spring rapeseed, it was from 1.1 to 1.5 cm; in Japanese millet, it was up to 2.3 cm; and in pearl millet, it was from 2.0 to 2.6 cm (Table 9).

**Table 9.** Average growth of sole crops and their mixtures by sowing date (2021–2022) (cm).

| Sole Crops/Crop Mixes | Sowing Date | | |
|---|---|---|---|
| | II/V | III/V | I/VI |
| Sudanese (st) | 3.2 | 3.4 | 3.3 |
| Spring rapeseed | 1.1 | 1.5 | 1.3 |
| Japanese millet | 2.3 | 2.3 | 2.3 |
| Pearl millet | 2.0 | 2.6 | 2.3 |
| Spring rapeseed + barley + peas + Sudanese + sorghum–Sudanese hybrid | 1.5 | 1.8 | 1.9 |
| Japanese millet + barley + peas + Sudanese + sorghum–Sudanese hybrid | 1.9 | 1.9 | 2.2 |
| Pearl millet + barley + peas + Sudanese + sorghum–Sudanese hybrid | 2.2 | 2.4 | 2.2 |

The average daily growth (Figure 1) of the mixture of spring rapeseed with barley, peas, Sudanese grass, and the sorghum–Sudanese grass hybrid in the periods of binding, tubing, and branching of the peas and rape was from 1.5 to 1.9 cm. Depending on the sowing time, the average daily increase in the mixture of Japanese millet with the above crops was from 1.9 to 2.2 cm, and the average daily increase in the mixture of pearl millet with these crops ranged from 2.2 to 2.4 cm.

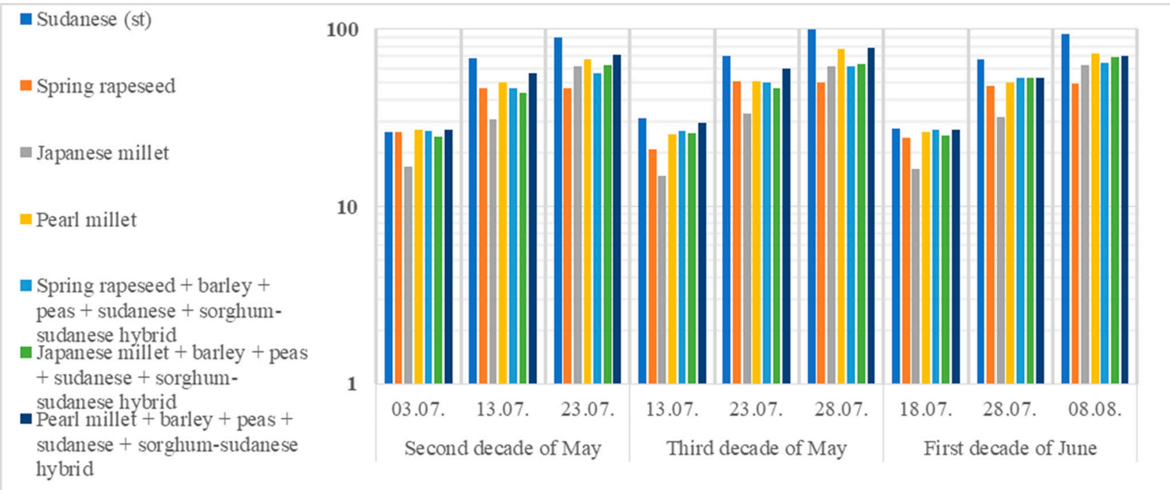


**Figure 1.** Average daily growth dynamics of crops and their mixtures by sowing date (2021–2022) (cm).

The maximum average daily increase in Sudanese grass was observed in the control plot. In addition, there were no significant differences in the average daily increases in any of the sole crops and mixtures according to the sowing dates. There was insufficient precipitation in 2021 and 2022 due to severe drought, resulting in insufficient moisture in the soil, which negatively affected plant growth and development. Depending on the sowing dates, the height of the Sudanese grass before tube exit ranged from 68.1 to 70.2 cm, and during the entire scattering stage, it ranged from 88.5 to 90.8 cm. Also, in summer, the rapeseed height, depending on the sowing times, ranged from 67.5 to 71.6 cm during the flowering stage, while the height of the legumes during the formation stage ranged from 92 to 95.1 cm. The height of the Japanese millet at the tube exit stage was between 71.1 and 73.6 cm, and at the stage of full heading, it was 90 to 96.6 cm. However, the height of the pearl millet at the mentioned stages of development was 70.2–80.6 cm and 94.9–97.7 cm, respectively. The maximum height of the above-mentioned annual sole-cropped forage crops was observed in the fields sown in the third 10-day period of May (Table 10).

