



Agrobiological Characteristics of Aftermath Ability and Shoot Structure in Cultivation of Fodder Sorghum

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Abstract

The article presents long-term results of the study of the aftergrowth mechanism depending on the morphobiological parameters of the structure and development of fodder sorghum plants, the time of cutting, cutting height, application of mineral fertilizers and other technologies of sorghum crops cultivation. The aim of the research was to study the agrobiological characteristics of aftergrowth and the shoot structure of crops of sugar sorghum, Sudan grass and sorghum-Sudan hybrids in conditions of gray forest soils of the south-western part of the Central region of Russia (Bryansk region). Research methods include field, laboratory and statistical methods. Four types of aftergrowth have been identified: 1) - formation of new shoots from the buds of the tillering node (mesocorm); 2) - formation of new shoots from the uncut first (lower) internodes in the leaf axils; 3) - growth of shoots whose apical point was untouched during cutting (from uncut short shoots); 4) - from the meristem tissue of cut shoots through their reproduction. According to the aftergrowth ability, a group of grass sorghum with good aftermathability and sugar sorghum with slight aftergrowth of the shoots can be singled out. The magnitude and differences in the aftermath yields are associated with the phytomeric structure of the sorghum plant shoots that grow and develop their primordia due to the activity of the apical meristem. Prevalent in the pastures of the studied genotypes of sorghum were generative, elongated vegetative and lateral aerial shoots with a complete and incomplete development cycle. The formation of a greater number of lateral aerial shoots (with branching) and shortened shoots was observed in plants on fertilized variants, especially those treated with nitrogen supplements. Prevalent in the aftergrass pastures of Sudan grass and a sorghum-Sudan hybrid were elongated vegetative shoots with a high proportion of leaves from 45 to 57%. When cut at 10–12 cm, a more intense aftergrowth of grass sorghum was observed. The yield of the aftermath of the sorghum and sorghum-Sudan hybrid was on average 14.3–22.7% higher than by a low cut (5–6 cm). The maximum yield of dry matter of more than 15.0 t/ha was obtained using the aftermath of Sudan grass.

Keywords: Fodder sorghum, Phytomer, Mineral fertilizers, Cutting height, Aftermath

1 Introduction

Expanding the species diversity of agrocenoses using sorghum fodder crops, which are characterized by high plasticity, neutral response to day length, stable yield, intense growth and the possibility of obtaining 2-3 aftermaths or grazing cycles, resistance to stress factors of the abiotic environment, is an innovative trend in production of high-quality fodder in many regions of Russia. The expansion of the range of distribution and use of fodder sorghum is promoted by new achievements in selection for the creation of thermo- and photoneutral genotypes characterized by rapid early growth, resistance to cold, ability to form high and stable fodder yields. The name "fodder sorghum" usually

encompasses Sudan grass, sorghum-Sudan hybrids (SSH) and sugar sorghum, which are widely represented in Russia from its western regions to the Far East (1, 6, 9, 14, 18, 19, 20, 24).

Currently, scientists at the All-Russian Research and Development Institute of Cereal Crops named after I.G. Kalinenko, All-Russian Research Institute of Sorghum and Soybean "Slavyanskoe pole", Russian Research and Design Institute of Sorghum and Corn, Stavropol Research Institute of Agriculture, OOO Agroplasma and other research institutions are doing extensive and fruitful work on selection, seed production and development of agricultural technology in Russia. Today, when characterizing modern varieties and hybrids of sorghum, particular importance is attached to its

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aftergrowth. Sorghum aftermath as a fodder crop is a positive feature that allows collecting two or more full-scale yield of the top weight and makes it possible to rationally regulate the period of use and collect green weight for forage or for ensilaging in late autumn. To maximize the productive potential of fodder sorghum, it is necessary to make wider use of the biological ability of plants for aftergrowth. This is also explained by the fact that the formation of a aftergrowth is significantly influenced by such factors as the timing and height of the first cutting, tillering intensity, the ability of sorghum plants to grow in different ways, the amount of nutrients in the soil, weather and other conditions (2, 4, 13, 15).

The results of many years of research by scientists of the Bryansk State Agrarian University on practical introduction of sorghum crops in the field fodder production made it possible to suggest multivariate technologies of their cultivation in the southwestern part of the Central Region. It should be noted that in the conditions of the Bryansk region, for the first time in Russia, a new technology was developed for the creation and use of a commercial sorghum pasture, which was implemented in the Kistersky agricultural production cooperative of the Pogarskiy district of the Bryansk region (3, 8, 10, 11, 22, 23).

