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GRAIN PROTEIN OF SORGHUM DEPENDING ON NITROGEN RATES

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Abstract

*The response of grain protein concentration and yield of sorghum to nitrogen fertilization in rates 0, 60, 120, 180, 240 and 300 kg N.ha^{-1} was studied in the experimental field of Agricultural University of Plovdiv, Bulgaria in 2017-2018 under non-irrigated conditions. Without nitrogen fertilization sorghum hybrid EC Alize formed grain with 10.98%-11.10% protein. Rate N_{300} significantly increased concentration of grain protein by 15.0% and 21.9%, respectively in 2017 and 2018, compared to N_0 plants. Fertilization N_{60} - N_{300} proven increased grain protein yield over the N_0. Rate N_{180} provided higher grain protein yield of 708 kg.ha^{-1} in 2017 and higher N_{240} and N_{300} rates showed a downward trend in protein yield within limits 677-708 kg.ha^{-1}. In more favourable in terms of rainfall 2018, the highest grain protein yield 907 kg.ha^{-1} was obtained at N_{240}. Application of N_{300} proven reduced by 80 kg.ha^{-1} the protein yield, compared to N_{240}. Rates 0-300 kg N.ha^{-1} highly positively correlated with grain protein concentration (0.864**-0.962**) and protein yield (0.839**-0.874**) of sorghum.*

Key words: *protein, concentration, yield, grain.*

INTRODUCTION

Sorghum (*Sorghum bicolor* (L.) Moench) is the fifth leading cereal grain produced worldwide after wheat, corn, rice, and barley (FAO, 2013). In Bulgaria the production of grain sorghum has increased in recent years and sorghum is one of the top ten grown crops in the country. The modern varieties are hybrids with high productivity potential appropriate for application of intensive forage grain production technologies (Kertikov, 2007; Kikindonov et al., 2008). This crop has better ability to tolerate drought stress compared with other crops and is known as an index for drought resistance of agronomic crops (Kebede, 2001; Wenzel, 2001). Sorghum is mainly grown under non-irrigated fields where stressful conditions during grain filling can limit productivity and increase the dependence of the yield of spare assimilations (Kaye et al., 2007). It is a multipurpose crop belonging to the Poaceae family, which are C_4 carbon cycle plants with high photosynthetic efficiency and productivity (Tari et al., 2012).

Soil fertility management is important to facilitate the rapid development of sorghum plants, but many agricultural soils have a limited ability to supply available nitrogen for target yields and nitrogen is the most limiting nutrient for cereal crops including for sorghum production (Gerik et al., 2014). Nitrogen is the main nutrient for C_4 plant productivity (Hao et al., 2014). It plays a critical role in cell division during the plant growth (Stals & Inzé, 2001) and the deficit of soil nitrogen leads to lower sorghum biomass due to reductions in leaf area, chlorophyll index, and photosynthetic rate (Zhao et al., 2005; Hirel et al., 2007; Mahama et al., 2014). Nitrogen fertilizer is known to boost the aboveground biomass yield (Amaducci et al., 2004; Anderson et al., 2013). Nitrogen fertilization had a significant impact on the concentration of protein in the grain and grain protein yield (Anfinrud et al., 2013). Application of nitrogen in rates 120-240 kg N.ha^{-1} increase crude protein content to higher levels to support rapid weight gains and milk yields (Hoffman et al., 2001; Kaufman et al., 2013). The nitrogen doses 50-200 kg. ha^{-1} contributed to an increase in the crude protein together with an increase in dry matter and/or protein concentration and crude protein increased 59.5-312.9% (Melo et al., 2017). The phosphorus and potassium fertilization slightly affected grain protein yield of sorghum grown under good phosphorus and potassium soil availability (Franco et al., 2017).

Improper nitrogen fertilization and excess nitrogen resulted in environmental impacts, such as the pollution by nitrate (NO_3-N) leaching and nitrous oxide emissions (Miller & Cramer, 2004; Ramu et al., 2012), as well as increasing production costs (Marsalis et al., 2010). Thus, coordination of sorghum N demand with N supply is critically important to maximize economic efficiency, optimize biomass quality, and minimize loss of soil NO_3-N and environmental pollution (Schroder et al., 2000; Zhu et al., 2000; Rooney et al., 2007; Cui et al., 2008; Meki et al., 2017).

The objective of this study was to determine the effect of nitrogen fertilization rates on the concentration of protein in the grain and grain protein yield of sorghum grown under non-irrigated conditions.