**Table 10.** Height of the plants before harvesting, depending on the timing of sowing and harvesting (2021–2022) (cm).

| Sole Crops/Crop Mixes | Sowing Date | | |
|---|---|---|---|
| | II/V (st) | III/V | I/VI |
| Exit from the tube, spikelet, flowering periods | | | |
| Sudanese (st) | 68.1 | 70.2 | 67.9 |
| Spring rapeseed | 69.5 | 71.6 | 67.5 |
| Japanese millet | 71.1 | 73.6 | 72.1 |
| Pearl millet | 70.2 | 80.6 | 79.6 |
| Spring rapeseed + barley + peas + Sudanese + sorghum–Sudanese hybrid | 70.5 | 79.9 | 73.4 |
| Japanese millet + barley + peas + Sudanese + sorghum–Sudanese hybrid | 73.5 | 76.7 | 73.2 |
| Pearl millet + barley + peas + Sudanese + sorghum–Sudanese hybrid | 76.2 | 85.5 | 83.3 |
| Milkweed ripeness/fringing/formation of legume periods | | | |
| Sudanese (st) | 89.8 | 90.8 | 88.5 |
| Spring rapeseed | 93.5 | 95.1 | 92.0 |
| Japanese millet | 90.0 | 96.6 | 92.2 |
| Pearl millet | 96.1 | 97.7 | 94.9 |
| Spring rapeseed + barley + peas + Sudanese + sorghum–Sudanese hybrid | 96.5 | 98.7 | 94.3 |
| Japanese millet + barley + peas + Sudanese + sorghum–Sudanese hybrid | 91.7 | 97.9 | 95.9 |
| Pearl millet + barley + peas + Sudanese + sorghum–Sudanese hybrid | 99.2 | 101.9 | 97.6 |

The highest plant height was observed in pearl millet among the above-mentioned annual crops sown in their sole cropping form. The height of the pearl millet at the complete heading stage ranged from 6.4 to 6.9 cm higher than the height of Sudanese grass at the development stage, depending on the sowing dates. At the same time, the maximum height of the pearl millet was observed in the control plots in fields sown on the third 10-day period of May. It was 1.6 cm higher than those in the fields sown in the second 10-day period of May, and 2.8 cm higher than in the fields sown in the first 10-day period of June.

The average height of the mixture of spring rapeseed with barley, peas, Sudanese grass, and the sorghum–Sudanese grass hybrid, depending on the sowing dates, ranged from 70.5 to 79.9 cm in the tuber formation stage of the grain crops and the flowering stage of the legumes and oilseeds, and also ranged from 94.3 to 98.7 cm in the spikelet formation stage of the legumes and rape. On the other hand, the average height of mixed barley, peas, Sudanese grass, and the sorghum–Sudanese hybrid ranged from 73.2 to 76.7 cm during the spikelet formation of the grain crops, and during the flowering stage of legumes, the height ranged from 91.7 to 97.9 cm. The average height of pearl millet with barley, peas, Sudanese grass, and the sorghum–Sudanese grass hybrid at the mentioned stages of development ranged from 76.2 to 85.5 and 97.6 to 101.9 cm, depending on the sowing dates.

The maximum height of the plants before harvesting was determined for the crop mixture containing pearl millet at the milkiness stage, full heading stage, and the legume formation stage. The average height of the plants in the mentioned crop mixture was 9.4 to 11.1 cm higher than for Sudanese grass, depending on the sowing dates. At the same time, the maximum height of the plants in the crop mentioned above was observed in the second mowing period and in the fields sown during the third 10-day period of May. However, according to this study's results, due to low weed infestation, the average height of the crop mixtures was slightly higher than that of sole crops at both stages of development. In addition, much higher heights of all crops (in sole cropping and polyculture) were attained in the fields sown during the second and third 10-day periods of May, depending on the prevailing temperature conditions and moisture supply.

*4.4. Green Mass and Hay Products*

The sowing dates significantly affected green mass and hay production. It was shown to depend not only on the change in the water regime and the plant life cycle but also on the length of the day. The yield of sole-cropped Sudanese grass in both years ranged from 119.3 to 139.2 c/ha$^{-1}$. For the hay yield, it was 23.6 to 24.7 c/ha$^{-1}$, and for spring rapeseed, it was 156.5 to 176.3 and 25.1 to 26.2 c/ha$^{-1}$, respectively. In Japanese millet, the yield ranged from 191.2 to 214.7 c/ha$^{-1}$, and for pearl millet, it ranged from 191.7 to 253.4 and 25.3 to 26.2 c/ha$^{-1}$. The yield of spring rapeseed mixed with barley, peas, Sudanese grass, and the sorghum–Sudanese grass hybrid ranged from 163.4 to 196.9 and 25.7 to 26.3 c/ha$^{-1}$, respectively, while the yield of spring rapeseed mixed with barley, peas, Sudanese grass, and the sorghum–Sudanese grass hybrid varied from 221.9 to 249.3 c/ha$^{-1}$, respectively.