The formation of aftermath in grass sorghum (Sudan grass, sorghum-Sudan hybrids) is sufficiently studied, whereas the aftermath has not been taken into account in revealing the full productivity of sugar sorghum for various reasons (due to alkaloidness of young plants, low aftermath ability of the culture, etc.). In this case, we should express our point of view and support the opinion of reputable scientists and researchers of the Don, Kuban, and Volga regions, who propose changes to the Methodology of the State Commission for the Sorghum Variety Trial Testing (1989), since it can not ensure accurate account of aftermath of modern varieties and hybrids. In their studies, the harvesting of the main crop of the above-ground mass and aftermath of fodder sorghum was carried out using single-cut and two-cut patterns. However, the afterbirth formation features related to the phytomeric structure of sorghum stems, the height and frequency of cutting, mineral nutrition conditions and harvest time were not fully revealed. Therefore, a study of the mechanism of aftergrowth depending on the agrobiological characteristics of sugar and grass sorghum, is interesting both from scientific and industrial points of view.

In view of this, the study of the production process of aftergrowth of fodder sorghum depending on growth and cultivation conditions has become the basis of this research. The main task was to assess the agrobiological characteristics of aftermath formation and the shoot structure of crops of sugar sorghum, Sudan grass, and sorghum-Sudan hybrids on gray forest soils in the southwest of the Central region of Russia.

2 Material and methods

Field experiments were conducted during 2007–2018 at the permanent study area of the experimental field of Bryansk State Agrarian University. The soil is agrogray forest of medium loamy granulometric composition. The structure of the soil is lumpy and granular, turning lumpy and silty in the upper layer and capable of crust formation after rains. The thickness of the humus horizon is 20–50 cm, the humus content is 3.8–4.0% (according to Tyurin). The reaction of the soil solution is at a pH of 5.6–5.8; hydrolytic acidity (Hg) is

2.63 mEq. per 100 g of soil. The soil is characterized by a low content of labile phosphorus and exchange potassium.

The research methods included field, laboratory and statistical methods.

The objects of research were viable sorghum-Sudan hybrids selected at the All-Russian Research Institute of Sorghum and Soybean “Slavyanskoe pole”, (Rostov region, Zernograd): Slavyanskoe pole 15, Slavyanskoe pole 18 and Priusadebnyy; hybrids selected at the All-Russian Research and Development Institute of Cereal Crops named after I.G. Kalinenko (Rostov region): Intensive F₁ and sugar sorghum – Zersil F₁; Sudan grass – Kinelskaya 100 variety (originator – Volga Volga Research Institute of Selection and Seed Farming named after P.N. Konstantinov). The predecessor cultures were soybean, winter triticale and annual grasses. Agricultural technologies used were common in the region for forage crops. The research was performed in accordance to widely accepted methods (7, 16, 17).

The mineral fertilizers in the form of azofoska – background 1 (N₆₀P₆₀K₆₀) and borofoska – background 2 (P₆₀K₆₀) were applied during pre-seeding treatment with the combined unit RVK-3.6, and nitrogen fertilizers in the form of ammonium nitrate (top dressing): doses – N₃₀, N₆₀ and the N₉₀ – during the beginning of the tillering phase on these backgrounds. Each genotype (variety, hybrid) was sown using a SN-16 seeder in 4 rows with 60 cm between them; the plot length was 70 m; the experiment was replicated four times; the test plot area was 10m²; the variants were placed systematically. During the growing season of the studied genotypes of fodder sorghum, phenological monitoring of growth and development was carried out, and plant height, number of shoots, parameters of leaves and panicles were determined according to The Broad Unified CMEA Classifier of Cultivated Species of the Genus *Sorghum* Moench (25). Assessment of above-ground mass was performed using the cut-sample method by weighing - during the late stem elongation stage and early heading stage (fodder variant, two-cut pattern) and the milk-wax stage of ripeness of the grain (hay-silage variant, single-cut). To perform a structural analysis, sheaves of the green mass yield of 1 kg were sampled. Laboratory analysis was performed in the scientific training laboratory of field fodder production and the Center for collective use of instrument and scientific equipment of the Bryansk State Agrarian University.