MATERIALS AND METHODS

The investigation was carried out during the period 2017-2018 on the experimental field of Agricultural University of Plovdiv, Bulgaria, under non-irrigated conditions after wheat as predecessor. The effect of nitrogen fertilization in rates 0, 60, 120, 180, 240 and 300 kg $N.ha^{-1}$ on the concentration of protein in the grain and grain protein yield was studied at grain sorghum hybrid EC Alize. The experimental design consisted of a randomized, complete block design with four replications. The size of individual trial plots was 20 m^2. Total nitrogen as NH_4NO_3 was applied as pre-sowing fertilization on the background $P_{50}K_{50}$ fertilization as triple superphosphate and potassium chloride, respectively. Standard farming practices for the region of Southern Bulgaria were applied.

Table 1. Content of available nitrogen, phosphorus and potassium in the soil

Year	Soil depth, cm	N min, $mg.kg^{-1}$	P_2O_5, mg.100 g^{-1}	K_2O, mg.100 g^{-1}
2017	0-30 30-60	27.6 22.1	15.8 13.9	21,0 24.0
2018	0-30 30-60	33.8 20.4	17.3 14.1	23.1 22.9

The soil type of the experimental field is alluvial-meadow *Mollic Fluvisols* (FAO, 2006) with slightly alkaline reaction pH_{H2O} = 7.80. The content of available nutrients in the soil before sowing of the sorghum was determined in soil layers 0-30 and 30-60 cm and pointed out in Table 1. The soil had low content of mineral nitrogen and it was good supplied with available phosphorus (Egner-Ream method) and exchangeable potassium (extracted by 2N HCL).

Meteorological conditions during vegetation period of sorghum were recorded daily in the experimental area and are given in Table 2, together with the long-term average of temperature and precipitations.

Table 2. Hydro-thermal conditions during sorghum vegetation period

Year	April	May	June	July	August
	Temperature (^oC)				
2017	12.7	17.6	23.7	25.1	25.4
2018	16.4	19.2	28.8	30.5	24.2
Long-term norm	12.2	17.2	20.9	23.2	22.7
	Precipitation ($l.m^{-1}$)				
2017	26.1	52.7	15.4	29.8	9.2
2018	25	112.3	118.9	94.7	35.1
Long-term norm	45	65	63	49	31

The values of temperature and precipitations during the vegetation period of sorghum characterized hydro-thermal conditions of 2017 as warm and dry. In contrast, the months of May, June and July of 2018 were characterized as extremely humid. The amount of precipitation exceeded nearly twice the values of long-term norm for the region.

The total nitrogen concentration of sorghum grain in maturity was analyzed by Kjeldahl method after wet digestion by H_2SO_4 and H_2O_2 as a catalyst (Tomov et al., 2009). The grain protein concentration was calculated from the percentage of nitrogen in the grain multiplied by a coefficient of 5.6 (Mariotti et al., 2008). Grain protein yield in $kg.ha^{-1}$ was calculated according to the formula:

(Grain yield in $kg.ha^{-1}$ multiplied by the percentage of protein in the grain)/100.

An overall analysis of variance (ANOVA) was performed to evaluate the effect of the experimental treatments on the referred variables. In order to establish the difference among the means Duncan's multiple range test at level of significance $p \leq 0.05$ was used. The regression analysis was done for assessment of the effect of nitrogen fertilization rates on the grain yield, grain protein concentration and grain protein yield of sorghum. Correlation test with significance level reported ($p < 0.05$ or $p < 0.01$) was based on Pearson's correlation coefficient.

RESULTS AND DISCUSSIONS

During the comparatively dry 2017 experimental year, the average grain yield was 5234 kg.ha^{-1}, and under the meteorologically favourable year of 2018, average grain yield was 6803 kg.ha^{-1} (Table 3). Regarding the grain yield of sorghum, the strong proven effect of the nitrogen fertilization of dose N_{180} was established in 2017. The yield increase was by 25.8% above the control plants. In 2017, the application of N_{120}, N_{240} and N_{300} resulted in similar grain yields 5355-5455 kg.ha^{-1}. Higher grain yields of sorghum in 2018 were found in rates N_{240} and N_{180}, which exceeded the N_0 by 38.4 and 35.7%, respectively.

