The Nutrition Influence of Nitrogen Fertilizers on the Sugar Content of Sweet Sorghum Plants in the Southeast of Kazakhstan[1]

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Abstract—Two-year results of studies on the effect of fertilizing nitrogen fertilizers and nutrient levels on the accumulation of sweet by plants of varieties of sweet sorghum on irrigated light chestnut soils of the southeast of Kazakhstan are presented. The accumulation of sweet in sorghum plants continued throughout the entire vegetation period, but its maximum content was observed in milk-waxy ripeness stage of the grain. The quantitative composition of the juice significantly changed along the internodes of the stem. Most of sweets were contained in the middle internodes (5–9) as the main shoot, and lateral shoot. This pattern was traced in all phases of development, beginning with the flowering of plants. It is shown that up to 7.1–8.3% of sweet was accumulated in the sorghum at flowering stage in both varieties and backgrounds of provision. With the growth and development of plants, the sweet content in the main shoot increased, depending on the fertilization with nitrogen fertilizer against the background of varieties and the availability of soils with mobile phosphorus. So, if the content of sweet on the control variant was 13.9–14.3% at the milk waxy ripeness stage, when fertilizing in the initial stages of plant growth with nitrogen fertilizer in a dose of N_{50}, it increased to 15.4–15.5% for Kazakhstanskoye 16 and 15.0–15.2% for Kazakhstanskoye 20. The dose of N_{100} contributed to a further increase in its content, respectively, to 17.1–17.6% and 16.2–16.9%.

Keywords: sweet sorghum, fertilizers, nutrition, sugariness, variety, background, soils supply

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Sweet sorghum is promising for growing in conditions of southern arid low-fertile and saline lands [1–5]. There are a large number of varieties of this culture, which, in contrast to cereal and corn sorghum, contains up to 20% of sugars and more in the stem juice [6–10]. Despite the relative undemanding to the fertility of soils and the ability to extract nutrients, it is responsive to organic and mineral fertilizers [11–13]. Its powerfully developed root system with high digestive capacity provides a grain yield even without adding additional mineral nutrition to the soil [14]. Therefore, an opinion was formed on the weak responsiveness of sweet sorghum to increasing the level of mineral nutrition and relatively small in comparison with corn removal of nutrients from the soil necessary for harvesting. Culture consumes economically nutrients for the production of 1 centner grain: 75% of nitrogen, 60% of phosphorus and 90% of potassium from the amount that corn consumes [15].

The content of sugars in sugar sorghum plants is significantly influenced by the conditions of their cultivation. The ability of plants to accumulate a large amount of soluble sugars in the stem makes them a potential source of raw materials for the food industry [14, 16–18]. Juice squeezed from the stems has a light green color, a pleasant sweet taste and a weakly acid reaction [19]. According to the data of work [6, 14], the content of sugars in sweet sorghum plants increases as they develop. The improvement of nitrogen-phosphorus nutrition somewhat increases the amount of juice in the stems and the concentration of sugars in it. Consequently, cultivation of this crop on soils with high content of mobile phosphorus, medium and even low content of mobile forms of phosphorus and mineral nitrogen is permissible and does not require additional mineral fertilization [14].

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Table 1. Sugar content (%) by internodes of plants of Kazakhstanskoye 16 variety in the stage of milky-wax ripeness, average for 2015–2016

