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YIELD AND WATER USE EFFICIENCY OF IRRIGATED SUDAN GRASS (*SORGHUM SUDANENSE* L.) IN THE CLIMATE CONDITIONS OF VOJVODINA

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SUMMARY: In order to study the effectiveness of irrigation on Sudan grass fresh forage yield an irrigation water use efficiency (I_{wue}) and evapotranspiration water use efficiency (ET_{wue}) were determined. A field experiment was conducted on the calcareous chernozem soil in the Vojvodina region, a northern part of the Serbia Republic, during 2005 and 2006 growing season. The experiment was arranged in a randomized complete block design and adapted to conditions of sprinkling irrigation. The trial included irrigated treatment (I - 60-65% of field water capacity - FWC) and a treatment without irrigation (I_o). On average, irrigation did not significantly affect the fresh forage yield of Sudan grass (108.893 t ha^{-1} - 103.314 t ha^{-1}) as the study period had precipitation higher than the long-term seasonal average. Evapotranspiration water use efficiency of Sudan grass, in irrigation conditions (ET_m I_{wue}) ranged from 19.0 to 20.9 kg m^{-3} with an average value of 20.0 kg m^{-3}, while evapotranspiration water use efficiency in conditions without irrigation (ET_a I_{wue}) varied from 18.1 to 25.4 kg m^{-3} with an average value of 21.8 kg m^{-3}. Irrigation water use efficiency (I_{wue}) varied from 2.8 to 3.7 kg m^{-3} with an average value of 3.2 kg m^{-3}. Effect of irrigation on yield of Sudan grass and results of both ET_{wue} and I_{wue} which were similar to those obtained from the literature indicate that irrigation schedule of Sudan grass in the study period was properly adapted to plant water requirements and water-physical soil properties. Determined values of ET_{wue} and I_{wue} could be used for the planning, design and operation of irrigation systems, as well as for improving the production technology of Sudan grass in the region.

Key words: *irrigation, yield, Sudan grass (Sorghum sudanense L.), water use efficiency (WUE).*

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INTRODUCTION

Regarding the intended intensification of livestock production, solutions should be sought in high-yielding, high-quality crops which fit a system of continual feed production (relay cropping). Diversity of use, favorable biological characteristics, relatively modest requirements, high and stable yield and high quality of biomass make Sudan grass an important facet in resolving the problem of rough forage (Ćupina et al., 2002). Being an annual forage crop, Sudan grass is typically used for grazing, production of fresh forage and ensiling. It may be planted at different time interval (main crop, catch crop, double crop), it has a high regrowth rate and it may annually produce two-three cuts. In favorable years, i.e., with adequate water supply, high yields of fresh forage (60-70 t ha^{-1}) may be achieved with minimal cultivation practices (Erić et al., 1995; Erić et al., 2004). In practice, however, yields frequently oscillate on dependence of weather conditions, primarily the amounts and distribution of rainfall. In irrigation, an economic irrigation schedule consistently provides high yields of fresh forage exceeding 100 t ha^{-1} (Pejić i sar 2005).

The importance of analyzing evapotranspiration water use efficiency (ET_{wue}) is illustrated by the efforts of numerous studies that consider the total water use for evapotranspiration towards transpiration use as to the productive part of water to plants (Wallace and Batchelor, 1977; Howell et al., 1990). The parameter ET_{wue} mostly depends on precipitation amount and distribution and establishes whether the growing period is favorable for plant production or not. Irrigation schedules and applied management practices in relation to obtained yields of growing plants substantially influences this coefficient. Wang et al. (1996) pointed out that crop yield depends on the rate of water use and that the factors that increase yield and decrease water used for ET favorably affect the water use efficiency. Howell (2001) indicated that ETwue generally is highest with less irrigation, implying full use of the applied water and perhaps a tendency to promote deeper soil water extraction to make better use of both the stored soil water and the growing-season precipitation. The irrigation water use efficiency (I_{wue}) provides a more realistic assessment of the irrigation effectiveness as many management factors such as fertility, variety, pest management, sowing date, soil water content at planting, planting density and row spacing could affect yield substantially between irrigated and dryland agriculture. The parameter, I_{wue} generally tends to increase with a decline in irrigation if that water deficit does not occur at a single growth period (Howell, 2001).

