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ACCUMULATION AND DISTRIBUTION OF NPK IN ABOVE GROUND PARTS OF GRAIN SORGHUM AND MAIZE IN INTENSIVE PRODUCTION

SUMMARY

In intensive production, commercial hybrids of grain sorghum and maize were compared in terms of production and distribution of aboveground parts, NPK content in aboveground parts and efficiency of plant nutrient utilization. Yield of total aboveground biomass was higher in maize than in sorghum, and the highest ratio of yield belonged to grain, both in sorghum and maize. Nitrogen content in all aboveground plants was higher in sorghum than in maize. Phosphorus content was the highest both in sorghum and maize grain, and was nearly identical. In other plant parts P content was higher in sorghum. Potassium content was the highest in stalk, both in sorghum and maize. Maize utilized plant nutrients more efficiently than sorghum, but due to its higher harvest index for NPK, lower amounts of nutrients were returned to soil through harvest residues.

Keywords: grain sorghum, harvest index, maize, nitrogen, nutrient utilization, phosphorus, potassium

INTRODUCTION

Owing to its agronomical and biological traits, production of grain sorghum in our country gains in importance (Sikora & Berenji, 2005, Ikanović et al., 2013). Due to its tropical origin and tolerance to unfavourable environmental conditions the cultivation of sorghum is recommended as an alternative to maize on poor soils and dry conditions (Sikora & Berenji, 2011).

Lemaire et al. (1996) reported on more increased accumulation of dry weight in maize than in sorghum in moderate climate and intensive production, which was interpreted by early development of leaf area in maize, compared to sorghum, and inherited larger amounts of assimilated radiation.

In terms of accessible nutrients limiting quantities, absorption capacity of nitrogen (N) from the soil was still higher in sorghum than in maize, according to the same authors. Muchow & Davis (1988) suggested that in conditions of sufficient water supply there was no difference in production of aboveground parts between these two crops, regardless of soil nutrient supply level. Our

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previous studies (Sikora et al., 2010, 2012) showed that in conditions of South Bačka, maize was more superior related to grain sorghum in terms of aboveground part yields, especially in the case of late maturity hybrids.

The aim of this paper was to compare commercial hybrids of grain sorghum to maize in terms of production and distribution of aboveground plant parts, content of nitrogen (N), phosphorus (P) and potassium (K) in aboveground parts, and efficiency of plant nutrients utilization in intensive production.

MATERIAL AND METHODS

Field trials with two hybrids of grain sorghum (Alba and Gold) and two maize hybrids (NS 444 ultra and NS 6010) were set up at three localities (Bački Petrovac, Sombor and Kikinda) during 2010. Agrochemical soil properties at these three sites are given in Table 1.

Combined fertilizer NPK 15:15:15 in the amount of 300 kg ha^{-1} was applied to every plot before primary tillage in autumn, while N fertilizer was applied before sowing in the amount necessary to ensure undisturbed growth and development of plants during the growing season. Irrigation was provided at all three localities, so that plants were supplied with sufficient quantities of moisture during the whole growing season.

Table 1. Agrochemical soil properties

Locality	pH		$CaCO_3$ %	Humus %	*Total N* %	P_2O_5 mg/100g	K_2O mg/100g
	in KCl	*in* H_2O					
BP	7.52	8.68	13.40	2.16	0.150	8.1	16.4
SO	7.21	8.36	12.94	2.21	0.139	7.9	16.0
KI	6.98	8.44	12.89	2.02	0.144	7.7	15.2

Ten whole plants were sampled three times from every elementary plot and average stand at the stage of physiological maturity. Specific plant parts were separated in linen bags (stem, leaf, sheath, panicle and grain in sorghum, and additionally husk and cob in maize). Plant material was dried in a greenhouse during two weeks, after which air-dried material was weighed; for each sample, moisture and yield of absolute dry matter (ADM) were calculated. In an average sample of each aboveground part, N concentration was determined by Kjeldahl method, P concentration was determined by spectrophotometer and K concentration was measured by atomic absorption spectrophotometry (AAS).