Variant	Internodes											
	1	2	3	4	5	6	7	8	9	10	11	12
Main shoot												
Background 1												
Control	11.2	12.8	14.1	15.4	16.5	16.9	16.6	15.5	14.4	14.1	13.6	12.7
N_{50}	12.7	13.2	14.7	15.8	16.8	16.6	18.3	17.8	16.6	15.7	14.9	14.2
N_{100}	13.6	14.3	15.1	16.8	18.1	19.3	20.1	19.6	18.9	18.4	17.7	17.2
SSD, %	0.45	0.32	0.49	0.38	0.36	0.46	0.59	0.54	0.49	0.42	0.47	0.43
Background 2												
Control	11.3	13.0	14.2	15.2	16.5	16.9	16.5	15.5	14.5	14.0	13.5	12.6
N_{50}	12.6	13.4	14.9	15.9	16.7	17.6	18.4	17.6	16.5	15.7	14.9	14.2
N_{100}	13.9	14.4	15.3	16.9	18.7	19.9	20.8	20.1	19.5	18.6	17.9	17.2
SSD, %	0.36	0.56	0.45	0.58	0.27	0.33	0.37	0.36	0.35	0.34	0.34	0.57
Lateral shoot												
Background 1												
Control	10.6	11.8	13.3	14.5	15.6	16.2	15.9	15.1	14.7	13.7	12.8	11.9
N_{50}	11.8	13.8	14.0	15.1	15.7	17.6	17.2	16.9	16.1	15.1	14.4	13.2
N_{100}	13.0	14.2	15.5	16.3	17.3	18.6	18.4	17.5	16.5	15.8	14.7	14.0
SSD, %	0.46	0.45	0.44	0.45	0.65	0.38	0.51	0.57	0.50	0.69	0.84	0.63
Background 2												
Control	10.7	11.8	13.3	14.4	15.6	16.2	15.8	15.0	14.3	13.4	12.6	11.7
N_{50}	11.7	13.0	14.0	15.1	15.7	16.5	17.1	16.5	15.9	15.2	14.4	13.9
N_{100}	13.3	14.0	14.9	16.0	17.7	18.7	19.4	18.6	17.7	16.7	16.0	15.4
SSD, %	0.56	0.56	0.44	0.60	0.66	0.50	0.43	0.66	0.49	0.79	0.94	0.94

In this regard, the aim of this work was to study the nutrition effect of nitrogen fertilizer at different doses on the sugar content of sweet sorghum plants against the backdrop of uneven soil mobile phosphorus supply in the conditions of the southeast of Kazakhstan.

METHODS

Field investigations were carried out in 2015–2016 on irrigated light chestnut soil in the foothills of the Zailiysky Alatau with different levels of soil availability with mobile phosphorus. Agrochemical characteristics of light chestnut soils: humus content—2.34–2.54%, alkaline hydrolyzable nitrogen—81.2–97.7 mg/kg and exchangeable potassium—320–340 mg/kg of soils. The experience scheme included the following variants: (1) control (without fertilizers); (2) N_{50} (nutrition in the phase of 3–5 leaves); (3) N_{100} (nutrition with N_{50} in the phase of 3–5 leaves + N_{50} in the phase of 5–7 leaves). The experiments are based on two backgrounds of mobile phosphorus supply according to Machigin: medium (30–35 mg/kg of soils)—background 1 and increased (40–45 mg/kg of soils)— background 2. Nitrogen fertilizers were added in the form of ammonium nitrate (34% rate of application).

The objects of research were varieties of sweet sorghum—Kazakhstanskoe 16 and Kazakhstanskoe 20. Field experience was laid in 4-fold replication with the use of agricultural techniques adopted for this zone [20]. Follow-up analyzes of soil and plant samples were carried out according to generally accepted procedures: alkaline hydrolyzable nitrogen was determined by Kornfield: mobile phosphorus by the Machigin method; exchange potassium from the same extract as mobile phosphorus—on a flame photometer; total nitrogen, total phosphorus and total potassium in plants—after wet ashing of plant material from one sample—according to Kjeldahl, colorimetrically, on a flame photometer. The content of water-soluble sugars in plants under field conditions was determined on a manual refractometer of the brand ATAGO N1. Statistical processing of the research results was carried out according to the methodology of B.A. Dospekhov (1985) using the Agros program (version 2.09) according to S.P. Martynov (1999).

