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Assessments on Water Productivity of Rice Crop under Application of Various Irrigation Techniques

Recep ÇAKIR

Çanakkale Onsekiz Mart University, Lapseki Vocational College, Çanakkale- Turkiye
Email: crec56b@yahoo.com; rcakir@comu edu.tr

Abstract This article comprises assessments on water productivity of rice, grown under conditions of conventional flooding (CF), continuous saturation, intermittent irrigation with different water depths and sprinkler irrigation applied at various frequency with different water amounts, on the base of the experimental data obtained from two different studies carried out earlier, on the lands of the Agricultural Research Institute in Edirne. Water productivity of paddy crop was evaluated on the base of the average yields, average water used for any of the applied techniques during the growing season and average total precipitation amounts for the growing period, as WP_I and $WP_{(I+P)}$ respectively. The highest yields are obtained from CF treatment, irrigated with the highest water amounts. However, high water savings in the ranges of 24- 49% and 35-60%, versus grain decreases in the ranges of 0.60-8.04 % and 10.9-57.5 %, are provided under application of intermittent and sprinkler irrigation techniques, respectively. It was determined also that, the lowest water productivity (WP) values, expressed both as (WP_I) and (WP_{I+P}), in the ranges of 0.267 kg m^{-3} and 0.258 kg m^{-3}, and 0.297 kg m^{-3} and 0.270 kg m^{-3}, respectively for the first and second evaluated studies, are determined for CF irrigated rice. The productivity of water applied though intermittent or sprinkler irrigation techniques was much higher and reached the ranges of 0. 349- 0.417 kg m^{-3} (WP_I) and 0.333- 0.39 kg m^{-3} (WP_{I+P}), and 0.322- 0.419 kg m^{-3} (WP_I) and 0.257-0.371 kg m^{-3} (WP_{I+P}), respectively.

Keywords paddy, irrigation, water efficiency, beneficially water use

Introduction

The agriculture is the main water consuming sector in Turkey, as well as in the world. About 70 % of the fresh water sources of the country, are used in order to provide foods required for human nutrition, and/or to meet the needs of agro-industry for sources of herbal and animal origin. On the other side, the agriculture is a sector accounting more than 19% of total national income and 9% of exports of Turkey. The mentioned sector provides also employment opportunities to approximately half of the population of the country.

Though the territory of Thrace region constitutes only about 3% of the country's surface area, 5% of the total agricultural lands of Turkey country are located in the boundaries of Edirne, Kirklareli and Tekirdag districts, where the evaluated studies were carried out. Polycultural agriculture is practised in the region, however approximately 45 % of the country's total paddy area is concentrated across the lands of the mentioned provinces, and more than 50 % of the total rice production is provided by the farmers of the Thrace region [1]. Actually, paddy, which is the second grain product after wheat in the world in terms of cultivation area, production and consumption, is also grown on large areas in the experimental region.

Citing previous publications, Anning et al. [2], concluded that, water is one of the most important components for rice production in the world, since it consumes the highest amount of water than any other crop, and about 40 % of the total world irrigation water is used for the needs of rice farming. Shashidhar [3] claimed that, about three thousand to five thousand litres of water is required to produce one kilogram of rice. Materu et al. [4] explained these enormous water requirements of the rice culture, with large quantities of water lost through evapotranspiration, seepage, surface runoff, and deep percolation in the traditional rice production systems, comprising conventional flooding.

The high importance of paddy rice farming for the country and the region of the study, as well as for the most of the rice producing and consuming countries of the word, very high amounts of the water sources required for irrigation using conventional methods of flooding, pose the danger of rising groundwater level and salinization of the paddy lands. On the other hand, decreasing of the fresh water sources, which could be delivered for the purposes of rice irrigation, makes obligatory searching for other, more effective alternatives for irrigation of the paddy culture. Alternative wetting and drying (AWD), intermittent irrigations, shallow irrigation, low-density drought farming and the application of pressurized irrigation methods such as sprinkler and drip irrigation, could be mentioned among the alternatives which could be applied, instead of high water spending traditional flooding irrigation approach. He [5] concluded that, flooding irrigation was the traditional and most popular system for rice farming in Asia. However, as the problem associated with water shortages increases, there has been increasing research on effective water use in rice farming.

According to some researchers, rice is grown by sprinkler irrigation in countries such as Zimbabwe [6] and the USA [7,8]. In the sprinkler irrigation study conducted by Inthapan and Fukai [9] in Australia, 500-600 mm irrigation water is applied seasonally to the plants of Shinhakaburi variety and high yields of 6.84 t/ha are obtained. On the other hand, in studies conducted in our country and abroad, it has been determined that sprinkler irrigation application provided significant water savings, but reduced grain yield by 20% to 50% , compared to conventional flooded rice [10-13]. In a similar study Bouman et al. [14] determined that, seasonal water use on paddy lands could be reduced by up to 50% under aerobic cultivation, and water use efficiency could be 64-88% higher than traditional cultivation technique. In a study investigating paddy varieties suitability for different aerobic cultivation conducted in IRRI, was found out that, the yields varied in the ranges of 2.4 and 4.4 t/ha, and more than 50 % of the irrigation water amount was saved, depending on the applications in aerobic conditions, versus 14-40 % yield decrease, compared to flooding culture [15].

