AGRICULTURAL UNIVERSITY - PLOVDIV

DEPARTMENT AGROCHEMISTRY AND SOIL SCIENCE

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EFFECT OF NITROGEN FERTILIZATION ON YIELD AND QUALITY OF GRAIN SORGHUM

ABSTRACT

FOR OBTAINING PHD DEGREE "DOCTOR"

DOCTORAL PROGRAMME – "AGROCHEMISTRY"

PROFESSIONAL FIELD: 04.01.04 AGRONOMY

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PLOVDIV
2020

The research was conducted during the period 2017-2020 at the Department of Plant Breeding at the Agricultural University, Plovdiv.
The dissertation is written on 208 pages and contains 108 tables and 10 figures. The cited literature includes 278 sources, of which 31 in Cyrillic and 222 in Latin.
The dissertation was discussed and focused on the defense of a meeting of the Department of Agrochemistry and Soil Science, Agricultural University - Plovdiv.
The defense of the dissertation will consist of ………. from ……. hours in …………………. of the Faculty of Agronomy at the University of Agriculture - Plovdiv, at a meeting of the Specialized Scientific Jury, appointed by the Rector of the Agrarian University composed of:

Reviews from: ……………

Opinions from: …………………...

The materials on the defense are available to those interested in the library of the University of Plovdiv - and are published on the website of the university.

I express my sincere gratitude to my supervisor Prof. Dr. Svetla Kostadinova, colleagues from the Department of Agrochemistry and Soil Science and others.

1. INTRODUCTION

Sorghum [Sorghum bicolor (L.) Moench] is one of the five most cultivated crops in the world and is grown for various purposes: as food (grain), fodder (grain and biomass), fuel (bioethanol), fiber (paper production)), fermentation (methane production), organic fertilization (use as a by - product).

Sorghum is a tropical plant that originated in Africa and later spread to southern European countries. Although native to the tropics, it is also well adapted to temperate climates. Sorghum has a better ability to tolerate drought stress than other crops.

Sorghum is usually grown under non-irrigated conditions and the lack of moisture in the soil increases the risk of obtaining a potential yield and at the same time limits the responsiveness of the yield to nitrogen fertilization. Nitrogen deficiency in sorghum can reduce water efficiency as a result of low yields and greater evaporation of soil moisture.

The largest producers are the USA, India, China, Mexico and others. In the United States, grain sorghum is considered an extremely effective crop. In the European Union, the production of 600 thousand tons is concentrated mainly in France, Italy and Spain. It is also grown in Romania, Hungary and the countries of the former USSR and Yugoslavia.

The total consumption of 850 thousand tons in Europe exceeds the production, most of which is imported from Spain - 300 thousand tons, Italy - 50 thousand tons and 110 thousand tons from other countries. Imports are mainly from the USA.

2. AIM AND TASKS

The **aim** of this dissertation is to study the influence of nitrogen fertilization on the productivity, quality and efficiency of nitrogen use in sorghum for grain.

Achieving this goal will contribute to optimizing the nitrogen nutrition of sorghum, for agronomically and economically efficient production while protecting the environment and soil fertility.

For the successful implementation of the set goal we set ourselves the following **tasks**:

1. To establish the influence of different levels of nitrogen nutrition on the formation of dry mass, export of nitrogen, phosphorus and potassium and their distribution in sorghum under conditions of pot experiments.

2. To study the productivity and the main quality indicators of sorghum grain depending on nitrogen fertilization.

3. To establish the influence of nitrogen fertilization on the accumulation, distribution and reuse of dry biomass, nitrogen and phosphorus in plants.

4. To study the main indicators for agronomic, energy and economic efficiency of nitrogen fertilization in sorghum.

5. To establish mathematical dependences of productivity, grain quality and basic parameters for nitrogen efficiency in order to optimize nitrogen fertilization in grain sorghum.

3. MATERIALS AND METHODS

2.1 Vegetative pot fertilizer experiments

The first pot experiment was performed under the conditions of a cultivation facility to study the influence of nitrogen nutrition at levels 0 - 800 mg N / kg of soil on the formation and distribution of dry biomass, nitrogen, phosphorus and potassium in the organs of sorghum hybrid EU Alize. The experiment was performed in four replications according to the following scheme:

1. N_0
2. N_{200}
3. N_{400}
4. N_{600}
5. N_{800}

Containers with a volume of 5 L filled with 3.8 kg of air-dry soil from the experimental field on which the field experiment with basic agrochemical characteristics was derived were used: pH water = 7.80, mineral nitrogen content 27.6 mg N / kg soil, mobile phosphates 15.8 mg P_2O_5 / 100 g soil and absorbable potassium 21.0 mg K_2O / 100 g soil. Drainage was placed in each vessel and the water-water regime of the soil was maintained at 65-70% of the field moisture content. Nitrogen levels are created by introducing NH_4NO_3 dissolved in water.

A second pot experiment was performed to study the influence of different levels of mineral nutrition on the formation of dry aboveground mass, the content of nitrogen, phosphorus, potassium and their distribution between the grain and straw of sorghum under the conditions of a cultivation facility. Nitrogen (N), phosphorus (P_2O_5) and potassium (K_2O) levels in the soil were created by adding NH_4NO_3, Ca (H_2PO_4) and KCl dissolved in water. Eight levels of mineral nutrition, studied in four replications, were studied:

1. $N_0P_0K_0$
2. $N_0P_{200}K_{200}$
3. $N_{200}P_{200}K_{200}$
4. $N_{400}P_{200}K_{200}$
5. $N_{600}P_{200}K_{200}$
6. $N_{800}P_{200}K_{200}$
7. $N_{600}P_0K_0$
8. $N_{600}P_{400}K_{400}$.

3.2. Field fertilizer experiment

A field fertilizer experiment was performed in the experimental base of the Department of Plant Breeding, Agricultural University - Plovdiv on alluvial meadow soil under non-irrigated conditions to study the influence of increasing rates of nitrogen fertilization from 0 to 30 kg N / da. The tested levels of nitrogen fertilization are:

1. N_0
2. N_6
3. N_{12}
4. N_{18}
5. N_{24}
6. N_{30}.

The experiment was set by the block method in 4 repetitions with the size of the experimental plot 20.16 m2 (7.20 m length x 2.80 m width). The predecessor of sorghum is wheat. Nitrogen fertilization was performed presowing with NH_4NO_3 with background fertilization with 5 kg P_2O_5 / da and 5 kg K_2O / da as triple superphosphate and potassium chloride, respectively.

Scheme of field fertilizer experiment

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N_6	N_{24}	N_0	N_{12}	N_{30}	N_{18}
N_{18}	N_{12}	N_{30}	N_{24}	N_6	N_0
N_{24}	N_{30}	N_{18}	N_6	N_0	N_{12}
N_0	N_6	N_{12}	N_{18}	N_{24}	N_{30}

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3.2.1. Soil characteristic

Table 1. Content of mineral nitrogen and mobile forms of phosphorus and potassium before sowing of sorghum

Year	0-30 sm			30-60 sm		
	Nmin, mg/kg	P_2O_5, mg/100 g	K_2O, mg/100 g	Nmin, mg/kg	P_2O_5, mg/100 g	K_2O, mg/100 g
2017	27.6	15.8	21,0	22.1	13.9	24.0
2018	33.8	17.3	23.1	20.4	14.1	22.9
2019	31.8	16.9	24.1	24.2	12.8	24.4

The soil is low in mineral nitrogen and well stocked with mobile phosphorus and digestible potassium (**Table 1**). The reaction of the soil from the field on which the experiment was performed (pH_{water}) is slightly alkaline with an average value of 7.80 in the layer 0-30 cm and 7.70 in the layer 30-60 cm.