Furthermore, the yield of pearl millet in the mixture of barley, peas, and Sudanese grass ranged from 26.5 to 26.8 c/ha$^{-1}$. On the other hand, in the fields of tea mixed with the sorghum–Sudanese grass hybrid, yields were obtained in the ranges of 239.5 to 280.4 and 27.3 to 27.6 c/ha$^{-1}$, respectively. Moreover, the highest yield of green mass and hay for both sole- and mixed-cropped annual forage crops was obtained from the fields sown in the third 10-day period of May (Table 11).

**Table 11.** Green mass and hay products formed depending on the sowing dates of annual crops and their mixtures (c/ha$^{-1}$).

| Sole Crops/Crop Mixes | Productivity, c/ha$^{-1}$ | | | | | |
|---|---|---|---|---|---|---|
| | Green Mass | | | Hay | | |
| | Sowing Date | | | | | |
| | II/V | III/V | I/VI | II/V | III/V | I/VI |
| Sudanese (st) | 119.3 | 139.2 | 119.6 | 24.7 | 23.6 | 24.7 |
| Spring rapeseed | 156.5 | 176.3 | 160.7 | 26.2 | 25.1 | 26.0 |
| Japanese millet | 191.2 | 214.7 | 196.3 | 25.6 | 25.5 | 25.6 |
| Pearl millet | 191.7 | 253.4 | 217.0 | 25.3 | 26.2 | 25.3 |
| Spring rapeseed + barley + peas + Sudanese + sorghum–Sudanese hybrid | 163.4 | 196.9 | 186.3 | 26.1 | 25.7 | 26.3 |
| Japanese millet + barley + peas + Sudanese + sorghum–Sudanese hybrid | 221.9 | 249.3 | 236.3 | 26.5 | 26.8 | 26.5 |
| Pearl millet + barley + peas + Sudanese + sorghum–Sudanese hybrid | 239.5 | 280.4 | 258.8 | 23.7 | 27.6 | 23.3 |
| *p*-value | 0.05 | 0.05 | 0.05 | 0.221 | 0.232 | 0.446 |

The data analysis showed that the distribution was normal ($p > 0.05$), and the variables obeyed the law of normality ($p = 0.216$, $p = 0.297$, and $p = 0.216$), and the Levene test showed homogeneity among the variances ($p = 0.096$; $p = 0.251$). The statistical analysis showed that the studied traits' green mass significantly differed, but no significant differences were observed in terms of the dry mass.

Sudanese grass sown as a sole crop formed a hay product with values of 104.8–117.8 c/ha$^{-1}$ and 22.6–26.7 c/ha$^{-1}$ in the tube exit phase, while green mass formed a hay product with values of 133.7–160.6 and 32.9–39.5 c/ha$^{-1}$ in the complete sprouting stage. The yield of green mass for the sole-cropped rapeseed at the flowering stage ranged from 128.6 to 144.6 c/ha$^{-1}$ and yielded hay at values from 34.2 to 58.6 c/ha$^{-1}$, and at the legume formation stage, the values ranged from 184.3 to 207.9 and from 47.3 to 55.4 c/ha$^{-1}$, respectively (Figure 2). The green mass and hay products of the Japanese millet ranged from 169.4 to 189.0 and 41.1 to 48.3 c/ha$^{-1}$, respectively. Depending on the sowing time, the highest green mass and hay products were achieved for the pearl millet sown in the third 10-day period of May (Figure 3), ranging from 253.4 to 26.2 c/ha$^{-1}$, respectively. In the third 10-day period of May, the green mass and hay of pearl millet directly depended on the height of the plants during harvesting. The highest green mass and hay products were achieved for the pearl millet sown in the third 10-day period of May in the range of 253.4 to 26.2 c/ha$^{-1}$, respectively, which was significantly higher than the control.

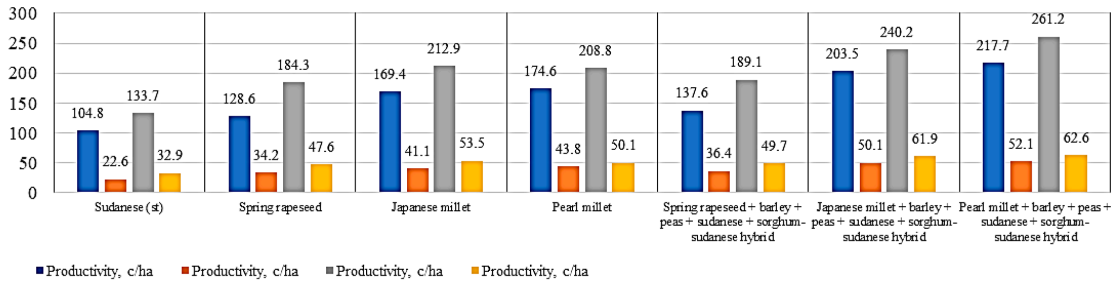


**Figure 2.** Second 10-day period of May. Yields of green mass and hay formed by annual crops and their mixtures depending on the timing of mowing: green mass and hay produced in tube exit, spikelet, and flowering periods; green mass and hay produced in milkweed ripeness/fringing/legume formation periods.

