The influence of seed sowing norms rate and row spacing on the yield of sorghum grain grown at eastern forest-steppe of Ukraine

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Abstract: In fact, there are no data on the effect of different combinations of plant density and the shape of their nutrition zone on the level of grain productivity of various stem systems (main and lateral rods of different orders) and their contribution to the total production of the plant yield capacity. This is precisely why our research was aimed to identifying the optimal combinations of sowing rates with sowing practices, which would allow for the development of the largest sorghum hybrid grain production capacity and determine the effect of different systems of stems on the formation of the highest cereal productivity of grain sorghum hybrids. The aim of research was to determine the connection between the components of growing technology (seeding rates and ways of sowing) that reflect the level of coenotic stress in plant crops.

Keywords: productivity; area of nutrition; interaction; density of plants; stage of development; range criterion.

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1 Introduction

Sorghum is the fifth crop among the most widely spread ones in the world, after wheat, rice, corn and barley (Kiprotich et al., 2015). This crop is the main source of protein and energy for millions of people on the planet, and first for those who live in poor countries of Africa and Asia (in particular in India, South-East Asia) (Elkhier and Hamid, 2008). This crop is popular in Australia, the USA and Mexico. Some of its species are cultivated in Europe, mostly in Romania and Serbia. Recently, the interest to sorghum has increased in Brazil, Argentina and other countries (Monteiro et al., 2012). Despite high adaptive ability of sorghum to environmental conditions, its high biological potential is not realised to its full capacity (Oprea et al., 2017). Sorghum can develop well when annual precipitation rate is less than 450 mm (Aleminew, 2015), so it is recommended to grow it in the areas with precipitation deficit and high air temperature (Staggenborg et al., 2008).

One of the important elements of grain sorghum cultivation technology, due to which it is possible to get high and stable yields of grain, is the choice of an optimal sowing rate taking into consideration soil and weather conditions of the region, biological peculiarities of cultivars and hybrids (Danilenko and Bolotin, 2005; Dronov, 2002; Fernandez et al., 2012; Gondal et al., 2017; Kelly and Lawson, 2013; Lapa and Farafonov, 2008).

When growing grain sorghum, the choice of the most effective method of seeding and forming the optimal density of plants according to the morpho-biological characteristics of cultivars and hybrids is of paramount importance and often crucial for obtaining high returns (Krylov and Filatov, 2002; Snider et al., 2012). They are determined by the direction of cultivation, peculiarities of cultivars and hybrids, moisture supply and weed infestation of the areas.

Their functions depend on the form of a nutrition area of plants, in particular transpiration intensity, photo-synthetic activity, mineral nutrition, water consumption and others. Besides that, due to various combinations of sowing rate and practice it is possible, to a great extent, to correct microclimate in sown areas, biological processes in the soil, incidence nature of diseases, pests and weeds and the degree of their damage effect (Karazhbey and Tegun, 2012; Rozhkov, 2012a). An optimal combination of sowing rate and practice is defined when certain climate-soil conditions, morpho-biological characteristics of the cultivars and hybrids, as well as the direction of use of the products are taken into account (Alabushev and Antipenko, 2003; Barbaruk et al., 2006; Makarov and Skoriy, 2009; Shavsha, 1982; Snider et al., 2012).

Grain sorghum is grown with help of wide sowing practice, when row spacing is 60 cm and 70 cm; however the improvement of the production technology and the use of new hybrids made it advisable to test the efficiency of wide sowing practices with narrower row spacing – 30 cm and 45 cm (Gondal et al., 2017).

On the other hand, Rukhlevich (2017), recorded the advantage of wide sowing practice in the districts with sufficient moisture and mineral nutrition, when row spacing was 15 cm, and he got higher yield and higher grain quality. Snider et al. (2012) reported that maximal productivity of sorghum fields was formed in wide sowing practice with row spacing 19 cm together with sowing rate 116 th psc/ha.

In the context of general productivity (grain and raw vegetative mass), Ahmad et al. (2007) stated that the advantage of wide sowing practice is with row spacing of 45 cm as compared to the row seeding. At the same time, Chattha et al. (2017) considered the row sowing practice with row spacing 30 cm to be better in this respect. Researchers Sauer et al. (2014) note that the best conditions and the highest grain productivity of high-yielding hybrids of grain sorghum are formed in wide sowings with row spacing 75 cm and plant density 110 th pcs/ha.

Wide sowing practice with row spacing 70 cm is the most widely spread method in the southern regions of Ukraine and in the Crimea. Wide sowing practice with row spacing 45 cm and proper technical support give better results in forest-steppe areas. It ensures some increase of grain yield – about 0.4–0.5 t/ha (Boyko, 2016; Demidov, 1998) gives preference to row sowing with row spacing 15 cm when sorghum is grown for grain.

The highest yielding capacity of sorghum grain in the steppe of Ukraine was reached when sowing rate was 140–160 th psc/ha. In the southern areas of the steppe and especially in the extreme areas of Sivash vicinity, sowing rate ranged from 60 to 140 th psc/ha depending on the year of cultivation (Malinovskaya and Gulov, 2006; Pashchenko and Andrienko, 2003).

Many researchers stress the need to differentiate sowing rates according to sowing conditions (Boyko, 2016; Ovsienko, 2015). In particular, according to Ovsienko (2015), the maximum yield capacity of sorghum grain, was when planting done during the first dekad of May, at a sowing rate of 100 pct/ha, while in the second and third-decades May, it was 200 e/ha. Boyko (2016) advised to sow grain sorghum hybrids updated at a rate of

140–180 th psc/ha at the beginning of optimal sowing conditions and at the end of optimum sowing conditions of 180–220 th pcs/ha.

The studies prove that biologically adequate sorghum grain is formed on main plant stems, shoots of the second and third orders give less viable seeds. It is possible to reduce the share of undesirable seeds on tillering shoots due to the increase of sowing rate to a scientifically grounded level (Shavsha, 1982; Shukis and Shukis, 2009).

Galichkin (2008) points out that the strong sorghum compensation capacity, which makes it possible to form the same grain yield in a wide density range. Their boundaries are defined depending on sowing practices, soil-climatic and weather conditions, and also on morpho-biological peculiarities of cultivars and hybrids. When wide sowing practice is used, the density level of common hybrids, at which the highest plant productivity is formed, ranges from 100 to 320 th pcs/ha. It reaches an upper point 200–300 th. pcs/ha in moist years, and it shifts to a lower point 100–200 h pcs/ha in dry years.