The main objectives of this study were to: (1) assess the effectiveness of irrigation on Sudan grass fresh forage yield using irrigation water use efficiency (I_{wue}) and evapotranspiration water use efficiency (ET_{wue}) coefficients, (2) and to compare determined values with those obtained from past studies of different climatic conditions, particularly to assist in developing strategies for improved production technology of Sudan grass in the Vojvodina and similar regions.

MATERIALS AND METHODS

The experiments were conducted at Rimski Šančevi, an experimental station of the Institute of Field and Vegetable Crops in Novi Sad (N 45° 19`, E 19° 50`, elev. 84 m) on the chernozem soil of the loess terrace during 2005-2006. The soil of the experiment site is as a highly calcareous loam (Table 1). Structural stability to 0.6 m is good, with

60-71% of soil aggregates larger than 0.25 mm being persistent in water (Pejić et al., 2005). Concerning the physical and water properties (Table 1) this soil is quite suitable for any crop and irrigation system (Živković et al., 1972).

Table 1. Physical and water properties of the soil at the experimental site

Depth (cm)	Textural status (%)			Bulk density (kg m^{-3})	Total porosity (vol.%)	Air porosity (vol.%)	Field water capacity (weight %) (mas.%) 33 kPa	Wilting point (weight %) (mas.%) 1500 kPa	Total available soil water (mm)
	Sand	Silt	Clay						
0-30	34	48	18	1270	54.9	21.9	26.0	10.9	57.5
30-60	29	44	27	1310	48.8	14.1	26.5	11.2	60.0

The experiment was conducted in a system of random blocks and adapted to technical specifications of the sprinkler irrigation system. The criteria used for irrigation in the field experiment included application of water when soil moisture was at 60-65% of field capacity (FC) i.e., irrigation was applied when about half of available water in the soil layer to 60 cm was depleted (Pejić, et al., 2005). The non-irrigated plot was used as control. Irrigation was scheduled by monitoring soil moisture levels at 10 cm intervals down to 60 cm depth. This was estimated by using a gravimetric method at about 10 day intervals depending upon the weather conditions. Maximum evapotranspiration (ET_m) of Sudan grass during growing season was calculated using the bioclimatic method (1) that employs hydrophytothermic index (K) with the value of 0.19 taken from Pejic et al., (2006). After determining the ET_m value the actual evapotranspiration (ET_a) was calculated on the basis of precipitation data and pre-vegetation soil water reserve.

$$ET_m = K\ T \quad (1)$$

Where:

ET_m = monthly maximum evapotranspiration for Sudan grass (mm)

K = hydrophytothermic index for Sudan grass

T = sum of mean daily air temperatures in a given month (°C)

Evapotranspiration water use efficiency (ET_{WUE}) and Irrigation water use efficiency (I_{WUE}) were estimated as Bos (1980 and 1985):

$$ET_{wue} = Y_{irr} \text{ or } Y_{dry}/ET_m \text{ or } ET_a \quad (2)$$

$$I_{wue} = Y_{irr} - Y_{dry}/W_{irr} \quad (3)$$

Where:

Y_{irr} = the yield and ETm for irrigation level

Y_{dry} = the yield and ETa for dryland or rainfed plot

W_{irr} = the amount of water applied by irrigation

The experimental object was the Sudan grass variety NS Srem. Planting in 12.5 cm rows was performed with a portable planter in the second half of April. The seeding rate was 30 kg ha^{-1}. The size of the experiment unit was 12 m^2 (12 x 1 m) replicated four times. The cutting was done when the plants height was about 90 cm, and fresh forage yield (Y) was calculated by t ha^{-1}. The experimental Sudan grass plots received conventional growing technology adjusted to the conditions of irrigation. Statistical processing of data was done by the analysis of variance (ANOVA) and testing the obtained results by the Fisher's LSD test (P< 0.05 levels between the means).

Precipitation (P) and temperature (T) data were obtained from Rimski Šančevi Meteorological Station (Table 2). To characterize the climate of the experiment area, data gathered by a meteorological station at Rimski Šančevi in a 43-year period (1964-2007) were used. The climate is moderate, with four marked seasons. The mean annual precipitation is 609 mm (361 mm or 59% in the growing season, April - September) and the mean air temperature is 11.2°C (17,7°C in the growing season). Variability of meteorological conditions from one year to another is characteristic for the climate of the Vojvodina Province. This particularly concerns the rainfall, which varies in both, amounts and distribution.

Seasonal precipitation in 2005 and 2006 were 451 and 419 respectively, and therefore the study period had precipitation higher than the long-term seasonal average (1964/2007 – 361 mm) (Table 2).