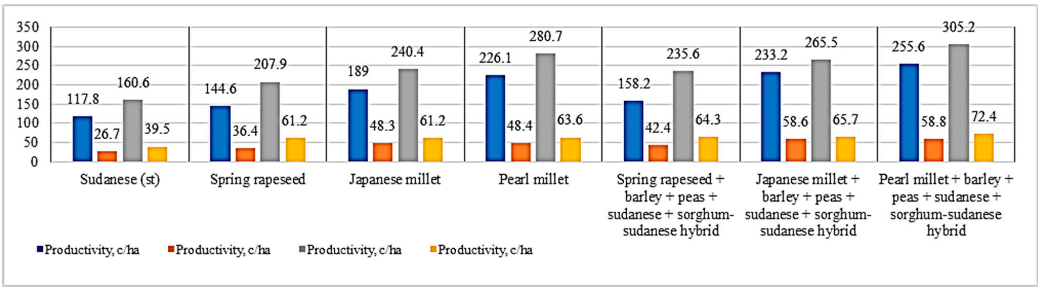


**Figure 3.** Third decade of May. Yields of green mass and hay formed by annual crops and their mixtures depending on the timing of mowing: green mass and hay produced in tube exit, spikelet, and flowering periods; green mass and hay produced in milkweed ripeness/fringing/legume formation periods.

In sole cropping, the crops were harvested during the periods of complete scattering of the green mass and hay, and the formation of beans and flowering of the rape ranged from 34.2 to 65.4 c/ha$^{-1}$, which was 19.6 to 43.8% higher than the crops mowed during the flowering periods, which had values ranging from 34.2 to 65.4 c/ha$^{-1}$ and from 2.1 to 24.8 c/ha$^{-1}$ or 3.9%, forming a high hay yield of 68.1%. At the same time, the mixtures of crops harvested during the milky ripening, complete sprouting, and formation of legumes stages for the bean and rape were dependent on the timing of harvesting and type of crop mixture, showing values of 30.0 to 81.5 c/ha$^{-1}$, which were 13.6 to 56.0% higher than those harvested during the grain-heading, spikelet, and flowering stages, and the green mass formed a high hay yield of up to 22.5 c/ha$^{-1}$ or from 12.1 to 58.6% (Figure 4).

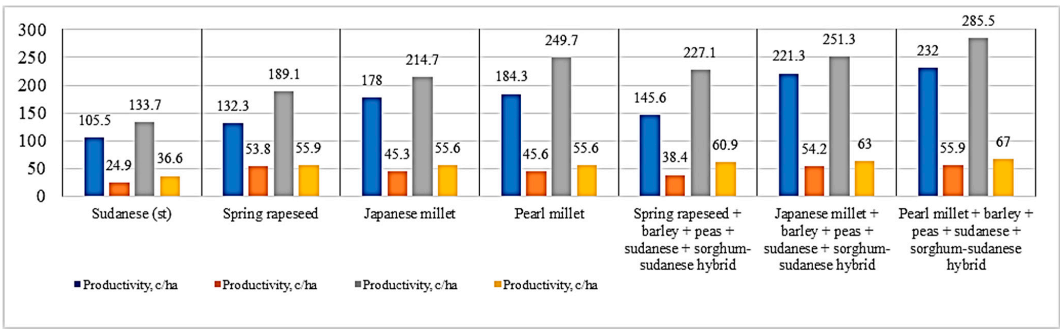


**Figure 4.** First 10 days of June. Yields of green mass and hay formed by annual crops and their mixtures depending on the timing of mowing: green mass and hay produced in tube exit, spikelet, and flowering periods; green mass and hay produced in milkweed ripeness/fringing/legume formation periods.

### 4.5. Chemical Compositions of Green Mass and Hay Products

The sowing time and forage crop composition significantly affected the yield of annual forage crops and their chemical compositions (Tables 12 and 13). Depending on the sowing time, the content of raw protein in the Sudanese grass during the germination stage in the tube ranged from 2.83 to 5.58%, with the content of raw protein ranging from 6.21 to 9.06%, raw fat from 0.21 to 1.07%, raw ash from 1.49 to 3.75%, without nitrogen extractives (WNEs) from 8.29 to 13.16%, starch from 0.32 to 2.48%, carotene from 4.66 to 5.48 mg/kg, calcium from 0.09 to 0.93%, and phosphorus from 0.06 to 0.20%.

