STUDY OF THE ADAPTIVE CAPACITY OF GRAIN SORGHUM DEPENDING ON THE SOWING TIME IN THE STEPPE ZONE

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Abstract

According to the studies, which were conducted on the experimental field of the Lugansk Agrarian University (steppe zone), on average for 2008-2017, the percentage of the contribution to the formation of grain sorghum yield by optimizing the sowing time was 38.8%. According to the set of indicators of adaptive capacity and ecological plasticity, the first earliest (April 25) sowing time for grain sorghum of the middle-early hybrid Sprint W was identified as the most appropriate. This sowing time provides not only the highest yield of the hybrid, but also the most favorable combination of the main indicators of adaptive capacity. At this sowing time, the hybrid behaves like a highly plastic genotype (bi ≈ 1.0), which simultaneously has a reduced stability (Si2= 0.67). It indicates that it has better adaptability to environmental deterioration. The earliest sowing time also provides the maximum rates of genetic flexibility (6.58 t/ha), drought tolerance index (88.2%), general adaptive capacity (+1.25 t/ha), yield stability index (0.27) and hybrid stability indicator (169.6%).

Key words*: *sorghum, sowing time, grain yield, adaptive capacity

INTRODUCTION

Global warming, which can be observed during the last 25-30 years, has also affected the territory of Russia [10]. According to the Institute of Global Climate and Ecology of Russian meteorological service and the Russian Academy of Sciences, the average annual air temperature in Russia in 1976-2017 increased faster than the average planetary temperature by more than 2.5 times [7] and the increase was 0.47°C/10 years, although the global world values of this indicator increased by only 0.18°C/10 years [18]. Warming is also occurring in the steppe conditions of the Donbas. According to the Lugansk Meteorological Office, in comparison to the average long-term norm during 160 years (from 1838-1997), over the past 25 years (1997-2021), the average annual air temperature has increased by 1.7°C and reached 9.7°C, with an increase rate of 0.68°C/10 years. The frequency and duration of hot drought seasons have noticeably increased in summer. An urgent task in the conditions of increasing aridity of the climate is to increase the cultivation area of a promising, extremely drought, heat and salt tolerant, ecologically plastic and high-yielding crop – grain sorghum, which has a universal application for food, fodder and technical purposes [4]. According to the long-term research in the conditions of the Lugansk Region, this crop significantly exceeds the main spring sown cereals – barley, oats and corn in terms of yield [3, 4, 11], providing an average grain yield of 5-6 t/ha or more [12].

It is known that the more a variety produce in a wide range of growing conditions (i.e., the higher its average yield), the higher the level of its adaptability [21].

Frequently, weather conditions lead to a significant reduction in the yield of many grain and fodder crops, while sorghum is able to withstand air and soil droughts for a long time. It is necessary to introduce varieties in production that are characterized by responsiveness to improving of growing conditions and the stability of the grain yield. Therefore, for the zonal placement of sorghum varieties and hybrids, it is important to know their adaptive potential, which is estimated by the parameter value of ecological plasticity and stability, which show the adaptation characteristics of varieties to environmental conditions (genotype × environment interactions) [1, 2, 13, 15, 17].

In the grain production of the Lugansk Region, a high-yielding hybrid of grain sorghum Sprint W (production of "Richardson Seeds", USA) is widely used. Therefore, we set the task to establish the most optimal sowing time for this hybrid (the best hydrothermal environmental conditions), which ensure the maximum adaptability of this genotype.

MATERIALS AND METHODS

The research was carried out in 2008-2017 on the experimental field of the Lugansk National Agrarian University in the field crop rotation of the Department of Agriculture and Environmental Ecology. The soil was ordinary, thin, slightly eroded chernozem on loess-like loam with an average content of 3.3-3.4% humus in the arable layer (according to Tyurin); 113.2 mg/kg of hydrolysable nitrogen (according to Cornfield); 80.1 mg/kg of mobile phosphorus (according to Chirikov) and 156.2 mg/kg of exchangeable potassium (according to Chirikov) [8]. The reaction of the soil solution was weakly alkaline (7.7-8.6%).

