Prospects of millet crops cultivation for forage purposes in the non-black earth zone North-West area

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Abstract. The article deals with the issues of barnyard millet, Turkestan millet, foxtail millet, and proso millet cultivation in the Novgorod region conditions. In the three research years, positive results were obtained for all studied crops and varieties. Regarding climatic zone conditions, the duration of the period before harvesting ripeness, calendar harvest dates, and the level of the studied crops varieties herbage yield were identified. The herbage analysis for the content of crude protein, fiber, available energy, and feed units was conducted. It was established that the proso millet Sputnik and Regent varieties and foxtail millet Stepnoy Mayak variety ripen for seeds in the Novgorod region. The introduction of new crops in crop rotation will provide an opportunity to expand forage crops range and to strengthen the Non-Black Earth Zone forage base.

1. Introduction
The foundation of a livestock forage base is composed of perennial legumes and grasses in a crop rotation system and in natural hay fields and pastures [1]. In order to increase the productivity of cattle, pigs, and poultry stocks, additional sources of feed are needed [2]. Improving the balance of feed in terms of nutritional elements is possible by supplementation of concentrated feeds as well as high-nutritional annual feed crops in livestock rations. The green conveyor system annual elements are grasses and legume-grass mixtures based on autumn-sown rye, oats, maize, peas/field peas, spring and winter vetch [3]. The list of strengthening forage production tasks includes expanding of annual forage grasses range and their period of use.

In recent years, the Department of Forage and Crop Production at the Federal State Budgetary Scientific Institution “Novgorod Research Institute of Agriculture” has been addressing the issue of southern forage crops production range expansion to the north [4, 5]. That is no coincidence. The present century is characterized by a stable vector of climate change. There is an annual increase in the average annual temperature of the planet [6]. Thus, in the Novgorod region over the past 15 years of observations, the average annual temperature has increased by 1.8°C compared to the long-term average and amounted to +6.2°C. There are new, not previously encountered natural phenomena occurring in the region: tornadoes, unusual storm winds, periods of drought or prolonged rains, green winters, alternation of cold and hot days during the summer period. The climate warming trend has contributed to the involvement of southern crops as subjects of research [7].

Such crops as barnyard millet, Turkestan millet, proso millet, foxtail millet, sweet sorghum, Sudan grass, sorghum-sudanese hybrids were introduced into the agriculture since ancient times and are widely cultivated in the regions of the North Caucasus, Transcaucasia, Central Asia, the Volga Region.
The seeds of these crops are used as (bread) cereals for human consumption and for animal feed, the grains of pearl millet, barnyard millet, sweet sorghum are used in the alcohol industry, in brewing. The plants are drought-tolerant, and therefore are widespread as forage in the southern regions with a growing season precipitation deficit, are suitable to be cultivated for green feed, hay, haylage, silage. Waste in the production of grain, flour, alcohol is also suitable for feeding to animals. Furthermore, sweet sorghum is used to produce molasses and plant-based syrup. Thus, proso millet and sorghum crops are of obvious interest to the Non-Black Earth Zone North-West area farmers as alternative sources of forage. In creative cooperation with the North Caucasian Federal Scientific Agrarian Center (North Caucasian FSAC, Stavropol), we are engaged in addressing the issue of proso millet and sorghum tribes cultivating in the conditions of the North-West of Russia for forage purposes [8–11]. Partnerships are connected with the Federal State Budgetary Scientific Institution “Federal Scientific Center of Legumes and Great Crops” (FSBSI FSC LGC, Oryol), which also provides its selection varieties of barnyard millet, proso millet, Turkestan millet, and foxtail millet for research work.

The purpose of the ongoing agroecological studies is to assess the prospects for warm-season annual crops cultivation with a growing area in the southern latitudes in conditions of low natural soil fertility of the Novgorod region, in unstable weather conditions with a short growing season.

2. Research subjects and methods
The research was carried out on an experimental field of the Federal State Budgetary Scientific Institution “Novgorod Research Institute of Agriculture” (FSBSI “Novgorod RIA”) in 2017–2019. The soils of the site are sandy loam, sod-podzolic; the mass fraction of organic matter is 2.81–3.57%, and the pH value of the acidity is in the range of 5.1–6.6. The mass fraction of mobile potassium compounds (K2O) is 10.1–22.9 mg/100 g of soil, phosphorus compounds (P2O5)–12.0–73.7 mg/100 g of soil. The observations and documentation were carried out in accordance with the All-Russian Williams Fodder Research Institute Methodological Instructions on the Conduct of Field Experiments with Forage Crops [12]. The preceding crops are row crops (potato), cropped fallow on the layer of perennial grasses. The registration plots area is 4 m² in 2016–2017 and 10 m² in 2018–2019, and the sowing was carried out manually in the second half of May upon the occurrence of optimal conditions for seed germination with pre-sowing NPK fertilization at 60 kg/ha in the active substance.