Table 2. Mean monthly air temperatures and monthly precipitation sum during Sudan grass growing season (Rimski Šančevi)

Year	Month												Seasonal average	
	April		May		June		July		August		September			
	°C	mm	°C	mm	°C	mm	°C	mm	°C	mm	°C	mm	°C	mm
2005	12.7	20.9	17.0	38.1	19.3	135.4	21.3	122.5	18.8	133.9	21.5	0.2	18.4	451.0
2006	15.0	10.3	16.6	70.1	19.7	104.3	23.5	30.9	19.7	124.9	14.6	79.0	18.2	419.5
1964/ 2007	11.2	47	16.6	59	19.6	85	21.3	70	20.7	59	16.8	41	17.7	361.0

Given data indicate that climatic patterns in Vojvodina are changeable and longer-term predictions of precipitation are not possible. That confirms the supplementary character of irrigation in Vojvodina, (Pejić et al., 2011a, Pejić et al., 2011b), i.e. that precipitation can affect the soil water regime and irrigation schedule of growing plants. In 2005 and 2006 the average seasonal air temperature was higher for 0.7 °C and 0.5 °C respectively than the long-term seasonal average (1964/2007 – 17.7 °C, Tab. 2). That difference influenced the water used on evapotranspiration but is still in optimum range for normal growing of Sudan grass.

However, despite its abundance, the precipitation was not favorably distributed, so additional water had to be supplied by irrigation of 210 and 120 mm during 2005 and 2006 respectively (Table 3).

Table 3. Irrigation schedules and irrigation water applied

Year	Irrigation rate (mm)			Irrigation water applied in the season (mm)
	Month			
	May	June	July	
2005	$^{+}$30 mm 16	60 mm – 04 60 mm – 22	60 mm – 26	210
2006	-	60 mm – 06 60 mm – 21	-	120

+irrigation were performed after sowing to ensure uniform sprouting of plants

+navodnjavanje obavljeno posle setve da obezbedi ujednačeno nicanje biljaka

RESULTS AND DISCUSSION

In Vojvodina, a typical temperate region, Sudan grass is considered to be an irrigation dependant crop because it rarely meets its water requirements from precipitation received during the growing season. In the study period, evapotranspiration rate in irrigation conditions (ET_m) ranged from 505-584 mm and in the rainfed conditions (ET_a) in the range from 469-502 mm (Table 4). The results observed in this research were in agreement with Pejić et al. (2006), who stated that for the Vojvodina region Sudan grass water requirements are 570 mm.

Table 4. Maximum (ET_m) and actual (ET_a) evapotranspiration (mm), maximum (Y_m) and actual (Y_a) yield (t ha^{-1}), evapotranspiration ($ET_{m,\ a\ wue}$, kg m^{-3}) and irrigation water use efficiency (I_{wue}, kg m^{-3})

Year	ET_m	ET_a	Y_{irr}	Y_{dry}	I_{wue}	ET_{mwue}	ET_{awue}
2005	505	502	95.765	87.983	3.7	19.0	18.1
2006	584	469	122.021	118.644	2.8	20.9	25.4
Average	544	485	108.893a	103.314a	3.2	20.0	21.8

LSD 0.05 = 20.126

The average fresh forage yield increase of Sudan grass due to irrigation was in average 5.4% or 5.579 t ha^{-1}, ranging from 8.8 % (7.782 t ha^{-1}) in 2005 to 2.28% (3.777 t ha^{-1}) in 2006 (Table 4 and 5). On average, irrigation did not significantly affect the fresh forage yield of Sudan grass (I irrigated - 108.893 t ha^{-1} , I_o nonirrigated - 103.314 t ha^{-1}) as the study period had precipitation higher than the long-term seasonal average. The results are in agreement with those given by Nasser and Al-Suhaibani (2006) who obtained pretty the same fresh forage yield of Sudan grass in Saudi Arabia in irrigation conditions (122.393 t ha^{-1}). They concluded that the best results were obtained irrigating Sudan grass in 7 days interval instead of 3 or 11 days interval. In the study period the highest yield was obtained in third cut, both in rain-fed and irrigation conditions in 2005 and 2006 respectively (Table 5).

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

Year		Fresh forage yield- Prinos sveže mase				
		Cut I	Cut II	Cut III	Cut IV	Total
2005	I	26.476	29.706	39.583	-	95.765
	I_o	28.125	29.910	29.948	-	87.983
2006	I	29.500	29.769	44.884	17.868	122.021
	I_o	28.188	28.844	45.634	15.978	118.644

I - irrigated; I_o - nonirrigated.