**Table 12.** Chemical compositions of green mass of annual sole crops and their mixtures sown in the second 10-day period of May (%).

| Sole Crops/Crop Mixes | Dry Matter | Raw Protein | Raw Fat | Raw Lentils | Raw Ash | WNE | Starch | Carotene, mg/kg | Calcium | Phosphorus |
|---|---|---|---|---|---|---|---|---|---|---|
| Exit from the tube, spikelet, and flowering periods (st) | | | | | | | | | | |
| Sudanese (st) | 23.47 | 3.51 | 0.44 | 7.64 | 2.12 | 11.12 | 0.49 | 5.23 | 0.09 | 0.06 |
| Spring rapeseed | 22.60 | 2.71 | 0.32 | 6.09 | 1.94 | 9.55 | 0.30 | 5.07 | 0.05 | 0.04 |
| Japanese millet | 24.38 | 2.84 | 0.37 | 4.97 | 2.17 | 8.15 | 0.36 | 5.36 | 0.05 | 0.06 |
| Pearl millet | 23.38 | 3.29 | 0.44 | 6.70 | 2.13 | 11.00 | 0.20 | 5.00 | 0.08 | 0.06 |
| Spring rapeseed + barley + peas + Sudanese + sorghum–Sudanese hybrid | 22.60 | 3.29 | 0.45 | 6.11 | 2.22 | 9.30 | 0.26 | 5.63 | 0.06 | 0.07 |
| Japanese millet + barley + peas + Sudanese + sorghum–Sudanese hybrid | 23.93 | 2.86 | 0.32 | 4.60 | 2.10 | 8.12 | 0.28 | 5.10 | 0.06 | 0.04 |
| Pearl millet + barley + peas + Sudanese + sorghum–Sudanese hybrid | 22.70 | 3.46 | 0.32 | 7.34 | 2.22 | 11.29 | 0.11 | 5.02 | 0.07 | 0.05 |
| Milky ripeness/fringing/formation of legume periods | | | | | | | | | | |
| Sudanese (st) | 25.58 | 2.19 | 0.29 | 4.40 | 2.15 | 10.47 | 0.07 | 4.66 | 0.06 | 0.04 |
| Spring rapeseed | 23.92 | 2.84 | 0.26 | 4.06 | 2.23 | 9.44 | 0.13 | 5.17 | 0.06 | 0.02 |
| Japanese millet | 25.71 | 2.19 | 0.28 | 7.00 | 2.15 | 10.86 | 0.14 | 5.47 | 0.07 | 0.04 |
| Pearl millet | 23.54 | 2.96 | 0.29 | 6.59 | 2.04 | 13.13 | 0.14 | 4.38 | 0.10 | 0.05 |
| Spring rapeseed + barley + peas + Sudanese + sorghum–Sudanese hybrid | 25.10 | 2.73 | 0.29 | 7.04 | 2.33 | 12.76 | 0.11 | 4.93 | 0.08 | 0.03 |
| Japanese millet + barley + peas + Sudanese + sorghum–Sudanese hybrid | 22.70 | 2.03 | 0.32 | 4.57 | 2.13 | 9.96 | 0.12 | 4.33 | 0.08 | 0.06 |
| Pearl millet + barley + peas + Sudanese + sorghum–Sudanese hybrid | 26.19 | 2.18 | 0.21 | 6.18 | 1.97 | 12.04 | 0.11 | 4.53 | 0.07 | 0.06 |

During the flowering stage, the green mass of spring rapeseed attained a value of 2.09 to 4.31%, raw protein from 4.72 to 7.04%, raw lentils from 0.22 to 0.89%, raw fat from 1.37 to 3.51%, raw ash from 7.19 to 11.13%, without nitrogen extractives (WNEs) from 0.21 to 2.24%, starch from 4.58 to 5.27 mg/kg, and phosphorus from 0.04 to 0.11%. The content of raw protein in the Japanese millet during the tube stage ranged from 2.25 to 4.39%, raw protein from 4.42 to 5.88%, raw fat from 0.29 to 0.90%, raw ash from 1.63 to 3.70%, without nitrogen extractives (WNEs) from 5.84 to 9.67%, starch from 0.22 to 2.26%, carotene from 4.82 to 5.52 mg/kg, calcium from 0.05 to 0.86%, and phosphorus from 0.06 to 0.17% (Tables 12 and 13).

The content of raw protein in pearl millet ranged from 2.44 to 5.52%, raw protein from 5.11 to 8.29%, raw fat from 0.21 to 1.24%, raw ash from 1.33 to 3.93%, without nitrogen extractives (WNEs) from 8.01 to 13.20%, starch from 0.20 to 2.36%, carotene from 4.28 to 5.42 mg/kg, calcium from 0.08 to 1.07%, and phosphorus from 0.06 to 0.35% (Table 14). On the other hand, the content of raw protein in the mixture of crops along with spring rapeseed in the flowering stage of legumes and rape ranged from 2.69 to 5.19%, raw protein from 4.76 to 7.36%, raw fat from 0.28 to 1.0%, raw ash from 1.69 to 3.77%, without nitrogen extractives (WNEs) from 6.64 to 9.30%, starch from 0.12 to 2.78%, carotene from 2.09 to 5.80 mg/kg, calcium from 0.06 to 0.90%, and phosphorus from 0.07 to 0.18% (Tables 12–14).