3.2.2. Climate conditions

Table 2. Temperature of air (°C)

2017 г.								
Months / Ten days	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**
I	-4.4	-0.8	8.8	11.5	16.4	21.1	26.1	28.1
II	-2	1.4	9.3	13.2	18.3	22.1	23.7	26
III	-5.4	9	11.1	13.4	18	28	25.4	22.1
Average	-3.9	3.2	9.7	12.7	17.6	23.7	25.1	25.4
Long-term norm	-0.4	2.2	6	12.2	17.2	20.9	23.2	22.7
2018 г.								
Months / Ten days	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**
I	3.8	6.4	4.5	14.4	18.6	30.8	23.6	31.7
II	2.1	3.9	10.5	15.8	19.1	29.8	25.2	32.1
III	2.8	0.1	6.3	19	19.9	25.9	24.1	32.6
Average	2.9	3.5	7.1	16.4	19.2	28.8	24.3	32.1
Long-term norm	-0.4	2.2	6	12.2	17.2	20.9	23.2	22.7
2019 г.								
Months / Ten days	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**
I	-0.2	5.2	10.9	10.8	15.8	21.2	24.6	24.9
II	2.8	4.9	11.4	11.6	18.1	24.9	21.4	24.1
III	4.9	3.9	9.6	15.3	20.9	24.2	24.5	24.9
Average	2.5	4.7	10.6	12.6	18.2	23.4	23.5	24.6
Long-term norm	-0.4	2.2	6	12.2	17.2	20.9	23.2	22.7

The average monthly air temperatures are close to the multi-year values for the region and during the study period no drastic deviations from the long-term value were reported (**Table 2 and Fig. 1**).

Table 3. Rainfall (mm)

2017 г.								
Months / Ten days	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**
I	22.2	5.4	33.3	1.9	27.2	2.8	7.8	0
II	46.8	3.2	10.3	20.9	0.7	3.3	6.2	7.5
III	1.1	2.5	4.3	3.3	24.8	9.3	15.8	1.7
Average	70.1	11.1	47.9	26.1	52.7	15.4	29.8	9.2
Long-term norm	42	32	38	45	65	63	49	31
2018 г.								
Months / Ten days	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**
I	0.7	12.5	11.4	16	10.5	1.1	54.7	5.2
II	12.9	38	14.6	1.3	52.9	12.3	1.3	5.3
III	8.1	42.1	26.2	7.7	48.9	105.5	38.7	24.6
Average	21.7	92.6	52.2	25	112.3	118.9	94.7	35.1
Long-term norm	42	32	38	45	65	63	49	31
2019 г.								
Months / Ten days	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**
I	2.7	6.9	1.4	46.9	3.6	129.6	29	22.6
II	1.1	4.3	7.2	26.1	4.7	21.7	34.5	5.5
III	27.1	6	0.2	3.5	13	45.4	4	2.5
Average	30.9	17.2	8.8	76.5	21.3	196.7	67.5	30.6
Long-term norm	42	32	38	45	65	63	49	31

The amount of precipitation during the growing season of sorghum in 2017 differs sharply from the long-term value (**Table 3 and Fig. 2**). The precipitation in April and May is 18.9 mm and 12.3 mm less than the long-term average for the respective month. However, the sorghum managed to germinate and germinate normally. Particularly unfavorable in terms of precipitation are the conditions in June, July and August, which are characterized by 4.1, 1.6 and 3.4 times less precipitation compared to the long-term value for the month.

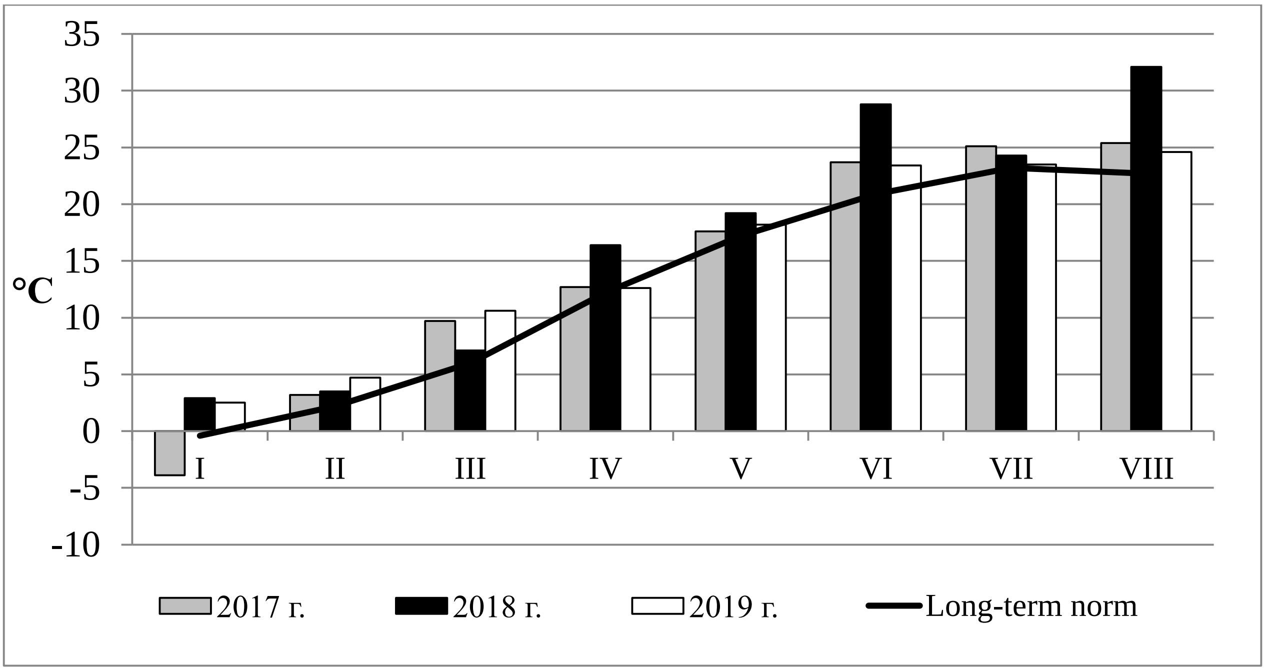

Figure 1. Change in average monthly air temperatures during the sorghum growing season, ^{o}C.

The vegetation period of sorghum in 2018 took place under relatively favorable meteorological conditions (**Tables 2 and 3; Figs 1 and 2**). The amount of precipitation during the growing season of sorghum in 2018 differs sharply from the long-term value. In April, preceding the sowing of sorghum, 20 mm less precipitation fell than the average for the month or almost 2 times less precipitation. The months of May, June and July are extremely humid with precipitation exceeding twice the long-term value for the respective month.

The amount of precipitation during the sorghum growing season in 2019 differs sharply from the long-term value. In the month of May in which the sorghum was sown, 3 times less precipitation fell or 43.7 mm less, compared to the long-term value for the month. The month of June is characterized by extremely uneven distribution of precipitation. During the first ten days of June, 129.6 mm of precipitation fell out of a total of 196.7 mm for the whole month. The excess of the long-term value is 3 times or 133.7 mm more precipitation for the respective month.