Table 2. The content of sugars (%) by plant internodes of the Kazakhstanskoye 20 variety in the stage of milky-wax ripeness, average for 2015–2016

Variant	Internode											
	1	2	3	4	5	6	7	8	9	10	11	12
Main shoot												
Background 1												
Control	10.8	12.7	13.8	15.0	16.1	16.5	16.1	15.0	14.2	13.8	13.2	12.2
N_{50}	12.2	13.5	14.4	15.5	16.5	17.2	18.0	17.4	16.3	15.4	14.5	13.8
N_{100}	13.0	13.8	15.0	16.3	16.8	18.6	19.1	18.4	17.5	16.6	15.9	15.3
SSD, %	0.43	0.41	0.40	0.39	0.30	0.32	0.52	0.74	0.49	0.31	0.40	0.34
Background 2												
Control	11.0	12.5	13.4	14.6	15.8	16.5	17.0	16.6	15.6	14.6	13.8	12.8
N_{50}	12.2	13.6	14.6	15.5	16.2	17.3	17.9	16.8	15.9	15.1	14.1	13.2
N_{100}	13.7	14.9	16.3	17.4	18.4	19.7	20.4	19.0	18.0	17.2	15.7	14.5
SSD, %	0.43	0.33	0.52	0.40	0.54	0.47	0.57	1.05	0.89	0.76	0.96	1.05
Lateral shoot												
Background 1												
Control	10.3	11.6	13.0	14.2	15.3	15.9	15.6	14.8	14.1	13.2	12.3	11.4
N_{50}	11.4	12.7	13.6	14.6	15.4	16.3	17.0	16.4	15.8	14.6	13.8	13.1
N_{100}	12.7	13.8	14.8	15.8	17.4	18.0	17.8	17.1	16.2	15.3	14.5	13.5
SSD, %	0.46	0.50	0.41	0.54	0.58	0.48	0.70	0.82	0.97	0.86	0.94	0.99
Background 2												
Control	9.9	11.4	12.7	13.9	15.0	15.8	16.6	16.4	15.3	14.4	13.4	12.7
N_{50}	11.3	13.2	14.4	15.1	16.4	17.0	17.0	16.0	15.1	14.4	13.8	12.9
N_{100}	12.9	14.2	15.5	16.5	17.6	18.8	18.9	18.0	17.1	16.0	15.2	14.4
SSD, %	0.34	0.36	0.44	0.38	0.47	0.48	0.82	0.58	0.54	0.53	0.68	0.42

RESULTS AND DISCUSSION

Growing plants when applying nitrogen fertilizer in doses of N_{50} and N_{100} caused a significant increase in the content of sugars in the juice. Accumulation of sugars in plants begins in the early stages of development. Thus, already 1 month after emergence (during tillering), when the height of the plant reaches 8–12 cm, the content of sugars is 2.6–4.3%. During the period of intensive plant growth, it increases in various varieties up to 6.5–12.0%; in the wax ripeness stage of grain—up to 10.3–15.0 and full ripeness—up to 13.2–15.9% [17].

In our experiments, intensive accumulation of sugars in plant juice was observed prior to the wax ripeness stage. Maximum it was in the milky-wax ripeness stage and remained at this level for 10–20 days, then gradually decreased.

The quantitative composition of the juice varies significantly in the internodes of the stem. Most of the sugars are contained in the middle internodes (5–9) of the main and lateral shoots [6, 7]. This pattern can be traced in all stages of development beginning with the flowering of plants.

In the plants of the main shoot in Kazakhstanskoye 16 variety, the content of sugars in the control variant did not depend on the availability of soils with mobile phosphorus and amounted to 11.2–16.9% (Table 1). Nutrition with nitrogen fertilizer in the early phases of plant development of Kazakhstanskoye 16 significantly increased the content of sugars in the main shoot. Thus, in the dose of N_{50} it was 12.7–18.3%, N_{100}—13.6–20.1% for the background of medium availability and accordingly 12.6–18.4 and 13.9–20.8% for the background of increased availability of mobile P_2O_5. It should be noted that the maximum concentration of sugars is noted in the variant without fertilizers at the sixth internode, whereas applying fertilizers it is noted at the seventh internode. An analogous regularity in the content of sugars was also observed on the lateral shoot of plants. At the same time, it was lower by 5.4–7.1% in the control and by 3.8–7.5% in fertilizer variants than in the corresponding variants of the main shoot.