Table. 6. Time of cutting

Year	Cut I	Cut II	Cut III	Cut IV
2005	29. 06	29. 07	03. 09	-
2006	27. 06	19. 07	18. 08	03. 10

The third cut had the best conditions for Sudan grass growing. The sum of precipitation in August, in both years, (133,9 mm and 124,9 mm in 2005 and 2006 respectively, Tab. 2) was on the rate of Sudan grass water requirement. Forth cut of Sudan grass is rarely possible, even in irrigation, in climate conditions of Vojvodina. Fertile soils such as chernozem have suffered a significant reduction in humus content, in some cases as much as 50% (Bićanić, 1988; Ćupina et al., 2011) thus, forth cut could be used as a green manure to improve fertility, physical and water properties of the soil. Nasser and Al-Suhaibani (2006) also emphasized that in arid climate of Saudi Arabia in first two cuts yield was about 85% of the total obtained forage. According to that study, the growers are advised to take only two Sudan grass forage cuts, using the 7 days irrigation interval. That practice would conserve more than 50% of irrigation water while the reduction in forage may be less than 15% of potential yield.

The best method to describe the role that irrigation has in water use efficiency (WUE) in irrigated agriculture is by expressions given by Bos (1980, 1985). Many researchers have evaluated water use efficiency in different ways (Viets, 1962; Begg and Turner, 1976; Howell, 2001). Consequently, care should be taken when comparing WUE values. Evapotranspiration water use efficiency of Sudan grass, in irrigation conditions (ET_m I_{wue}) ranged from 19.0 to 20.9 kg m^{-3} with an average value of 20.0 kg m^{-3}, while evapotranspiration water use efficiency in conditions without irrigation (ET_a I_{wue}) varied from 18.1 to 25.4 kg m^{-3} with an average value of 21.8 kg m^{-3}. Irrigation water use efficiency (I_{wue}) varied from 2.8 to 3.7 kg m^{-3} with an average value of 3.2 kg m^{-3}. Higher values of fresh forage yield of Sudan grass in irrigation than in rainfed conditions and results of both ET_{wue} and I_{wue} which were similar to those obtained from the literature indicate that irrigation schedule of Sudan grass in the study period was properly adapted to plant water requirements and water-physical soil properties. Determined values of ET_{wue} and I_{wue} could be used for the planning, design and operation of irrigation systems, as well as for improving the production technology of Sudan grass in the region.

CONCLUSIONS

On average, irrigation did not significantly affect the fresh forage yield of Sudan grass (108.893 t ha^{-1} - 103.314 t ha^{-1}) as the study period had precipitation higher than the long-term seasonal average. Evapotranspiration rate in irrigation conditions (ET_m) ranged from 505-584 mm and in the rainfed conditions (ET_a) in the range from 469-502 mm. Evapotranspiration water use efficiency of Sudan grass in irrigation conditions (ET_{mwue}) ranged from 19.0 kg m^{-3} to 20.9 kg m^{-3} with an average value of 20.0 kg m^{-3}, while evapotranspiration water use efficiency in conditions without irrigation (ET_{awue}) ranged from 18.1 kg m^{-3} to 25.4 kg m^{-3} with an average value of 21.8 kg m^{-3}. Irrigation water use efficiency (I_{wue}) varied from 2.8 kg m^{-3} to 3.7 kg m^{-3} with an average value of 3.2 kg m^{-3}. Higher values of fresh forage yield of Sudan grass in irrigation than in rainfed conditions and results of both ET_{wue} and I_{wue} which were similar to those obtained from the literature indicate that irrigation schedule of Sudan grass in the study period was properly adapted to plant water requirements and water-physical soil properties. Determined values of ET_{wue} and I_{wue} could be used for the planning, design and operation of irrigation systems, as well as for improving the production technology of Sudan grass in the region.

REFERENCES

BEEG, J.E., Turner, N.C.: Crop water deficit. Adv Agron., 28:161-217, 1976.

BOS, M.G.: Irrigation efficiences at crop production leve. ICID Bull., 29(60)18-25, 1980.

BOS, M.G.:. Summary of ICID definitions of irrigation efficiency. ICID Bull, 34:28-31, 1985.