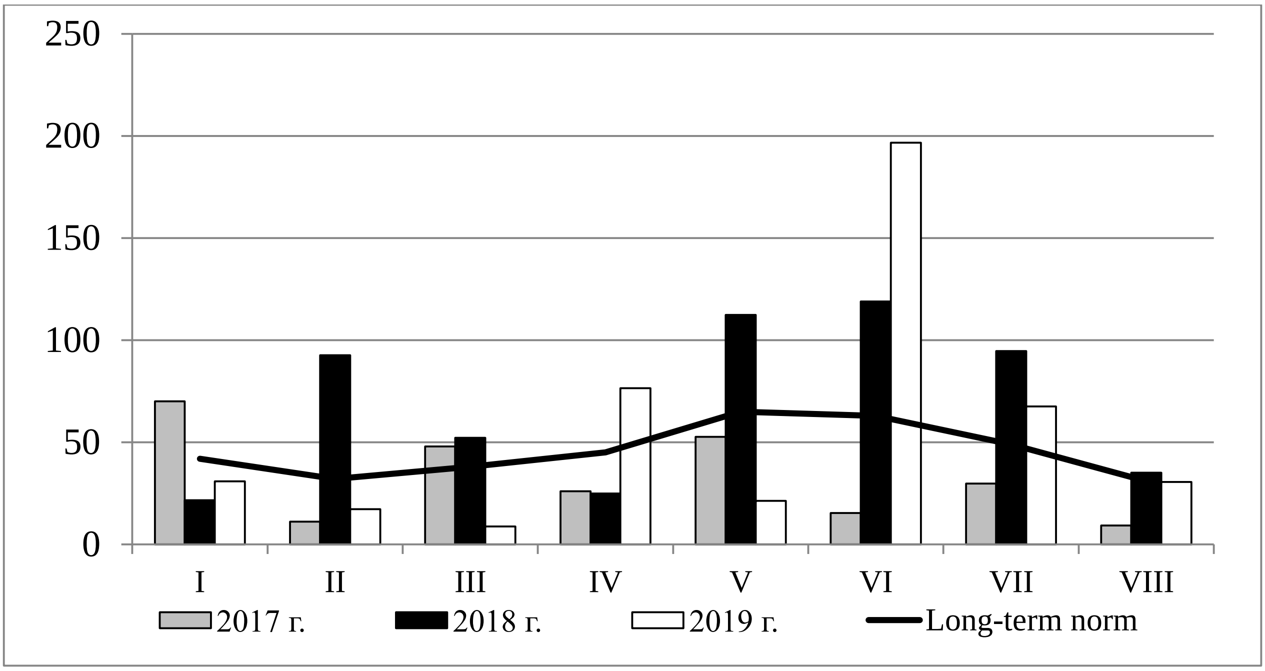

Figure 2. Change in the average monthly amount of precipitation by months during the sorghum growing season, mm.

3.2.3. Plant material and growing conditions

The EU Alize hybrid from the selection of the French agricultural group "Euralis Semences" was studied. He is moderately wounded for grain. In Bulgaria it is an absolute leader for all regions in the country, gives a stable and secure yield in dry conditions. Quickly releases moisture at the end of the growing season. It is characterized by a low plant, resistant to lodging, easy to harvest and low levels of grain scattering during harvesting. There are days to technical maturity 100-115, grain color red, plant height 116 cm, panicle size 27 cm, weight of 1000 seeds 30 g, panicle type semi-open. It is characterized by a fast-initial start, resistant to lodging, drought, grain decay, Fusarium, with a very good Stay Green effect. Recommended growing density 16-19 000 plants per decare and recommended sowing density 20-24 0000 seeds per decare.

3.3. Soil and plant analyzes

Soil analyzes for agrochemical characteristics of the soil include determination of mineral nitrogen (ammonium + nitrate) in an extract with 1% KCl and distillation in the Parnassus-Wagner apparatus; mobile phosphates according to Egner-Reim; digestible potassium in an extract with 2N HCl acid and soil reaction (pH) - potentiometrically in an aqueous extract.

Plant analyzes: The percentage of total nitrogen (N), phosphorus (P_2O_5) and potassium (K_2O) in the plant samples from the vessel experiments and from the field fertilizer experiment was determined after wet mineralization of an aliquot with a mixture of concentrated H_2SO_4 - H_2O_2. The gross energy per 1 kg of absolute pure matter (DAC) was calculated by the formula of Schiemann et al., (1971): BE = 0.0242 SP + 0.0366 CM + 0.0209 SVl + 0.017 BEV - 0.0007 * Zx;

The accumulation, distribution and displacement of dry biomass, nitrogen and phosphorus are determined on the basis of net accumulation of dry mass, nitrogen and phosphorus after the flowering phase. The efficiency of nitrogen fertilization is measured by the indices Partial productivity, Agronomic efficiency, Partial nutritional balance, Return efficiency, Physiological and Internal efficiency. The economic efficiency of fertilization is determined on the basis of the production function for the relationship between the average yield and the different levels of fertilization, the biological and economic optimum are calculated. To find this norm, the standard procedure for maximizing a function is used. The optimization of the process was done with a price of sorghum BGN 0.30 / kg and nitrogen fertilizer BGN 1.11 / kg. For mathematical processing of the obtained results, analysis of variance (ANOVA) for one-factor experiments, Duncan multifactor comparison test (1955), regression analysis was applied. Only the differences at □ = 0.95 are accepted as proven. The statistical package of Excel and SPSS programs is mainly used.

4. RESULTS AND DISCUSSIONS

4.1. Influence of the level of nitrogen nutrition on the dry mass and the content of nitrogen, phosphorus and potassium in young sorghum plants

Young sorghum plants accumulate an average of 2.39 g CM / pot when grown under conditions of good water supply and nitrogen fertilization 0 - 800 mg N / kg of soil (**Table 4**).

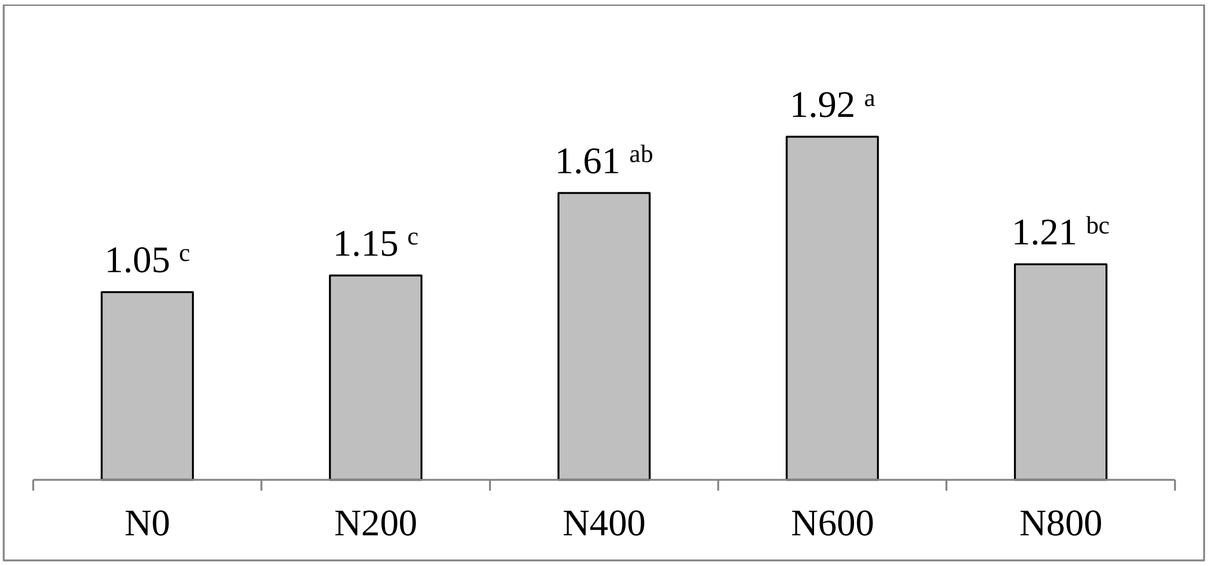

Figure 3. Influence of the level of nitrogen nutrition on the dry biomass of leaves + plant stems, g DM / pot

The largest share of the total dry biomass of plants is distributed on dry mass of roots (41.8%), followed by dry biomass of leaves (33.9%), and the lowest share (24.3%) is the dry biomass of stems. The level of nitrogen has a positive effect on the accumulation of dry biomass in the organs of sorghum (**Table 4 and Fig. 3**). Plants form the largest amount of dry biomass when grown at the N_{600} level. The dry mass of the roots at this level is twice the dry mass of the unfertilized control N0.

