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MORPHOLOGICAL TRAITS, YIELD AND CHEMICAL COMPOSITION OF FORAGE SORGHUM GENOTYPES, GROWN UNDER DIFFERENT NITROGEN RATES

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ABSTRACT

In order to reduce total costs on farms and to sustain agricultural production, it is necessary to provide a new approach to this problem on a global level. The biomass of silage sorghum [*Sorghum bicolor* (L.) Moench] may replace maize, whose profitability decreases in semi-arid regions of the world. Growing forage sorghum as an alternative to silage maize and utilising smaller amounts of nitrogen allows using natural resources more rationally and increases production efficiency. A 2-year study was conducted to investigate the effects of using different amounts of nitrogen (low 105 kg ha^{-1}, intermediate 150 kg ha^{-1} and high 180 kg ha^{-1}) on morphological traits (MT), yield (Y) and chemical composition of biomass (CCB) in Sudan grass (cv. Zora), forage sorghum (cv. NS-Džin) and their interspecies hybrid (cv. Siloking). The standard technology for the production of forage sorghum was applied and ammonium nitrate was applied to the soil before planting. Results indicated that these genotypes have a high yield potential for ground biomass. The genotype Siloking gave the highest ground biomass yield, 90.22 t ha^{-1}, and the genotype Zora the lowest, 85.41 t ha^{-1}. Yield variations were also significant in relation to nitrogen plant nutrition. The lowest average yield was in the control. In the year with more favourable rainfall distribution (2010), ground biomass yield (Y) was, on average, higher by about 15%. The genotype had the greatest influence on morphological traits. Intensified nitrogen plant nutrition caused an increase of stem length, stem mass and leaf mass, as well as an increase of leaf portion of total ground biomass. Nitrogen had a two-fold effect on the quality of biomass, as a bulk livestock feed, through an increased proportion of leaf in total ground biomass, and through higher total protein content. Using more intensive nitrate nutrition, the percentage of nitrogen-free extract (NFE) decreased.

Key words: forage sorghum, morphological traits, yield, chemical composition, nitrogen, agro-ecological parameters.

INTRODUCTION

For bulk feed production, maize silage can be successfully replaced by Sudan grass and forage sorghum. Forage sorghum biomass is commonly used fresh or for silage, and rarely for hay or grazing (Camakci, 1999; Erić and Ćupina, 2001; Ikanović et al., 2010). Cellulose, hemi-cellulose and lignin, the main chemical components of sorghum biomass, are the most abundant renewable resources on earth and can be used as alternatives to petroleum and other fossil resources (Venuto and Kindiger, 2008).

The western Balkans region has the characteristics of a semi-arid climate, with hot dry summers and adverse rainfall distribution. Growing maize silage becomes unreliable due to the high drought-sensitivity of plants in water-critical periods. Farmers are faced with an increasingly frequent problem of water shortage and are forced to change their cropping structure.

According to the results of previous studies (Merrill et al., 2007), forage sorghum needs less water than maize and is more tolerant to drought in critical periods; thus it has become a very important forage crop in many regions in the world. Semi-arid conditions are more favourable to forage sorghum than to maize for many reasons, including lower transpiration quotient, less need for irrigation, and faster regeneration after periods of drought (Lamm et al., 2007).

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Previous studies confirmed that forage sorghum as an alternative silage crop showed better cropping potential than popcorn [*Zea mays* (L.) *everta*] or sweet corn [*Zea mays* (L.) *saccharata*] (Kurle et al., 1991).

It is evident that there is a growing need for dairy products in the world, which has caused an increased need for high-quality bulk feed for dairy cattle. One of the options for sustaining bulk livestock feed production, declining due to frequent droughts, is replacing maize with forage sorghum [FS; *Sorghum bicolor* (L.) Moench].

Optimal amounts of nitrogen used in forage maize production are in a range from 150 to 250 kg N ha^{-1} and often more (Subedi and Ma, 2009). The imperative is to decrease production inputs as much as possible to sustain profitability and productivity (Marsalis et al., 2010). Nitrogen is an essential element for all stages of plant growth and maturity.