In addition to sprinkler irrigation, practices including intermittent irrigation, keeping the soil surface constantly saturated, and other approaches are also investigated in order to increase the efficiency of water use in paddy agriculture. In this sense, the latest approach used in paddy irrigation is drip irrigation, which is recently less applied and studied, compared to flood and AWD irrigation methods, mainly due to higher cost of the water application system. According to Wu et al. [16] rice cultivation has been challenged by increasing food demand and water scarcity. The authors examined the responses of water use, grain yield, and water productivity to four various modes of field water managements in Chinese double rice system, and determined that compared to CF (conventional flooding), the F-D-F (flooding-midseason drying-flooding) system, consumed more irrigation water, which still decreased grain yield, leading to a decrease in water productivity by 25% in early-rice season and by 8% in late-rice season.

Nowadays, the decreases in water amounts that can be allocated to agricultural irrigation, in parallel with the decrease in water resources in the world, has brought forward the issue of increasing the productivity of water in paddy, which is the most water consuming crop. A number of studies aiming increasing the water productivity, have been conducted on the base of alternative irrigation techniques and technologies, as well as on the alternative farming techniques and approximations. Xihua et al. [17] studied the effect of irrigation depth on rice production and WP. The experiment included four treatments: (i) traditional irrigation; (ii) shallow wet irrigation; (iii) intermittent irrigation; (iv) controlled irrigation. The results of the study showed that, controlled irrigation provided the highest WP (1.64 kg m^{-3}). However, the highest rice yield was obtained from the shallow wet irrigation (9867 kg ha^{-1}), which achieved the second highest WP of 1.63 kg m^{-3}. In a study carried out in Bangladesh Agricultural Research Institute, were compared two tillage methods (conventional tillage and reduced tillage) and three irrigation methods, sprinkler irrigation, alternate wetting and drying (AWD) and flood irrigation and was determined that, the grain yields were 7.62% higher under sprinkler, and 4.72% higher in AWD irrigation applications over flood irrigation method. The highest water productivity values of 0.83 kg m^{-3} and 0.773 kg m^{-3} were recorded respectively for sprinkler irrigation method and reduced tillage method [18].

Mdemu and Francis [19] evaluated the physical water productivity of rice under the conditions of the Kapunga rice irrigation scheme, in the Usangu plain of Tanzania, and determined that overall water productivity of the irrigation scheme varied between 0.17 kg m^{-3} and 0.62 kg m^{-3}, for water productivity values assessed on the base of $WP_{(I+P)}$ and WP_{ET}, respectively. However, the water productivity, based on irrigation water amount (WP_I) was reported as 0.22 kg m^{-3} for the lands of the irrigation scheme. In another study [20], WP of rice determined on the base of the total water inputs (irrigation and rainfall) was depicted as varying from 0.2 to 1.2 kg m^{-3}, with an average value of 0.4 kg m^{-3}. However relatively lower water productivity values between 0.41- 0.45 kg m^{-3} and 0.4-0.44 kg m^{-3} for AWD and CF (wet seson) and 0.87-0.88 kg m^{-3} and 0.83- 0.90 kg m^{-3} for AWD and CF (dry season) respectively were determined by [21]. Higher values of 0.9-1.54 (avg. 1.07) kg m^{-3}, 1.73-2.48 (avg. 1.99) kg m^{-3} and 0.71-0.98 (avg.) kg m^{-3}, respectively for WP_{ETc}, WP_I and $WP_{(I+P)}$ for 7 rice genotypes, were reported by [22], recently. The authors concluded that, the differences in WP values reported in different literature sources were due to instability of in rice yields, varying in the ranges of 3.0 and 8.0 t ha^{-1}, and the different concepts of water use in production of the crop. However, Aziz et al [23] determined higher values for $WP_{(I+P)}$ and WP_I, in the ranges of 0.83 to 1.20 kg m^{-3} and 1.91 to 2.85 kg m^{-3}, respectively for the conditions of Tuanlin Irrigation Experimental Station in Hubei Province of China.

Several studies related to irrigation of rice have been carried out in Thrace region of Turkey, the main producer of rice of the country. In some of them; the effects of intermittent irrigations of deferent water depths [24], or the impacts of sprinkler irrigation with various irrigation amounts applied at different frequency [12,13] or the influence of drip irrigation on growth and yields of different rice cultivars and genotypes [25,26], were compared to conventional flooding applications. However no analyses on water productivity on the bases of irrigation water amounts (WP_I) or irrigation water+ seasonal precipitation ($WP_{(I+P)}$) were performed and published earlier.