Farm testing of scientific developments was carried out in several farms in the Bryansk, Vygonichsky, Zhiryatinsky, Pochevsky, Pogarsky, Trubchevsky and Novozybkovsky districts of the Bryansk region. For more than ten years, the base farms have been the Kokino instructional farm, LLC Bryansk Meat Company, the Okhotno Agrohholding, the agricultural production cooperative Agrofirma Kultura, the Kistersky agricultural production cooperative, and the experimental fields of the Novozybkovskaya agricultural experimental station in the zone of radioactive contamination as result of the accident at the Chernobyl nuclear power plant.

3 Results and discussion

According to the data of the meteorological station of the Bryansk State Agrarian University, the climatic conditions of vegetation seasons during the years of research were characterized by a significant variation in both the average daily air temperature and the amount of precipitation.

However, in general, it should be noted that the weather conditions were favorable for the formation of sufficiently high yields of fodder mass of varieties and sorghum hybrids in atypical agro-climatic conditions of the south-western part of the Central region of Russia. According to the meteorological station of the Bryansk State Agrarian University, the climatic conditions of vegetation periods during the years of research were characterized by a significant variation in both the average daily air temperature and the amount of precipitation. However, in general, it should be noted that the weather conditions were favorable for the formation of sufficiently high yields of forage mass of varieties and sorghum hybrids in non-traditional agro-climatic conditions of the south-western part of the Central region of Russia. The results of field experiments showed that the application of mineral fertilizers contributed to an increase in the height of plants and the intensity of shoot formation of sorghum fodder crops. A general trend was observed that fertilized crops were characterized by taller shoots and more intense tillering. On the unfertilized variants full-scale lateral tillering shoots almost did not form. The plants on the control plots were almost of the same height of 140–165 cm. The shoot apical growth was significant, especially during stem elongation and heading stage when mineral fertilizers were used. Plant height was over 200 cm, tillering energy increased, and partial branching of the upper nodes of the main shoots was observed, which resulted in unequal stem height and prolonged growing season.

Analyzing the structure of the crop above-ground mass of fodder sorghum, the variability of this indicator should be emphasized, which characterized the parameters of shoot formation and branching. Sudan grass and sorghum-Sudan hybrids were noted to show some differences in the nature of the formation of stem nodes of elongated phytomers of apogeotropic shoots (elongated vegetative and generative). Typical for sorghum-Sudan hybrids was the formation of intravaginal lateral shoots (in the prefloral zone of the elongated shoot. Elongated vegetative and latently regenerative shoots branch after the flower initiation or apex removal, and lateral aerial structures are formed acropetally, after differentiation of the apical bud, without “its own” root system. In this regard, it should be noted that the scattered branching of apogeotropic shoots of sorghum is a positive fodder quality.

Thus, our research confirmed that prevalent in the grass stands of the studied hybrids were generative, elongated

vegetative and lateral aerial shoots with a complete and incomplete development cycle. The formation of a large number of lateral aerial shoots (with branching) and shortened shoots was observed in plants on fertilized plots, especially with nitrogen top dressing. Of great importance is identification of leaves and stems ratio and the various organs proportion, which indicates the use peculiarities and quality of the fodder. According to our data, the leaves and stems ratio of grass sorghum varied slightly – leaves accounted for 42.1–50.2% of the harvest, stems – for 42.4–50.0%, panicles – 6.4–7.9 %. Thus, the analysis of the harvest structure showed that the ratio of various types of shoots and their elements was greatly influenced by introduction of mineral fertilizers, especially nitrogen top dressing.

As a result of the experiments conducted on the gray forest soils of the Bryansk high plains during the cultivation of sorghum crops for fodder production, we found four types of aftergrowth: the first is due to the formation of new shoots from the buds of the tillering node (mesocorm); the second is the formation of new shoots from the uncut first (lower) internodes in the leaf axils; the third – growth of shoots whose apical point was untouched during cutting (from uncut short shoots); 4) the third – from the meristem tissue of cut shoots through their reproduction. And, as a result of different forms (types of mechanism) of aftergrowth, its aftermath ability and the number of shoots of different origin are not the same (Table 1).

The results of our experiments show that among the studied species, the weak growth was observed in plants of sugar sorghum, and the fastest and most intense was observed in grass sorghum. On average, the aftermath was formed as follows: 83.4% – from tillering node buds, 12.4% – from lower internodes, 3.2% – from the buds of uncut (shortened) stems and 1.0% – from apical (growing) buds of elongated shoots.