Table 4. Influence of the level of nitrogen nutrition on the dry biomass of leaves, stems and roots. g DM / pot

Level	Leafs	% to N_0	Stems	% to N_0	Roots	% to N_0	Plants	% to N_0
N_0	0.63 ^{c}	100	0.43 ^{b}	100	0.96 ^{ab}	100	2.02 ^{c}	100
N_{200}	0.70 ^{c}	110.3	0.45 ^{b}	104.8	1.03 ^{a}	107.2	2.17 ^{bc}	107.7
N_{400}	0.93 ^{ab}	148.0	0.68 ^{ab}	157.3	1.08 ^{a}	112.8	2.69 ^{ab}	133.2
N_{600}	1.04 ^{a}	165.2	0.88 ^{a}	205.5	1.17 ^{a}	121.8	3.09 ^{a}	153.1
N_{800}	0.74 ^{bc}	117.7	0.47 ^{b}	108.8	0.75 ^{b}	77.9	1.96 ^{c}	96.9
Average	*0.81*		*0.58*		*1.00*		*2.39*	

The average concentration of nitrogen in the organs of sorghum plants in phase 4 - 5 leaves is 4.81% N in the leaves, 3.89% N in the stems and 2.33% N in the roots (**Table 5**). The leaves of plants grown without nitrogen fertilization contain 5.01% N. The influence of nitrogen levels on the concentration of nitrogen in the various organs of the plant is one-way.

Table 5. Influence of nitrogen level on nitrogen concentration in sorghum plants, N %

Level	Leafs	% to N_0	Stems	% to N_0	Roots	% to N_0
N_0	5.01 ^{a}	100	3.72 ^{b}	100	1.78 ^{d}	100
N_{200}	4.91 ^{ab}	98.0	3.75 ^{b}	100.9	2.22 ^{c}	124.9
N_{400}	4.85 ^{ab}	96.8	3.87 ^{ab}	104.0	2.23 ^{c}	125.3
N_{600}	4.66 ^{b}	93.0	4.07 ^{a}	109.4	2.48 ^{b}	139.2
N_{800}	4.62 ^{b}	92.2	4.06 ^{a}	109.1	2.95 ^{a}	165.9
Average	*4.81*		*3.89*		*2.33*	

Table 6. Influence of nitrogen level on phosphorus concentration in sorghum plants, P_2O_5%

Level	Leafs	% to N_0	Stems	% to N_0	Roots	% to N_0
N_0	0.558 ^{c}	100	0.634 ^{b}	100	0.528 ^{b}	100
N_{200}	0.589 ^{b}	105.6	0.631 ^{b}	99.6	0.506 ^{b}	95.8
N_{400}	0.633 ^{a}	113.5	0.661 ^{b}	104.2	0.560 ^{ab}	106.0
N_{600}	0.655 ^{a}	117.4	0.762 ^{a}	120.1	0.628 ^{a}	118.9
N_{800}	0.632 ^{a}	113.2	0.751 ^{a}	118.4	0.601 ^{a}	113.8
Average	*0.613*		*0.688*		*0.565*	

The average concentration of phosphorus in sorghum plants has similar values, which are 0.613% P_2O_5 in the leaves, 0.688% P_2O_5 in the stems and

0.565% P_2O_5 in the roots (**Table 6**). Growing plants at a higher level of nitrogen (N_{600} and N_{800}) leads to a significantly higher content of phosphorus in the organs of sorghum.

The highest average potassium concentration of 4.59% K_2O in phase 4–5 sorghum leaves was found in the stems, followed by the potassium content in the leaves, which averaged 4.00% K_2O (**Table 7**).

Table 7. Influence of nitrogen level on potassium concentration in sorghum plants, K_2O%

Level	Leafs	% to N_0	Stems	% to N_0	Roots	% to N_0
N_0	3.64 ^{d}	100	4.02 ^{e}	100	1.72 ns	100
N_{200}	3.79 ^{d}	103.9	4.39 ^{d}	109.2	1.78	103.5
N_{400}	3.97 ^{c}	109.1	4.64 ^{c}	115.4	1.84	107.0
N_{600}	4.20 ^{b}	115.4	4.87 ^{b}	121.1	1.82	105.8
N_{800}	4.42 ^{a}	121.4	5.03 ^{a}	125.1	1.79	104.1
Average	*4.00*		*4.59*		*1.79*	

4.2. Influence of the level of mineral nutrition on the yield and content of nitrogen, phosphorus and potassium in sorghum

The average grain yield of all tested fertilization levels was 56.3 g / container and the average straw yield was 84.0 (**Table 8**). The lowest yield of dry aboveground biomass in maturity was obtained in the unfertilized control. All variants in which nitrogen fertilization N_{200} to N_{800} was applied have been shown to increase the productivity of sorghum compared to the control $N_0P_0K_0$. In grain yield the increase is by 64.0 - 108.6%, and in the obtained straw 82.0 - 144.0%, respectively compared to the yields from unfertilized plants.

Table 8. Yields of sorghum grain and straw depending on the level of mineral nutrition, g / pot

Level	Grain	% to $N_0P_0K_0$	Stover	% to $N_0P_0K_0$
$N_0P_0K_0$	35.0 ^{f}	100.0	45.1 ^{e}	100.0
$N_0P_{200}K_{200}$	39.2 ^{f}	112.0	51.9 ^{e}	115.1
$N_{200}P_{200}K_{200}$	57.4 ^{d}	164.0	82.1 ^{d}	182.0
$N_{400}P_{200}K_{200}$	68.5 ^{bc}	195.7	102.7 ^{b}	227.6
$N_{600}P_{200}K_{200}$	73.0 ^{a}	208.6	110.0 ^{a}	244.0
$N_{800}P_{200}K_{200}$	47.0 ^{e}	134.3	80.1 ^{d}	177.6
$N_{600}P_0K_0$	61.1 ^{c}	174.6	93.1 ^{c}	206.5
$N_{600}P_{400}K_{400}$	69.1 ^{ab}	197.1	107.0 ^{ab}	237.3
Average	*56.3*		*84.0*	

The concentration of nitrogen in the sorghum grain increases significantly in parallel with the increase in the amount of imported nitrogen 200, 400, 600 and 800 mg N / kg of soil combined with phosphorus-potassium fertilization $P_{200}K_{200}$. The effect of $N_{600}P_0K_0$ nitrogen fertilization alone on the grain nitrogen percentage is unproven compared to variants $N_{600}P_{200}K_{200}$ and $N_{800}P_{200}K_{200}$. (**Table 9**)

The positive effect of nitrogen in levels N_{400}, N_{600} and N_{800} on the nitrogen content in the sorghum straw was proved and the increase was by 10.0 to 44.6% compared to that in the unfertilized control. Straw has the highest nitrogen concentration when sorghum is grown at high nitrogen levels $N_{800}P_{200}K_{200}$, but the differences with variant $N_{600}P_{200}K_{200}$ have not been mathematically proven.

The concentration of nitrogen in the sorghum straw in the variant fertilized only with nitrogen $N_{600}P_0K_0$ is 1.10%.

Table 9. Concentration of nitrogen in the grain and straw of sorghum depending on the level of mineral nutrition, N%

Level	Grain	% to $N_0P_0K_0$	Stover	% to $N_0P_0K_0$
$N_0P_0K_0$	1.65 ^{f*}	100.0	0.90 ^{ef}	100.0
$N_0P_{200}K_{200}$	1.69 ^{f}	102.4	0.87 ^{f}	96.9
$N_{200}P_{200}K_{200}$	1.77 ^{e}	107.3	0.84 ^{f}	93.2
$N_{400}P_{200}K_{200}$	1.83 ^{d}	110.9	0.99 ^{de}	110.0
$N_{600}P_{200}K_{200}$	1.97 ^{c}	119.4	1.22 ^{ab}	135.7
$N_{800}P_{200}K_{200}$	2.03 ^{b}	123.0	1.30 ^{a}	144.6
$N_{600}P_0K_0$	1.99 ^{bc}	120.6	1.10 ^{cd}	122.1
$N_{600}P_{400}K_{400}$	2.14 ^{a}	129.7	1.18 ^{bc}	131.4
Average	*1.88*		*1.05*	

The level of mineral nutrition has a significant effect on the percentage of phosphorus and potassium in the grain and straw in maturity (**Table 10**). The lowest concentration of phosphorus in the grain was obtained in the variant with independent nitrogen fertilization and control.