The objective of this study was; to analyse the matter of beneficial water use in rice farming, on the bases of WP_I and $WP_{(I+P)}$), evaluated on the ground of the results obtained from studies with various irrigation techniques and approximations, accomplished earlier under conditions of Edirne province, the main producer of rice in the country.

Material and Methods

The evaluated two experimental studies were carried out on the fields of the Agricultural Research Institute of Edirne, the centre of the district major producer of rice in the country. The lands of the Institute are covered with soils of silty loam texture (SCL), containing more than 50 % sand in all of the layers except for the upper 0-20 soil depth and belonging to Entisol soil (Udic Ustifluvent) and poor (0.23-2.22 %) in organic matter. The values of some of the physical and chemical properties of different layers of the experimental soils are presented as summarised in Table 1.

Approximately 50-year average data related to climatic characteristics of the experimental area, published by the General Directorate of State Meteorological Affairs [27] and given in Table 2 show that, the sum of the average 50-year precipitation in Edirne station is 603.5 mm. However, the precipitation is irregularly distributed throughout the seasons and years. The highest annual average monthly precipitation values of 73.6, 70.6 and 65.6 mm, are recorded respectively for the winter months of December, November and January, while the summer months of August, July, and September are characterised as the driest months of the year, with averages of 24.2, 31.9 and 33.8 mm for a long-year period.

Table 1: Soil Properties for representing rice growing soils in the region

Soil depth, cm	**% of Saturation**	**pH**	**Lime, %**	**Organic matter %**	**Texture Fractions and Texture Class**			
					Clay %	**Loam %**	**Sand %**	**Class***
0-20	57	7.47	6.99	2.22	30.99	20.81	48.20	SCL
20-40	52	7.48	2.06	1.25	26.80	20.84	52.36	SCL
40-60	46	7.58	3.17	0.74	22.65	16.38	61.37	SCL
60-80	39	7.57	1.74	0.23	15.91	16.34	67.75	SL
80-100	50	7.55	1.11	0.97	29.10	18.83	52.07	SCL
100-120	52	7.56	0.47	0.57	27.15	21.12	51.73	SCL

*S-sand, C-clay and L-loam

The average annual relative humidity determined for the experimental region is 76%, with the maximum average monthly values in the ranges of 82-86 %, observed during the months of the winter season, from November to February. Though the lowest air humidity values in the ranges of 64- 67 % are recorded for the summer months of June- August, the period when the rice crop actively grow.

According to long-year climatic data, the sum of the average evaporation in the region is twice higher, than the sum of the average precipitation amount, and reaches to 1323 mm. In contrast to lowest relative humidity values during the plant growing summer months, the sum of the average monthly evaporation values observed during June, July, August and September are the highest and reach up to 216, 266, 251 and 173 mm, respectively. This phenomenon, along with the highest maximum average temperature values (38-42 °C), observed during the mentioned period of the year, increases plant water requirements, and consequently the needs of the crop for more irrigation water.

Analysis related to water productivity of rice crop were performed on the base of the results obtained from two field experiments completed on the fields of Agricultural Research Institute located in Edirne.

Table 2: Long year average climatic values of the rice regions of Edirne Province [27]

Climatic Parameters values	**MONTHS**												**Yearly**
	I	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**	**IX**	**X**	**XI**	**XII**	
Precipitation, mm	65.6	49.0	47.7	49.2	50.1	51.3	31.9	24.2	33.8	56.7	70.6	73.6	603.5
Rel. Humidity, %	83	84	82	76	72	66	64	67	74	78	82	86	76
Evaporation, mm	7.9	7.6	26.7	69.3	127	216	266	251	173	103	53.5	24.0	1323
Avg Temperature, C^o	2.1	3.8	7.1	12.6	17.8	22.0	24.4	23.9	19.6	14.3	9.3	4.4	13.5
Max Temperature, C^o	20.0	21.1	28.0	33.5	38.3	39.3	41.5	40.8	37.8	36.5	25.1	20.8	41.5
Min Temperature, C^o	-22	-19	-14	-2.3	0.6	6.7	8.0	8.0	0.2	-3.3	-11	-19	-22

The firs experiment was carried out by Yakan and Sürek [24], using Baldo rice cultivar and scoped application of intermittent irrigation with different water depths (10, 15 and 20 cm), and compared with conventional flooding (CF) and continuous saturation (CS). Each of the plots of the trial were sown and farmed following procedures applied by the rice farmers in the region, except of the irrigation application, though the CF plots were irrigated as is practised by the farmers. The experimental plots comprising intermittent water application were flooded to proposed (projected) depth, and the subsequent irrigation practices were applied just after the withdrawal of water from the soil surface of the plot. More details related to procedure and the results of the study are available in [24].