The effects of nitrogen deficiency are easy to notice (McLaren, 2003). An increased amount of nitrogen effects positively on photosynthesis, intensity and duration of vegetative organs' activity, so it can be assumed that increased amounts of nitrogen will be a precondition for higher yields and better quality of forage sorghum. On the other hand, excessive use of nitrogen in plant nutrition makes production more expensive and increases the accumulation of harmful and toxic products in plants. These products can jeopardise feed safety (Erisman et al., 2007).

Previous studies on nitrogen plant nutrition confirmed its positive effect on biomass quality, and the main criteria for specifying nutrition value is digestive substances portion and the decreased content of lignin *(*Casler, 2001). The importance of nitrogen in plant metabolism has already been studied and is well-known, and optimal nitrogen supply enables the intensive synthesis of nitrogen compounds (Dykes and Rooney, 2006; Marinciu and Saulescu, 2009). Good application of nitrogen mineral feed should enable better and more economical utilisation of agro-ecological and soil conditions and crop genetic potential. Yield represents the plant's potential to accumulate dry matter as well as to adapt to different agro-ecological conditions. Under agro-ecological conditions in eastern Serbia, a less-productive soil needs 150 kg ha^{-1} of nitrogen (Erić and Ćupina, 2001). The objective of these studies was to investigate the influence of nitrogen on morphological and productive traits of forage sorghum, Sudan grass and their interspecies hybrid.

MATERIAL AND METHODS

Experiment location and general methodology

The studies were conducted in 2009 and 2010 at the National University of the Republic of Serbia, on an experimental plot of the Faculty of Agriculture, called Radmilovac, located 30 km north-east of Belgrade.

The experiments were conducted using a randomised block design with 10 replicates. The size of the basic plots was 10 m^2 (5 m x 2 m). The objective of studies were to analyse biomass samples from the first cut of three genotypes (A) Džin (forage sorghum), Zora (Sudan grass) and Siloking (interspecies hybrid), selected by the Institute of Field and Vegetable Crops from Novi Sad. Three increased amounts of nitrogen compared to natural soil fertility were studied: 105 kg ha^{-1} (N_2), 150 kg ha^{-1} (N_3), 180 kg ha^{-1} (N_4) and control (N_1), without N added (according to agrochemical analyses, natural soil fertility had 60 kg ha^{-1} of available N). Standard production techniques were applied. The preceding crop was sunflower. Inter-row sowing, with spacing up to 50 cm, was conducted on April 24. Depending on the species, a sowing rate of 20-25 kg ha^{-1} was used.

Mineral fertiliser, ammonium-nitrate, was applied to the soil before sowing. In both years the plants gave two cuts, but measures were taken just of the first one. In the first year the plants were mowed on July 18, and in the second year on July 22. The samples of fresh biomass from every basic plot were used for measuring the yield (t ha^{-1}), and samples of ten plants were taken for measuring plant height, stem mass, leaf mass and their proportions in total biomass.

The total of proteins and carbohydrates were determined in ground, air-dried samples of the biomass. The total protein content was determined by macro-Kjeldahl method, and the content of nitrogen-free extract (NFE) was determined by calculation, subtracting the amount of protein from the total amount of organic matter (Rakić, 2006).

Meteorological data

The experimental plot, due to annual rainfall of 635 mm, belongs to a semi-arid climate area. In the first year, rainfall in the vegetation period was about 9.5% bigger than the ten-year average (Table 1). There was less rainfall in April and May, but the summer months were wetter. Rainfall in the second year was 27% above the multi-annual average, and about 20% higher than in the first year.

Rainfall distribution across the vegetation period was even, and the maximum amount was in June (180 mm). Heat distribution per month in the first year showed that average temperatures in the summer months were lower that the multi-annual average for this area. In the second year, air temperatures were lower in spring and autumn, and the temperatures in summer were the same as the ones in the first year.

Table 1. Rainfall (mm) and daily mean temperature (^{o}C) for the sorghum growing period (Hydro meteorological station, Belgrade)

Year	Parameter	Month						Average sum
		IV	V	VI	VII	VIII	IX	
2009	Temperature	16	20	21	24	24	20	21
	Rainfall	6	34	153	79	45	45	362
2010	Temperature	14	18	21	24	24	18	20
	Rainfall	41	85	180	41	54	51	452
Ten-year average	Temperature	15	26	23	25	25	18	21
	Rainfall	15	58	102	53	54	49	331

Statistics

Experimental data were analysed using the statistical package "STATISTICA 7.1 for Windows" (Stat Soft 2005).