Consequently, considering these data, it should be noted that the aftermath formation in the process of aftergrowth occurred through regeneration of cut shoots if they retained their apex, as well as due to the formation of new shoots from dormant vegetative buds that were below the level of cutting. The results obtained on this issue are consistent with previous studies (5, 12, 13) in the conventional zones of sorghum plantation. In our opinion, the ability of sorghum plants for intense growth depends on biological characteristics and properties, first of all, tillering, which does not weaken during the entire vegetation period.

Table 1: Types of aftermath mechanism of sorghum cultures

Culture	Growth from:			
	tillering node buds	buds of lower stem internodes	short shoots	meristem tissue of cut shoots
Sugar sorghum	+++	++	+	-
Sudan grass	++++	+++	++	+
Sorghum-Sudan hybrid	++++	+++	++	+

In addition, the formation of shoots, their growth and number are influenced by the phytomeric structure of the shoot, the scattered branching of the elongated (apogeotropic) shoots and the applied agricultural technology (fertilizers, cutting height, cutting frequency etc.).

Different aftermath yield of fodder sorghum is associated with the phytomeric structure of the shoot that grow and develop their primordia due to the activity of the apical meristem. Russian and foreign scientists (5, 21, 26, 27, 28) define "phytomers" as independent segments of the shoot, formed in the form of leaf primordia or leaf-bearing shoots. The number of phytomers in the studied assortment of sugar sorghum and sorghum-Sudan hybrids was 10–13, depending on the height of the variety or hybrid, in Sudan grass – 4–6. We noted that sorghum plants showed some differences in the nature of the formation of stem nodes of elongated phytomers of apogeotropic shoots (elongated vegetative and generative). Like corn, sorghum crops formed distinct stem nodes with visible lignification of the lower internodes. In the aerial sorghum stem nodes at the internode, a lateral bud with clearly marked leaf and root primordia forming a one-level ring on the outer side at the level of the bud can be seen under the leaf sheath (roots primordia are most typical for lower phytomers). Measurements of the lateral buds length revealed a general tendency: starting from the lower to the upper metamers, the length of the resting bud increases from 1.6–3.7 to 6.4–7.2 cm and more; this trend was particularly prominent in generative shoots of grass sorghum.

The aftermath green mass yield largely depended on the cutting height of the first cut. Different cutting height also had a certain influence on the growth rate of plants and the intensity of their aftergrowth. In all cases, when the buds on the apical point were not cut, the shoots grew much faster than from the buds of the tillering node. Faster plant growth by a high cut (10–12 cm) can be explained by the fact that shoots growing from tillering node buds feed, like the main shoots, from old roots. By a low cut (5–6 cm), growth occurs mainly occurs from dormant buds located in the axils of the lower internodes, new roots are formed, and shoots that grow from the tillering node feed only partially from old roots. For example, the Sorghum-Sudan hybrid Intensive F₁ showed a faster aftermath formation by a high cut, whereas by a low cut, the formation of new shoots in the aftermath mainly occurred from the tillering node buds. The total height of aftermath and the yield turned out to be somewhat lower compared to higher cuts. Aftermath yield formation depending on the height of the sorghum first cutting is shown in Table 2. It was established that along with the buds of the tillering zone renewal, a great role in the formation of the fodder sorghum aftermath was played by lateral buds of elongated phytomers, and a minor role – by apical buds of the shortened shoots. It should be noted that, regardless of the cutting height, shoots grew most quickly and intensively on variants treated with nitrogen top dressing

(N₃₀₋₉₀) after the first cutting in Sudan grass and sorghum-Sudan hybrid than in sugar sorghum, which affected the yield of the second cutting.

The data obtained indicate that in the southwestern part of the Central region of Russia, two full-scale green mass yields of fodder sorghum can be obtained within a single vegetation period (cutting phase – early heading stage). The period between cuts was 47–56 days. The height of sorghum plants at the second cut was between 60.1–115.3 cm. It was characteristic that the tilling capacity of the aftermath plants increased more than twice. On average, over four years, the plantations of the hybrid of sugar sorghum Zersil F₁ formed a small aftermath yield (6.48–8.38 t/ha, fertilized variant, with almost twice less than that on control plots). Regardless of the cutting height of the main cut, the aftermath of Sudan grass was 18.23–18.64 t/ha, whereas the different cutting height of the above-ground mass of the sorghum-Sudan hybrid in the first cut significantly affected the aftermath ability of plants, the formation of the leaf surface and the aftermath yield. When cut at 10–12 cm, intense aftergrowth was observed, and the aftermath yield was on average 19.74 t/ha, which is 14.3% higher than by a low cut (16.91 t/ha). Prevalent in the structure of the grass stands of Sudan grass and sorghum-Sudan hybrid were vegetative elongated shoots with a high proportion of leaves of 45–57%.