The research material includes barnyard millet Krasava and Gulliveria varieties, proso millet Sputnik and Regent varieties, Turkestan millet Olya variety, FSC LGC breeding foxtail millet Atlant variety, and Stavropol ARI (North Caucasian FSAC) breeding varieties: barnyard millet Stapize, foxtail millet Stamoga and Stepnoy Mayak.

3. Research results
The growing season of 2017 was determined by extreme weather conditions. In April and the first half of May, the weather remained cold, with frost. The growing degree days above 10°C were 1908°C and were 11% lower than the long-term average temperature; the onset of phenophases took place with a delay of 2–3 weeks; the frost-free period lasted until October 21; the amount of precipitation exceeded the norm by 1.7 times; the hydrothermal coefficient (HTC) was 2.67. In 2018, there were night frosts with low daytime temperatures and stagnation of water in the fields until mid-May; June was cold, with frosts during the first ten days; July, August, and September were warm and sunny. During the growing season, there was a deficit of precipitation (HTC 0.89), and the frost-free period lasted until September 25. A distinctive feature of the growing season of 2019 is sharp contrasts of the water, air, and thermal regimes. Until April 20, the air temperature dropped below zero at night, and there were night frosts in the first ten days of May. The temperature background in May was 1.1°C higher than normal, in June – 2.6°C higher than normal, in July – 1.6°C lower than normal, August and the first half of September were characterized by a moderate thermal background. From September 18, night frosts, which stopped the southern crops vegetation, were observed during the week. In June, there were only three days with precipitation; July, August, and September were rainy; in August, a tornado passed. The vegetation period HTC was 2.0.
In 2017, crops seedlings emerged three weeks after sowing; in 2018, it took them a month; in 2019, there were even sprouts of all crops by the end of May (two weeks after sowing). Plant height growth and vegetative growth during seedling-tillering is slow; in the period from the stem extension stage to the heading/paniculation stage, the growth rate increases sharply, and it is this period that is optimal for harvesting herbage for green feed and hay, haylage, flour making. The length of the period from seedling to the paniculation/heading stage differs by years and crops (Table 1). Thus, with a lack of heat in 2017, the period length was maximum, and there was no difference between the crops in terms of their growth stages onsets. In fact, all of them were ready for harvesting at the same time—in the first twenty days of August.

| Table 1. Millet crops interstage periods length by years; days*. |
|---------------------------------------------------------------|
| **Year** | **Barnyard millet** | **Turkestan millet** | **Foxtail millet** | **Proso millet** |
|          | **Stepize** | **Gulliveria** | **Krasava** | **Olya v.** | **Stamoga** | **Stepnoy Mayak** | **Atlant** | **Sputnik** | **Regent** |
|----------|-------------|-----------------|-----------------|---------------|-------------|-----------------|-----------|------------|-----------|
|       | From seedling to the paniculation/heading stage | | | | | | | | |
| 2017 | 82 | 88 | 82 | 82 | 82 | – | 82 | 74 | 82 |
| 2018 | 71 | 81 | 70 | 62 | 90 | 62 | 72 | 60 | 69 |
| 2019 | 81 | 81 | 74 | 70 | 81 | 60 | 70 | 46 | 59 |
| From seedling to the maturity stage | | | | | | | | | |
| 2017 | 138 | – | – | 138 | – | – | – | 106 | 106 |
| 2018 | – | 118 | 118 | 90 | 118 | 112 | – | 95 | 105 |
| 2019 | 111 | – | – | 103 | – | 103 | – | 84 | 103 |

*a Autumn frost dates: 2017—October 21, 2018—September 25, 2019—September 18

In 2018, June was cold and dry, and the plants suspended their growth and development at the seedling-tillering stage. Foxtail millet Stepnoy Mayak variety, Turkestan millet, barnyard millet Krasava variety, the proso millet varieties could be harvested from the second half of July to the end of the month, the remaining barnyard millet varieties and foxtail millet Stamoga and Atlant varieties—from mid-July to the end of the first ten days of August. In 2019, the hot last ten days of May and hot June accelerated the first development stages; the following abnormally cold July, on the contrary, slowed the further plant development. Therefore, foxtail millet Stepnoy Mayak variety could be harvested within a month, from June 25 to July 25, Atlant variety—from June 25 to August 05, and Stamoga variety—from June 25 to August 15. Also, during the month from July 10 to August 10, there were optimal dates for Turkestan millet and proso millet varieties harvesting. The barnyard millet could be harvested within a month and a half, from July 01 to August 15. Thus, foxtail millet Stepnoy Mayak variety enters the heading stage in two months, Turkestan millet Olya variety—in 2–2.5 months, the proso millet varieties tassel in 1.5–2.5 months, and the barnyard millet varieties—in 2.5 months.