Table 3. Grain yield of sorghum depending on nitrogen fertilization rates, kg.ha^{-1}

Rates	2017 year	% to N_0	2018 year	% to N_0
N_0	4572 ^{d*}	100	5023 ^{d}	100
N_{60}	4897 ^{c}	107.2	5441 ^{c}	108.4
N_{120}	5378 ^{b}	117.7	6090 ^{b}	121.3
N_{180}	5750 ^{a}	125.8	6812 ^{a}	135.7
N_{240}	5455 ^{b}	119.3	6951 ^{a}	138.4
N_{300}	5355 ^{b}	117.3	6180 ^{b}	123.1
Average	*5234*		*6803*	

*Values with identical letters within each column are not significantly different at $p<0.05$ according to Duncan's multiple range test.

According to various authors, the total nitrogen content in the sorghum grain usually changed from 1% N to 3% N (Singh & Axtell, 1973). The concentration of grain protein ranged from 6% to 18% and the average content was 11% (Lasztity, 1996; de Mesa-Stonestreet et al., 2010). Our results showed the similar values of grain protein in the range of 10.98-13.38% (Table 4). In experimental 2017, the grain protein concentration changed from 11.10% (N_0 control) to 12.77% (N_{300}). The concentration of grain protein in experimental 2018 varied from 10.98% (N_0 control) to 13.38% (N_{300}). The higher average grain protein concentration of all studied nitrogen rates was established in 2018, which characterized as more favourable on precipitation compared to the dry conditions during sorghum vegetation of harvested 2017. In each of the two experimental years, the protein concentration of the grain enhanced with the increase of applied mineral nitrogen. No proven differences of grain protein concentration were found between the control plants and the plants cultivated at low N_{60} rate. A tendency was indicated an increase of the protein concentration of the sorghum grain between the variant of high N_{300} fertilization and N_{180} and N_{240} rates. Application of 300 kg N.ha^{-1} showed a significant higher protein concentration of grain compared to the grain protein percentage of plants cultivated at N_{60} and N_{120} rates. This was observed during both experimental years. Sorghum formed a grain which contained an average of 11.04 % protein when the plants grown without nitrogen fertilization. As the nitrogen fertilization increased to the N_{300} rate, the concentration of grain protein significantly increased up to 12.77% (in 2017) and 13.38% (in 2018). These values were higher by 15.0% and by 21.9%, respectively, compared to N_0 control plants of the two experimental years. The present results confirm the main effect of nitrogen fertilization on the protein concentration in cereals grain and they correspond to the results for grain sorghum of the other researchers (Assefa et al., 2010; Ciampitti et al., 2016; Van Oosterom et al., 2010).

Table 4. Protein concentration of grain of sorghum depending on nitrogen fertilization, %

Rates	2017 year	% to N_0	2018 year	% to N_0
N_0	11.10 ^{c*}	100	10.98 ^{c}	100
N_{60}	11.34 ^{c}	102.2	11.82 ^{bc}	107.7
N_{120}	12.11 ^{b}	109.1	12.38 ^{b}	112.8
N_{180}	12.32 ^{ab}	111.0	12.82 ^{ab}	116.8
N_{240}	12.42 ^{ab}	111.9	13.05 ^{a}	118.9
N_{300}	12.77 ^{a}	115.0	13.38 ^{a}	121.9
Average	*12.01*		*12.40*	

*Values with identical letters within each column are not significantly different at $p<0.05$ according to Duncan's multiple range test.

The results of grain protein yield of sorghum presented in Table 5 indicated that nitrogen application in N_{60} - N_{300} rates significantly increased grain protein yield over the unfertilized control. This was observed in both experimantal years. The hydro-thermal conditions during sorghum vegetation affected the grain and grain protein yields. The sorghum vegetation period of experimental 2018 was characterized with more rainfall. As a result of that, the average grain protein yield of all studied treatments was 759 $kg.ha^{-1}$ or by 127.8 $kg.ha^{-1}$ higher compared to the obtained average protein yield in harvested 2017. Sorghum had the lowest yields of grain protein when cultivated without nitrogen fertilization. In 2017, the obtained grain protein yield from N_0 variant was 508 $kg.ha^{-1}$.

The protein yield of the control plants in harvested 2018 was 551 $kg.ha^{-1}$. Nitrogen fertilization in 60, 120, 180, 240 and 300 kg $N.ha^{-1}$ proven increased yield of grain protein of sorghum in comparison of unfertilized control in both experimental years. The grain protein yields of nitrogen received plants exceeded the yield of N_0 grown plants by 9.3%-39.4% and by 16.7% to 64.6%, respectively, in the harvested 2017 and in 2018 years.