The second experiment evaluated in this study, was carried out by Çakir et al [13], using Ergene rice cultivar, and aiming determination of the impacts of sprinkler irrigation applications with various irrigation amounts, based on different (1.0, 1.5 and 2.0) A pan coefficients, applied at two or four days irrigation intervals. The results related to the effects of sprinkler irrigation application, involving various water rates and two different irrigation frequency, were compared with those obtained from the plots containing conventional flooding, used as a control in the study. The sprinkler irrigation treatments consisted of pulsating sprinkler heads mounted at 0.5 m height. Since the space between laterals and sprinklers was 12 m, the plot size was designed as 12 x 12 m= 144 m^2. Two sprinklers, with 4.5 mm nozzle diameter, providing uniform coverage at an angle of 90^o were used per each experimental plot. The control plots of the study, containing conventional flooding (CF) were also 12 x 12 m= 144 m^2 sized and all the procedures, including water application were performed as applied by the rice farmers in the region. More information for the followed procedures and the results obtained from the study are available could be found in [12,13].

Water productivity of paddy crop was determined on the base of the average yields, average water used for any of the applied techniques during the growing season and average total precipitation amounts for the growing period. Following formulas were used for determination of water productivity (WP) under conditions of a certain irrigation application.

$WP_I = Y/I$

$WP_{(P+I)} = Y/ (P + I);$

where: WP_I is the water productivity on the base of seasonal irrigation water amount applied to any treatment, kg m^{-3}; $WP_{(P+I)}$ is the water productivity based on the sum of irrigation water amount and seasonal precipitation rate, kg m^{-3}; Y is the grain yield of the treatment, kg da^{-1} ; I- seasonal irrigation water applied to a certain treatment, mm; and P- precipitation rate average for the growing season, mm. The assessments of WP on the base of the panicle number per da, were done after transformation of the numbers from m^2 to decare using the formula; WP panicle = (panicle nu m^{-2} X 1000)/I

Results and Discussion

The data related to average results obtained from 2-year experiment containing intermittent irrigations with 10, 15 and 20 cm water depths, as well as the treatments comprising conventional flooding (CF) and continuous saturation (CS), are included in table 3, and the decreases in the number of panicles per m^2 and grain yields per decare versus water saving ratios, are presented respectively on Fig 1 and Fig 2.

As can be seen from data for the average panicle numbers per m^2 and grain yields in kg da^{-1} given in the table, the mentioned parameters are not statistically influenced by the irrigation techniques, however the higher yields have been recorded for treatments growing under conventional flooding (CF) and intermittent irrigations with application of 15 cm and 20 cm water depths, in D and E treatments, respectively. However average seasonal irrigation water amounts, applied to any of the experimental treatments have been varying in large extends; from 2488.3 mm for CF to 1279 mm for B treatment, grown under conditions of continuous saturation. The average total irrigation water quantities applied to three intermitted applications of the study have been determined as 1495.9, 1674.1 and 1894.8 mm, for water depths of 10, 15 and 20 cm, respectively.

Assessments performed on the base of the findings for the number of the panicles per m^2 and grain yield in kg da^{-1} on one side, and total water applied to any of the experimental treatments on the other, showed that comparatively high water savings of 48.6, 39.9, 32.7 and 23.9% ,versus low decrease rates of 10.1, 15.9, 12.5 and 1.5 % exists in the number of panicle in the plots of B, C, D and E treatments, grown under continuously saturated conditions (CS) and intermittent irrigated plots with 10, 15 and 20 cm water depths respectively, compared to conventional flooded (CF) application (Fig 1). Relatively low decreasing rates, between 0.60-8.04 %, versus the saved water amounts mentioned above, are recorded in terms of the grain yields obtained from the treatments of the study (Fig 2).

Water productivity data quantified as grain yield or panicle number per decare, determined on the base of the seasonal irrigation water volume or a sum of irrigation water and precipitation rates volume are presented in Table 3.

Table 3: Yielding parameters and water productivity of conventional flooded and intermittent treatments of the study (2-yr averages)

Irrigation Application	Panicle number per m^2		Grain yield		Seasonal Total amount		Water productivity			
							WP_I		$WP_{(I+P)}$	
	nu m^{-2}*	Deviation from the control A (-) (+) %	kg da^{-1}*	Deviationf rom the control A (-) (+) %	IW mm*	Rain-fall mm	Panicle nuda^{-1} m^{-3}	Grain Yield kg m^{-3}	Panicle nuda^{-1} m^{-3}	Grain Yield kg m^{-3}
A	336	-	665.5	-	2488.3	94	135.0	0.267	130.1	0.258
B	302	-10.1	612.0	-8.04	1279.0	94	236.1	0.478	220.0	0.446
C	283	-15.8	624.5	-6.16	1495.9	94	189.2	0.417	178.1	0.393
D	294	-12.5	674.5	+1.35	1674.1	94	175.6	0.403	166.3	0.381
E	331	-1.5	661.5	-0.60	1894.8	94	174.7	0.349	166.4	0.333

*Yearly data available in [24]