**Table 13.** Chemical compositions of green mass of annual sole crops and their mixtures sown in the third 10-day period of May (%).

| Sole Crops/Crop Mixes | Dry Matter | Raw Protein | Raw Fat | Raw Lentils | Raw Ash | WNE | Starch | Carotene, mg/kg | Calcium | Phosphorus |
|---|---|---|---|---|---|---|---|---|---|---|
| Exit from the tube, spikelet, and flowering periods (st) | | | | | | | | | | |
| Sudanese (st) | 25.76 | 5.58 | 1.07 | 9.06 | 3.75 | 13.16 | 2.48 | 5.48 | 0.93 | 0.20 |
| Spring rapeseed | 24.82 | 4.31 | 0.89 | 7.04 | 3.51 | 11.13 | 2.24 | 5.27 | 0.82 | 0.11 |
| Japanese millet | 26.85 | 4.39 | 0.90 | 5.88 | 3.70 | 9.67 | 2.26 | 5.52 | 0.86 | 0.17 |
| Pearl millet | 25.69 | 5.52 | 1.24 | 8.29 | 3.93 | 13.20 | 2.36 | 5.42 | 1.07 | 0.35 |
| Spring rapeseed + barley + peas + Sudanese + sorghum–Sudanese hybrid | 25.09 | 5.19 | 1.00 | 7.36 | 3.77 | 11.17 | 2.17 | 5.80 | 0.88 | 0.18 |
| Japanese millet + barley + peas + Sudanese + sorghum–Sudanese hybrid | 25.82 | 4.63 | 1.02 | 5.73 | 3.79 | 9.86 | 2.34 | 5.42 | 0.99 | 0.27 |
| Pearl millet + barley + peas + Sudanese + sorghum–Sudanese hybrid | 26.57 | 5.71 | 0.89 | 8.95 | 3.79 | 13.51 | 2.04 | 5.21 | 0.83 | 0.11 |
| Milky ripeness/fringing/formation of legume periods | | | | | | | | | | |
| Sudanese (st) | 28.75 | 3.44 | 0.83 | 5.02 | 3.69 | 11.70 | 1.97 | 4.82 | 0.87 | 0.14 |
| Spring rapeseed | 27.17 | 4.54 | 0.76 | 5.12 | 3.80 | 11.11 | 2.06 | 5.36 | 0.89 | 0.16 |
| Japanese millet | 27.49 | 3.53 | 1.03 | 7.70 | 3.90 | 12.17 | 2.26 | 5.85 | 1.03 | 0.31 |
| Pearl millet | 26.75 | 5.31 | 0.93 | 8.31 | 3.67 | 15.46 | 2.14 | 4.64 | 0.99 | 0.24 |
| Spring rapeseed + barley + peas + Sudanese + sorghum–Sudanese hybrid | 27.24 | 4.66 | 0.90 | 8.32 | 3.94 | 14.66 | 2.08 | 5.16 | 0.91 | 0.16 |
| Japanese millet + barley + peas + Sudanese + sorghum–Sudanese hybrid | 25.25 | 3.56 | 1.12 | 5.45 | 3.93 | 11.46 | 2.28 | 4.75 | 1.14 | 0.41 |
| Pearl millet + barley + peas + Sudanese + sorghum–Sudanese hybrid | 29.66 | 3.75 | 0.77 | 7.11 | 3.53 | 13.59 | 2.03 | 4.71 | 0.91 | 0.20 |

**Table 14.** Chemical compositions of green mass of annual sole crops and their mixtures sown in the first 10 days of June (%).