Yielding capacity of grain is a final indicator, so it is recommended to conduct an objective analysis of the efficiency and speed of the use of certain farm practice (Boyko, 2016). Taking into consideration certain agro-biological features of sorghum (combining in autumn period, and, as a consequence, high probability of grain reaching a bin with higher humidity content and grain and non-grain impurities), the yield has to be counted in terms of certified grain (14% of humidity and 100% of purity); this will allow to evaluate the effect of each factor on crop productivity (Moraru and Lubarov, 1989; Rozhkov, 2012b).

The analysis of existing information concerning the research problem confirms the insufficient level of studies, contradictions and lack of systemic approach to define an optimal correlation between seeding rates and seeding practices. In fact, there are no data on the effect of different combinations of plant density and the shape of their nutrition zone on the level of grain productivity of various stem systems (main and lateral rods of different orders) and their contribution to the total production of the plant yield capacity. This is precisely why our research was aimed to identifying the optimal combinations of sowing rates with sowing practices, which would allow for the development of the largest sorghum hybrid grain production capacity and determine the effect of different systems of stems on the formation of the highest cereal productivity of grain sorghum hybrids.

2 Methods

The experiments were conducted according to generally accepted technique in the experimental field of Kharkiv NAU named after V.V. Dokuchaiev in 2007–2009, 2012–2015 (Rozhkov et al., 2016). A multi-factor trial was laid out with the method of splitting plots in a four-fold replication. Four hybrids of grain sorghum were studied in the experiment (plots of the first order – factor A):

1 Stepovyi 8 (control)

2 Prime

3 Dash E

4 Sprint W.

Plots of the second order (factor B) were two wide sowing practices with row spacing 45 cm and 70 cm, plots of the third order (factor C) – four variants of sowing rate: 120, 160, 200 and 240 th pcs/ha. The area of an elementary reporting plot of the trial was 20.0 $_{M}$2.

The soil of an experimental plot was chornozem typical heavy loam on carbonate loess. Humus content in a plowing layer was 4.4%–4.7%, liable phosphorus (according to Chirikov) – 13.8 mg, potassium – 10.3 mg per 100 g of the soil.

The climate of the study area is characterised by a temperate continental climate. A disproportion between the high fertility of the soil and a warm vegetative period, on the one hand, and a water deficit with some signs of drought, on the other hand, is clearly visible. The main limiting factor for realising biological potential is moisture.

Weather conditions of 2007–2009, 2012–2015, as to temperature indicators (first of all in 2010 and 2012), precipitation amount and their distribution, differed greatly from average-multi-year indicators, and in some period, they approached the extreme ones. This made it possible to do a comprehensive research of the effect of the studied elements of the production technology on the adaptive ability of grain sorghum plants to the variability of abiotic factors.

In 2009, 2012–2013 a vegetative period of sorghum was very dry (HTC < 0.8), in 2008 – moist enough (HTC < 1.), and in 2007, 2014–2015 – dry. The amount of precipitation in different places varied greatly. Quite often precipitation deficit was together with high temperatures, which, to some extent, affected the nature of grain crop development and reduced the realisation level of their genetic potential. However, weather conditions for grain sorghum were within biologically admissible.

Essential differences in the main meteorological indicators in the years of research made it possible to thoroughly identify the effect of the above-mentioned elements of the production technology on the realisation level of the genetic potential of grain productivity of the studied hybrids of grain sorghum.

During the growing season in the main stages of varieties and sorghum hybrids performed biometric measurements: plant height, area leaf surface, the yield of green mass. Phonological observations were carried out on permanently dedicated sites in two non-contiguous repetitions. At the beginning of the phase, the time of its onset was taken at 10%, and for the full phase – in 75% of plants. Be sure to note the date of sowing and passing major phases of development. The crop density was determined twice during the growing season on the same fixed areas that have been allocated after the emergence of the stairs. The first count carried out in the phase of complete sprouting, the second – before harvesting. By the first accounting, data determined the field germination of seeds and formed density according to the scheme of experience, and the second – the conservation of plants by the growing season.

Soil moisture in the test plots was determined by thermostatic method on two replicates of the experiment. Soil samples were taken in 10 cm layers to a depth of 0–100 cm to calculate the total water consumption of sorghum. Repeat definition twice.

Elements of structural and morphological indicators of productivity ten typical plants selected from each site were examined. Determined the length and mass of the parish, the mass of grain in the parish, the ratio of mass grain to the parish weight, 1,000 grains.

Harvesting and accounting were carried out in the full ripeness phase of the grain method of continuous threshing of the whole area of the accounting area. Direct combining using a breeding combine Sampo-130 performed collection.

The results of measurements, determinations and accounting of yield were subjected computer-aided analysis and analysis techniques, using field guidelines experiments.

Farm practices in growing grain sorghum in the conducted experiments were generally accepted for the Eastern forest-steppe zone of Ukraine, except for technological elements under study (sowing rates and sowing practices). The fore crop in the trial was spring barley, which was grown using agro-technical recommendations accepted for the region. When the fore crop was harvested, the field was scuffled with a disc plow БДТ-3.0 at 10–12 cm depth with the interval of 14 days, which helped destroy most of the weeds and plow down crop residues. 2–3 weeks later plowing with ПЛН-5-35 plow was done at the depth of 24–26 cm.

Pre-sowing tillage, considering research variants, was carried out in compliance with the farm practices, generally adapted to the region under study. A spring set of processes began with early spring soil harrowing. Then two cultivations – the first one at the depth of 10–12 cm, the second one (pre-sowing) – at the depth of seed plowing down – 6–8 cm – were carried out. Sowing was done with СН-16 seeder at the depth of 6–8 cm, sowing rates were those defined in the trial scheme. To control a complex of diseases, seeds were treated with system preparation Vitavaks 200 ФФ, 34% в.с.к. (2.5 l/тт). After sowing, the soil was cultivated with ring-crowfoot 3ККШ-6 rollers. Sorghum fields were treated with insecticide Fastak (0.3 l/ha) against pests during the formation of generative plant organs. Inter-row cultivations were carried out in the period of vegetation.