Agricultural technique of sorghum cultivation in the field experiment was conventional for the zone. The studies were carried out in accordance with the methodology of the field experiment [8]. The preceding crop was winter wheat. The seeding rate was 250-300 thousand/ha of viable seeds with manually formed density at the level of 130-140 thousand/ha. We used the middle-early hybrid of grain sorghum, which was recommended for the region – Sprint W. It was a two-factor experiment. The replication of the experiment was fourfold. The area of the plot was 33.6 m^2. The registration plot was 28.0 m^2. Six sowing dates of sorghum were studied in the experiment: I – April 25; II – May 5; III – May 15; IV– May 25; V – June 5; VI – June 15.

According to the works of Rybas I.A., Marchenko D.M., Nekrasov E.I. et al. [19]; Biktimirov R.A., Nizaeva A.A. [6], in order to calculate the adaptability parameters, the coefficient of variation was used in accordance with the method of field experiment [8]; indicators of stress resistance (Y_{min}-Y_{max}) and genetic flexibility ((Y_{max}+Y_{min})/2) according to equations of Rosielle and Hamblin (1981) as expounded by Goncharenko A.A. (2005); indicators of plasticity (b_i) and stability (S_i^2) according to the method of S.A. Eberhart, W.A. Russell [9] as expounded by Zykin V.A., Belan I.A., Yusov V.S. et al. [22]; Pakudin V.Z., Lopatina L.M. [16]; Kilchevsky A.V., Khotyleva L.V. [14].

The weather conditions of the growing season during the years of the experiment were very contrasting (Table 1).

Despite the extremely uneven precipitation during the growing season, the most favorable hydrothermal conditions were in 2008, 2011, 2014, 2016 and 2017 (HTC was 0.94-1.14).

Due to the increased air temperature and the extreme lack of precipitation in the second half of the growing season of sorghum (July-August), in the most critical reproductive period of development, the most extremely dry conditions were in 2009, 2010, 2012, 2015.

Table 1. Weather conditions during the growing season of grain sorghum, 2008-2017 (Hydrometeorology Center data, Lugansk)

Measurements during the growing season (April-September)	**Years**										
	2008	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**Normal value**
Mean air temperature, ºC	17.8	18.0	20.1	18.0	20.2	18.8	17.9	19.0	18.6	18.0	**17.3**
Precipitation amount, mm	292	162	252	318	196	202	310	274	335	283	**309**
Relative air humidity, %	67.0	61.1	62.6	67.6	61.7	61.3	65.7	61	64.2	62.5	**66.0**
Number of days with relative air humidity ≤ 30%	51	89	75	54	70	68	63	82	32	64	**45.2**
Sum of active (≥10ºC) temperatures, ºC	3,414	3,455	3,560	3,287	4,008	3,868	3,253	3,408	3,546	3,166	**3,148**
Hydro-thermal Coefficient of Selyaninov (HTC)	1.10	0.54	0.78	0.94	0.58	0.68	1.14	0.68	1.08	0.99	**1.00**

Source: developed by the authors based on [8, 18].

Moisture conditions of these years during this period corresponded to the natural zones of the semi-desert (HTC = 0.4-0.2), and in August of 2008, 2010, 2015, 2017 – the desert zone (HTC < 0.2). On average, for 2008-2017 years of the experiment, the hydrothermal coefficient (HTC) for July-August was 0.54 or decreased relative to the average long-term (average for 1986-2005) climatic norm by 32.5% [20] (Table 2).

Table 2. Conditions of water availability in July-August during 2008-2017

Measurements	**Years**										**Normal value**
	2008	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	
Precipitation amount, mm	65.7	60.2	52.8	87.2	49.1	91.4	105.5	41.6	129.6	98.8	108
HTC during July-August	0.46	0.44	0.32	0.61	0.32	0.66	0.76	0.29	0.88	0.69	0.80

Source: developed by the authors based on [8, 18].

Therefore, we set the task to establish the effect of the shift in the sowing time of the crop relative to the one, which is conventional in production (May 15) towards earlier or later dates.

RESULTS AND DISCUSSIONS

The sowing time of sorghum significantly influenced the length of the period "sowing – germination". In April sowing period, sorghum sprouts appeared only on the 15th day. On average, it was 5.5 days earlier. As for the late (May 15) date, it was almost 9 days earlier or 2.4 times faster (Table 3). An analysis of the duration of the sorghum growing season showed that with an earlier sowing time (April 25), the growing season of crop development (germination – flowering) was significantly longer than with medium (May 15) or late (June 15) sowing time. This difference, on average for 10 years, was 4.1 days in comparison with the average period (varied on an annual basis from 1 to 11 days) and 8.6 days (with fluctuations from 3 to 19 days). The exception was 2011, when with a late sowing time, this period was longer (by 5 days) than at an early one.