Harvest index was determined by Kemanian et al. (2007). In dry matter it represents grain ratio in total aboveground yield, and in N, P and K it represents the ratio of these nutrients taken out by grain. Efficiency of nutrient utilization represents the quantity of grain produced per unit of absorbed N, P and K accumulated in aboveground plant part at the time of harvest (Novoa & Loomis 1981). Obtained experimental data were statistically analysed using analysis of variance.

RESULTS AND DISCUSSION

Production and distribution of aboveground biomass

Significant differences between analysed sorghum and maize hybrids were determined in terms of yield of total aboveground biomass (Tab. 2). Average yields in sorghum were relatively equal and ranged from 28.5 t ha^{-1} for Alba to 26.3 t ha^{-1} for Gold. Higher yields of total biomass in hybrid Alba compared to hybrid Gold were also reported in our earlier studies (Sikora et al. 2010). Significant differences were determined in maize, because average yields of total aboveground biomass of early maturity hybrid (NS 444 ultra) were at the level of sorghum and amounted 25.1 t ha^{-1}, while in late maturity hybrid (NS 6010) biomass was higher by 26% and amounted 31.7 t ha^{-1}. Due to provided optimal conditions, yield variability among three localities was not significant in any hybrid.

The highest ratio of aboveground biomass yield both in sorghum and maize belonged to the grain. The harvest index ranged from 49% (Alba and NS 6010) to 50% (NS 444 ultra). In analysis of variance, statistically significant difference in harvest index was obtained due to grain sorghum hybrid Gold, which amounted to 43%. The highest average yield of grain ADM (15.47 t ha^{-1}) was recorded in late maturity maize hybrid (NS 6010), and lowest (11.34 t ha^{-1}) in sorghum hybrid Gold. Sorghum hybrid Alba had average yield of 14.03 t ha^{-1}, while maize hybrid NS 444 ultra had 12.63 t ha^{-1}. Panicle had the lowest yield, which amounted to 1% in maize and 7-8% in sorghum total yield. Average ratio of cob (8%) and husk (7%) in total yield was identical for both maize hybrids. Leaf ratio in total yield of aboveground biomass was equal in sorghum hybrids and localities and ranged from 17% to 18%, which is the same amount as in early maturity maize hybrid.

Table 2. Mean squares for aboveground absolute dry matter yield of grain sorghum and maize

Source	Yield of Aboveground ADM			Harvest index
	Grain	Aboveground biomass	Total	
Hybrid	2865185.36**	21666128.21**	74612483.33**	95.91**
Locality	2234895.14	977276.18	2050972.20	13.99
Hybrid x Locality	6678312.39**	1205039.56	8900992.16**	27.66**
Pooled error	891764.44	691123.75	1612510.97	5.26

Leaf ratio was higher (21%) in late maturity maize hybrids. Sheath ratio was the same within a crop, but double in grain sorghum (12%) compared to maize (6%). Stalk ratio in total biomass had significant differences among the hybrids within one crop. Hybrids Alba and NS 444 ultra had stalk ratio of 17%, which quantitatively amounted to 4.9 t ha^{-1}, and 4.6 t ha^{-1}, respectively, while in other two hybrids that amount was 20% or 5.2 t ha^{-1} for Gold, and 6.5 t ha^{-1}for NS 6010 (Fig. 1).