In terms of aftergrowth ability, a group of grass sorghum with good aftermath and sugar sorghum – with weak aftergrowth of the above-ground mass should be singled out. A characteristic feature of aftergrowth was vegetative buds of the mesocorm, elongated and shortened phytomers located below the cutting level. The magnitude and differences in the aftermath yields are associated with the phytomeric structure of the sorghum plant shoots that grow and develop their primordia due to the activity of the apical meristem.

Consequently, the aftermath ability of sorghum crops is one of the important agrobiological characteristics in increasing their productivity potential. The formation and yield of fodder sorghum aftermath largely depends on the morphobiological characteristics of the structure and development of plants, the time of cutting, the cutting height, application of nitrogen top dressing and other elements of cultivation.

Thus, in the cultivation of sorghum crops for fodder production, four types of the aftergrowth mechanism have been established. The yield and the formation of full-scale aftermath of fodder sorghum depended on the time and height of the first cut, the introduction of nitrogen fertilizers in the subcortex, shoot development ability of plants, and other growth factors. When cut at 10–12 cm, more intense aftergrowth of grass sorghum was observed, and the yield of sugar sorghum and the sorghum-Sudan hybrid was on average 14.3–22.7% higher than by a low cut (5–6 cm).

Table 2: Effect of the first cutting height on the aftermath yield of fodder sorghum, (2012–2015)

First cutting height, cm	Green mass yield, t/ha		
	Sugar sorghum Zersil F ₁	Sudan grass Kinelskaya 100	Sorghum-Sudan hybrid Intensive F ₁
5–6	6.48	18.23	16.91
10–12	8.38	18.64	19.74