3 Results and findings

The results received prove a considerable effect of the studied technological factors on the level of grain productivity of grain sorghum hybrids. Yield of sorghum grain underwent bigger changes under the effect of sowing rate. It ranged within 4.45 t/ha (sowing rate – 120 th. pcs./ha) and 6.39 t/ha (sowing rate – 240 th. pcs./ha) (Table 1).

It is important to state the tendency towards reduction of grain yield increase under gradual increase of sowing rate at the range accepted in the trial – 40 th. pcs./ha. In particular, if sowing rate increases from 120 to 160 th. pcs/ha, sorghum grain yield increases by 1.24 t/ha on the average, and with the increase of sowing rate from 200 to 240 th. pcs./ha – it increases only by 0.01 t/ha. The analysis of the main effect of such factor as sowing rate did not show any important difference between indicators of sorghum grain yield, which were received when sowing rate was 200 and 240 th pcs./ha. According to the results of the statistical analysis with the use of Duncan range criterion, it was found out that they belonged to the same range group which proved inexpediency to increase sowing rate of the studied sorghum hybrids from 200 to240 th pcs./ha.

A similar regularity was observed when partial comparisons of grain yield indicators of sorghum hybrids were analysed at different sowing rates on the studied variants of row spacing width. In particular, a serious increase of grain yield was recorded only when sowing rate was up to 200 th pcs./ha, and further on it increased slightly and in some variants it even decreased.

The tendency towards a smaller increase of the yield indicators of sorghum grain along with the increase of sowing rate with row spacing 70 cm was important. We consider it to be quite regular, as with this row spacing width and increased sowing rate the competition among plants in the fields will be higher, besides, favourable conditions are created for weeds and their larger 'pressure' on sorghum plants. On the average, the difference in grain yield indicators by hybrids in the studied variants with row spacing width 45 cm – was 2.22 t/ha (49.2%), with row spacing 70 cm – 1.65 t/ha (37.6%).

Table 1 Grain yield of grain sorghum hybrids depending on the effect of sowing rate and row spacing width, t/ha

Hybrid (factor A)	*Sowing rate th. pcs./ha, (factor C)*	*Row spacing width (factor B)*				*Average by sowing practices*	
		45 cm		*70 cm*			
		Indicator	*RG**	*Indicator*	*RG*	*Indicator*	*RG*
Stepovyi 8	120	4.27	I	4.11	I	4.19	I
	160	5.50	II	5.28	II	5.39	II
	200	6.23	III	5.61	III	5.92	III
	240	6.28	III	5.53	III	5.91	III
Prime	120	4.26	I	4.22	I	4.24	I
	160	5.48	II	5.25	II	5.37	II
	200	6.31	III	5.93	III	6.12	III
	240	6.42	III	5.80	III	6.11	III
Dash *E*	120	4.90	I	4.80	I	4.85	I
	160	6.31	II	6.08	II	6.20	II
	200	7.25	III	6.75	III	7.00	III
	240	7.23	III	6.61	III	6.92	III
Sprint *W*	120	4.61	I	4.41	I	4.51	I
	160	5.90	II	5.69	II	5.80	II
	200	6.84	III	6.14	III	6.49	III
	240	6.96	IV	6.20	III	6.58	III
Average by hybrids	Stepovyi	5.57	I	5.13	I	5.35	I
	Prime	5.62	I	5.30	I	5.46	I
	Dash *E*	6.42	III	6.06	III	6.24	III
	Sprint *W*	6.08	II	5.61	II	5.85	II
Average by sowing rate	120	4.51	I	4.39	I	4.45	I
	160	5.80	II	5.58	II	5.69	II
	200	6.65	III	6.11	III	6.38	III
	240	6.73	III	6.04	III	6.39	III

Notes: *RG – range groups by statistic analysis made with the use of Duncan range criterion.
Average in 2007–2009, 2012–2015.

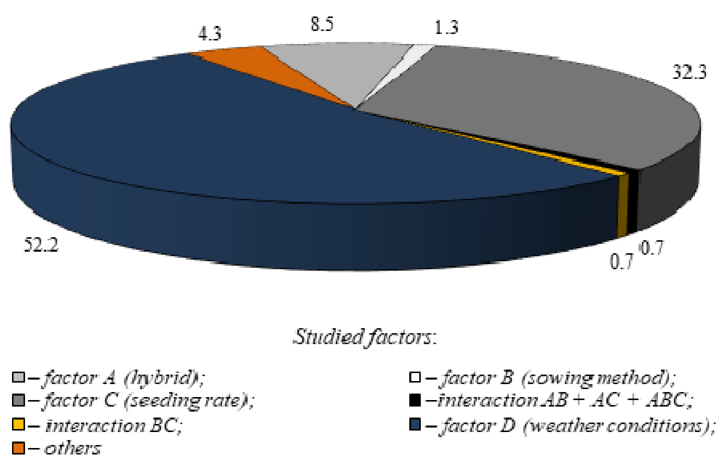
On the average in the years of research, the maximal grain yield – 6.24 t/ha – was produced by grain sorghum hybrid Dash E. It is important to underline the advantage of this hybrid in all the studied variants of sowing rate and row spacing width. With row spacing 45 cm, the best sowing rate for this hybrid was 200 th pcs./ha, which ensured the highest statistically reliable increase of grain yield. If to compare with sowing rate 160 th pcs./ha, grain yield increased by almost 15.0%.

When row spacing is 70 cm, it is advisable to differentiate sowing rate considering weather conditions, as in less favourable years the difference in the yield indicators of sorghum grain in the variants with sowing rate 160 and 200 th pcs./ha was minimal. Thus, it is recommended for grain sorghum hybrid Dash E to have sowing rate 160 th pcs./ha in wide sowings with row spacing 70 cm in expected unfavourable years.

Based on the studied technological factors of hybrid Prime, a serious increase of grain yield indicators, as compared with the control, was not recorded, but it showed a positive tendency towards the increase of grain yield productivity in comparison with the control, and in some years, namely in the year of 2007, the grain yield of this hybrid was much higher than that of the control.

The analysis of the studied factors as sources of the effect on the variability of grain yield of grain sorghum showed a dominant role of weather conditions of a vegetative period, the share of which exceeded 50% (Figure 1). Among the technological factors, sowing rate had the largest effect on the variability of sorghum grain yield. Its share in a general change of grain yield indicators was 32.3%. About 8.5% of the change of this indicator was due to hybrid peculiarities, and only 1.3% of the indicator variability depended on the effect of different width of row spacing.