In 2017, grain protein yield increased in a parallel with the levels of applied mineral nitrogen up to the N_{180}. The fertilization rate of 180 kg of $N.ha^{-1}$ provided a high yield of grain protein and the increase was by 39.4% relative to the protein yield of unfertilized control. The results showed a tendency for lower grain protein productivity of sorghum within limits 677-708 $kg.ha^{-1}$ at application of higher N_{240} и N_{300} rates. In 2017, the effect of the higher mineral nitrogen 240 kg $N.ha^{-1}$ and 300 kg $N.ha^{-1}$ on the grain protein yield was mathematically unproven with regard to the obtained grain protein yields of sorghum fertilized with N_{180} and N_{120} rates.

Table 5. Grain protein yield of sorghum depending on nitrogen fertilization, $kg.ha^{-1}$

Rates	2017 year	% to N_0	2018 year	% to N_0
N_0	508 ^{d*}	100	551 ^{e}	100
N_{60}	555 ^{c}	109.3	643 ^{d}	116.7
N_{120}	651 ^{b}	128.2	754 ^{c}	136.8
N_{180}	708 ^{a}	139.4	873 ^{ab}	158.5
N_{240}	677 ^{ab}	133.3	907 ^{a}	164.6
N_{300}	684 ^{ab}	134.6	827 ^{b}	150.1
Average	*631.2*		*759*	

*Values with identical letters within each column are not significantly different at p<0.05 according to Duncan's multiple range test.

In 2018 harvested yiear, which was more favorable in terms of rainfall, the positive effect of applied nitrogen on the protein yield was observred up to the rate N_{240}. The highest grain protein yield (907 kg grain $protein.ha^{-1}$) was obtained with 240 kg $N.ha^{-1}$ application, but the difference with the yield at N_{180} fertilization (873 kg grain $protein.ha^{-1}$) was not proven. Application of the higher N_{300} rate significantly reduced the grain protein yield of sorghum plants by 80 $kg.ha^{-1}$ in comparison with the obtained yield in variant N_{240}.

Table 6. Correlation coefficients of nitrogen fertilization rates with grain yield, grain protein concentration and grain protein yield of sorghum

Year	Grain yield	Grain protein concentration	Grain protein yield
2017	0.724*	0.864**	0.839**
2018	0.770*	0.962**	0.874**

*Correlation is significant at the 0.05 level
**Correlation is significant at the 0.01 level

Positive correlations between examined parameters of sorghum were recorded in the study (Table 6). The results indicated that nitrogen fertilization in rates 0-300 kg $N.ha^{-1}$ was highly positively correlated with the grain yield, grain protein concentration (r = 0.864**) and protein yield (r = 0.839**) in experimental 2017. Also, a positive significant correlation was achieved between the nitrogen fertilization rates and yields of grain and protein, and protein concentration of grain (r = 0.962**) in harvested 2018.

Table 7. Regression models of sorghum grain yield, grain protein concentration and grain protein yield depending on nitrogen fertilization rates.

Parameter	Equation	R^2
2017		
Grain yield	$y = -0.026x^2 + 10.6x + 4497$	0.923
Protein concentration	$y = -1E{-}05x^2 + 0.01x + 11.0$	0.959
Grain protein yield	$y = -0.004x^2 + 1.68x + 494$	0.940
2018		
Grain yield	$y = -0.04x^2 + 17.1x + 4816$	0.884
Protein concentration	$y = -2E{-}05x^2 + 0.014x + 11.0$	0.995
Grain protein yield	$y = -0.006x^2 + 2.83x + 525$	0.947

Regression analysis for the dependencies between the resulting parameters (grain yield, grain protein concentration, and grain protein yield) and the factor nitrogen fertilization on sorghum hybrid EC Alize indicated that correlations were represented by equations of the second degree (Table 7). High values of coefficients of determination ($R^2 > 0.850$) were found for the studied parameters of sorghum productivity in dependence of nitrogen fertilization. The regression model indicated that the grain yield increased with the raise of applied nitrogen rate up to N_{180} and the grain protein concentration increased up to N_{300} fertilization of in both experimental years.

CONCLUSIONS

Without nitrogen fertilization sorghum hybrid EC Alize formed grain with 10.98%-11.10% protein. Applied mineral nitrogen enhanced the protein concentration of sorghum grain, but effect of N_{60} was not proven compared to the N_0 control. Rate 300 kg N.ha^{-1} significantly increased concentration of grain protein by 15.0% and 21.9%, respectively in 2017 and 2018, compared to N_0 plants.