| Sole Crop/Crop Mixes | Dry Matter | Raw Protein | Raw Fat | Raw Lentils | Raw Ash | WNE | Starch | Carotene, mg/kg | Calcium | Phosphorus |
|---|---|---|---|---|---|---|---|---|---|---|
| Exit from the tube, spikelet, and flowering periods (st) | | | | | | | | | | |
| Sudanese (st) | 21.40 | 2.83 | 0.21 | 6.21 | 1.49 | 8.29 | 0.32 | 4.66 | 0.18 | 0.16 |
| Spring rapeseed | 21.00 | 2.09 | 0.22 | 4.72 | 1.37 | 7.19 | 0.21 | 4.58 | 0.10 | 0.08 |
| Japanese millet | 22.83 | 2.25 | 0.29 | 4.42 | 1.63 | 5.84 | 0.22 | 4.82 | 0.11 | 0.13 |
| Pearl millet | 21.15 | 2.44 | 0.21 | 5.11 | 1.33 | 8.01 | 0.36 | 4.28 | 0.31 | 0.31 |
| Spring rapeseed + barley + peas + Sudanese + sorghum–Sudanese hybrid | 20.70 | 2.69 | 0.28 | 4.76 | 1.67 | 6.64 | 0.12 | 5.09 | 0.12 | 0.13 |
| Japanese millet + barley + peas + Sudanese + sorghum–Sudanese hybrid | 22.16 | 2.11 | 0.15 | 4.13 | 1.40 | 5.59 | 0.26 | 4.44 | 0.28 | 0.25 |
| Pearl millet + barley + peas + Sudanese + sorghum–Sudanese hybrid | 20.45 | 2.84 | 0.25 | 5.97 | 1.65 | 8.27 | 0.10 | 4.53 | 0.12 | 0.09 |
| Milky ripeness/fringing/formation of legume periods | | | | | | | | | | |
| Sudanese (st) | 24.33 | 1.60 | 0.22 | 4.52 | 1.62 | 8.45 | 0.08 | 4.12 | 0.14 | 0.11 |
| Spring rapeseed | 22.22 | 2.22 | 0.19 | 4.25 | 1.66 | 6.97 | 0.09 | 4.61 | 0.17 | 0.13 |
| Japanese millet | 24.37 | 1.38 | 0.11 | 5.45 | 1.39 | 8.75 | 0.30 | 4.78 | 0.28 | 0.26 |
| Pearl millet | 21.18 | 2.27 | 0.10 | 5.16 | 1.40 | 10.01 | 0.20 | 3.76 | 0.22 | 0.19 |
| Spring rapeseed + barley + peas + Sudanese + sorghum–Sudanese hybrid | 23.18 | 2.08 | 0.18 | 5.63 | 1.73 | 10.08 | 0.15 | 4.37 | 0.19 | 0.14 |
| Japanese millet + barley + peas + Sudanese + sorghum–Sudanese hybrid | 21.18 | 1.18 | 0.26 | 4.14 | 1.33 | 7.67 | 0.37 | 3.54 | 0.37 | 0.36 |
| Pearl millet + barley + peas + Sudanese + sorghum–Sudanese hybrid | 24.62 | 1.57 | 0.19 | 4.82 | 1.40 | 9.71 | 0.10 | 3.96 | 0.15 | 0.15 |

The content of raw protein in the crop mixture containing Japanese millet in the flowering stages of legumes varied from 2.11 to 4.63%, raw protein from 4.13 to 5.73%, raw fat from 0.15 to 1.02%, raw ash from 1.40 to 3.79%, without nitrogen extractives (WNEs) from 5.59 to 9.86%, starch from 0.26 to 2.34%, carotene from 4.44 to 5.42 mg/kg, calcium from 0.06 to 0.99%, and phosphorus from 0.04 to 0.27%. The raw protein content in the crop mixed with pearl millet in the first mowing period, depending on the harvesting time, ranged from 2.84 to 5.71%, with raw protein ranging from 5.97 to 8.95%, raw fat from 0.25 to 0.89%, raw ash from 1.65 to 3.79%, without nitrogen extractives (WNEs) from 8.27 to 13.51%, starch from 0.11 to 2.04%, carotene from 4.53 to 5.21 mg/kg, calcium from 0.07 to 0.83%, and phosphorus from 0.05 to 0.11%.

For the Sudanese grass hay, the most significant raw protein content was observed in the second sowing period—the third 10-day period of May—and in the complete sprouting period, ranging from 11.37 to 9.94%, which was higher than in the control (the first sowing period was the second 10-day period of May) by 2.72 and 3.6%, respectively, depending on the duration and intensity of the lighting. Moreover, when the crops were sown at later sowing dates, the protein content and other nutrients in the leaves of the plants were higher than in the stem. The most significant amount of raw greenery was attained in the early sowing period (in the second decade of May) and ranged from 28.35 to 30.5%, depending on the periods of growth and development.

The data analysis showed that the raw protein, which determines the feed value of the mass of any plant, was higher in the hay of spring rapeseed sown in the third 10-day period of May, and it varied from 7.24 and 10.05%, depending on the stages of growth and development. The content of raw protein in the dry matter of Japanese millet was 8.13% in the first sowing period, 11.03% in the second sowing period, 6.95% in the third sowing period, and 7.55, 9.75, and 6.57% during the entire sowing period, respectively. The amount of raw protein was also enhanced and varied from 28.1 to 29.1% in the first sowing period, 29.91 to 31.43% in the second sowing period, and 26.13 to 26.95% in the third sowing period. The highest raw oil content in the dry matter of Japanese millet was obtained during heading and sowing in the second 10-day period of May with a value of 2.70%. The highest contents of raw ash (8.68%) and other nutrients (47.69% for without nitrogen extractives (WNEs); 3.38% for starch; 23.25 mg/kg for carotene; 0.39% for calcium; and 0.46% for phosphorus) were observed when planting in the second sowing period (third decade of May), and harvesting at the stages of heading and flowering was performed (Tables 12–14).