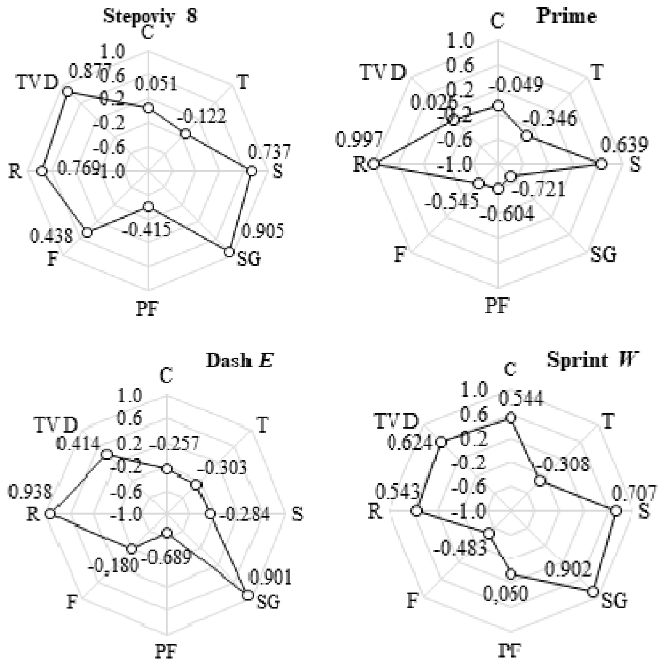
Figure 1 Shares of studied factors in variability of yielding indicators of grain sorghum hybrids, % (see online version for colours)



A specific connection between grain yield and pheno-phase duration of the plant development of the studied sorghum hybrids was mentioned in the trial. In particular, between grain yield and duration of the 'emergence-third leaf' period in the fields sown with Stepovyi 8 and Prime there was no connection – r = 0.051 and r = 0.049 respectively, in the fields sown with hybrid Dash E this connection was weak reverse – r = –0.257, and in the fields of hybrid Sprint W – average straight – r = 0.544 (Figure 2).

In the fields of all sorghum hybrids studied, the only common factor was the close and average relationship between grain yield and maturation period duration. These were r = 0.769, r = 0.997, r = 0.938 and r = 0.543 for the Stepovyi 8, Prime, Dash E and Sprint hybrids, respectively. For the other connections, a specific difference, caused by the morphobiotype specificities of the hybrids studied, was recorded.

Figure 2 Correlative pleiads of links between grain yielding capacity and duration of phenol-phase development of grain sorghum hybrids



Notes: Symbols: Plant development phases: C – emergence-third leaf; K – tillering; T – hooting; SG – stem growth; PF – panicle formation; F – flowering; R – ripening; TVD – total vegetation duration.

The organic grain yield is formed from all the structural components of the yield and is the final result of the efficiency of the use of these elements or other elements of the cultivation technology. The biological yield, compared to that of production, makes it possible to make a detailed analysis of the efficiency of use of certain elements and to identify a difference between them. Here, it is very important to indicate that it is possible to determine the share of each stem system and even of each grain fraction in the formation of total grain productivity of plants through a detailed analysis.

Also, it is necessary to define the role of each stem system in the formation of total biological grain yield of the plants in the experiments aimed at the identification of optimal competition parameters due to the formation of various indicators of plant density and the nature of plant distribution on the surface, i.e., due to the form of the nutrition area. Several indicators prove that main stems develop better grains with high sowing properties, so it is very important to find out the role of various stem systems in the formation of total plant productivity.

In the experiments conducted, the organic grain yield of the main stem system increased steadily as the sowing rate gradually increased. A decrease in the intensity of organic grain yield was recorded in the event of a gradual increase in sowing rate to a constant indicator – 40 th. pcs./ha. On average, according to other factors, when the sowing rate was increased from 120 to 160 th. pcs./ha the biological grain yield of the main stem system increased by 1.10 t/ha (28.0%), when sowing rate was from 160 to

200 th. pcs./ha – by 0.82 t/ha (16.3%) and when sowing rate was 200 to 240 th. pcs./ha biological grain yield increased only by 0.26 t/ha, or 5.9% (Table 2).

Table 2 Biological grain yield of main stem systems of grain sorghum hybrids depending on the effect of sowing rates and sowing practices, t/ha

Row spacing width, cm (factor B)	*Sowing rate, th./ha (factor C)*	*Hybrid (factor A)*				*Average*
		Stepovyi 8	*Prime*	*Dash E*	*Sprint W*	
45	120	3.47	3.94	4.10	4.33	3.96
	160	4.41	5.19	5.33	5.59	5.13
	200	5.19	6.11	6.26	6.61	6.04
	240	5.37	6.47	6.65	6.94	6.42
70	120	3.33	4.01	4.07	4.12	3.88
	160	4.30	4.,90	5.13	5.35	4.92
	200	4.91	5.73	5.87	6.10	5.65
	240	4.98	5.95	6.15	6.37	5.86
Average by factor C	120	3.40	3.98	4.09	4.23	*3.93*
	160	4.36	5.05	5.23	5.47	*5.03*
	200	5.05	5.92	6.07	6.36	*5.85*
	240	5.18	6.21	6.40	6.66	*6.11*
Average by factor B	45	4.61	5.43	5.59	5.87	*5.38*
	70	4.38	5.15	5.31	5.49	*5.08*
Average		*4.49*	*5.29*	*5.45*	*5.68*	*5.23*
SSD_{05} of main effect of factor A						0.17–0.28
SSD_{05} of main effect of factor B						0.10–0.17
SSD_{05} of main effect of factor C						0.19–0.33
SSD_{05} of effect of interaction of AB						0.27–0.42

Note: Average in 2007–2009, 2012–2015.

This trend is regular, as with a gradual increase in sowing rate, in our trial it is 100% (from 120 to 240 th.pcs./ha), and due to increasing competition among plants, both grain productivity of a main stem panicle and sorghum plant preservation till the end of vegetation decrease. For this reason, the organic yield of the main sorghum stalk system increased only by 55.1% when sowing rate was increased by 100%.

