Adaptation of Sorghum Crops in the North-West of the Non-Black Earth Zone

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Abstract. The article addresses the issue of whether it is possible to grow thermophilic crops of the sorghum family for forage purposes in the North-West zone. For 4 years of research, a high degree of adaptation of the plants to growing conditions and their ecological plasticity, declared in the characteristics of the studied crops, have been confirmed. It has been found that the lack of heat in the zone of excessive moisture and long daylight hours is the main limiting factor that has a direct effect on both the duration of interstage periods and the height and yield of green mass of the plants. Even under extreme conditions of acute heat deficit, sorghum crops have been able to form a full-fledged harvest of green mass. The sum of active temperatures in the zone is not enough for the sorghum to complete the full development cycle.

1. Introduction
Ensuring the food security of the population in the Russian Federation remains one of the urgent tasks of our time. Historically, the agricultural sector of the Novgorod region specialized in meat and dairy animal husbandry. Due to a number of economic and organizational problems, since the beginning of the 2000s, the stock of dairy cattle has decreased by 3.6 times, and the volume of areas occupied for fodder crops has decreased by more than two times. The demand of the population of the region for milk and its processed products within the region is met by half. To fully saturate the domestic market with dairy products, it is necessary to restore the livestock of the dairy herd of the region and the feed base of dairy farming.

Agrocenoses based on perennial grasses are the main source of cheap feed production, however, they are not able to completely cover the needs of animal husbandry throughout the season. As a rule, an additional source is the crops of annual forage plants [1]. In the north-west of the Non-Black Earth (Non-Chernozem) Zone – in the zone of risky agriculture – the variety of crops is limited by climatic conditions, but the intensification of animal husbandry requires, accordingly, the intensification and improvement of the structure of forage crops.

One of the ways to solve the issues of strengthening the feed base is to diversify forage crop types. Analysis of the data of meteorological observations carried out in the Novgorod region over the past 60 years has shown an increase in the sum of active temperatures by 240°C, in the amount of precipitation of the growing season by 60 mm, an increase in the average annual temperature by 2.8°C [2]. The emerging tendencies of climate change towards warming give grounds for searching for new highly
productive crops from other, warmer, cultivation zones. Sorghum crops, ranked fifth among grain crops in the world in terms of cultivation area, need attention [3]. Large volumes of areas for the crops are associated with low maintenance, high ecological plasticity, heat resistance in the presence of high productivity, fodder advantages and flexibility of use [4, 5]. The main part of all cultivated areas for sorghum – up to 93–98% – are located in the Volga (Privolzhsky) Federal District and the Southern Federal District [6]. The area of cultivation of sorghum crops in the Russian Federation is gradually expanding; technologies for sorghum cultivation in the southern regions of the Non-Black Earth Zone are being actively developed [7]. In the north-western region of the Non-Black Earth Zone, experimental crops of sorghum and millet were carried out in 2016; the obtained results provided the basis for more in-depth studies [8, 9].

The aim of the research was to find out the adaptive properties of sorghum crops (sugar sorghum, Sudan grass, sorghum-Sudanese hybrids) for forage purposes in the Novgorod region.

2. Objects and methods of research
The research was carried out on the experimental field of the Novgorod Research Agriculture Institute in 2017–2020. The soils of the site are light-loamy, sod-podzolic; the mass fraction of organic matter is 2.81–3.57%, the acidity index (pH) is 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) is 12.0–73.7 mg/100 g of soil. Phenological observations, measurements and enumerations were carried out in accordance with the Methodological Guidelines for conducting field experiments with fodder crops of the All-Russian Williams Fodder Research Institute. The forecrops are row crops (potato), cropped fallow over the layer of perennial grasses. The area of registration plots is 10 m²; sowing was carried out manually in the second half of May with optimal conditions for seed sprouting and pre-sowing NPK application of 60 kg/ha in the active substance.