The change in the content of sugars in the plants of the main shoot in the Kazakhstanskoye 20 variety had a similar tendency (Table 2). Thus, in the control vari-

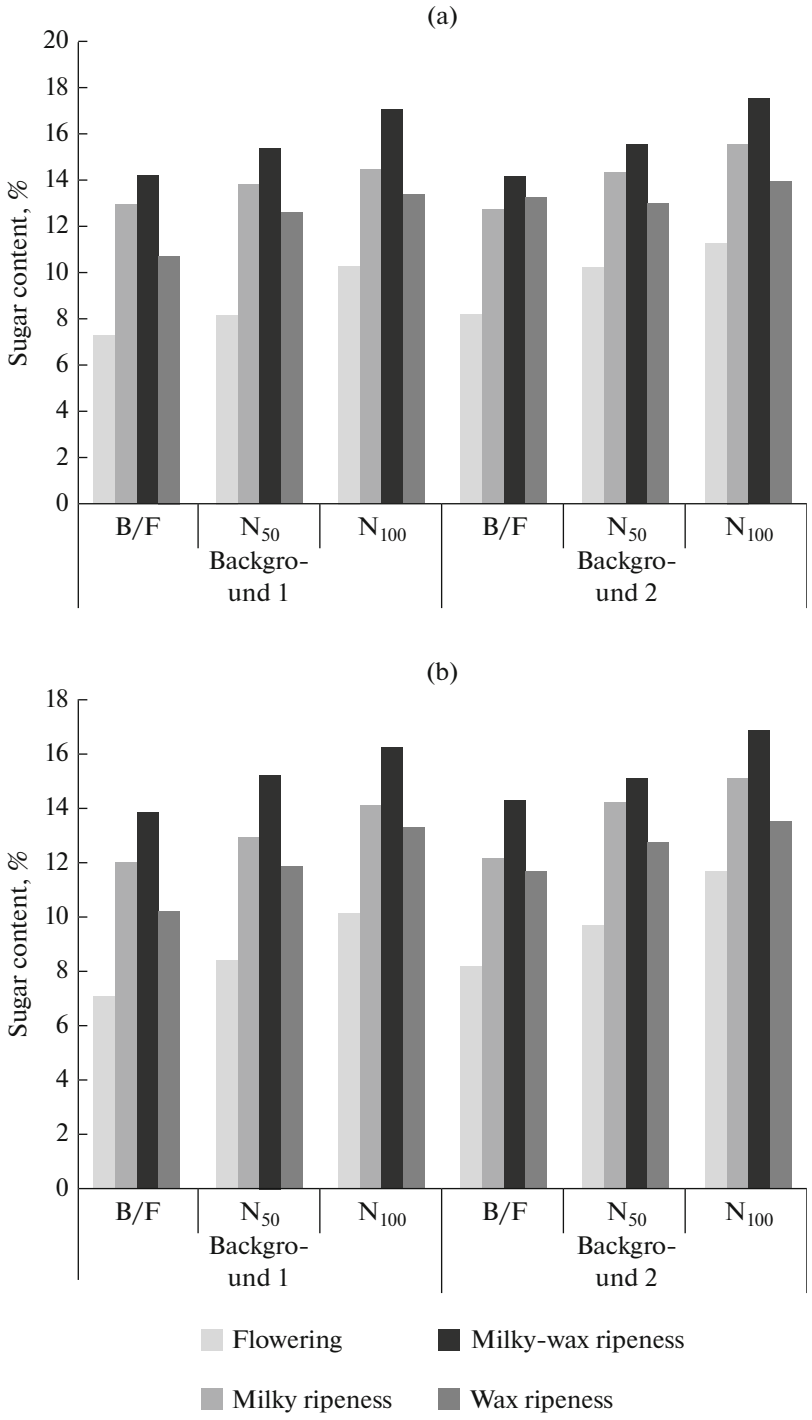

Fig. 1. Sugar content in the main shoot of plants of Kazakhstanskoe 16 (a) and Kazakhstanskoe 20 (b) varieties; columns from left to right in the stages of flowering, milky, milky-wax and wax ripeness, average for 2015–2016.

ant it was 10.8–16.5% for the background 1 and 11.0–17.0% for the background 2, in the variant N_{50}—12.2–18.0 and 12.2–17.9%, respectively, N_{100}—13.0–19.1 and 13.7–20.4% (Table 2). In plants of this variety, the content of sugars was maximal at the seventh internode on both backgrounds of soil availability with mobile phosphorus. It should be noted that in fertilizer variants it was slightly lower than in Kazakhstanskoye 16 variety. Such a pattern of sugar distribution along internodes is also characteristic of lateral shoots of Kazakhstanskoye 20 variety plants.