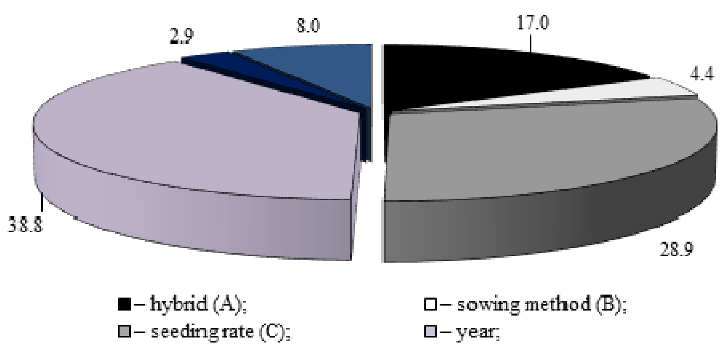
The effect of sowing rate on the variability of the studied indicator is mainly observed in the variants of wide sowing with row spacing 45 cm, because under such plant distribution on the nutrition area, due to the improvement of the nutrition area form of each plant, the competition between plants with similar sowing rates will be lower. Namely, the most important difference between organic grain performance indicators of the main stems system under the effect of sowing rate in the ranks of spacing variations of 45 cm and 70 cm was 62.1% and 51.0%, respectively.

As mentioned above, a wide planting at a spacing of 45 cm rows created more favourable pre-conditions for the plants grow best in the entire range studied sowing rates. All sorghum hybrids reacted in the same way at different row spacing widths. Their effect on the variability of the organic grain yield of the main stem system was observed more clearly in the variants with the maximum sowing rate – 240 th. pcs./ha. Namely, the difference between the performance indicators in biological grain main rod system with different row spacing was 0.08 t/ha (2.1%) in the variants with a sowing rate of 120 e. pcs./ha, while in variants with maximum rate of seedlings, it was 0.56 t/ha (9.6%).

Hybrids Dash E and Sprint W produced the largest biological grain yield of the main stem system. On the average in different years, at different sowing rates and sowing practices, biological grain yield of these hybrids was 5.45 and 5.68 t/ha, respectively, which was higher than that of hybrid Stepovyi 8 by 0.96 and 1.19 t/ha. In the years of the research, hybrids Dash E and Sprint W formed the highest biological grain yield comparing to the control.

The largest changes in biological grain yield of the main stem system of sorghum occurred under the effect of weather conditions of the year. The share of this factor in the indicator variability was 38.8% (Figure 3). Among the studied technological factors, sowing rate had the highest effect on the variability of biological grain yield of the main stem system – 28.9%. The share of hybrid and sowing practice was 17.0% and 4.4%, respectively.

Figure 3 Effect of the studied factors on the variability of biological grain yield of the main stems of sorghum plants, % (factors) (see online version for colours)



Only the interaction between sowing rate and width of row spacing had a considerable effect on the variability of the studied indicator. Approximately 3.0% of yield variability in organic grain from the main stem of sorghum was due to the interaction of these factors. The rest of the interactions had no essential effect on the variability of this indicator.

The analysis of organic grain yield indicators lateral rod system has shown absolutely different regularities of the effect of the variants studied culture technology elements. When sowing rate was increased to 160 th. pcs./ha, biological grain yield of the lateral stem system increased slightly due to the increase of the number of plants with somewhat lower tillering, and when later on sowing rate was increased to 200 and 240 th.pcs./ha, it decreased considerably (Table 3).

A serious decrease of biological grain yield of the lateral stem system of sorghum, when sowing rate was increased to over 160 th. pcs./ha, was caused, first of all, by a serious decrease of tillering productivity. The effect of the interaction of hybrids and sowing rates was not recorded, i.e., for all studied hybrids a similar distribution of the indicators under the effect of the studied variants of sowing rates was recorded.

Table 3 Biological grain yield of lateral stem systems of grain sorghum hybrids depending on the effect of sowing rates and row spacing width, t/ha

Row spacing width, cm (factor B)	*Sowing rate, th./ha (factor C)*	*Hybrid (factor A)*				*Average*
		Stepovyi 8	*Prime*	*Dash E*	*Sprint W*	
45	120	1.08	0.93	1.37	0.62	1.00
	160	1.32	1.14	1.63	0.60	1.17
	200	1.39	1.22	1.81	0.67	1.27
	240	1.01	0.67	1.22	0.43	0.83
70	120	1.25	0.87	1.26	0.47	0.96
	160	1.21	1.07	1.51	0.59	1.10
	200	0.88	0.95	1.38	0.42	0.91
	240	0.58	0.58	0.91	0.27	0.59
Average by factor C	120	1.17	0.90	1.32	0.55	*0.98*
	160	1.27	1.11	1.57	0.60	*1.14*
	200	1.14	1.09	1.60	0.55	*1.10*
	240	0.80	0.63	1.,07	0.35	*0.71*
Average by factor B	45	1.20	0.99	1.51	0.58	*1.07*
	70	0.98	0.87	1.27	0.44	*0.89*
Average		*1.09*	*0.93*	*1.39*	*0.51*	*0.98*
SSD_{05} of the main effect of factor A						0.05–0.10
SSD_{05} of the main effect of factor B						0.05–0.08
SSD_{05} of the main effect of factor C						0.07–0.13
SSD_{05} of the effect of the interaction of AB						0.11–0.19

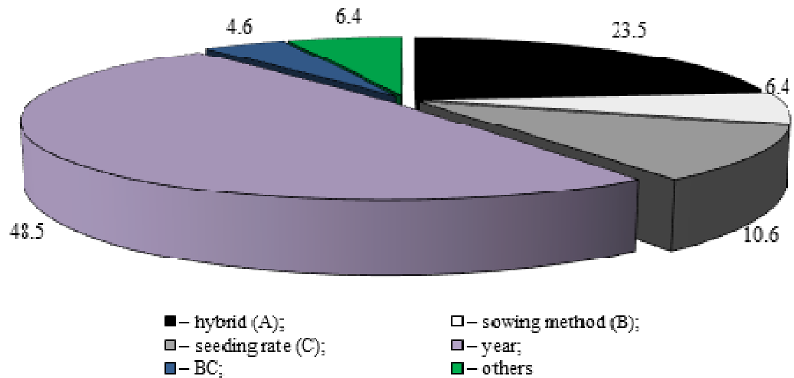
Note: Average in 2007–2009, 2012–2015.

Hybrid Dash E produced the highest biological grain yield of the lateral stem system. This regularity was recorded in all the years of research in all the variants of sowing rate and sowing practice. This is a very important advantage of the mentioned hybrid, as it tries to correct 'mistakes', which were made when choosing sowing rate and sowing practice, and to reach a required productivity level of sorghum sown areas.