The grain with the highest concentration of phosphorus was obtained in variant N_{600} in combination with increased levels of phosphorus and potassium $P_{400}K_{400}$. Growing sorghum with self-nitrogen fertilization has a negative effect on the percentage of phosphorus in the grain and leads to values close to the control. Growing sorghum without nitrogen fertilization and self-introduction of phosphorus and potassium has a small effect on the percentage of phosphorus in the grain and the values do not differ significantly from those in the control.

Table 10. Concentration of phosphorus and potassium in the grain and straw of sorghum depending on the level of mineral nutrition, %

Level	% P_2O_5		% K_2O	
	Grain	Stover	Grain	Stover
$N_0P_0K_0$	0.90 [de]	0.29 [bc]	0.31 [f]	0.91 [d]
$N_0P_{200}K_{200}$	0.97 [bcd]	0.33 [a]	0.35 [e]	0.99 [c]
$N_{200}P_{200}K_{200}$	1.01 [ab]	0.27 [c]	0.37 [de]	1.05 [bc]
$N_{400}P_{200}K_{200}$	1.02 [ab]	0.30 [b]	0.41 [bc]	1.12 [ab]
$N_{600}P_{200}K_{200}$	0.99 [abc]	0.33 [a]	0.42 [b]	1.15 [a]
$N_{800}P_{200}K_{200}$	0.93 [cde]	0.29 [bc]	0.39 [cd]	1.12 [ab]
$N_{600}P_0K_0$	0.87 [e]	0.27 [c]	0.30 [f]	0.85 [d]
$N_{600}P_{400}K_{400}$	1.05 [a]	0.23 [d]	0.45 [a]	1.18 [a]
Average	*0.97*	*0.29*	*0.38*	*1.05*

4.3. Productivity of sorghum depending on nitrogen fertilization

Nitrogen fertilization has a proven positive effect on sorghum grain yield during the three experimental years and the average for the period. Grain yield on average from the tested norms of nitrogen fertilization is the lowest in the dry year 2017 and the highest in 2018, as the experimental 2019 occupies an intermediate position (**Table 11**).

Table 11. Yield of sorghum grain (kg / da) depending on nitrogen fertilization.

A. Norm	2017 г.	2018 г.	2019 г.	2017-2019 г.
N_0	457 ^{d}	502 ^{d}	489 ^{e}	482.7 ^{c}
N_6	490 ^{c}	544 ^{c}	516 ^{d}	516.7 ^{bc}
N_{12}	538 ^{b}	609 ^{b}	576 ^{bc}	574.3 ^{ab}
N_{18}	575 ^{a}	681^{a}	634 ^{a}	630.0 ^{a}
N_{24}	545 ^{b}	695 ^{a}	658 ^{a}	632.7 ^{a}
N_{30}	536 ^{b}	618 ^{b}	594 ^{b}	582.7 ^{ab}
B. Year	*523* ^{b}	*608* ^{a}	*578* ^{ab}	

Table 12. Yield of sorghum grain protein (kg / da) depending on nitrogen fertilization.

A. Norm	2017 г.	2018 г.	2019 г.	2017-2019 г.
N_0	50.8 ^{d}	55.1 ^{e}	53.4 ^{f}	53.1 ^{c}
N_6	55.5 ^{c}	64.3 ^{d}	61.7 ^{e}	60.5 ^{b}
N_{12}	65.1 ^{b}	75.4 ^{c}	72.6 ^{d}	71.0 ^{ab}
N_{18}	70.8 ^{a}	87.3 ^{ab}	82.0 ^{b}	80.1 ^{a}
N_{24}	67.7 ^{ab}	90.7 ^{a}	86.6 ^{a}	81.7 ^{a}
N_{30}	68.4 ^{ab}	82.7 ^{b}	79.5 ^{c}	76.8 ^{a}
B. Year	*63.1* ^{ns}	*75.9*	*72.6*	

The results obtained from the present study for the period 2017 - 2019 indicate that the yield of grain protein in the range of 50.8 - 90.7 kg / da as well as the concentration of 11.55 - 13.29% of grain protein in the grain (**Table 12**).

4.4. Main quality indicators of sorghum depending on nitrogen fertilization

4.4.1. Content, export and consumption of nitrogen, phosphorus and potassium in sorghum depending on nitrogen fertilization

Nitrogen fertilization has a positive effect on the percentage of nitrogen in the grain (**Table 13**). The average nitrogen concentration in sorghum grain varies from 1.96 N% at N_0 and up to 2.35% at N_{30}. The increase of the average concentration of nitrogen in the grain is up to norm N_{18}, as the differences between this norm and the increased fertilization variants N_{24} and N_{30} are insignificant. Plants grown without nitrogen fertilization contained at least nitrogen in the range of 1.95 and 1.98% N, except in 2017, where the difference between control and N6 was not proven.

Table 13. Nitrogen nitrogen concentration (N%) depending on nitrogen fertilization.

A. Norm	2017 г.	2018 г.	2019 г.	2017 – 2019 г.
N_0	1.98 ^{d}	1.96 ^{e}	1.95 ^{e}	1.96 ^{d}
N_6	2.03 ^{d}	2.11 ^{d}	2.13 ^{d}	2.09 ^{c}
N_{12}	2.16 ^{c}	2.21 ^{c}	2.25 ^{c}	2.21 ^{b}
N_{18}	2.20 ^{ab}	2.29 ^{b}	2.31 ^{b}	2.27 ^{ab}
N_{24}	2.22 ^{ab}	2.33 ^{b}	2.35 ^{ab}	2.30 ^{ab}
N_{30}	2.28 ^{a}	2.39 ^{a}	2.39 ^{a}	2.35 ^{a}
B. Year	**2.14 ns**	**2.22**	**2.23**	

The average concentration of phosphorus in the sorghum grain varies in values of 1.01% P_2O_5 at N_0 and 0.86% at N_{30} (**Table 14**). Plants grown without nitrogen fertilization and under conditions of lower fertilizer rates contain the most phosphorus in the range 1.01 and 1.08% P_2O_5. Sikora et al., (2015) also report a similar grain phosphorus concentration in grain sorghum of 0.60%.

Table 14. Grain phosphorus concentration (P_2O_5%) depending on nitrogen fertilization.

A. Norm	2017 г.	2018 г.	2019 г.	Средно
N_0	1.04 ns	0.97 ns	1.02 [b]	1.01 [ab]
N_6	1.08	1.01	1.07 [ab]	1.05 [a]
N_{12}	1.10	1.03	1.11 [a]	1.08 [a]
N_{18}	0.93	0.86	0.97 [c]	0.92 [bc]
N_{24}	0.85	1.00	0.93 [c]	0.93 [bc]
N_{30}	0.89	0.83	0.85 [d]	0.86 [c]
B. Year	**0.98 ns**	**0.95**	**0.99**	

Table 15. Grain potassium concentration (K2O%) depending on nitrogen fertilization.

A. Norm	2017 г.	2018 г.	2019 г.	2017 – 2019 г.
N_0	0.43 [c]	0.52 [d]	0.49 [c]	0.48 ns
N_6	0.44 [b]	0.58 [c]	0.53 [b]	0.52
N_{12}	0.46 [a]	0.60 [bc]	0.58 [a]	0.55
N_{18}	0.48 [a]	0.64 [a]	0.61 [a]	0.58
N_{24}	0.47 [a]	0.63 [ab]	0.62 [a]	0.57
N_{30}	0.42 [c]	0.50 [d]	0.53 [b]	0.48
B. Year	**0.45 [b]**	**0.58 [a]**	**0.56 [a]**	

The obtained average values for the period 2017 - 2019 do not indicate a proven effect of nitrogen fertilization on the concentration of potassium in the sorghum grain, despite a tendency for higher values with increasing fertilization to N24 (**Table 15**).