Fertilization N_{60} - N_{300} significantly increased grain protein yield over the unfertilized control. The N_{180} rate provided higher grain protein yield of 708 kg.ha^{-1} in 2017. The increase was by 39.4% relative to the protein yield of N_0 control. Application of higher N_{240} and N_{300} rates showed a downward trend in protein yield within limits 677-708 kg.ha^{-1}. In more favourable in terms of rainfall 2018 harvested yiear, the highest grain protein yield 907 kg.ha^{-1} was obtained at fertilization 240 kg N.ha^{-1}. Application of N_{300} significantly reduced by 80 kg.ha^{-1} the grain protein yield of sorghum, compared to N_{240}. The fertilization in rates 0–300 kg N.ha^{-1} highly positively correlated with grain protein concentration (0.864**-0.962**) and protein yield (0.839**-0.874**).

REFERENCES

Amaducci, S., Monti, A., Venturi, G., (2004). Non-structural carbohydrates and fibre components in sweet and fibre sorghum as affected by low and normal input techniques. Ind. *Crop Prod*., *20*. 111–118.

Anderson, E.K., Parrish, A.S., Voigt, T.B., Owens, V.N., Hong, C., Lee, D.K., (2013). Nitrogen fertility and harvest management of switch grass for sustainable bioenergy feedstock production in Illinois. *Ind. Crop Prod*., *48*. 19–27.

Anfinrud, R., Cihacek, L., Johnson, B.L., Ji, Y., Berti, M.T., (2013). Sorghum and kenaf biomass yield and quality response to nitrogen fertilization in the Northern Great Plains of the USA. *Ind. Crop Prod*., *50*, 159–165.

Assefa, Y., and Staggenborg, S.A. (2010). Grain sorghum yield with hybrid advancement and changes in agronomic practices from 1957 through 2008. *Agronomy Journal*, *102*, 703–706.

Ciampitti, I.A., and Prasad, P.V. (2016). Historical Synthesis-Analysis of Changes in Grain Nitrogen Dynamics in Sorghum. *Front. Plant Sci*., *7*, 275.

Cui, Z., Zhang, F., Chen, X., Miao, Y., Li, J., Shi, L., Xu, J., Ye, Y., Liu, C., Yang, Z., Zhang, Q., Huang, S., Bao, D., (2008). On-farm evaluation of an in-season nitrogen management strategy based on soil Nmin test. *Field Crop Res*., *105*, 48–55.

de Mesa-Stonestreet, N.J., Alavi, A.S., Bean, S.R. (2010). Sorghum Proteins: The Concentration, Isolation, Modification, and Food Applications of Kafirins. *Journal of Food Science*, *75*(5), 90–104.

FAO, 2013. FAOSTAT online database: http://faostat3.fao.org/download/Q/QC/E.

Franco, A. (2011). Marcha de absorção e acúmulo de nutrientes na cultura do sorgo. Dissertação (Mestrado em Produção Vegetal), *Universidade Estadual de Montes Claros*, Beasil, 13–19.

Gerik, T., Bean, B. & Vanderlip, R. (2014). Sorghum Growth and Development, Productivity Rotations on farms in Texas, *7*(3), 2–7.

Hao, B., Xue, Q., Bean, B.W., Rooney, W.L., Becker, J.D., (2014). Biomass production, water and nitrogen use efficiency in photoperiod-sensitive sorghum in the Texas High Plains. *Biomass Bioenergy, 62*, 108–116.

Hirel, B., Le Gouis, J., Ney, B., Gallais, A. (2007). The challenge of improving nitrogen use efficiency in crop plants: towards a more central role for genetic variability and quantitative genetics within integrated approaches. *J. Exp. Bot*., *58*, 2369–2387.

Hoffman, P.C., Esser, N.M., Bauman, L.M., Denzine, S.L., Engstrom, M., Chester-Jones, H., (2001). Short communication: effect of dietary protein on growth and nitrogen balance of Holstein Heifers1. *J. Dairy Sci*., *84*, 843–847.

Kaye, N.M., Mason, S.C., Jackson, D.S., Galusha, T.D. (2007). Crop Rotation and Soil Amendment Alters Sorghum Grain Quality. *Crop Science, 47*, 722–729.

Kaufman, R.C., Wilson. J.D., Bean, S.R., Presley, D.R., Blanco-Canqui, H., Mikha, M. (2013). Effect of Nitrogen Fertilization and Cover Cropping Systems on Sorghum Grain Characteristics, *Journal of Agricultural and Food Chemistry*, *61*, 5715–5719.