Weather conditions of the year had a dominating effect on the variability of the indicators of biological grain yield of the lateral stem system. The share of this factor in the total variability was 48.5%. Among the studied technological factors, hybrid had the highest effect on the variability of biological grain yield of the lateral stem system – 23.5%. The share of sowing rate and sowing practice was the smallest, however statistically proved – 10.6% and 6.4%, respectively (Figure 4). Similar to a studied above indicator, the interaction of the studied variants of sowing rate and width of row spacing had a considerable effect on the variability of biological grain yield of the lateral stem system – 4.6%.

For modelling the formation of hybrid yields grain sorghum is a method of artificial neural networks. Multiple correlations to account for nonlinear patterns of influence of factors on the yield of sorghum grain hybrids were 0.86. As a result of the evaluation the sensitivity of the neural network ranked factors for the influence of dynamics yields of grain sorghum hybrids: in the first place – row spacing, the impact factor is 4.94; on the second year of research (weather conditions) – 3.15; on the third hybrid – 1.38; on the fourth density of standing plants – 1.22, which is a confirmation of the presence of nonlinear regularities formation of grain sorghum hybrids yield and results analysis of variance and regression modelling.

Figure 4 Effect of the studied factors on the variability of biological grain yielding capacity of the main stems of sorghum plants, % (factors) (see online version for colours)



As it was said before, the main role in the formation of total biological grain yield is played by the main stem system which is well explained by a biological peculiarity of sorghum plants to form low total, the more so productive, tillering. In the conducted experiment, on the average by the studied factors, the share of main stems in the formation of total biological grain yield for hybrids Stepovyi 8, Prime, Dash E and Sprint W was 79.7%; 84.9%; 79.3% and 91.5%, respectively (Table 4).

These hybrids differed considerably in the total biological grain yield by the share of various stem systems. The role of the lateral stems in the formation of this indicator was much more important in the sown areas of hybrids Stepovyi 8 and Dash E.

Maximal indicators of biological grain yield of the main sorghum stems of all the hybrids were produced in the variants of maximal sowing rate – 240 th. pcs./ha, however total biological yield of all hybrids was the largest at the lowest sowing rate – 200 th. pcs./ha, and in some variants – at sowing rate 160 th. pcs./ha (Table 5).

The regularity of the enhanced role of the main stems in the formation of the total biological grain yield, when sowing rate increases, results from higher competition among plants, and in turn, grain productivity of the lateral stems, as compared with the stems of the main system, decreases. The increase of biological grain yield in the fields with row spacing 45 cm took place due to both stem systems (main and lateral ones).

The indicator distribution of biological grain yield of both stem systems of grain sorghum, depending on the effect of sowing rate, was identical. The first range group included the indicators which were received in the variants with sowing rate 120 th. seeds/ha, the second range group had the indicators received in the variants with sowing rate 160 th. seeds/ha, and the third group contained the indicators which were received in the variants with sowing rate –200 and 240 th. pcs./ha.

Table 4

Share of different stem systems of grain sorghum hybrids in the formation of biological grain yield depending on the effect of the studied variants of sowing rates and row spacing width, %

Row spacing width, cm (factor B)	*Sowing rate, th. psc./ha (C)*	*Hybrid (factor A)*								*Average*	
		Stepovyi 8		*Prime*		*Dash E*		*Sprint W*			
		*MS**	*LS*	*MS*	*LS*	*MS*	*LS*	*MS*	*LS*	*MS*	*LS*
45	120	76.3	23.7	80.9	19.1	75.0	25.0	87.5	12.5	79.9	20.1
	160	77.0	23.0	82.0	18.0	76.6	23.4	90.3	9.7	81.5	18.5
	200	78.9	21.1	83.4	16.6	77.6	22.4	90.8	9.2	82.7	17.3
	240	84.2	15.8	90.6	9.4	84.5	15.5	94.2	5.8	88.4	11.6
70	120	72.7	27.3	82.2	17.8	76.4	23.6	89.8	10.1	80.3	19.7
	160	78.0	22.0	82.1	17.9	77.3	22.7	90.1	9.9	81.9	18.1
	200	84.8	15.2	85.8	14.2	81.0	19.0	93.6	6.4	86.3	13.7
	240	89.6	10.4	91.1	8.9	87.1	12.9	95.9	4.1	90.9	9.1
Average by factor C	120	*74.5*	*25.5*	*81.6*	*18.4*	*75.7*	*24.3*	*88.7*	*11.3*	*80.1*	*19.9*
	160	*77.5*	*22.5*	*82.1*	*17.9*	*77.0*	*23.0*	*90.2*	*9.8*	*81.7*	*18.3*
	200	*81.9*	*18.1*	*84.6*	*15.4*	*79.3*	*20.7*	*92.2*	*7.8*	*84.5*	*15.5*
	240	*86.9*	*13.1*	*90.9*	*9.1*	*85.8*	*14.2*	*95.1*	*4.9*	*89.7*	*10.3*
Average by factor B	45	*79.1*	*20.9*	*84.2*	*15.8*	*78.4*	*21.6*	*90.7*	*9.3*	*83.1*	*16.9*
	70	*81.3*	*18.7*	*85.3*	*14.7*	*80.5*	*19.5*	*92.4*	*7.6*	*84.9*	*15.1*
Average		*80.2*	*19.8*	*84.8*	*15.2*	*79.5*	*20.5*	*91.6*	*8.4*	*84.0*	*16.0*

Note: Average in 2007–2009, 2012–2015.