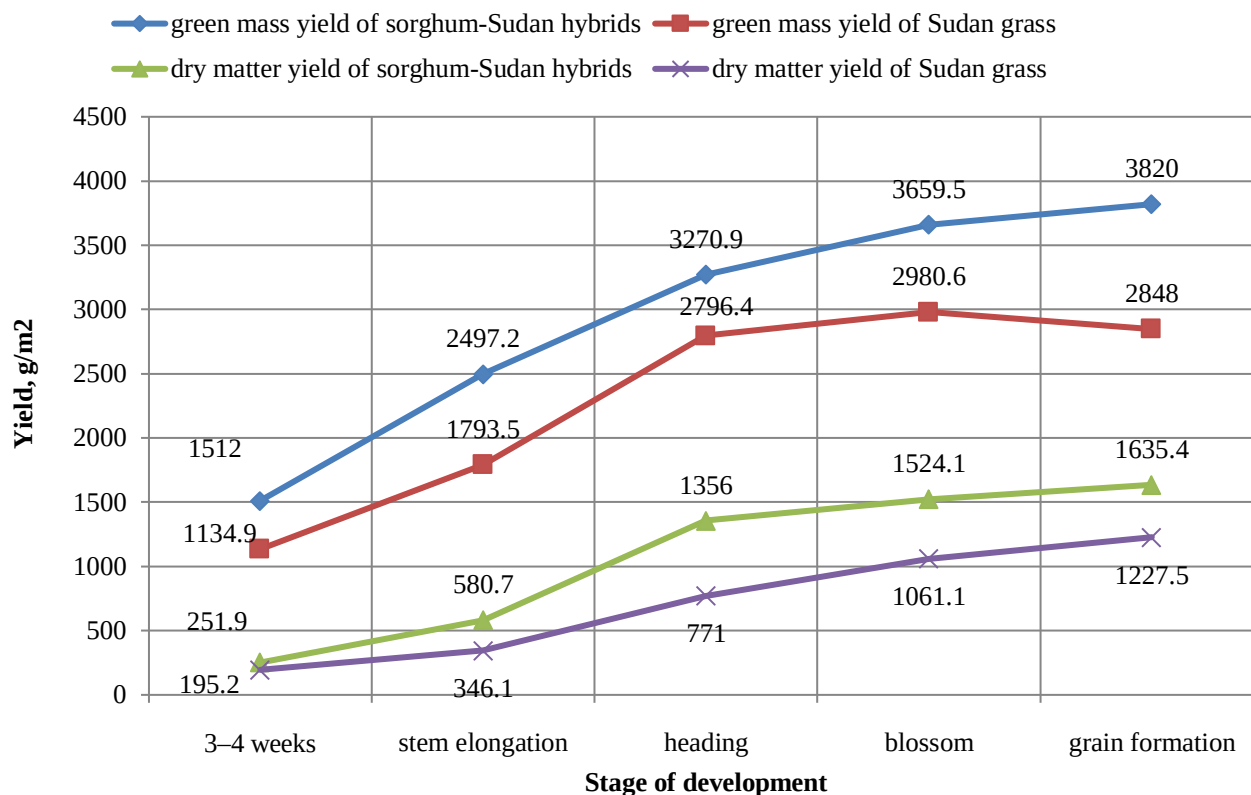


Figure 1: Dynamics of grass sorghum above-ground mass formation (average for 2016–2018)

Regardless of the height of the first cut of Sudan grass, the aftermath green mass yield was 18.32–18.64 t/ha. When justifying the use of multicut grass sorghum, it is important to establish the optimal timing and frequency of cutting that ensure a normal aftermath formation. In view of this, the experimental work that we conducted in 2016–2018 allowed us to establish the pattern of the above-ground mass accumulation of grass sorghum during the main stages of development of the sorghum-Sudan hybrid Intensive F₁ and Sudan grass Kinelskaya 100 (Fig. 1).

At the beginning of their development, the sorghum cultures grew very slowly, since at that time the root system was actively developing, and the yield of the above-ground mass during the tillering stage was insignificant. However, already in the stem elongation stage, the plant height was 40–50 cm, and the yield of the green mass was 1512.0–1134.9 g/m², and that of the dry matter – 195.2–251.9 g/m². It should be noted that the sorghum-Sudan hybrid was characterized by a faster initial biomass formation. Above-ground mass formed at the fastest rates after the plants entered stem elongation stage. Daily growth of Sudan grass was 25–30 g/m² of dry matter and 70–80 g/m² of green mass, of sorghum-Sudan hybrid – 40–45 g/m² and 120–130 g/m², respectively. The

maximum yield of green mass of Sudan grass Kinelskaya 100 variety was observed during the full blossom stage – 2980.6 g/m², while the maximum yield of the dry matter – during the milk-wax stage of ripeness of the grain – 1227.5 g/m². Consequently, after the flowering, Sudan grass did not show any green mass growth, although the dry matter continued to accumulate. Intensive F₁ sorghum hybrid showed accumulation of both green mass and dry matter until the end of the growing season. Comparing the dynamics, it should be noted that the Sorghum-Sudan hybrid Intensive F₁ showed faster rates of formation of above-ground mass, as well as a rather high productivity potential (over 35 t/ha of green mass and 15 t/ha of dry matter). Sudan grass formed the above-ground mass much slower, being significantly lower in productivity than the sorghum-Sudan hybrid. Modern fodder production imposes certain requirements on the raw materials in terms of the content of dry matter for the preparation of high-quality grass forage. This indicator serves as an important criterion for assessing the suitability of the culture above-ground mass for the production of certain types of forage. Figure 2 shows a graph illustrating the change in the dry matter content in the above-ground mass of grass sorghum by growth and development stages.