The lowest WP_I based on the number of panicle and grain yields, respectively 135 nu da^{-1} m^{-3} and 0.267 kg m^{-3} were defined for conventional flooded (CF) plots, while the highest water productivity of 236.1 nu da^{-1} m^{-3} and 0. 478 kg m^{-3} were determined for continuously saturated (CS) treatment. Relatively high WP_I values were detected for the three treatments including intermitted irrigation, where each m^3 of applied water provided 0.417, 0.403 and 0.349 kg of rice grain, respectively for water depths of 10, 15 and 20 cm. Similarly to WP_I, the lowest values of water productivity based on the sum of the seasonal irrigation and precipitation amounts ($WP_{(I+P)}$), as 130.1 nu da^{-1} m^{-3} and 0.238 kg m^{-3} were determined for the treatment CF, and the highest figures recorded for the CS treatment. Each unit of water (m^3), applied to plots comprising intermittent irrigation with 10, 15 and 20 cm water depths, produced 0.393, 0.381 and 0.333 kg of rice grain.

The second experiment evaluated in this study, was carried out by Çakir et al. [13] with early ripening Ergene cultivar as a biological material of the study, grown under conditions of sprinkler irrigation at two different irrigation intervals (A1 and A2) and three irrigation water supply levels (B1, B2 and B3), based on three different (1.0, 1.5 and 2.0) A- pan coefficients. The results obtained for the sprinkler irrigated plots were compared to data recorded for the plots, involving conventional flooding (CF), used as a control in the study (Table 4).

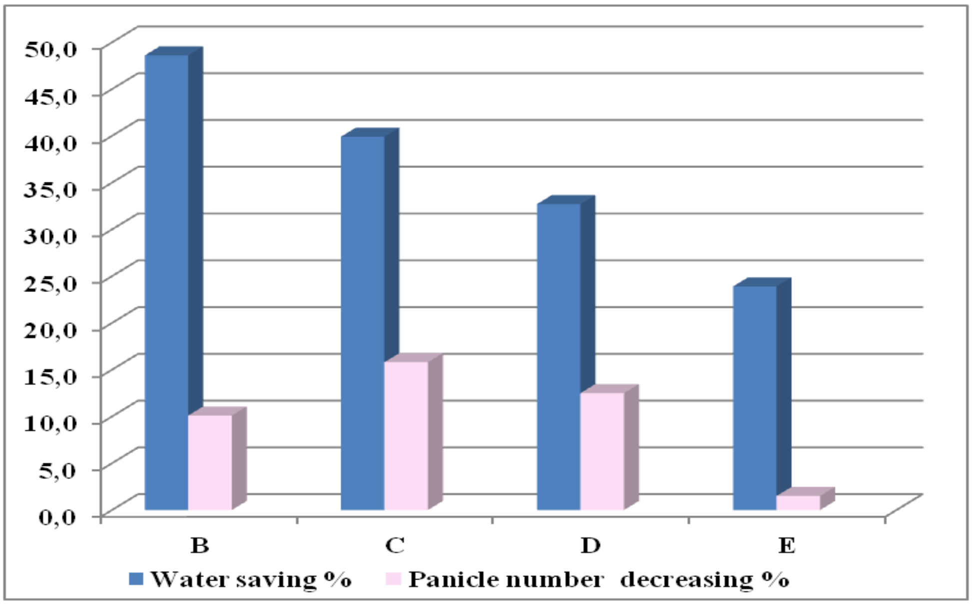

Figure 1: Decrease in the number of panicles per m^2 vs. water savings under various intermittent irrigation techniques

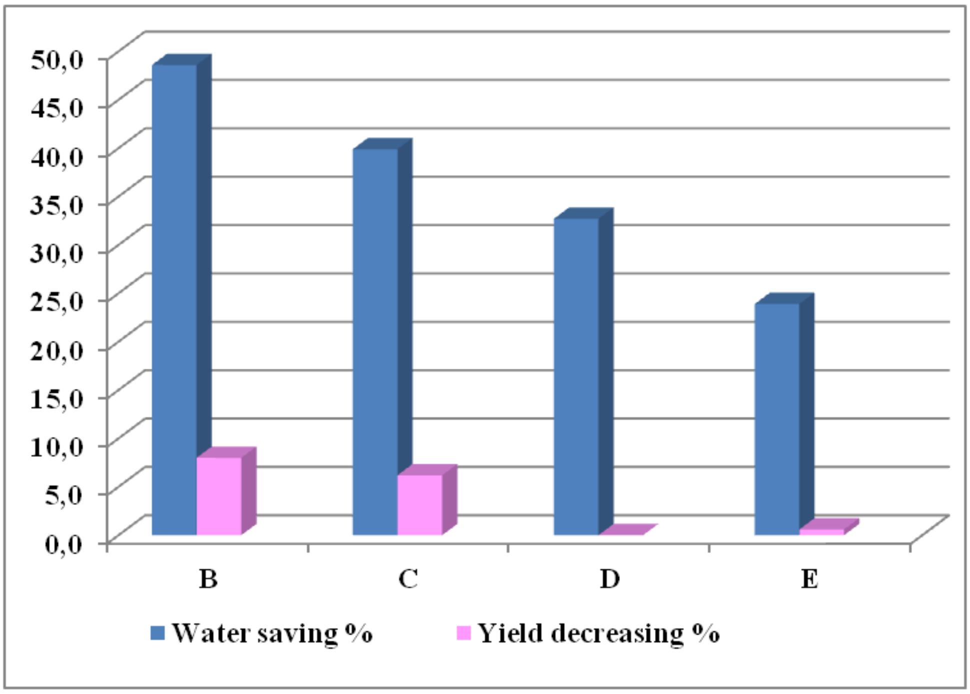

Figure 2: Grain yield decrease vs. water saving ratios under conditions of different intermittent irrigation techniques