Table 5 Total biological grain yield of grain sorghum hybrids and its statistical estimation with the use of Duncan range criterion (C)

Row spacing width, cm (factor B)	*Sowing rate, th. psc./ha (factor C)*	*Hybrid (factor A)*								*Average*	
		Stepovyi 8		*Prime*		*Dash E*		*Sprint W*			
		*BY**	*OG*	*BY*	*OG*	*BY*	*OG*	*BY*	*OG*	*BY*	*OG*
45	120	4.55	I	4.87	I	5.47	I	4.95	I	*4.96*	*I*
	160	5.73	II	6.33	II	6.96	II	6.19	II	*6.30*	*II*
	200	*6.58*	*III*	*7.33*	*III*	*8.07*	*III*	*7.28*	*III*	*7.32*	*III*
	240	6.38	III	7.14	III	7.87	III	7.37	IV	*7.19*	*III*
70	120	4.58	I	4.88	I	5.33	I	4.59	I	*4.85*	*I*
	160	5.51	II	5.97	II	6.64	II	5.94	II	*6.02*	*II*
	200	5.79	II	6.68	III	7.25	III	6.52	III	*6.56*	*III*
	240	5.56	II	6.53	III	7.06	III	6.64	III	*6.45*	*III*
Average by factor C	120	*4.57*	*I*	*4.88*	*I*	*5.40*	*I*	*4.77*	*I*	*4.91*	*I*
	160	*5.62*	*II*	*6.15*	*II*	*6.80*	*II*	*6.07*	*II*	*6.16*	*II*
	200	*6.19*	*III*	*7.01*	*III*	*7.66*	*III*	*6.90*	*III*	*6.94*	*III*
	240	*5.97*	*III*	*6.84*	*III*	*7.47*	*III*	*7.01*	*III*	*6.82*	*III*
Average by factor B	45	*5.81*	*I*	*6.42*	*I*	*7.09*	*I*	*6.45*	*I*	*6.44*	*I*
	70	*5.36*	*II*	*6.02*	*II*	*6.57*	*II*	*5.92*	*II*	*5.97*	*II*
Average		*5.59*	–	*6.22*	–	*6.83*	–	*6.19*	–	*6.21*	–

Notes: * – BY – total biological grain yielding capacity, t/ha, OG – order group.
Average in 2007–2009, 2012–2015.

Due to the fact that grain sorghum belongs to the late spring crops, and the onset of optimal sowing dates coincides with that of a moment characterised by a significant deficit of active soil moisture, the main revenue element of the water balance of culture over the years research was rainfall. Productive precipitation in the average for the years of research was 1,232 m^3/ha and 1,190 m^3/ha at a later time, while the soil moisture content was unstable and fluctuated within 605–705 m^3/ha and depended on the subjects factors. Among the studied grain sorghum hybrids, hybrid Dash E produced the highest biological grain yield – 7.66 t/ha. This hybrid had the highest indicators in all years under study, in all variants of sowing rate and row spacing width, which confirmed a high adaptation ability of the hybrid to weather conditions of the cultivation.

The results of mathematical modelling of the formation process grain sorghum yields under different growing conditions indicate that the highest adaptive capacity with respect to the complex of abiotic and of the left-bank forest-steppe zone biotic conditions is characterised by a Dash E hybrid, good hybrids of Stepovyi 8, Prime also have adaptive capacity.

4 Conclusions

The theoretical justification and the results of experimental studies to determine the optimal sowing norms and density of plants of sorghum grain hybrids Stepovyi 8, Prime, Sprint W, Dash E and the impact of growth regulators on growth and plant development, yield and grain quality in the left-bank forest-steppe zone. A comprehensive analysis of the state of production of sorghum grain in Ukraine indicates a significant level of unused agrobiological and production, the economic potential of the crop, and the environmental properties of grain sorghum fully meet the agroclimatic conditions of the eastern part of left-bank forest-steppe zone.

The practice of wide sowing with row spacing 45 cm in combination with sowing rate 200 th. pcs./ha had an absolute advantage. All studied hybrids of grain sorghum produced the highest grain yield when this combination of sowing rate and row spacing width was used.

If sowing of grain sorghum is done with wide sowing practice and row spacing 70 cm in unfavourable weather conditions, sowing rate can be reduced to 160 th. pcs./ha, because its further increase not always results in the increase of grain yield indicators due to higher competition among plants in the fields.

Hybrids Dash E and Sprint W produced the largest biological grain yield of the main stem system.

Weather conditions of the year had a dominating effect on the variability of the indicators of biological grain yield of the lateral stem system. The share of this factor in the total variability was 48.5%.

All the studied technological factors had the highest effect on the variability of biological grain yield of the lateral stem system. It is very important tendency to improve the elements of sorghum grain growing technology in the conditions of global warming, especially in Ukraine.

References

Ahmad, A., Ahmad, R. and Mahomet N. (2007) 'Production potential and quality of mixed sorghum forage under different intercropping systems and planting patterns', *Pak. J. Agri. Sci.*, Vol. 44, No. 2, pp.203–207.

Alabushev, A.V. and Antipenko, L.N. (2003) *Sorghum (Breeding, Seed Digging, Technology, Economics*, 368pp, Rostov Book Publishing House, Rostov-on-Don.

Aleminew, A. (2015) 'Yield response of local long maturing sorghum varieties to timing of nitrogen fertilizer application in Eastern Amhara Region, Ethiopia', *Journal of Biology, Agriculture and Healthcare*, Vol. 5, No. 3, pp.184–189.

Barbaruk, V.T., Sviridov, A.M. and Lapa, O.M. (2006) *Technology of Cultivation of Grain Sorghum in the Conditions of the Steppe and Eastern Forest-Steppe of Ukraine*, Practical Recommendations, 40pp, Syngenta LLC, Kyiv.

Boyko, M.O. (2016) 'Influence of sowing density and timing of sowing on the productivity of hybrids of grain sorghum in the conditions of the South of Ukraine', *Bulletin of the Agrarian Science of the Black Sea Region*, in Ukrainian, Vol. 3, No. 91, pp.96–104.

Chattha, M., Iqbal, A. and Hassan, M. (2017) 'Forage yield and quality of sweet sorghum as influenced by sowing methods and harvesting times', *Journal of Basic & Applied Sciences*, Vol. 13, No. 1, pp.301–306.

Danilenko, U.L. and Bolotin, A.G. (2005) 'Increase in the yield of grain sorghum in irrigated agro landscapes in the Volgograd Region', *Corn and Sorghum*, Vol. 6, No. 1, pp.21–23.

Demidov, A.I. (1998) *Terms of Sowing of Sugar Sorghum Depending on Varieties, Diet, Norms and Methods of Sowing on Leached Chernozem Zakamya*, 22pp., thesis abstract on competition of a Scientific Degree of Candidate of Agricultural Sciences, Specialty 06.01.09, Saratov.

Dronov, A.V. (2002) 'Cultivation of Sorghum in the Southwest of the Non-Black Earth Region', *Fodder Production*, Vol. 6, No. 1, pp.14–16.