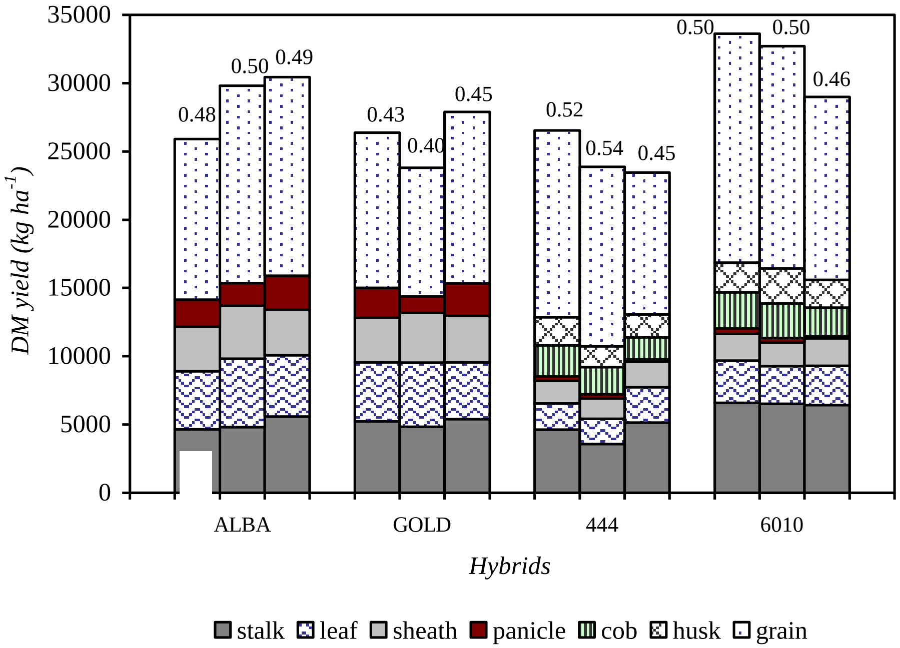

Figure 1. Aboveground biomass yield of grain sorghum and maize (Localities: Bački Petrovac left, Sombor middle, Kikinda right. Values above the bars are harvest indices (HI) for dry matter)

NPK concentration in aboveground biomass

In terms of N concentration in aboveground plant parts between grain sorghum and maize, there were differences primarily because the highest concentration in sorghum was found in leaves (1.99% and 1.83%), and grain (1.58% and 1.78%), while maize had higher N concentration in grain (1.21% and 1.29%), compared to leaves (0.82% and 0.85%). Similar N concentration in sorghum grain was reported by Mirhady & Kobayashi (1981) and Turkhede & Prasad (1978), while Russelle et al. (1981) confirmed the same for maize. In all other aboveground parts, N concentration was higher from 18% (sheath) to 41% (stalk) in grain sorghum than in maize. Similar results were also reported by Jones (1983) in his review article, according to which the difference was slightly smaller and approximately amounted to 10%.

Both analysed crops had the highest P content in the grain (0.35% and 0.38% in grain sorghum; 0.31% and 0.33% in maize). P concentration was generally lower in all other aboveground parts and ranged from 0.05% (cob) to 0.11% (leaf). P concentration was twice as high in sorghum stalk and panicle as it was in maize, and three times as high in sorghum leaves and sheath as it was in maize. Han et al. (2011) also reported higher P concentration in the grain compared to other plant parts and in leaves compared to stalk in sorghum.

K content was the highest in stalk, both in sorghum and maize, except that in sorghum it was twice as high as it was in maize (2.64% compared to 1.38%). Its content in the grain was the same in both crops and amounted to 0.37%. These results are in compliance with Han et al. (2011) reports, according to which K accumulation in sorghum was significantly higher in green biomass compared to grain. In grain sorghum panicle, K concentration was three times as high in leaves and sheath as it was in maize (Tab. 3).

Identical results in terms of N, P and K concentration in grain sorghum were also found by Sikora & Berenji (2010) in broomcorn.

Higher uptake and accumulation of NPK in aboveground plant parts of sorghum suggests its more prominent ability to absorb, compared to maize. In his study, Oikeh (1996) emphasised larger and more branched root system of sorghum with more intense ability to absorb, compared to maize.

Table 3. NPK content (%) in the aboveground part of grain sorghum and maize

Plant part	ALBA			GOLD			NS 444 ultra			NS 6010		
	N	P	K	N	P	K	N	P	K	N	P	K
stalk	0.47	0.14	2.76	0.51	0.17	2.51	0.32	0.07	1.42	0.26	0.09	1.33
leaf	1.99	0.29	0.82	1.83	0.29	0.84	0.82	0.11	0.37	0.85	0.09	0.41
sheath	0.46	0.21	0.82	0.41	0.18	0.90	0.36	0.07	0.31	0.37	0.06	0.37
panicle	0.81	0.19	1.49	0.76	0.17	1.14	0.57	0.10	0.43	0.55	0.09	0.33
grain	1.58	0.35	0.37	1.78	0.38	0.36	1.21	0.31	0.35	1.29	0.33	0.39
cob							0.35	0.05	0.50	0.28	0.05	0.37
husk							0.42	0.08	0.43	0.41	0.08	0.51

Efficiency of NPK utilization

The efficiency of N utilization by grain sorghum and maize plants exhibits great variability and it is largely affected by climate, soil and agro-technical factors (Muchow 1998). In intensive production when plants had optimal conditions for growth and development, statistically important difference between sorghum and maize was determined in terms of N, P and K utilization efficiency (Tab. 4). Analysis of variance showed a significant effect of localities on the analysed crops utilization efficiency.