Table 4: Yielding properties and water productivity of sprinkler irrigated rice crop (3-year av.)

Irrigation Application	**Panicle number per m^2**		**Grain yield per da**		**Seasonal Total amount**		**Water productivity**			
							WP_I		**$WP_{(I+P)}$**	
	num*	**Decrease %**	**kg da^{-1}***	**Decrease %**	**IW mm***	**Rain-fall mm**	**Panicle nu da^{-1} m^{-3}**	**Grain Yield kg m^{-3}**	**Panicle nu da^{-1} m^{-3}**	**Grain Yield kg m^{-3}**
$A_{1,2}$ B_4 (CF)[1]	362.0	-	538.1[a]	-	1809.1	181	200.1	0.297	181.9	0.270
A_1B_1	238.5	33.8	228.5[c]	57.5	708.9	181	336.4	0.322	268.0	0.257
A_1B_2	265.5	26.7	394.3[b]	26.7	940.4	181	282.3	0.419	236.8	0.325
A_1B_3	254.5	29.7	479.4[a]	10.9	1171.2	181	217.3	0.409	188.2	0.355
A_2B_1	240.0	33.7	254.0[c]	52.8	708.9	181	338.6	0.358	269.7	0.285
A_2B_2	259.5	28.3	416.5[b]	22.6	940.4	181	275.9	0.442	231.4	0.371
A_2B_3	280.5	22.5	465.9[a]	13.4	1171.2	181	239.5	0.398	207.4	0.345

[1]CF-conventional flooding (control)

*More details are available in) [13]

As it is evident from data presented in Table 4, irrigation intervals had no significant effect on yield. Though the results related to impact of the irrigation water amounts, determined on the base of three A-pan coefficients, on grain yields were statistically proved. The grain yields averages (kg da^{-1}) and number of panicles per m^2 for 3-year study, ranged from 228.5 kg da^{-1} to 538.1 kg da^{-1} and from 238.5 nu m^2 to 362.0 nu m^2, respectively. The highest grain yields per da and panicle numbers for m^2 were recorded for conventionally flooded (CF) treatment, with the application of the highest irrigation water amount of 1809.1 mm. While the lowest grain yields and panicle number per m^2 were obtained from sprinkler irrigated plots with 100 % replacement of A pan evaporation, and irrigated at 2-day intervals (A_1B_1) treatment, where the lowest irrigation water amounts of 708.9 mm were applied. The average grain yields detected for the sprinkler irrigated treatments, with applied water amounts of 940.4 mm (A_1B_2 and A_2B_2), and 1171.2 mm (A_1B_3 and A_2B_3), were depicted as 394.3 kg da^{-1} and 416.15 kg da^{-1}, and 479.4 kg da^{-1} and 465.9 kg da^{-1}, respectively.

Evaluation of the data in terms of grain yield loss and panicle number decrease, versus water saving percentage under any of the sprinkler irrigated plots showed that, high water savings of 60.8, 48.0 and 35.3 % versus; 57.5 and 52.8 % (A_1B_1 and A_2B_1), 26.7 and 22.6 % (A_1B_2 and A_2B_2), and 10.9 and 13.4 % (A_1B_3 and A_2B_3) yield loss, were achieved especially for plots with lower A-pan coefficients applied. However the decreasing in the number of panicles per m^2 was much lower than the grain yield and varied in the ranges of 22.5 % (A_2B_3) and 33.8 % (A_1B_1) than that of the CF plots (Fig. 3 and Fig. 4).

Results for the water productivity on base of the grain yields and panicle numbers per unit area (da), assessed in terms of the total irrigation water volume, applied during the entire growing season (WP_I) and in terms of the sum of irrigation water and seasonal precipitation rate (WP_{I+P}) are available in Table 4.