Elkhier, M. and Hamid, A. (2008) 'Effect of malting on the chemical constituents, anti-nutrition factors, and ash composition of two sorghum cultivars (Feterita and Tabat)', *J. Agric. Biol. Sci.*, Vol. 4, No. 5, pp.500–504.

Fernandez, C.J., Fromme, D.D. and Grichar, W.J. (2012) 'Grain sorghum response to row spacing and plant populations in the Texas coastal Bend region', *International Journal of Agronomy*, Article ID 238634, p.6, DOI: doi.org/10.1007/s40003-019-00427-5.

Galichkin, A.I. (2008) *Influence of Seeding Methods, Seeding Rates and Desiccants on the Yield of Green Mass and Sugar Sorghum Seeds on Light Chestnut Soils of the Volgograd Zavolzhy*, 21pp., thesis abstract on competition of a Scientific Degree of Candidate of Agricultural Sciences, Specialty 06.01.09, Volgograd.

Gondal, M., Hussain, A., Yasin, S., Musa, M. and Rehman, H. (2017) 'Effect of seed rate and row spacing on grain yield of sorghum', *SAARC J. Agri.*, Vol. 15, No. 2, pp.81–91.

Karazhbey, G.M. and Tegun, S.V. (2012) *Sorghum Yield of Ordinary Double-Colored (Sorghumbicolor L.) Depending on the Level of Mineral Nutrition and Standing Density*, Vol. 14, pp.67–70, collection of scientific works of the Institute of Bioenergetics Cultures and Sugar Beet NAAS.

Kelly, J. and Lawson, K. (2013) *Arkansas Grain Sorghum Quick Facts*, pp.106–110, University of Arkansas, Fayetteville, USA.

Kiprotich, F., Mwendia, M., Cheruiyot, E. and Wachira, F. (2015) 'Nutritional suitability of bred sorghum (sorghum bicolor) accessions from East Africa', *African Journal of Food Science*, Vol. 9, No. 5, pp.326–333.

Krylov, A.V. and Filatov, V.I. (2002) 'Productivity and main indicators of photosynthetic activity of grain sorghum depending on the norm of sowing', *Corn and Sorghum*, Vol. 3, No. 1, pp.21–24.

Lapa, O.M. and Farafonov, V.A. (2008) 'Cultivation of grain sorghum in Ukraine', *The Manual of the Ukrainian Farmer: Scientific and Practical Collection*, pp.72–76, Znanja, Ukraine.

Makarov, L.X. and Skoriy, M.V. (2009) *Soriz (Technology, Breeding, Seed Production, Processing)*, Monograph, 224pp., Ailant, Kherson.

Malinovskaya, E.V. and Gulov, Y.A. (2006) 'Effect of seed density and intergenotypic competition on the productivity of grain sorghum', *Corn and Sorghum: Scientific and Production Magazine*, Moscow, Vol. 2, No. 3, pp.23–24.

Monteiro, J., Havrland, B. and Ivanova, T. (2012) 'Sweet sorghum (*Sorghum bicolor (L.) moench*) bioenergy value – importance for Portugal', *Acricultura tropica et subtropica*, Vol. 45, No. 1, pp.12–19.

Moraru, G.A. and Lubarov, V.V. (1989) 'The yield of new forms of food sorghum', *Youth in the Intensification of the Agro-Industrial Complex: Collection of Scientific Papers*, 121pp, Hlebizdat, Moscow.

Oprea, C., Bolohan, C. and Marin, D. (2017) 'Effects of fertilization and row spacing on grain sorghum yield grown in south-eastern Romania', *AgroLife Scientific Journal*, Vol. 6, No. 1, pp.173–177.

Ovsienko, I.A. (2015) 'Features of the formation of grain yield of sorghum depending on the timing of sowing', *Agriculture and Forestry*, Vol. 1, No. 2, pp.21–28.

Pashchenko, U.M. and Andrienko, A.L. (2003) 'Plant density of hybrids of sorghum in the conditions of the northern steppe of Ukraine', *Bulletin of the IGC*, Vols. 20–25, No. 1, pp.17–25.

Rozhkov, A.A. (2012a) 'Relationship between crop factors: sowing rate, methods of sowing and friendly development of spring wheat crops', *Crop, Breeding and Seed-Growing, Vegetable Growing*, pp.14–29, KhNAU, Kharkiv.

Rozhkov, A.A. (2012b) 'Estimation of spring wheat crop development by phenological observations', Visnyk PDAA, Vol. 3, pp. 49–55.

Rozhkov, A.A., Puzik, V.K. and Kalenska, S.M. (2016) 'Experimental case in agronomy: tutorial: in 2 books', Book 1, *Theoretical Aspects of the Experimental Case*, 316 pp., Maidan, Kharkiv.

Rukhlevich, N.V. (2017) *Perfection of Methods of Sorghum Cultivation on Grain in the Conditions of the Forest Steppe of the Middle Volga Region*, 19pp., thesis abstract on competition of a Scientific Degree of Candidate of Agricultural Sciences: Specialty 06.01.01, Ust-Kinelsky.

Sauer, S.M., Johnson, J.J. and McMaster, G.S. (2014) 'Agronomic factors affecting dryland grain sorghum maturity and production in northeast Colorado', *Crop Economics, Production & Management*, Vol. 106, No. 6, pp.2001–2011.

Shavsha, N.A. (1982) 'Effect of timing, methods of sowing and seeding rates on yield and seed quality of Sudan grass seeds', *Scientific and Technical Bulletin*, Novosibirsk, Vol. 36, No. 2, pp.24–29.

Shukis, S.K. and Shukis, E.R. (2009) 'Influence of seeding rates and methods of sowing on yield and quality of seeds of sorghum crops', *Bulletin of the Altai State Agrarian University*, Vol. 11, No. 61, pp.5–10.

Snider, J.L., Raper, R.L. and Schwab, E.B. (2012) 'The effect of row spacing and seed rate on biomass production and plant stand characteristics of non-irrigated photoperiodsensitive sorghum', *Industrial Crops and Products*, Vol. 37, No. 1, pp.527–535, DOI: 10.1016/ j.indcrop.2011.07.032.

Staggenborg, S.A., Dhuyvetter, K.C. and Gordon, W.B. (2008) 'Grain sorghum and corn comparisons: yield, economic, and environmental responses', *Agronomy Journal*, Vol. 100, No. 6, pp.1600–1604.