Determination of the differences between the treatments and their significance was conducted by using variance analysis (MANOVA) and LSD-test (1% and 5%).

Apart from applied parametric tests (variance analysis and LSD-test), the homogeneity of variances was also tested by using Hartley, Cochran, Bartlet and Levene′s tests. In terms of I-distance, the investigated nitrogen amounts were ranked annually:

$$D_i = \sum_{i=1}^{n} \frac{\left| X_{ik} - X^{-} \right|}{\sigma_i} \prod \left(1 - \rho_{ij}\right)$$

RESULTS AND DISCUSSION

Morphological traits (MT)

The investigated MT showed great variability in response to genotype and intensity of nitrogen plant nutrition (Tables 2, 3 and 4).

The samples of interspecies hybrid Siloking had significantly higher total biomass per plant, and forage sorghum had the biggest leaf mass per stem. Sudan grass formed the longest stems and had the biggest leaf portion in total biomass. Along with increasing intensity of nitrogen plant nutrition, the effect of nitrogen per kg decreased from 1.27 g to 0.57 g of total biomass where there was 180 kg ha^{-1}. In the year with more rainfall in the vegetation period, the effect of nitrogen per kg was smaller. This was confirmed by the results of a previous study (Marsalis et al., 2010).

Table 2. Morphological traits of sorghums

Genotypes N amounts	Plant height (m)	Leaf mass (g)	Stem mass (g)	Leaf portion (%)
2009 Year				
Genotype (A):				
Siloking	1.663^{b}	30.252^{b}	90.757	25.3^{c}
NS Džin	1.646^{b}	42.047^{a}	66.728^{b}	38.4^{a}
Zora	2.212^{a}	18.586^{c}	32.557^{c}	37.1^{b}
Amount N (B):				
N_{105}	1.946^{a}	39.520^{a}	83.737^{a}	33.6^{b}
N_{150}	2.004^{a}	31.283^{b}	70.713^{b}	32.2^{c}
N_{180}	1.877^{b}	29.249^{c}	54.977^{c}	36.5^{a}
Control	1.535^{c}	21.126^{d}	43.963^{d}	32.1^{c}
Average ± $S\bar{x}$	1.840±0.035	30.295±1.334	63.348±2.926	33.6±0.006
2010 Year				
Genotype (A):				
Siloking	1.685^{c}	43.038^{a}	103.960^{a}	29.7^{c}
NS Džin	1.383^{b}	50.334^{a}	70.536^{b}	34.2^{b}
Zora	2.040^{a}	19.454^{b}	32.609^{c}	37.5^{a}
Amount N (B):				
N_{105}	1.804^{a}	54.112^{a}	79.558^{a}	33.4^{b}
N_{150}	1.722^{b}	36.833^{ab}	83.230^{a}	31.4^{c}
N_{180}	1.772^{ab}	32.576^{ab}	61.132^{b}	36.7^{a}
Control	1.512^{c}	26.915^{b}	52.218^{c}	33.7^{b}
Average ± $S\bar{x}$	1.702±0.032	37.609±4.482	69.034±3.206	33.8±0.005

* LSD test significance (P=0.05)

Table 3. Statistical significance of the difference of investigated traits (F test and LSD test)

Traits	Test	2009			2010		
		Genotype (A)	Nitrogen (B)	AB	Genotyp e (A)	Nitrogen (B)	AB
Plant height	F test	***	***	***	***	***	***
	LSD: 5%	0.051	0.058	0.099	0.051	0.059	0.102
	1%	0.067	0.078	0.132	0.068	0.079	0.134
Leaf mass	F test	***	***	***	**	NS	*
	LSD: 5%	1.144	1.320	2.259	20.182	23.304	39.872
	1%	0.067	1.748	2.974	26.714	30.847	52.484
Stem mass	F test	***	***	***	***	***	***
	LSD: 5%	2.429	2.805	4.798	4.572	5.280	9.033
	1%	3.215	3.712	6.316	6.052	6.988	11.891
Leaf portion	F test	***	***	***	***	***	***
	LSD: 5%	0.009	0.011	0.018	0.011	0.013	0.022
	1%	0.012	0.014	0.024	0.015	0.017	0.030