The objects of the study were varieties, lines and hybrids of sugar sorghum, Sudan grass, sorghum-Sudanese hybrids (SSH) of the selection of the Federal State Budgetary Scientific Institution “North Caucasian Agrarian Center” (Stavropol), provided by the aforementioned scientific institution within the framework of the Agreement on Scientific and Technical Cooperation (table 1). All crops are included in the State Register of Breeding Achievements (the Register), approved for use by the State Commission of the Russian Federation for Selection Achievements Test and Protection (FSBI “Gossortcommission”).

| Name                  | Year of inclusion in the Register | Maturity period (maturity group) | Regions of approval                  |
|-----------------------|-----------------------------------|---------------------------------|--------------------------------------|
| Sugar sorghum         |                                   |                                 | All regions                          |
| Larets (L) (line)     | 2005                              | mid-season                      | Central Black Earth (CBE), North Caucasus (NC), Middle Volga (MV), Lower Volga (LV), Uralsky (U), Far Eastern (FE) |
| Silosnoye 88 (S-88)   | 1993                              | mid-season                      | CBE, NK, LV                          |
| Galia (G) (variety)   | 2013                              | middle-early                    |                                     |

The Register contains 66: 41 varieties, 7 – parental component, 8 lines, 8 1st generation hybrids, 1 simple hybrid and 1 three-line hybrid. The approval in the region is 1, the Larets line.

| Name                  | Year of inclusion in the Register | Maturity period (maturity group) | Regions of approval |
|-----------------------|-----------------------------------|---------------------------------|---------------------|
| Sudan grass           | 2005                              | mid-season                      | All regions         |
| Zemlyachka (Z) (line) |                                   |                                 |                      |
| Sputnitsa (S) (variety) | 2016                          | mid-season                      | NC, CBE             |
In the Register, there are 76 varieties, lines, parent components. One line of Zemlyachka is approved in the North-West region.

There are 31 hybrids in the Register; there are no approved options for cultivation in the North-West region.

*as of early 2021

Thus, in the North-West region among sorghum crops, the Sudan grass Zemlyachka line and the sorghum sugar Larets line are approved to be used.

3. Research results

The climate of the Novgorod region is formed under the influence of the marine, air masses of the Atlantic and is characterized by high humidity. The year of 2017 was marked by extreme weather conditions: the summer was abundant in precipitation, with a background temperature of 11% below normal, the HTC was 2.89, the development of plants was delayed by 2–3 weeks. In 2018, May and June were cold with frosts, the subsequent months were warm and sunny, with a deficit of precipitation (the HTC of the growing season was 0.89). In 2019, in the first half of the growing season, there were sharp changes in temperature and rare but heavy rainfall; in the second half, it was almost constantly raining, July was cold, August was moderately warm, the HTC was 1.8. In 2020, May and July were colder than the norm by 1.5°C and 0.5°C, respectively; June was hot, the HTC was 1.1.

According to the originators (North Caucasian Agrarian Center), all varieties/lines/hybrids are mid-season. SSH have a high degree of adaptation to cultivation conditions, cold resistance in the seedling stage. In Stavropol Krai, the growing season of sorghum is 100–120 days, flowering occurs in the first decade of August, the seeds ripen at the end of September [10]. Under the conditions of the Novgorod region, sowing of crops was carried out in the second half of May, when the temperature background increased to close to the optimal level (12–17°C and above during the day without the threat of night frosts). Seedlings appeared, as a rule, within two weeks; in 2018, due to cold and dry June, the seedlings growing lasted for a month. The duration of interstage periods of sorghum crops growing varied depending on weather conditions (table 2).