The effect of the more favorable in terms of precipitation 2018 and 2019 on the concentration of potassium in the grain of sorghum on average from the tested rates of nitrogen fertilization has been proven compared to the dry 2017.

4.4.2. Influence of nitrogen fertilization on some quality indicators and nutritional value of sorghum grain

The studied nitrogen norms increased the ash content in the grain by an average of 8.3% (N_{24}) to 18.8% (N_6). The accumulation of ash on average for the period 2017-2019 has lower values in the control and higher in the norm N_6 N_{12} and N_{30}. Standard N_{18} and N_{24} occupy an intermediate position and the difference between them has not been proven (**Table 16**).

Table 16. Influence of nitrogen fertilization on the chemical composition of grain in sorghum, average for the period 2017-2019.

N Norm	Dry Matter, %	Raw fats, % to a.d.	Crude fiber, % to a.d.	Ashes, % to a.d.
N_0	88.7 ns	3.42 ns	2.42 ns	1.44 b
N_6	86.4	3.48	2.69	1.71 a
N_{12}	87.9	3.25	2.52	1.65 a
N_{18}	88.8	3.73	2.54	1.58 ab
N_{24}	89.2	4.01	2.42	1.56 ab
N_{30}	88.0	3.74	2.65	1.68 a

Table 17. Gross energy yield from sorghum, MJ / da depending on nitrogen fertilization.

A. Norm	2017 г.	2018 г.	2019 г.	2017-2019 г.
N_0	7759.1 ^{d}	7992.2 ^{f}	7971.1 ^{e}	7907.5 ^{c}
N_6	8072.9 ^{c}	8440.9 ^{e}	8132.4 ^{e}	8215.4 ^{c}
N_{12}	9159.4 ^{b}	9596.6 ^{d}	9326.5 ^{d}	9360.8 ^{b}
N_{18}	9791.3 ^{a}	11026.5 ^{b}	10495.5 ^{b}	10437.8 ^{a}
N_{24}	9279.8 ^{b}	11426.6 ^{a}	11033.0 ^{a}	10579.8 ^{a}
N_{30}	9141.7 ^{b}	9994.8 ^{c}	9578.9 ^{c}	10437.8 ^{a}
B. Year	8867.3 ^{ns}	9984.9	9422.9	

The yield of gross energy from sorghum depending on nitrogen fertilization varies in the range of 7907.5 - 10579.8 MJ / da on average for the period (**Table 17**). The least is the amount of gross energy in the grain during the control and the lower fertilization rate N_6. It was found that sorghum grain contains the highest amounts of energy in plants grown with increased levels of nitrogen fertilization N_{18}, N_{24} and N_{30} and the differences between them has not been proven. At these nitrogen norms, the gross energy yield is in the range of 10437.8 to 10579.8 MJ / da.

4.5. Nitrogen fertilization efficiency of sorghum depending on nitrogen fertilization

The amount of reused nitrogen from sorghum increased on average for the period 2017-2019 with an increase in the nitrogen norm from 3.40 kg N / da in the control N_0 to 6.0 kg N / da in N_{18} (**Table 18**). Sorghum moves the largest average amount of nitrogen 5.81 kg N / da under drought conditions in 2017.

Table 18. Reutilized nitrogen (kg N / da) depending on nitrogen fertilization.

A. Norm	2017 г.	2018 г.	2019 г.	2017-2019 г.	% към N_0
N_0	3.25	3.76	3.19	3.40 ^{ns}	100.0
N_6	3.69	4.36	3.77	3.94	115.9
N_{12}	5.42	4.91	4.33	4.89	143.8
N_{18}	7.38	5.04	5.57	6.00	176.5
N_{24}	7.34	3.47	2.97	4.59	135.0
N_{30}	7.81	2.74	3.72	4.76	140.0
B. Year	*5.81* ^{a}	*4.05* ^{b}	*3.92* ^{b}		

The amount of recycled phosphorus has the lowest values in 2019 (0.26 kg P_2O_5 / da) for variant N_{30} and the highest in 2017. in variant N_{12} (2.43 kg P_2O_5 / da) (**Table 19**).

The amount of removed phosphorus from sorghum on average for the period 2017-2019 decreases with increasing nitrogen norm from 1.64 kg P_2O_5 / da at the control N_0 to 0.53 kg P_2O_5 / da at the high norm N_{30}. Most phosphorus is recycled (average 1.93 kg P_2O_5 / da) at fertilizer rate N_{12} and differences are demonstrated with respect to rates N_{24} and N_{30}.

Table 19. Reutilized phosphorus (kg P_2O_5/da) depending on nitrogen fertilization.

A. Norm	2017 г.	2018 г.	2019 г.	2017-2019 г.	% към N_0
N_0	1.68	1.80	1.45	1.64 ^{ab}	100.0
N_6	1.81	1.39	1.50	1.57 ^{ab}	95.7
N_{12}	2.43	1.28	2.08	1.93 ^{a}	117.7
N_{18}	2.06	0.54	1.32	1.31 ^{abc}	79.9
N_{24}	1.30	0.78	0.81	0.96 ^{bc}	58.5
N_{30}	1.05	0.29	0.26	0.53 ^{c}	32.3
B. Year	*1.72* ^{ns}	*1.01*	*1.23*		

The amount of reused pre-flowering dry mass of sorghum on average for the period 2017-2019 decreases with increasing nitrogen norm from 186.9 kg / da at the low rate N_6 to 55.8 kg / da at N_{30} (Table 20). Sorghum moves the largest average amount of dry mass 194.3 kg / da under drought conditions in 2017. The wetter conditions during the vegetation of 2018 and 2019 have been proven to reduce the recycled dry mass by 63.5% and 40.9%, respectively. The current results prove that in conditions of drought during the growing season of 2017 sorghum accumulates an average

2.72 times more dry mass in the pre-flowering period.

Table 20. Reutilized dry matter (kg/da) depending on nitrogen fertilization.

A. Norm	2017 г.	2018 г.	2019 г.	2017-2019 г.	% към N_0
N_0	180.4	124.7	103.0	136.0 [ns]	100.0
N_6	198.3	180.6	181.8	186.9	137.4
N_{12}	224.9	105.4	207.0	179.1	131.7
N_{18}	207.3	18.3	125.8	117.1	86.1
N_{24}	184.5	0.13	70.8	85.1	62.6
N_{30}	170.6	-3.8	0.7	55.8	41.0
B. Year	*194.3 [a]*	*70.9 [b]*	*114.9 [b]*		

4.5.2. Indicators of nitrogen efficiency at sorghum

The values obtained in the present study for the partial productivity of nitrogen for grain and grain protein on average for the period 2017 - 2019 decrease in parallel with the increase of the nitrogen fertilizer norm (**Table 21 and Table 22**). The decrease of these values at higher nitrogen fertilizer norms is due to the fact that per unit of imported nitrogen a lower production is formed compared to the lower norms. With the highest values on average for the period is the low nitrogen fertilizer rate 6 kg N / da - 86.1 kg / kg for grain and 10.1 kg / kg for grain protein, as the plants use the most efficient nutrient from fertilizer and soil and are proven to exceed the values for all other variants, respectively by 35.9 to 343.6% for grain, and for grain protein by 32.8 to 293.8%. The effect of nitrogen fertilization is the same in each of the experimental years, as the partial productivity of nitrogen for grain and grain protein has been proven to decrease with increasing nitrogen input.

Although higher average values were obtained in individual years for the partial productivity of nitrogen for grain and for grain protein in the wet 2018 and 2019 compared to 2017, the influence of the year has a weak effect on these indicators.

Table 21. Partial productivity of nitrogen per grain (kg N / kg grain) depending on nitrogen fertilization.