$^{NS}P>0.05$ $^{*}P<0.05$ $^{**}P<0.01$ $^{***}=P<0.001$

Table 4. Statistical significance of the difference of investigated traits of sorghums

Variety	Stem length (m)	Leaf number	Leaf mass (g)	Stem mass (g)
	$\bar{x} \pm s\bar{x}$			
Genotype (A):				
NS Džin	1.674^{c} ± 0.036	7.258^{b} ± 0.148	49.053^{a} ± 4.565	77.617^{b} ± 2.642
Zora	2.281^{a} ± 0.039	7.917^{a} ± 0.124	18.291^{c} ± 0.278	32.545^{c} ± 0.638
Siloking	1.840^{b} ± 0.029	7.692^{a} ± 0.099	39.531^{b} ± 0.969	100.798^{a} ± 1.639
LSD 5%	0.071	0.268	7.330	4.234
LSD 1%	0.094	0.354	9.661	5.581

a, b, c –Values without the same letter in superscript are significantly different (p<0.05).

Biomass yield (Y)

Fresh Y was significantly affected by nitrogen amount, as well as by genotype. Nitrogen fertiliser effect also depended on rainfall distribution in the vegetation period (Table 5).

Table 5. Fresh biomass yield (t ha^{-1})

Genotypes, N amounts	2009	2010	Two years average	LSD: 5% and 1%
Genotype (A):				
Siloking	84.52	95.92	90.22	3.3556
NS Džin	85.06	101.95	93.51	4.5661
Zora	80.22	90.60	85.41	
Amount N (B):				
N_{105}	84.64	94.06	89.35	5.851
N_{150}	86.31	101.60	90.00	9.245
N_{180}	86.58	102.10	94.36	
Control	79.55	86.96	83.30	
Average	83.84	96.17	89.45	

Sudan grass gave the lowest overall average Y, 85.41 t ha^{-1}. Significantly higher yield was given by the interspecies hybrid (90.22 t ha^{-1}) and by forage sorghum (93.51 t ha^{-1}). Nitrogen plant nutrition had an effect on fresh biomass yield, so that it was bigger compared to the control in each variant. The highest yield, on average for all genotypes, was given in the variant with 180 kg $ha^{-1}$of nitrogen. The average fresh biomass yield in the second year was higher by about 15% due to more favourable water regime. These data correspond to the ones in the previous studies in which yield fluctuations were listed by genotypes. The highest green forage yield was achieved by using the hybrid *Sweet Sioux* (111.3 t ha^{-1}), significantly lower by using forage sorghum (*NS* Šećerac) 73.9 t ha^{-1}, and the lowest by using the species of Sudan grass, Zora and Srem, only 81.5 t ha^{-1} to 89.8 t ha^{-1} (Ćupina et al., 2002).

According to previous studies (Erić et al., 2001), Sudan grass yield is positively correlated with vegetation period length, i.e. with sowing date. Due to higher and more favourable air temperatures, Sudan grass sowed in later periods has shorter length of vegetative growth, faster transition to the generative stage, and lower biomass yield. The results of a study (Venuto and Kindiger, 2008) that investigated the yield of twenty sorghum species and Sudan grass in 3-year period discovered significance of year, treatment, and cultivar and interaction effects. According to the results of this study, total dry matter yield (DM) fluctuated from 27.1 to 25.5 mg ha^{-1}, which corresponds with the results of our study.

On the other hand, increased amounts of nitrogen can have a negative effect on the yield of forage sorghum biomass under irrigation conditions (Marsalis et al., 2010).

Total protein content (2-year average) was highest in the variant with 180 kg ha^{-1} of nitrogen (Tables 6 and 7).

Total protein content in fresh biomass was strongly affected by nitrogen used as supplementary plant feed. The highest total protein content was in the variant with 180 kg ha^{-1} of nitrogen, and the lowest in control. The difference was about 13%.