| Table 2. Duration of interstage periods of sorghum crops by years, days. |
|---------------------------------------------------------------|
|                  | 2017  | 2018  | 2019  | 2020  |
| Seedling-stem elongation |
| Sugar sorghum     | 63    | 42    | 46    | 49    |
| Sudan grass       | 63    | 35–42 | 46    | 49    |
| SSH               | 63    | 35–42 | 46    | 49    |
| Seedling-head formation |
| Sugar sorghum     | -     | 70(S–88), 93 (G), – (L) | 92 | 72(S–88), 80(G), 99(L) |
| Sudan grass       | 106   | 51–59 | 69–80 | 72    |
| SSH               | -     | 70 (Navigator), – (Gv) | 80 | 72–80 |
| Seedling-flowering |
| Sugar sorghum     | -     | 93(S–88), – (G, L) | 103 (Galia) | 99(S–88, G), – (L) |
| Sudan grass       | -     | 70 (S), 83 (Z) | 88(S), 97 (Z) | 80 (S), 94 (Z) |
| SSH               | -     | 79 (Navigator), – (Gv) | 100 | 99    |

Dates of sowing, seedling, first frost, sum of active temperatures > 10°C by year

| Year | Sowing       | Seedling   | First Frost | HTC       |
|------|--------------|------------|-------------|-----------|
| 2021 | May, 22      | May, 22    | May, 15     | 0.89      |
| 2020 | May, 25      |            |             |           |
The period from seedling to stem elongation of sorghum is extended for 5–7 weeks, at this time there is no big difference in early ripening between the crops; the initial development is slow. The shortest period from seedling to flowering in the case of Sudanese grass is from 70 to 97 days; in the case of SSH, it is 79–100 days; in the case of sugar sorghum, this period is more than 90 days.

The main factors influencing the ontogenetic process are heat, moisture and the duration of solar insolation. Sorghum crops are heat-loving, drought-tolerant, short-day plants. In conditions of high humidity, lack of heat and long daylight hours, sorghum crops were unable to complete their life cycle in all the years of research. In 2017, there was no difference in the passage of stages of the crops, which was associated with abnormal weather conditions. That year, sorghum and SSH finished their growing season in the stage of stem elongation, without forming heads; it took Sudan grass more than a hundred days to develop heads. In 2018–2019, the further formation was prevented by early frosts in 2–3 decades of September. In 2020, a long frost-free period contributed to the continuation of the growing season, however, at this time, the temperature background was no longer high enough for sorghum crops, so the process of seed formation was never completed. The number of ripe and germinating seeds in the case of Sudan grass was 4–18%.

In the traditional cultivation zone, sorghum is a tall-growing crop that grows to two or more meters long. In the North-west region, by the end of the growing season, the height of plants on average for 4 years of research was over 200 cm (table 3).

| Seedling maturing | June, 07 | June, 20 | May, 31 | June, 08 |
|-------------------|----------|----------|---------|-----------|
| Frost             | October 21 | September 25 | September 18 | October 21 |
| Σ of active temperatures >10°C | 1782 | 2501 | 2231 | 2324 |

Table 3. Height of sorghum crops by the end of the growing season, cm.

|                      | 2017 | 2018 | 2019 | 2020 | average |
|----------------------|------|------|------|------|---------|
| Silosnoye 88 sugar sorghum | 96   | 280  | 171  | 275  | 206     |
| Galia sugar sorghum    | 113  | 220  | 232  | 233  | 200     |
| Larets sugar sorghum   | –    | 240  | 168  | 230  | 213     |
| Zemlyachka Sudan grass | 125  | 260+ | 222  | 268  | 219     |
| Sputnitsa Sudan grass  | 109  | 260+ | 205  | 258  | 208     |
| Navigator SSH          | 118  | 260+ | 205  | 259  | 211     |
| Gvardeyets SSH         | 104  | 250  | 211  | 290  | 214     |
| Average over a year    | 111  | 248  | 202  | 259  | 203     |

In 2017, with a lack of heat, the height of the plants did not exceed 130 cm; in other years, the plants proved to be tall-growing, reaching a height of 260–290 cm. It should be noted that the plants are indeed resistant to lodging. In 2019, after a tornado, an abnormal phenomenon for northern latitudes, the plants resisted, were not lodged, while there was mass lodging of the majority of cultivated crops. In 2020, following the passage of the cyclone, partial lodging of Larets and Silosnoye 88 sugar sorghum was noted. The plants did not endure it due to the high productivity of biological mass: by this time, the yield of green mass exceeded 110 t/ha (table 4).