In particular years (2010, 2011, 2012, 2015, 2016), the total growing season of sorghum of late June sowing time was even longer than early (April) ones. This was due to the fact that during these years late-sown sorghum didn't have enough sum of active temperatures for ripening in proper time (2010), or it did not reach the stage of full ripeness at all (2011, 2012, 2013, 2014, 2015, 2016) due to air and soil frosts in October. Late-sown sorghum stopped growing and died in the stages of milk-wax and wax ripeness.

Thus, the lasting (average for 1991-2020) probability of air and soil frosts in the III ten-day period of September was 6.0 and 12.3%, in the I ten-day period of October – 7.4 and 17.0%, and in the II ten-day period of October – 16.7 and 25.7% [5].

Table 3. The duration of interstage periods in the cultivation of grain sorghum during 2008-2017 depending on the sowing time of crops

Sowing time	**The duration of the interstage period during the years of the experiment, days**										$\bar{X}$
	2008	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	
	Period of sowing – germination										
I	16	20	15	22	9	10	13	15	16	15	15.1
II	11	16	11	15	9	9	11	12	9	13	11.6
III	10	11	9	11	8	8	9	10	8	12	9.6
IV	9	8	7	10	7	8	8	8	7	8	8.0
V	8	6	6	8	7	7	6	6	7	11	7.2
VI	7	6	5	7	6	6	6	6	7	7	6.3
	Period of germination – flowering										
I	82	72	65	65	68	66	69	63	67	78	69.5
II	85	70	63	64	62	62	68	61	65	75	67.5
III	79	68	59	64	63	63	68	62	61	67	65.4
IV	76	66	54	73	60	60	64	61	58	64	63.6
V	75	60	57	77	62	61	67	57	54	58	62.8
VI	70	55	59	70	59	59	66	57	55	59	60.9
	Period of germination – ripeness										
I	126	129	95	114	106	113	121	112	111	118	114.5
II	122	124	94	113	99	109	118	106	112	112	110.9
III	119	122	95	109	99	116	119	101	110	105	109.5
IV	114	121	90	121	98	119	119	100	111	104	109.7
V	112	120	92	122	128	109	111	118	120	105	113.7
VI	106	124	111	113	119	102	101	118	110	99	110.3

Source: developed by the authors based on [8, 18].

On average, during the years of the research (2008-2017), the yield of grain sorghum hybrid Sprint W varied in a very wide range (from 0.57-4.60 t/ha in dry 2010 to 6.56-8.82 t/ha in wet 2016). It was the highest at I and II sowing time and significantly exceeded this parameter with later dates (Table 4). The only exception was 2017, with a very cold and dry spring growing season, when the maximum crop yield was formed at III sowing period.

Table 4. Yield of grain sorghum hybrid Sprint W during 2008-2017

Sowing time	**Crop yield during the years of the research, t/ha**										$\bar{X}$
	2008	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	
I (25.04)	7.21	5.62	4.60	6.55	4.50	7.34	6.51	7.29	8.82	4.34	**6.28**
II (5.05)	7.06	5.33	4.15	6.43	4.22	6.87	5.85	7.07	8.71	5.02	**6.07**
III (15.05)	5.73	4.90	4.08	6.20	4.20	5.67	4.99	6.52	7.98	5.28	**5.56**
IV (25.05)	4.96	4.79	3.15	6.14	3.71	5.84	4.02	6.18	7.02	5.00	**5.08**
V (5.06)	4.36	4.52	1.91	3.59	2.79	5.58	2.34	3.50	7.25	4.44	**4.03**
VI (15.05)	3.55	4.72	0.57	2.61	1.56	4.18	1.48	1.52	6.56	4.65	**3.14**
$\sum Y_j$	32.87	29.88	18.46	31.52	20.98	35.48	25.19	32.08	46.34	28.73	**30.15**
Y_j	**5.478**	**4.980**	**3.077**	**5.253**	**3.497**	**5.913**	**4.198**	**5.347**	**7.723**	**4.788**	**5.025**
J_j	0.453	-0.045	-1.948	0.228	-1.528	0.888	-0.827	0.322	2.698	-0.237	
$S\bar{x}$	0.124	0.058	0.078	0.116	0.079	0.095	0.105	0.104	0.162	0.078	
LSD_{05}, t/ha	0.367	0.172	0.242	0.343	0.235	0.283	0.312	0.309	0.498	0.231	
$S\bar{x}$, %	2.26	1.16	2.53	2.21	2.26	1.61	2.50	1.94	2.10	1.63	

Y_j– average yield per year for all periods of sowing time; J_j – year conditions index
Source: developed by the authors based on [8].