Previous studies (Erić and Ćupina, 2001; Glamoclija et al., 2010) confirm that biomass chemical composition depends on nitrogen plant nutrition. There were no significant differences among the genotypes.

On the other hand, previous results showed that total protein content in fresh biomass and hay was dependent on the genotype (Erić et al., 1999). Thus, the biomass of genotypes with a shorter vegetation period had more total protein in the first cut (Ikanović et al., 2010).

Nitrogen-free extract (NFE)

Not only did different nitrogen amounts have no great effect on total amounts of NFE in green biomass, but they gradually decreased along with increasing plant nutrition (Tables 6 and 7). A study (Zerbini and Thomas, 2003) that investigated the effect of mineral nutrition on quality of forage sorghum and maize stated that the amount of nitrogen used on poor soils affects positively on NFE content in fresh biomass. On the other hand, one study (Carmi et al. 2006) also stated that NFE content in fresh biomass increases under conditions of intensified mineral plant nutrition under irrigation conditions. Statistically, NFE content depended on genotype. This content was the smallest in fresh biomass of the Siloking genotype. Fresh biomass samples of Džin genotype had about 4% more NFE content and the samples of Zora about 9% more than Siloking.

Table 6. Content (%) of protein and nitrogen-free extract (NFE)

Genotype N amounts	Content			
	Protein	Nitrogen-free extract (NFE)	Protein	Nitrogen-free extract (NFE)
	2009 Year		2010 Year	
Genotype (A):				
Zora	11.68[a]	46.80[a]	13.21[b]	45.93[a]
NS Džin	11.93[a]	44.59[b]	12.82[c]	43.43[b]
Siloking	11.99[a]	43.06[c]	13.56[a]	42.16[c]
Amount N (B):				
N_{105}	11.90[b]	44.67[b]	13.28[c]	43.62[b]
N_{150}	11.94[b]	43.97[c]	13.65[b]	43.36[b]
N_{180}	12.57[a]	44.80[b]	13.91[a]	43.37[b]
Control	11.06[c]	45.80[a]	11.97[d]	44.61[a]
Average ± Sx	11.87 ± 0.349	44.33 ± 0.286	13.2 ±0.180	43.84 ± 0.417

*LSD test significance (P=0.05).

Table 7. Statistical significance of the difference of protein and nitrogen-free extract content (NFE) (F test and LSD test)

Traits	Test	2009			2010		
		Genotype	Nitrogen	AB	Genotype	Nitrogen	AB
		(A)	(B)		(A)	(B)	
Protein content	F test	ns	**	ns	**	**	**
	LSD: 5%	0.366	0.423	0.733	0.189	0.218	0.377
	1%	0.498	0.575	0.996	0.256	0.296	0.513
Content of NFE	F test	**	**	**	**	**	ns
	LSD: 5%	0.300	0.347	0.601	0.438	0.506	0.876
	1%	0.408	0.472	0.817	0.595	0.687	1.190

CONCLUSIONS

On the basis of the results obtained, the following conclusions can be drawn:

– The results of the study indicated a significant, positive and economically justifiable effect of increased amounts of nitrogen on improvement of the morphological traits of the investigated genotypes of forage sorghum, Sudan grass and interspecies hybrid.

– Intensified nitrogen nutrition significantly affected tillering intensity, leaf number and portion of leaf mass in total ground biomass, which resulted in higher yield and better quality of green biomass.

– Weather conditions, especially rainfall amount and distribution, had a big effect on growth of the investigated genotypes. Under favourable water regime conditions, the highest green biomass yield was in the variant with 150 kg ha^{-1} of nitrogen.

– By using 105 kg ha^{-1} of nitrogen, plants had the longest stem and the highest tillering. Forage sorghum had the biggest leaf mass per stem, and Sudan grass formed the longest stem and had the biggest leaf portion in total plant mass.

– The highest green biomass yield was obtained by using 180 kg ha^{-1} of nitrogen.

– Total protein content in the investigated samples depended on harvest date. The hay with highest total protein and digestive protein contents was obtained from the first cut, and the second-cut biomass had a lower nutritive value.

– Nitrogen used in plant nutrition increased total digestible protein content in the samples of dry biomass.

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