Kebede, H., Subudhi, P.K., Rosenow, D.T., Nguyen, H.T, (2001). Quantitative trait loci influencing drought tolerance in grain sorghum (*Sorghum bicolor* L. Moench). *Springer-Verla. Theor Appl Genet, 103*. 266–276.

Kertikov, T. (2007). Study of productivity capacities for production of forage, crude protein and chemical composition in sorghum hybrids. *Bulgarian Journal of Agricultural Science, 13*(3), 281–289.

Kikindonov, Ts., Slanev, K., Kikindonov, G. (2008). Green mass productivity of sorghum origins. *Journal* *of Mountain Agriculture on the Balkans*, *11*(3), 503–511.

Lasztity, R. (1996). Sorghum proteins. In: Lasztity R, editor. *The chemistry of cereal proteins*. 2nd ed. Boca Raton, Fla.: *CRC Press*, 227–248.

Mahama, G.Y., Prasad, P.V.V., Mengel, D.B., Tesso, T.T., (2014). Influence of nitrogen fertilizer on growth and yield of grain sorghum hybrids and inbred lines. *Agron. J*., *106*, 1623–1630.

Mariotti, F., Tomé, D., Mirand, P. (2008). Converting Nitrogen into Protein - Beyond 6.25 and Jones' Factors. *Critical Reviews in Food Science and Nutrition*, *48*(2), 177–184.

Marsalis, M.A., Angadi, S.V., Contreras-Govea, F.E., (2010). Dry matter yield and nutritive value of corn, forage sorghum, and BMR forage sorghum at different plant populations and nitrogen rates. *Field Crop Res*., *116*, 52–57.

Meki, M.N., Ogoshi, R.M., Kiniry, J.R., Crow, S.E., Youkhana, A.H., Nakahata, M.H., Littlejohn, K., (2017). Performance evaluation of biomass sorghum in Hawaii and Texas. *Ind. Crop Prod., 103*. 257–266.

Melo, D., Orlando Da Ros, C., Ferreira da Silva, R., José Coldebella, I. (2017). Fffect of N, P or K doses on the dry matter and crude protein yield in maize and sorghum, *Pesquisa Agropecuária Tropical*, *47*(1), 21–43.

Miller, A.J., Cramer, M.D., (2004). Root nitrogen acquisition and assimilation. *Plant Soil, 274*. 1–36.

Ramu, K., Watanabe, T., Uchino, H., Sahrawat, K.L., Wani, S.P., Ito, O., (2012). Fertilizer induced nitrous oxide emissions from Vertisols and Alfisols during sweet sorghum cultivation in the Indian semi-arid tropics. *Sci. Total Environ*., *438*, 9–14.

Rooney, W.L., Blumenthal, J., Bean, B., Mullet, J.E., (2007). Designing sorghum as a dedicated bioenergy feedstock. *Biofuel Bioprod. Biorefin*., *2*, 147–157.

Schroder, J., Neeteson, J., Oenema, O., Struik, P., (2000). Does the crop or the soil indicate how to save nitrogen in maize production? Reviewing the state of the art. *Field Crop Res*., *68*, 151–164.

Stals, H., Inzé, D., (2001). When plant cells decide to divide. *Trends Plant Sci*., *6*, 359–364.

Tari, I., Laskay, G., Takács, Z., Poor, P. (2012). Responses of Sorghum to Abiotic Stresses: A Review. *Journal of Agronomy Crop Science*, *199*(4), 264–274.

Tomov, T., Rachovski, G., Kostadinova, S., Manolov, I. (2009). Handbook of Agrochemistry. *Academic publisher of Agricultural University of Plovdiv*, Bulgaria.

Van Oosterom, E.J., Chapman, S.C., Borrell, A.K., Broad, I.J., and Hammer, G.L. (2010). Functional dynamics of the nitrogen balance of sorghum. II. Grain filling period. *Field Crops Res*., *115*, 29–38.

Wenzel, W.G., and Van Rooyen, P.J., (2001). Moisture Stress and Potential Sorghum Yield. *ISMN*, *42*, 28–29.

Zhao, D., Reddy, K.R., Kakani, V.G., Reddy, V.R., (2005). Nitrogen deficiency effects on plant growth, leaf photosynthesis, and hyperspectral reflectance properties of sorghum. *Eur. J. Agron., 22*. 391–403.

Zhu, Z.L., Chen, D.L., (2002). Nitrogen fertilizer use in China contributions to food production, impacts on the environment and best management strategies. *Nutr. Cycl. Agroecosyst*., *63*, 117–127.