A. Norm	2017 г.	2018 г.	2019 г.	2017-2019 г.
N_6	81.6 [a]	90.67 [a]	86.05 [a]	86.11 [a]
N_{12}	44.8 [b]	50.75 [b]	48.02 [b]	47.86 [b]
N_{18}	31.9 [c]	37.83 [c]	35.21 [c]	34.99 [c]
N_{24}	22.7 [d]	28.96 [d]	27.43 [d]	26.37 [d]
N_{30}	17.9 [e]	20.60 [e]	19.79 [e]	19.41 [e]
B. Year	**39.8** ns	**45.76**	**43.30**	

Table 22. Partial nitrogen productivity for cereal protein (kg N / kg cereal protein) depending on nitrogen fertilization.

A. Norm	2017 г.	2018 г.	2019 г.	2017-2019 г.
N_6	9.6 [a]	10.71 [a]	10.29 [a]	10.08 [a]
N_{12}	5.7 [b]	6.28 [b]	6.05 [b]	5.92 [b]
N_{18}	4.1 [c]	4.85 [c]	4.55 [c]	4.45 [c]
N_{24}	2.9 [d]	3.78 [d]	3.61 [d]	3.40 [d]
N_{30}	2.4 [e]	2.76 [e]	2.65 [e]	2.56 [e]
B. Year	**4.9** ns	**5.68**	**5.43**	

The effect of 1 kg of fertilizer nitrogen in moderate fertilization with N_{18} is to obtain 8.17 kg of additional grain yield and an additional yield of 1.50 kg of grain protein. The high nitrogen fertilizer rate of 30 kg N / da reduces the agronomic efficiency on average for the period by 146.1% for grain and 89.9% for grain protein compared to N_{18} and is unjustified. The average increase of the additional grain and grain protein yield per unit of imported nitrogen fertilizer at the introduction of norms in N_6 - N_{24} has close values in the range of 5.65 - 8.17 in grain yield and 1.19 - 1.50 for grain protein (**Table 23**).

The agronomic efficiency of nitrogen for grain in the dry 2017 has been proven to decrease at high N_{24} and N_{30} norms, which are unjustifiably agrochemically (**Table 23 and Table 24**).

table 23. Agronomic efficiency of nitrogen for grain (kg increase in grain yield / kg N / kg) depending on nitrogen fertilization.

A. Norm	2017 г.	2018 г.	2019 г.	2017-2019 г.
N_6	5.41 [a]	7.00 [a]	4.55 [b]	5.65 [a]
N_{12}	6.71 [a]	8.92 [a]	7.27 [a]	7.63 [a]
N_{18}	6.54 [a]	9.94 [a]	8.04 [a]	8.17 [a]
N_{24}	3.68 [b]	8.04 [a]	7.06 [a]	6.26 [a]
N_{30}	2.61 [b]	3.87 [b]	3.49 [b]	3.32 [b]
B. Year	**4.99** ns	**7.55**	**6.08**	

Table 24. Agronomic efficiency of nitrogen for grain protein (kg N / kg of grain protein) depending on nitrogen fertilization.

A. Norm	2017 г.	2018 г.	2019 г.	2017-2019 г.
N_6	0.83 [abc]	1.53 [a]	1.39 [b]	1.24 [a]
N_{12}	1.25 [a]	1.69 [a]	1.60 [a]	1.50 [a]
N_{18}	1.16 [a]	1.79 [a]	1.59 [a]	1.50 [a]
N_{24}	0.74 [bc]	1.48 [a]	1.38 [b]	1.19 [a]
N_{30}	0.61 [c]	0.92 [b]	0.87 [c]	0.79 [b]
B. Year	**0.92** [b]	**1.48** [a]	**1.37** [a]	

While the conditions of the year have a weak effect on the agronomic efficiency of nitrogen for grain and the increase in values in the wetter 2018 and 2019 is a trend, in the agronomic efficiency of nitrogen for grain protein are proven to be higher and exceed by 160.9 and 148.9% of the values in 2017 (**Table 23 and Table 24**).

4.6. Mineral balance of nitrogen, phosphorus and potassium in sorghum

Table 25. Mineral balances of nitrogen, phosphorus and potassium

Norm	2017 г.	2018 г.	2019 г.	2017-2019 г.
± kg N/da				
N_0	-9.06	-9.84	-9.54	-9.48 ^{f}
N_6	-3.91	-5.48	-5.02	-4.80 ^{e}
N_{12}	0.37	-1.46	-0.96	-0.69 ^{d}
N_{18}	5.35	2.41	3.36	3.71 ^{c}
N_{24}	11.91	7.82	8.53	9.42 ^{b}
N_{30}	17.79	15.21	15.81	16.27 ^{a}
Year	**3.74**	**1.44**	**2.03**	
± kg P_2O_5/da				
N_0	0.26	0.15	0.01	0.14 ^{a}
N_6	-0.30	-0.48	-0.52	-0.44 ^{ab}
N_{12}	-0.93	-1.25	-1.40	-1.19 ^{b}
N_{18}	-0.34	-0.87	-1.15	-0.79 ^{ab}
N_{24}	0.39	-1.92	-1.12	-0.89 ^{ab}
N_{30}	0.24	-0.11	-0.05	0.03 ^{a}
Year	**-0.11**	**-0.75**	**-0.70**	
± kg K_2O/da				
N_0	3.03	2.40	2.60	2.68 ^{a}
N_6	2.82	1.86	2.26	2.32 ^{ab}
N_{12}	2.51	1.34	1.66	1.84 ^{ab}
N_{18}	2.24	0.65	1.13	1.34 ^{b}
N_{24}	2.45	0.65	0.92	1.34 ^{b}
N_{30}	2.75	1.89	1.85	2.16 ^{ab}
Year	**2.63**	**1.46**	**1.74**	

The mineral nitrogen balance showed positive mean values in all three experimental years in the range of 1.44 to 3.74 kg N / da (**Table 25**). The mineral nitrogen balance on average for the period 2017-2019 has negative values up to norm N_{12}, after this norm it becomes positive. The differences between the introduced nitrogen in the soil and the export of nitrogen with the sorghum grain at moderate and higher (N_{18}, N_{24}, N_{30}) norms are positive and its values increase in parallel with the applied nitrogen.

On average for the period 2017-2018, the mineral balance of phosphorus changes in a relatively narrow range from -1.19 kg P_2O_5 / da at N_{12} to 0.14 kg P_2O_5 / da in the nitrogen-free control. The phosphorus balance in the control N_0 was slightly positive during the three years of the study as well as on average for the period.

Potassium mineral balance was positive in all three experimental years. An average of 1.34 kg K_2O / da (in N_{18} and N_{24}) to 2.68 kg K_2O / da (in N_0) remains in the soil after sorghum cultivation. The positive balance of potassium is higher in 2017, which is associated with lower grain yields of sorghum and less absorption of potassium in the grain and higher in 2018 and 2019 due to higher yields.

5. CONCLUSIONS

1. Young sorghum plants form the largest amount of dry biomass and absorb more nitrogen, phosphorus and potassium when grown at the N_{600} level. The studied nitrogen levels in the range of 0 to 800 mg / kg have little effect on the amount of nitrogen, phosphorus and potassium distributed in the leaves of plants. The ratio of phosphorus and potassium accumulated in the roots of their total content in plants decreases with increasing levels of nitrogen fertilization.

2. Nitrogen fertilization at levels of 200 to 600 mg N / kg of soil increases grain yield by 64.0 - 108.6% and the highest yield was found in the triple combination $N_{600}P_{200}K_{200}$. Growing sorghum at level $N_{600}P_{400}K_{400}$ forms a grain with the highest concentration of nitrogen, phosphorus and potassium. Self-nitrogen fertilization $N_{600}P_0K_0$ reduces the total export of nitrogen, phosphorus. Growing sorghum at elevated nitrogen level N_{800} results in plants with the lowest nitrogen, phosphorus and potassium harvest index.