The results of the variance analysis of a two-factor experiment (Fig. 1) indicate that not only the conditions of the year (47.3%), but also the sowing time (38.8%), and to a much

lesser extent, their interaction (the contribution of the interaction influence of the factors “year conditions” × “sowing time” on the crop yield was only 13.9%).

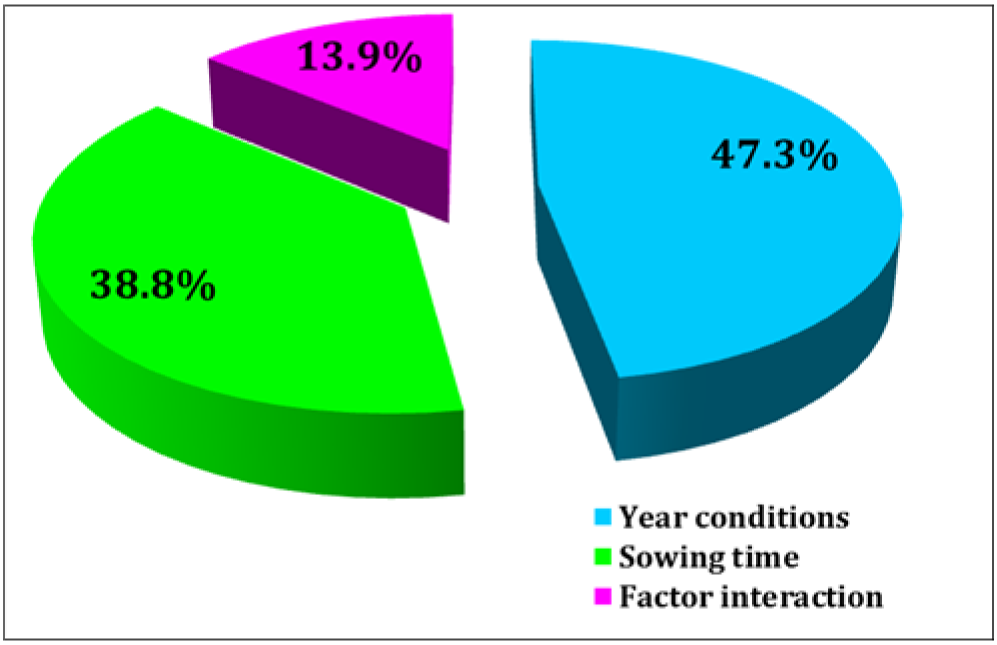

Fig. 1. Percentage of the contribution of factors in the formation of the yield of grain sorghum hybrid Sprint W on average for 2008-2017.
Source: developed by the authors based on [8].

The results of the variance analysis of a two-factor experiment (Fig. 1) indicate that not only the conditions of the year (47.3%), but also the sowing time (38.8%), and to a much lesser extent, their interaction (the contribution of the interaction influence of the factors “year conditions” × “sowing time” on the crop yield was only 13.9%).

As a result of calculations of the adaptive capacity indicators of grain sorghum of the studied hybrid Sprint W, it was found that the greatest responsiveness to improved moisture conditions during the growing season by optimizing the sowing time was the crop, which was sown at the earliest time – in the period from April 25 to May 5 (Table 5). This contributed to obtaining a linear regression coefficient (b_i) ≈ which is equal to 1.0 (under these conditions, this genotype behaves as highly plastic, and its yield corresponds to changes in environmental conditions). At these sowing dates, a greater stability of hybrid yield formation was also obtained since the measure (variance) of sample stability (S_i^2) has a decreasing tendency (0.67-0.30), which is not a sign of its intensity, but a factor of better adaptation of the genotype to deterioration of growing conditions. Sorghum crops of the latter sowing time (June 15) had the highest stability indicator (S_i^2= 1.39), which indicates the formation of a consistently low yield at this sowing time.