Approximately 36.1 kg of grain ADM was produced per each kilogram of absorbed N in aboveground biomass, while that amount in maize was by 67% higher, i.e. 60.3 kg.

P utilization is by 57% more efficient in maize than in sorghum, and K utilization by 83%. With each absorbed kilogram of P, approximately 160.4 kg of grain sorghum ADM and 251.8 kg of maize grain ADM was produced. Average

K values for sorghum were 47.1 kg and for maize 84.4 kg of grain ADM (Fig. 2).

Table 4. Mean squares for harvest index and NPK utilization efficiency in grain sorghum and maize

Source	Harvest index			Utilization efficiency (kg grain kg^{-1})		
	N	P	K	N	P	K
Hybrid	268.27**	1407.63**	647.95**	1806.39**	26062.57**	4784.85**
Locality	52.46	17.11	5.07	217.24**	12241	78.79
Hybrid x Locality	11.42	25.20	7.21	50.80**	1265.45	89.87
Pooled error	18.69	48.68	5.64	10.38	157.38	50.55

Regarding harvest index of N, P and K, trend identical to the efficiency of their utilization was recorded, because in sorghum it decreased by an average of 20% (Fig. 2). Out of total absorbed N quantity in aboveground biomass, on average 61% N in sorghum and 75% N in maize was taken out by grain yields. This means that 140 kg ha^{-1} of N in sorghum and 62 kg ha^{-1} in maize was returned to soil through harvest residues.

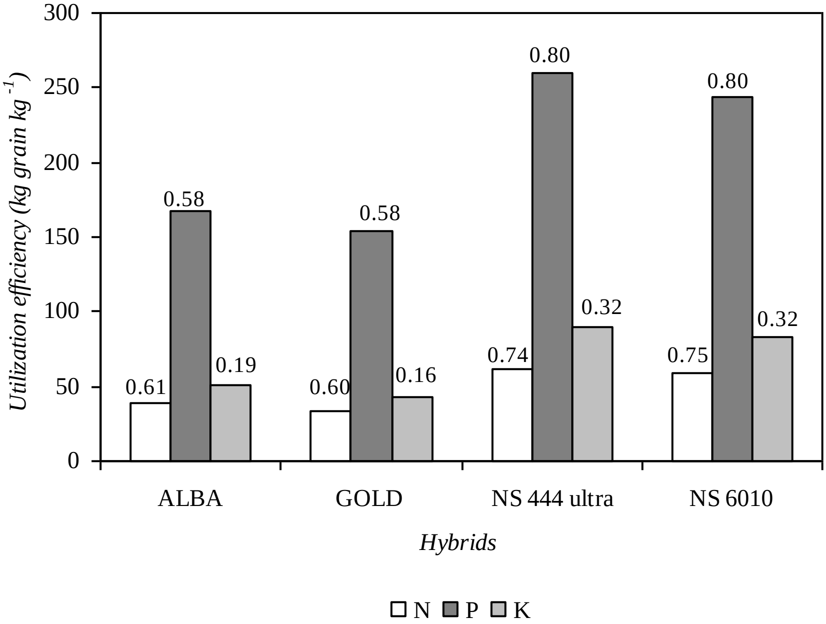

Figure 2. Utilization of assimilated NPK in grain sorghum and maize (Values above the bars are harvest indices (HI) for NPK)

Out of total absorbed P quantity in aboveground biomass, on average 58% P in sorghum and 80% P in maize was taken out by grain yields. Owing to this, 11 kg P ha^{-1} returned to soil through maize harvest residues and three times as much through sorghum (33 kg ha^{-1}). Harvest index for K is double in maize (32%) than in sorghum (18%), but only half returned to soil through harvest residues (111 kg ha^{-1} in maize, and 222 kg ha^{-1} in sorghum).

CONCLUSIONS

Results of multi-location comparative trials showed that in intensive production maize had higher yields of total aboveground biomass, in relation to sorghum. The highest ratio of aboveground biomass yield both in maize and sorghum belonged to grain.