3. Fertilization of EU variety Alize with norms of 18 and 24 kg N / da leads to the highest average grain yield of 630.0 kg / da, which is 30.0% above the control. Nitrogen fertilization has a positive effect on grain protein yield and the highest average yield is obtained at levels N_{18}, N_{24} and N_{30}. At a fertilization rate of 24 kg N / da, the sorghum forms an average of 81.1 kg / da of grain protein and exceeds the protein yield of the control by 53.9%. Nitrogen fertilization exceeding 24 kg N / da is not effective in increasing the yield of grain, grain protein and straw. The harvest yield index is higher at lower nitrogen levels. Nitrogen fertilization exceeding 12 kg N / da lowers the grain harvest index. The hectoliter mass of sorghum grain is weakly affected by nitrogen fertilization in norms N_0 - N_{12}. After norm N_{12} this indicator decreases with increasing nitrogen fertilization. The mass of 1000 grains are highest at norm N_{12} and lowest at control and high norm N_{30}. The mass of 1000 grains are more significantly affected by nitrogen fertilization in years with more moisture. Productivity in the EU Alize hybrid is determined mainly by nitrogen fertilization and to a lesser extent by the meteorological features of the growing season. The independent effect of the nitrogen fertilization factor on the yield of grain, straw, grain protein and the yield index of yield is over 50%.

4. The application of nitrogen norm N_{18} results in high values of the average concentrations of nitrogen, phosphorus and potassium in the sorghum grain. The average export of nitrogen, phosphorus and potassium in the aboveground parts of sorghum is the highest at the increased and high nitrogen norm N_{24} and N_{30}. The harvest indices of nitrogen, phosphorus and potassium are the highest in the control and the lowest in the high norm N_{30}. Fertilization with N_{24} and N_{30} increases the consumption of nitrogen, phosphorus and potassium per 100 kg of grain and the corresponding by-products.

5. The chemical composition of the grain is poorly determined by nitrogen fertilization, with the exception of ashes where the effect of nitrogen fertilization on plants not fertilized with nitrogen has been demonstrated. Nitrogen fertilization

at norms 6 - 30 kg N / da increases the gross energy yield from sorghum to the highest average values 10579.8 MJ / da at norms N18 and N24. The additional gross energy yield is the highest at the same norms and the effect of nitrogen fertilization is proven.

6. The reutilization of nitrogen, phosphorus and dry matter has higher average values to norms N_{12} and N_{18} and then decreases. In arid conditions, sorghum reuses 194 kg / da dry matter and 5.81 kg N / da nitrogen, which is 43.4% higher for nitrogen and 174% higher for dry matter than reutilization under wet conditions. Under humid conditions and norm N_{30} sorghum reutilizes nitrogen and phosphorus less than 1 kg per decare. The average efficiency of reutilization of nitrogen, phosphorus and dry mass and their participation in the grain decrease at the increased nitrogen norms with the lowest values at the N_{30} norm. In wetter conditions of the year, the participation of pre-flowering assimilation of dry mass in the grain of sorghum at nitrogen norm N_{30} has values close to zero, which indicates enhanced assimilation after flowering.

7. Nitrogen fertilization is the factor that influences (over 65%) the strongest on the indicators of nitrogen efficiency. The average agronomic efficiency of nitrogen for grain and for grain protein decreases with increasing nitrogen norm above 18 kg N / da. To preserve soil fertility in the long run, 12 kg N / da is effective fertilization, where the average partial productivity of nitrogen is 1.06. Nitrogen fertilization reduces the internal efficiency of using nitrogen for grain, grain protein and grain + straw.

8. The cultivation of sorghum for grain without nitrogen fertilization leads to a negative balance of nitrogen in the soil and fertilizer rates N_6 and N_{12} are also insufficient to compensate for the nitrogen removed from the soil. A positive nitrogen balance of the soil is created at a fertilizer rate of 18 kg N / da and when it is exceeded, an excess of mineral nitrogen remains in the soil and fertilization is unjustified. The phosphorus balance in the soil is negative despite the background fertilization of P_5K_5 and the good stock of the soil with mobile

phosphates, while the mineral balance of potassium remains positive for the whole studied period.

9. Nitrogen fertilization up to norm 18 kg N / da has good profitability. The import of 24 and 30 kg N / da significantly reduces profitability and is not economically justified.

5.1. Recommendations for practice

The EU Alize variety can be recommended for obtaining high and sustainable sorghum grain yields over years with different weather conditions. The variety is characterized by high physical and technological qualities and forms a grain with a high protein content.

For high yields, the optimal level of fertilization is 18 kg N / da in dry years, and in wetter years is 24 kg N / da and this is the limit above which the yield decreases for both grain and grain protein. The use of nitrogen fertilizer rate 30 kg N / da significantly reduces the profitability of production and is not an effective agro-technical activity.

Growing sorghum without nitrogen fertilization and good moisture supply predisposes sorghum plants to grow in an environment that does not meet their needs and nitrogen deficiency is strong. Under the conditions of vascular experience, nitrogen fertilization alone does not significantly affect the productivity and quality of sorghum grain. To achieve maximum results in productivity and quality, it is mandatory to combine nitrogen fertilization with phosphorus-potassium.

Soil fertility would remain relatively stable in the long run when fertilizing sorghum with 12 kg N / da, with a partial nitrogen yield of 1.06 on average. The balance of phosphorus is negative except in the control, which indicates that it is necessary to apply larger amounts of phosphorus fertilizers to maintain the total phosphorus content in the soil.

5.2. Information on the contributions of the dissertation

5.2.1. Scientific and applied contributions

The EC variety Alize stands out as promising in terms of grain and protein yields and has a high harvest index despite years with values differing sharply from long-term values and varying hydrothermal conditions.

The influence of deficient, optimal and high nitrogen fertilization under different hydrothermal conditions on the productivity and quality of sorghum grain has been established.

The complex influence of meteorological factors on the formation of biomass, yield and quality of sorghum grain has been established. The obtained data can be used in the development of quantitative assessments of the impact of current and expected agrometeorological conditions on condition and productivity.

The obtained new information on the concentration, content, distribution, recycling and export of nitrogen, phosphorus, potassium and dry mass and their cost for the formation of 100 kg of grain with a corresponding accumulation of biomass can be used in compiling models for fertilization and process control. when growing sorghum for grain.

New data on physiological efficiency, as well as other indicators of agrochemical efficiency of nitrogen, show that sorghum effectively converts fertilizer nitrogen into grain and grain protein yields, including at low levels of nitrogen nutrition.

Effective fertilization rates for grain sorghum to increase the profitability of production have been substantiated through economic analysis.

In order to avoid depletion of the soil with nitrogen, an optimal nitrogen balance during annual fertilization in the cultivation of sorghum for grain is created by applying a moderate nitrogen norm of 18 kg N / da. The data indicate that a fertilizer rate of 5 kg P205 / da is insufficient to maintain a positive soil phosphorus balance.

Publications in connection with the dissertation

1. **Velinov** I., Todorov Z., Kostadinova S., 2019. Accumulation and distribution of dry mass and nitrogen in sorghum plants grown at different nutritional level, Scientific Papers. Series A. Agronomy, Vol. LXII, No. 1, 2019, 213-218. ISSN 2285-5785; ISSN CD-ROM 2285-5793; ISSN Online 2285-5807; ISSN-L 2285-5785 Bucharest Romania
2. Kostadinova S., Todorov Z., **Velinov** I., 2019. Grain protein of sorghum depending on nitrogen rates, Scientific Papers. Series A. Agronomy, Vol. LXII, No. 1, 2019, 336-341. ISSN 2285-5785; ISSN CD-ROM 2285-5793; ISSN Online 2285-5807; ISSN-L 2285-5785 Bucharest Romania
3. **Velinov** I., 2019. Uptake of phosphorus and potassium in sorghum plants in dependence on nutritional level, Proceedings of the X International Scientific Agricultural Symposium "Agrosym 2019",

Participation in scientific conferences

1. International Conference Agriculture for Life Bucharest, Romania 2019 (article 1 and 2)
2. International Agriculture Symposium "AGROSYM 2019", Jahorina, 3-6 October 2019, Bosnia and Herzegovina (article 3)