The sugar distribution was uneven, not only in internodes, but also in periods of plant growth and development. So, their accumulation in plants is

Table 3. Dynamics of the sugar content in the lateral shoots of plants, average for 2015–2016 years

Variant	Content, %			
	Kazakhstanskoe 16		Kazakhstanskoe 20	
	background 1	background 2	background 1	background 2
Flowering stage				
Control	7.3	6.9	7.7	7.1
N_{50}	7.6	8.1	9.0	9.3
N_{100}	9.8	9.7	10.4	11.4
Wax ripeness stage				
Control	12.2	11.0	12.2	11.8
N_{50}	13.4	12.4	13.6	12.8
N_{100}	13.8	13.7	15.1	14.0
Milky-wax ripeness stage				
Control	13.6	13.2	13.6	14.0
N_{50}	14.9	14.4	14.8	14.6
N_{100}	16.0	15.3	16.4	16.0
Full ripeness stage				
Control	10.4	9.6	11.9	11.7
N_{50}	11.5	11.4	12.6	12.6
N_{100}	12.9	12.5	12.9	12.1

noted mainly up to milky and milk-wax ripeness of grain. By the flowering stage, in plants of both varieties, up to 7.1–8.3% of sugars were kept for backgrounds 1 and 2 (Figs. 1a, 1b).

As the plants grew and developed, the sugar content in the main shoot increased, depending on the nutrition with nitrogen fertilizer in both varieties on the background of the availability of soils with mobile phosphorus. So, if to the milky-wax ripeness stage in the control variant it was 13.9–14.3%, when holding nutrition with nitrogen fertilizer at a dose of N_{50} in the initial phases of plant growth, it increased to 15.4–15.5% in the Kazakhstanskoe 16 variety and 15.0–15.2% in the Kazakhstanskoe 20 variety. The dose of N_{100} promoted a further increase in the sugar content to 17.1–17.6 and 16.2–16.9%, respectively. At the same time, there was a clear increase in sugar content with an improvement in plant nutrition conditions, that is, with an increase in the degree of soil availability with mobile phosphorus and a dose of nutrition with nitrogen fertilizer. Thus, in comparison with absolute control, the relative increase in sugar content in plants of Kazakhstanskoye 16 variety in variants with nitrogen was 18.4–20.1% in background 1, and 9.0–23.4% in background 2. In the Kazakhstanskoe 20 variety these indicators were respectively 9.7–16.8 and 8.4–21.7%. Obviously, the best conditions for the accumulation of sugars were found in Kazakhstanskoye 16 on the background of increased availability of soil with mobile phosphorus.

An obtained data analysis on sugar content in the lateral shoots of plants showed that the sugar accumulation in both varieties also proceeds quite intensively, especially against the background 1, and reaches a maximum value for the milky-wax ripeness stage. For example, in the Kazakhstanskoe 16 variety, the sugar content increased from 7.3% in the flowering stage to 16.0% in the milky-wax ripeness stage on the background 1 and from 6.9 to 15.3%, respectively, on the background 2 (Table 3). In the Kazakhstanskoe 20 variety these indicators varied from 7.7 to 16.4 and from 7.1 to 16.0%, respectively.

Thus, the sugar accumulation in sweet sorghum plants continues throughout the vegetation season, but the maximum amount is observed in the milky-wax ripeness stage of the grain. At the same time, there is a tendency to increase their content in connection with the feeding of nitrogen fertilizer on both backgrounds of soil availability with mobile phosphorus depending on the biological characteristics of sweet sorghum varieties.

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