Sorghum crops of III and IV sowing time had the highest stress resistance (Y_{min}-Y_{max} ≤ -3.9 t/ha), i.e. the lowest negative values of the difference between the minimum and maximum yield of this variety. The maximum genetic flexibility of the hybrid (1/2 × (Y_{min} + Y_{max}) = 6.58-6.43 t/ha) was obtained at I and II sowing dates. The drought tolerance index of the hybrid (DTI = Y_{min}/Y_{max})×100%) was also the highest at the I sowing time (88.2%), which is 8.4% more than at the conventional sowing time of sorghum (May 15).

The highest adaptive capacity of the hybrid (GAC = the difference between the average yield of the hybrid at a specific sowing time and the average yield of the entire set of tests during all years of the experiment) was equal to +1.25 t/ha and was also obtained at the first, earliest April sowing time. The system index (SI = (Y_{max} – Y_{min}) / $\overline{Y}$ throughout the experiment × 100%) was the highest (106.2-

119.1%) at V and VI sowing dates, and the minimum was at III sowing time.

Table 5. Parameters of adaptability and stability of grain sorghum hybrid Sprint W based on the trait “crop yield” depending on the sowing time and year conditions during the growing season (2008-2017)

Sowing time	Grain yield, t/ha						Adaptivity parameters		DTI, %	GAC, t/ha	CV, %	System Index, %	SF	Stability Index	SLI, %	SLI, % to St
	Average Y_i	Inaccuracy Y_i	min-max	Range d, t/ha	Range d, %	$(min+max)/2$	b_i	S^2_d								
I (25.04)	6.28	0.47	4.34-8.82	4.48	50.8	6.58	0.968	0.667	88.2	+1.25	23.6	89.1	2.03	0.27	169.6	113.0
II (5.05)	6.07	0.45	4.15-8.71	4.56	52.4	6.43	1.022	0.304	59.0	+1.04	23.6	90.7	2.10	0.26	157.8	105.1
III (15.05)	5.56	0.37	4.08-7.98	3.90	48.9	6.03	0.824	0.204	79.8	+0.53	20.9	77.5	1.96	0.27	150.1	100.0
IV (25.05)	5.08	0.39	3.15-7.02	3.87	55.1	5.09	0.861	0.260	44.9	+0.05	24.1	76.9	2.23	0.21	106.7	71.1
V (5.06)	4.03	0.50	1.91-7.25	5.34	73.7	4.58	1.149	0.460	26.3	-1.00	39.4	106.2	3.80	0.10	40.3	26.8
VI (15.06)	3.14	0.60	0.57-6.56	5.99	91.3	3.57	1.177	1.390	8.7	-1.89	60.5	119.1	11.51	0.05	15.7	10.5

Source: developed by the authors based on [8].

The highest indicator of the stability factor ($SF = Y_{max} / Y_{min}$) was obtained precisely at V and especially at VI sowing dates, i.e. with the lowest hybrid yield. Stability index of sorghum grain yield ($SI = \overline{Y}_{throughout\ the\ experiment} / CV$, %) was the highest (0.26-0.27) at the first three sowing dates (April 25 through May 15). Also, the stability level indicator of the hybrid ($SLI = \overline{Y}_{hybrid} \times SI_{hybrid}$) was the highest at the first earliest sowing time (169.6%), which was higher by 13.0% in comparison to the conventional sowing time for sorghum in production (May 15).

CONCLUSIONS

On average, during 2008-2017 years of the research, the share of the contribution to the formation of the grain sorghum yield by optimizing the sowing time was 38.8%. According to the set of indicators of adaptive capacity and ecological plasticity, the first earliest (April 25) sowing time for grain sorghum of the middle-early hybrid Sprint W was identified as the most appropriate. This sowing time provides not only the highest yield for the hybrid, but also the most favorable combination of the main indicators of adaptive capacity. At this sowing time the hybrid behaves as a highly plastic genotype ($b_i \approx 1.0$), which simultaneously has a reduced stability ($S_i^2 = 0.67$). It indicates it has better adaptability to environmental deterioration. The earliest sowing time also provides the maximum indicators of genetic flexibility (6.58 t/ha), drought tolerance index (88.2%), general adaptive capacity (+1.25 t/ha), yield stability index (0.27) and stability level indicator of the hybrid (169.6%).

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