In the Novgorod region conditions before the onset of autumn frost, the proso millet varieties steadily managed to form full seeds (Table 1) with laboratory germination of 70-100% during the research years, the same was true for Turkestan millet Olya variety (66%) and foxtail millet Stepnoy Mayak variety (100%). In 2018, the barnyard millet seeds managed to form, but only the Krasava variety had laboratory seeds germination of 68%; the remaining varieties laboratory germination was determined within 14–30%. The foxtail millet Atlant variety seeds did not ripen in all research years.

Proso millet crops are middle-sized (in contrast to sorghum crops whose height reaches three meters). It is important to know the potential of plants growth in the conditions of lack of heat. Plants heights data for 2017–2019 are presented in Table 2. With a distinct lack of heat in 2017, the height of most crops did not exceed one meter by the end of the growing season, and only the barnyard millet and Turkestan millet varieties overcame the meter barrier. Barnyard millet Gulliveria variety height was 139 cm.
Table 2. Millet crops height, cm.

| Year | Barnyard millet | Turkestan millet Olya v. | Foxtail millet | Proso millet |
|------|-----------------|--------------------------|----------------|--------------|
|      | Stapize | Gulliveria | Krasava | Stamoga | Stepnoy Mayak | Atlant | Sputnik | Regent |
| In the panicle/heading stage |
| 2017 | 117     | 126    | 95     | 103    | 87    | 69    | 85    | 89    |
| 2018 | 146     | 141    | 129    | 116    | 133   | 114   | 105   | 127   |
| 2019 | 135     | 108    | 113    | 80     | 99    | 84    | 110   | 70    |
| At the end of the growing season |
| 2017 | 118     | 139    | 96     | 112    | 101   | 85    | 92    | 92    |
| 2018 | 175     | 152    | 144    | 139    | 150   | 140   | 145   | 168   |
| 2019 | 137     | 139    | 136    | 124    | 117   | 97    | 128   | 112   |

The most favourable year in terms of thermal and water regimes was 2018. By the time of harvesting for herbage and hay, the height of the crops exceeded 100 cm, and the barnyard millet varieties height reached 141–146 cm. By the end of the growing season, the height of most grasses was 130–150 cm; the barnyard millet Stapize variety height reached 175 centimeters. In 2019, the highest plants growth occurred toward the panicle stage. Further, low temperature background and an excess of precipitation led to the growth inhibition and growth arrest of most of crops.

In the Novgorod region conditions, alien crops exhibit high adaptive qualities. Growing in unusual conditions with a lack of heat, the plants form quite stable herbage yields (table 3).

Table 3. Millet crops herbage yield, t/ha.

| Year | Barnyard millet | Turkestan millet Olya v. | Foxtail millet | Proso millet |
|------|-----------------|--------------------------|----------------|--------------|
|      | Stapize | Gulliveria | Krasava | Stamoga | Stepnoy Mayak | Atlant | Sputnik | Regent |
| In the panicle/heading stage |
| 2017 | 24.5  | 29.1    | 26.3   | 23.0   | 23.8   | 11.8  | 17.0   | 23.8  |
| 2018 | 54.8  | 61.8    | 33.8   | 27.8   | 41.9   | 31.2  | 13.5   | 36.8  |
| 2019 | 65.3  | 27.8    | 79.5   | 18.8   | 34.1   | 40.9  | 91.9   | 23.8  |
| Average | 48.2 | 39.6    | 46.5   | 23.2   | 33.3   | 36.1  | 39.1   | 25.9  |
| At the end of the growing season |
| 2017 | 32.8  | 47.8    | 35.5   | 27.8   | 39.0   | 14.8  | 23.0   | 14.8  |
| 2018 | 55.1  | 53.2    | 46.4   | 50.5   | 44.3   | 36.3  | 34.5   | 28.1  |
| 2019 | 54.9  | 37.4    | 92.6   | 49.1   | 33.6   | 58.3  | 52.9   | 46.1  |
| Average | 47.6 | 46.1    | 58.2   | 42.5   | 39.0   | 47.3  | 34.1   | 32.4  |