ERIĆ P., ĆUPINA B., MIHAILOVIĆ V., PATAKI, I.: Uticaj roka setve i košenja na prinos i kvalitet krme NS-sorti sudanske trave. Savremena poljop., 43(1-2)53-59, 1995.

ERIĆ P., DUKIĆ, D., STANISAVLJEVIĆ, R.: Effect of plant height on hcn level in the forages of forage sorghum and sudan grass. Acta agriculturae Serbica, 9:349-354, 2004.

ĆUPINA, B., DJUKIĆ, D., ERIĆ, P.: Mesto i uloga sirka i sudanske trave u proizvodnji stočne hrane. Zbornik radova Instituta za ratarstvo i povrtarstvo, 36:93-102, 2002.

HOWELL, T.A.: Enhancing water use efficiency in irrigated agriculture. Agron. J., 93:281-289, 2001.

NASSER, A.A.S.: Effect of irrigation and nitrogen fertilizer rates on fresh forage yield of sudangrass [(Sorghum sudanense (Piper) Stapf.]. Res. Bult., No. (142), Food Sci. & Agric. Res. Center, King Saud Univ., pp. 1-14, 2006.

PEJIĆ, B., MAKSIMOVIĆ, L., KARAGIĆ, DJ., MIHAILOVIĆ, V., DRAGOVIĆ, S.: Prinos i evapotranspiracija sudanske trave u zavisnosti od predzalivne vlažnosti zemljišta. Vodoprivreda, 216-218(4-6)245-250, 2005.

PEJIĆ, B., ŠEREMEŠIĆ, S., BELIĆ, M., MILOŠEV, D., KURJAČKI, I.: Effects of crop rotation and irrigation on chernozem structure. Serbian Journal of agriculture, Annals of scientific work, 1:85-92, 2005.

VIETS, F.G.: Fertilizers and the efficient use of water. Adv Agron., 14:223-264, 1962.

WALLACE, J.S., BATCHELOR, C.H.: Managing water resources for crop production. Philos. Trans. R. Soc. London Ser. B, 352:937-947, 1977.

PRINOS I PRODUKTIVNOST UTROŠENE VODE SUDANSKE TRAVE (*SORGHUM SUDANENSE* L.) U USLOVIMA NAVODNJAVANJA U KLIMATSKIM USLOVIMA VOJVODINE

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Izvod

Eksperimentalna istraživanja sa ciljem da se preko obračunatih vrednosti koeficijenata iskorišćenosti vode oceni realizovan režim zalivanja Sudanske trave obavljena su na oglednom polju Instituta za ratarstvo i povrtarstvo na Rimskim Šančevima, na zemljištu tipa karbonatni černozem lesne terase u periodu od 2005-2006 godine. Ogled je postavljen po metodu blok sistema i prilagodjen uslovima navodnjavanja kišenjem. U ogledu su bile zastupljene varijanta sa navodnjavanjem (I - 60-65% od poljskog vodnog kapaciteta – PVK) i kontrolna, nenavodnjavana varijanta (I_0). U ispitivanom periodu, u proseku, prinos sveže zelene mase Sudanske trave bio je signifikantno veći u uslovima navodnjavanja (108.893 t ha^{-1}) u odnosu na kontrolnu, nenavodnjavanu varijantu (103.314

t ha^{-1}). Vrednosti iskorišćenosti vode Sudanske trave u odnosu na evapotranspiraciju u uslovina navodnjavanja (ET_m I_{wue}) kretale su se u intervalu od 19.0 do 20.9 kg m^{-3}, a u uslovima bez navodnjavanja (ET_a I_{wue}) u intervalu od 18.1 do 25.4 kg m^{-3}. Efikasnost iskorišćenosti vode dodate navodnjavanjem (I_{wue}) je bila u intervalu od 2.8 do 3.7 kg m^{-3}. Efekat navodnjavanja na prinos sveže mase Sudanske trave kao i vrednosti ET_{wue} i I_{wue} koeficijenata koji su saglasni vrednostima iz literature ukazuju da je realizovan optimalan zalivni režim Sudanske trave u odnosu na potrebe biljaka za vodom i vodno-fizička svojstva zemljišta. Utvrdjene vrednosti ET_{wue} i I_{wue} koeficijenata mogu biti korišćene u dimenzionisanju zalivnog sistema, a takodje i u unapredjenju proizvodnje ove krmne biljne vrste u klimatskim uslovima Vojvodine .

Ključne reči: navodnjavanje, prinos, sudanska trava (*Sorghum sudanense* L.), efikasnost korišćenja vode.

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