The lack of heat in 2017 also negatively affected the yield of green mass. The productivity of sorghum crops that year was the lowest for all the years of research, within 10–27 t/ha. In other years, the yield of green mass was significantly higher. In terms of yield, sugar sorghum was the leader, on average over 4 years the yield was 64–82 t/ha; the yield of sorghum-Sudanese hybrids was slightly lower – 43–56 t/ha; the yield of Sudan grass was 30–50 t/ha. It should be noted that the data on the yield are given at the time of their suitability for harvesting for green forage, hay, haylage, in the period from
stem elongation to head formation. However, the accumulation of biological mass by plants continues until flowering, then stops. During this period, they can be harvested for silage.

Table 4. Productivity of sorghum crops during the harvesting period considering green mass (in the stage of stem elongation-head formation), t/ha.

|                     | 2017 | 2018 | 2019 | 2020 | average |
|---------------------|------|------|------|------|---------|
| Silosnoye 88 sugar sorghum | 21.0 | 71.0 | 58.0 | 110.2 | 65.1    |
| Galia sugar sorghum    | 21.3 | 55.6 | 100.3| 78.6 | 63.9    |
| Larets sugar sorghum   | –    | 70.6 | 40.2 | 136.5| 82.4    |
| Zemlyachka Sudan grass | 17.5 | 88.8 | 51.9 | 41.2 | 49.9    |
| Sputnitsa Sudan grass  | 10.0 | 53.8 | 23.4 | 33.6 | 30.2    |
| Navigator SSH          | 23.8 | 75.7 | 55.7 | 69.9 | 56.3    |
| Gvardeyets SSH         | 27.0 | 59.0 | 36.9 | 50.6 | 43.4    |
| Average over a year    | 20.1 | 67.8 | 52.3 | 74.4 | 55.9    |
| LSD_{0.05}            | 1.9  | 2.5  | 4.4  | 3.9  |         |

Sorghum crops are able to form aftergrowth if the first hay crops are carried out in the early stem elongation stage. But, according to our observations, the yield from two crops in the cases of sugar sorghum and SSH is less, than this is from one crop carried out at the end of stem elongation stage, before head formation. In the case of Sudan grass, the yield of green matter from two crops was higher than from one.

The green mass of sorghum crops (in terms of absolutely dry matter) contains over the years in the range of 0.63–0.82 feed units, 8.8–10.1 MJ of metabolizable energy, 6.2–13.1% of crude protein. Thus, the quality indicators of green fodder are not inferior to the characteristics declared for the studied crops in the Register of the State Commission (for example, the content of crude protein of Larets sorghum sugar is stated to be 8.5%, of Silosnoye 88 sorghum sugar – at the level of 5.8–6.4%, of Sputnitsa Sudan grass – 12.3%).

4. Conclusion

In the conditions of the North-west of the Non-Black Earth Zone, the main limiting factor for plants is the lack of heat. The year of 2018 became the most favorable year in terms of temperature conditions with the sum of active temperatures above 10 °C over 2.5 thousand. The timing of the development stages that year was minimal; the period from seedling to flowering was: 70 days in the case of Spartanka Sudan grass, 83 days in the case of Zemlyachka Sudan grass, 88–93 days in the case of Silosnoye sorghum, 79 days in the case of Navigator SSH; Galia, Larets sorghum and Gvardeyets SSH did not have time to develop the panicles. It was in that year when the plants showed the maximum height and the minimum difference in the level of yield.

In unfavorable growing conditions, sorghum crops demonstrate high adaptive properties and quite actively realize their biological potential. Only in 2017, due to extreme weather conditions, the average yield of green mass of the crops was about 20 t/ha; in other years it was above 50 t/ha, reaching 68–74 t/ha. At the same time, the produced feed has a high nutritional value at the level (or higher) of the declared characteristics. Plants do have a high degree of adaptation to cultivation conditions and are very promising for strengthening and improving the fodder base of the Non-Black Earth Zone.

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