Under the extreme conditions of the growing season of 2017, the yield of grasses was 23–29 t/ha during harvesting for herbage and hay; the yield of foxtail millet Atlant variety and proso millet Sputnik variety was below 17 tons per hectare. In 2018 and 2019, the plants were able to make fuller use of their biological potential, and it was possible to harvest 62–92 tons of herbage per hectare in the period before the heading/panicle stage. As measured by the herbage yields, barnyard millet Stapize (up to 65 t/ha) and Krasava (up to 80 t/ha) varieties, which give consistently high yields, can be singled out. The proso millet varieties yield is somewhat lower, but they provide the supply of herbage earlier and are also characterized by the yield formation stability at the 24–39 t/ha rate. In general, all studied crops can be an additional source of forage in the late summer period. In the later vegetative stages, the crops can be used as silage. Barnyard millet, as a rule, is used for silage making in the period of panicles mass formation. The rest of the crops can be harvested for silage until the onset of the milk-wax grain ripeness stage. During this period, plants continue to gain mass to be harvested. However, by the end of the growing season, while seeds formation, a physiological decrease in biological mass may happen because
plants lose moisture. For example, foxtail millet Stamoga and Atlant varieties, barnyard millet Stapize variety had less mown mass than in the panicle stage by the end of the growing season in 2019.

Agrochemical analysis of the herbage of the cultivated crops samples was carried out by the accredited testing laboratory, the Federal State Budgetary Institution “Novgorod Agrochemical Agency” (FSBI Novgorod AA) in 2017–2019 (table 4).

Table 4. Millet crops herbage quality rates in terms of dry matter for 2017–2019.

| Crops                        | Dry matter mass fraction, % | Fiber, % | Crude protein, % | Available energy, MJ/kg | Feed units, kg/kg |
|------------------------------|-----------------------------|----------|------------------|-------------------------|------------------|
| Barnyard millet Stapize v.   | 13.6-21.5                   | 31.2-31.6| 9.58-12.89       | 9.3-9.4                 | 0.70-0.71        |
| Barnyard millet Gulliveria v.| 15.6-23.2                   | 29.7-34.0| 5.38-8.66        | 8.9-9.6                 | 0.64-0.75        |
| Barnyard millet Krasava v.   | 19.1-22.1                   | 32.3-35.6| 6.81-8.78        | 8.6-9.5                 | 0.60-0.74        |
| Turkestan millet Olya v.     | 17.1-28.4                   | 30.3-33.9| 9.47-9.59        | 8.9-9.5                 | 0.64-0.74        |
| Foxtail millet Stamoga v.    | 13.9-20.9                   | 35.3-36.5| 7.19-7.63        | 8.4-8.7                 | 0.58-0.61        |
| Foxtail millet Stepnoy Mayak v. | 19.1-25.6                   | 30.4-34.4| 9.38-11.73       | 8.8-9.5                 | 0.63-0.74        |
| Foxtail millet Atlant v.     | 16.2-22.2                   | 27.8-32.9| 9.05-14.57       | 9.1-10                  | 0.67-0.81        |
| Proso millet Sputnik v.      | 13.4-22.3                   | 27.4-28.4| 8.88-14.63       | 9.9-10.1                | 0.79-0.82        |
| Proso millet Regent v.       | 14.9-21.9                   | 28.2-32.4| 9.77-11.88       | 9.2-9.9                 | 0.68-0.80        |
|                              |                             |          |                  |                         |                  |
| GOST standards 27978–88:     |                             |          |                  |                         |                  |
| For maize                    | 9.0                         | 10.0     |                  |                         | 0.86             |
| For fodder grain             | 11.0                        | 10.1     |                  |                         | 0.83             |

Crude protein content of more than 11% in the herbage was observed in barnyard millet Stapize variety, foxtail millet Atlant and Stepnoy Mayak Mogar varieties, and in proso millet variety. In comparison with the standards established by GOST for maize, this is a good performance. At the same time, the crude protein level of barnyard millet Gulliveria and Krasava varieties, and foxtail millet Stamoga was below 9 percent over the research years. Regarding the content of available energy and feed units in the herbage, almost all samples fall short of the standards established by GOST for maize. It is evident that in long light day conditions with a lack of heat, the plants do not have time to accumulate the required amount of energy, which does not diminish their merits.

4. Conclusion

According to our observations, barnyard millet, Turkestan millet, foxtail millet, and proso millet, being cultivated in a zone of increased moisture, have the standing ability and are little affected by diseases and pests. During periods of lower temperatures, the plants may lose their coloring intensity and stop growing, and physiological rust may appear on some plants. When favorable conditions occur, the color is restored. Low seeding rates, affordability of seeds, standard schemes of sowing field weed control, stable harvests make the production of forage from alien crops low-cost. Thus, during the research period, the southern forage crops showed high adaptive potential. The crops cultivation for forage purposes in the North-West region holds great promise because it allows us to get sufficiently nutritious forage in the second half of summer – early fall.

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