Water productivity (WP_I and WP_{I+P}) data summarised in Table 4 demonstrated that, in spite of the highest grain yields, the lowest water productivity values of 0.297 kg m^{-3} and 0.270 kg m^{-3} rice grain, and 200.1 nu da^{-1} m^{-3} and 181.9 nu da^{-1} m^{-3} panicle number, respectively for WP_I and WP_{I+P} were achieved under conditions of CF, because of the high irrigation water amounts applied. On the other hand, the values of the WP_I and WP_{I+P} were also relatively low; 0.322 kg m^{-3} and 0.270 kg m^{-3} and 0.358 kg m^{-3} and 0.285 kg m^{-3} for A_1B_1 and A_1B_2 treatments, sprinkle irrigated at 2 and 4-day intervals with the lowest irrigation water amounts applied. However, water productivity values for the grain yields, assessed both on the base of WP_I and WP_{I+P}, were much higher under conditions of application of the higher A pan coefficients of 1.5 and 2.0, irrigated at 2 or 4-day intervals. Each unit of irrigation water (m3), applied to A_1B_2 and A_2B_2; and A_1B_3 and A_2B_3 plots provided 0.419 kg and 0.442 kg, and 0.409 kg, and 0.398 kg grain yield, respectively.

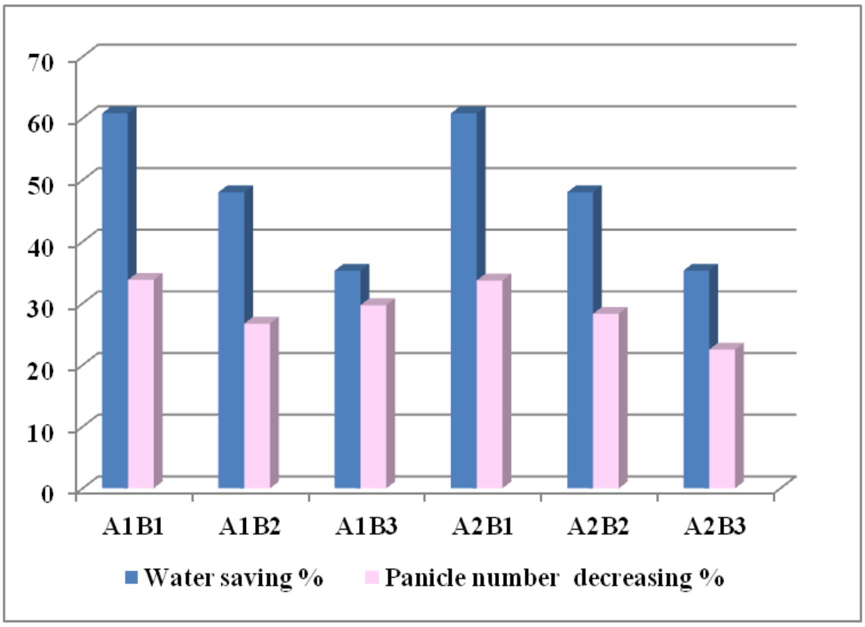

Figure 3: Panicle number decreases versus water savings under various sprinkler application conditions

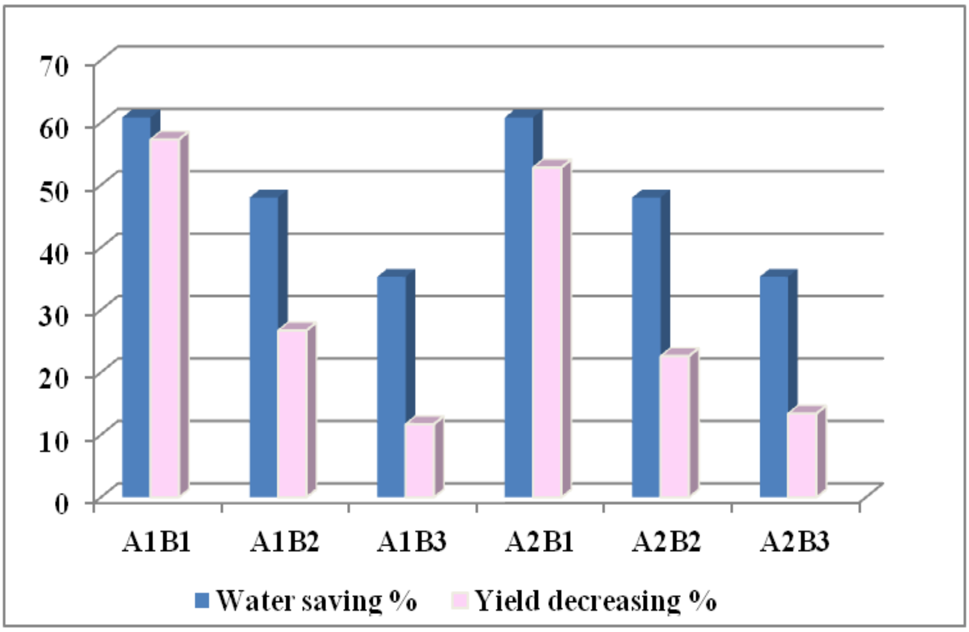

Figure 4: Yield decreases versus water savings under various sprinkler application conditions

Relatively high water productivity values in the ranges of 0.352-0.371 kg m^{-3}, were detected also under conditions of the listed sprinkler irrigation treatments, evaluated on the base of WP_{I+P}.