## 5. Discussion

Japanese millet planted in the third decade of May and harvested during full heading was observed to have a higher raw protein content and other nutrients than Sudanese grass hay. Moreover, among the mixtures of crops, the hay of the crop mixtures containing pearl millet, sown in the above period and harvested as hay during the milky stage, full heading, and formation of spikelets stage differed from the hay of Sudanese grass sown in the same period and collected during the full heading stage in the content of raw protein and other nutrients and the low content of raw ash. In the study by Stybaeyev et al. [33], the highest plant density at the complete shoot stage was achieved for Japanese millet, with a value of 145/m$^2$ in the crop mixture treatment, and the mixture of pea + Sudanese grass, with a value of 136 and 133/m$^2$, respectively.

The sowing time and stages of development of all crops involving forage crops significantly affected the yield level of one-year forage crops and their chemical composition [34]. In agreement with the results of the preceding authors, our findings indicate that Sudanese grass is a source of energy and protein, has high nutritive value, and is beneficial for improving forage palatability and digestibility [35]. The highest content of raw protein in Sudanese grass hay was attained in the second sowing period—the third 10-day period of May—and in the period of complete sprouting, ranging from 11.37 to 9.94% [36].

Currently, in many regions of the country, there is a shortage of feed in animal husbandry due to harsh climatic conditions [37,38], which leads to a shortage of livestock products and an increase in their cost, as well as a reduction in the livestock population. Thus, the selection of annual fodder crops and their mixtures with different nutritional values along with improvements in cultivation technology to obtain high-quality fodder in the conditions of the dry steppe zone of Kazakhstan are necessary [39].

The biological composition of crops plays a vital role in determining their consumption. At the same time, annual and perennial crops are used as fodder in different ways. For example, *Trifolium pratense*, with longer inflorescences, is commonly used in various grass mixtures [40,41]. Crop yields can be programmed, but currently, scientists are conducting simulations of alfalfa yields, but some limiting factors, such as weeds, do not allow for an accurate model [42,43]. Pearl millet is grown as a forage, cover, and grain crop in Brazil [44], highlighting the importance of using millet crops in the preparation of animal feed. Since millet is an essential crop in the countries of Central Asia [45,46] and global climate change effects are also felt in northern Kazakhstan, the conditions for growing millet become equivalent to other countries that produce pearl millet for fodder; therefore, it is logical to include pearl millet and African millet in grass mixtures for fodder [47].

Zhang et al. [46] and Shaltout et al. [48] reported that groundwater consumption and changes in its amount depend on the growth of forage plants. They also conducted in-depth studies on the state of soil moisture and changes in its amount, considering the consumption of fodder crops. The assessment of the economic and bioenergetic efficiency of the main elements of the cultivation technology (sowing time and mowing time) showed that for obtaining hay from annual fodder sole crops and their mixtures, the most effective elements are an early sowing time (the third 10-day period of May), with a profitability of 176% and energy efficiency of 3.8, and late mowing time, with a profitability of 189% and energy efficiency of 3.5 [49,50].

Due to the higher density of planted crops per unit area in the mixed cropping system, the weed population was significantly lower for the sole cropping method. The highest weed density in our study was attained among the crops sown using the sole cropping system in the second 10-day period of May, in the fields of pearl millet, spring rapeseed, and Japanese millet. These results followed those registered by Stybaeyev et al. [33], who reported that treatments including forage crop mixtures significantly reduced the population of weeds compared with the sole cropping treatments. In their study, the highest total weed density was attained for Japanese millet and common millet as sole cropping treatments of 45 and 39 plants per $m^2$, respectively. Another investigation by Petrosino et al. [51] observed that spring-planted triticale mixed with hairy vetch reduced Kochia weed density and biomass by 98% in western Kansas.

## 6. Conclusions

Among the annual crops sown via sole cropping, the hay of the Japanese millet crop, sown in the third decade of May and harvested during full heading, was distinguished by a higher content of raw protein and other nutrients than Sudanese grass hay. In addition, among the mixtures of crops, the hay of the crop mixtures containing pearl millet, sown in the above period and harvested as hay during the milky stage, full heading stage, and the formation of spikelets in the grain family stage, differed from the hay of Sudanese grass sown in the same period and collected during full heading in terms of the content of raw protein and other nutrients and low content of raw ash. The highest green mass, hay, dry matter, and raw protein were obtained for the pearl millet + barley + peas + Sudanese + sorghum–Sudanese hybrid mixture sown during the third 10-day period of May.

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