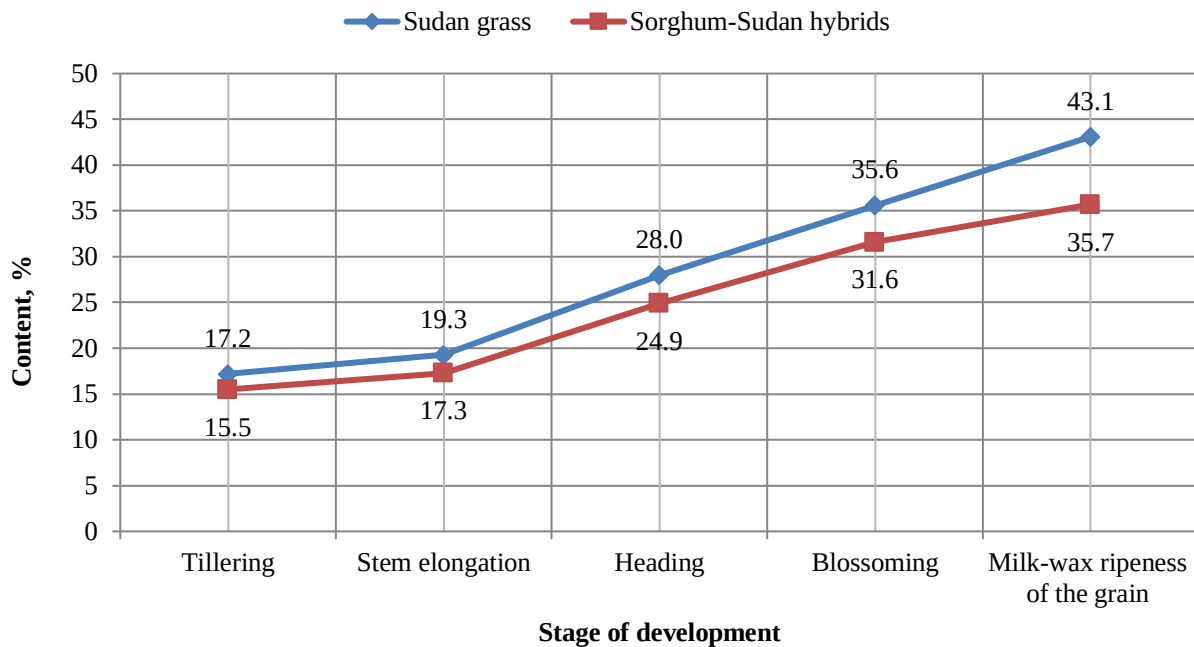


Figure 2: Dynamics of the dry matter content in the above-ground mass of grass sorghum, %

During the stem elongation stage, the above-ground mass was characterized by high sappiness – the dry matter content does not exceed 20%, which is important for good palatability of green mass by animals. During the heading stage, the dry matter content reaches 25–28%, and 32–35% – by the full blossom stage. Therefore, silage from Sudan grass should be prepared during the initial blossom stage before it is over. During grain formation and filling, the above-ground mass contains approximately 43% of dry matter; such raw materials in their pure form are not suitable for ensilaging and should be mixed with the green mass of corn, lupine, fodder beans, clover.

Considering that Sudan grass contains over 40% of dry matter by the phase of milk-wax stage of ripeness of the grain, the culture can be used to prepare grain hay (a promising type of forage prepared by harvesting the plants without threshing, their chopping during grain formation and filling when the content of moisture in the raw material is 45–55% and conservation in a haylage-like manner).

In an experiment designed to study the characteristics of aftergrowth of the Kinelskaya 100 variety of Sudan grass depending on the timing of the first cut and the intensity of cutting, the above-ground mass yield was assessed in accordance with the following variant (three use patterns). Variant 1 (three-cut) – the first cut is performed during the stem elongation stage when the plant height is 70 cm, the second and third – taking into account the aftermath 35–40 days after

cutting. Variant 2 (two-cut) – the first cut is performed during the heading stage, the second – 45–50 days after the first toward the end of the growing season. Variant 3 (single-cut) – single assessment during the full blossom stage at the beginning of the grain formation.

Experimental data on the total amount of dry matter in Sudan grass plantations are presented in Table 3.

The results show that in the agro-climatic conditions of the region, all the studied patterns of use of Sudan grass resulted in a fairly high yield of above-ground dry mass of 10.2–15.0 t/ha or from 35.8 to 52.0 t/ha of green mass. The maximum yield of dry matter was obtained with two-cut use – 15.2 t/ha.

4 Conclusion

When choosing the time for the main cutting and cutting height of fodder sorghum, the ability of plants or a variety (hybrid) to grow after cutting should be taken into account in order to prepare the maximum amount of nutritious forage using the green and feed stock conveyor system. Therefore, we recommend that farms plant three or four varieties (hybrid) of fodder sorghum with different duration of the growing season, especially from the emergence to the heading stage, when up to 50% of the dry weight of the crop accumulates, as well as with different aftergrowth pace in order to obtain full-scale aftermath.

Table 3: Yield of dry matter of Sudan grass by the use patterns, average for 2016–2018

Use pattern	Yield of dry matter, t/ha			
	1 cut	2 cut	3 cut	Total
Three-cut	3.46	5.90	0.89	10.25
Two-cut	7.71	7.49	-	15.20
Single-cut	12.39	-	-	12.39

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