In all aboveground plant parts, N concentration was higher in sorghum than in maize. Maize had the highest N content in grain and sorghum in leaves. P content was the highest in grain, both in sorghum and maize, and was approximately the same. In other plant parts, P content was higher in sorghum. K content was the highest in stalk, both in sorghum and maize, while its content in the grain was the same in both crops.

Maize utilized plant nutrients more efficiently than sorghum, but due to its higher harvest index for N, P and K, lower nutrient quantities are returned to soil through harvest residues.

Practical application of the results implies assessment of sorghum and maize as preceding crops and possibility of more economic fertilization of these crops. Genetic yield potential of individual hybrids should also be considered in intensive production. Similar analyses should be conducted in extreme environmental conditions for full understanding of these two crops and their relations.

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REFERENCES

Han LP, Steinberger Y, Zhao YL, Xie GH (2011): Accumulation and partitioning of nitrogen, phosphorus and potassium in different varieties of sweet sorghum. Field Crops Res. 120: 230-240.

Ikanović J., Popović V., Trkulja V., Živanović LJ., Lakić Ž., Pavlović S. (2013): Morphological characteristics of the interspecies hybrid between sorghum and sudan grass under intensive nitrogen nutration. Genetika, Belgrade, 45 (1), 31-40.

Jones CA (1983): A survey of the variability in tissue nitrogen and pfosphorus concentrations in maize and grain sorghum. Field Crops Res. 6: 133-147.

Kemanian AR, Stöckle CO, Huggins DR, Viega LM (2007): A simple method to estimate harvest index in grain crops. Field Crops Res. 103: 208-216.

Lemaire G, Charrier X, Hébert Y (1996): Nitrogen uptake capacities of maize and sorghum crops in different nitrogen and water supply conditions. Agronomie16: 231-246.

Mirhadi MJ, Kobayashi Y (1981): Studies on the productivity of grain sorghum. IV. Effect of various planting dates on the growth, grain yield and protein content of irrigated and nonirrigated grain sorghum. Jpn. J. Sci. 50: 115-124.

Muchow RC, Davis R (1988): Effect of nitrogen supply on the comparative productivity of maize and sorghum in a semiarid tropical environment. II. Radiation interception and biomass accumulation. Field Crops Res. 18: 17-30.

Muchow RC (1989): Nitrogen utilization efficiency in maize and grain sorghum. Field Crops Res. 56: 209-216.

Novoa R, Loomis RS (1981): Nitrogen and plant production. Plant Soil 58: 177-204.

Oikeh SO (1996): Dynamics of soil nitrogen in cereal-based cropping systems in the Nigerian Savanna. PhD dissertation, Ahmadu bello University, zaria, Nigeria.

Russelle MP, Deibert EJ, Hauck RD, Sevanovic M, Olson RA (1981): Effects of water and nitrogen management on yield and N-depleted fertilizer use efficiency of irrigated corn. Soil Sci. Soc. Am. J. 45: 553-558.

Sikora V, Berenji J (2005): Perspektive gajenja sirka za zrno u nas. Zbornik radova Naučnog instituta za ratarstvo i povrtarstvo Novi Sad, 41, 451-458.

Sikora V, Berenji J (2010): Distribucija NPK u nadzemnim delovima biljke sirka metlaša. Bilten za alternativne biljne vrste 83: 46-52.

Sikora V, Berenji J (2011): Sirak za zrno i sirak metlaš kao alternativne kulture. 45. Savetovanje agronoma Srbije, Zlatibor, 30.januar-05.februar, 171-180.

Sikora V, Berenji J, Latković D (2010): Uticaj klimatskih faktora na prinos biomase i žetveni indeks sirka za zrno i kukuruza. Bilten za alternativne biljne vrste 83: 12-21.

Sikora V., Berenji J., Latković D., Popović V. (2012). Path analiza kvantitativnih svojstava sirka metlaša - komponente visine biljke. Bilten za alternativne biljne vrste, 2012, 44, 85, 1-7. ISSN 2217-7205

Turkhede BB, Prasad R (1978): Effect of rates and timing of nitrogen application on hybrid sorghum (CSH-1). Indian J. agron. 23: 113-126.