Results related to yields and water savings reported in the study comprising the comparison between conventional flooding (CF) and intermittent irrigation with various depth of water, are similar to those obtained from trials containing similar applications as AWD, shallow irrigation, and controlled irrigation techniques published by other authors in the subject literature [2,4,18].

Yield losses due to water stress as a result of sprinkler irrigation of rice, confirmed the results determined previously by authors from Texas, Arkansas and Louisiana of the USA; as well as from different parts of Australia. Westcott and Vines [28] reported for yield losses up to 25-35 % due to the sprinkler irrigation. Blackwell et al. [8] studied the growth and yield of rice under sprinkler irrigation and found out that, while the grain yields from the flooded plots reached the level of 7.0 t ha^{-1}; yields recorded for the sprinkler irrigated plots were relatively lower. Muirhead et al [10] found out that sprinkler irrigation, even when applied at frequent intervals, drastically decreased the yield of rice by 50 % or more when compared with continuous flood. Ferguson and Gilmore [29,30] reported that, under sprinkler irrigation applied twice weekly, with water depth replacing evaporation, 50 % water saving and yields comparable to flood irrigation could be achieved. Though [18] found out that yields of the sprinkler and AWD irrigated paddy plots over yielded the CF plots by 7.62 and 4.72 % respectively.

The assessments on the both of the evaluated studies showed that, lower water productivity (WP_I and WP_{I+P}) values of 0.267 kg m^{-3} and 0.258 kg m^{-3}, and 0. 297 kg m^{-3} and 0. 270 kg m^{-3} are achieved under conditions of conventional flooding (CF) application in the first and second experiment respectively. However the productivity of any unit of water applied though intermittent or sprinkler irrigation techniques is much higher, and varies in the ranges of 0. 349- 0.417 kg m^{-3} (WP_I) and 0.333- 0.39 kg m^{-3} (WP_{I+P}), and 0.322- 0.419 kg m^{-3} (WP_I) and 0.257-0.371 kg m^{-3} (WP_{I+P}) respectively for intermittent and sprinkler applications. Other authors [2,18], also determined higher water productivity of rice, under conditions of sprinkler irrigation and AWD application and lower WP for flooded rice. However [21] reported that continuous flooding (CF) provides a favourable water and nutrient supply under anaerobic conditions and consumes a large amount of water, however the water productivity is almost the same for AWD and CF applications and varied in narrow ranges of 0.41- 0.45 kg m^{-3} and 0.4-0.44 kg m^{-3}, and 0.87-0.88 kg m^{-3} and 0.83- 0.90 kg m^{-3}, respectively for wet (WS) and dry (DS) seasons of Philippines. Much higher water productivity averages of 1.07, 1.99 and 0.76 kg m^{-3} for WP_{Etc}, WP_I and WP_{I+P}, of 7 rice genotypes, respectively were detected by [22], though much lower values, between the ranges of 0.17 kg m^{-3} and 0.62 kg m^{-3} are reported for the physical productivity of water for rice in Kapunga irrigation scheme of Tanzania [19]. Pirmoradian et al. [31] simulated water productivity of paddy rice, using AquaCrop model in both humid and semiarid regions of Iran and concluded that, the ranges of water productivity based on transpiration (WP_T) and water productivity determined on base of evapotranspiration (WP_{ET}), are affected by irrigation treatments. The authors determined that, the averages of WP_T and WP_{ET} for continuous flooding (CF), reached to 1.21 and 0.82 kg m^{-3}, and 1.26 and 0.76 kg m^{-3}, respectively for humid and semiarid conditions of Iran.

Conclusions

Assessments performed on data related to yield and seasonal water amounts used for irrigation of rice, grown on the fields of the Agricultural Research Institute in Edirne district, the major producer of rice in the country showed that, the water productivity of rice is closely dependent on irrigation methods and technique applied.

The highest yields of all of the application techniques, including conventional flooding (CF), sprinkler irrigation with various water depths, intermittent irrigation with different water depths and continuous saturation, are obtained from CF treatment, irrigated with the highest water amounts. However, high water savings in the ranges of 24-49 % versus low decrease in the grain yields, in the ranges of 0.60-8.04 % , are achieved under conditions of continuously saturation and intermittent irrigation application. Even more water saving rates compared to CF, between 35-60% can be provided using sprinkler irrigation technique, though grain yield losses reach the higher levels of 10.9-57.5 %, under conditions of plots comprising sprinkler irrigation with various water depths.

In spite of the highest grain yields, the lowest water productivity (WP) values, both on the base of irrigation water applied (WP_I) and the sum of the irrigation water and seasonal precipitation rates (WP_{I+P}), in the ranges of 0.267 kg m^{-3} and 0.258 kg m^{-3}, and 0.297 kg m^{-3} and 0.270 kg m^{-3}, respectively for the first and second evaluated studies, are determined for conventionally flooded (CF) rice. However the productivity of any unit (m^3) of water applied though intermittent or sprinkler irrigation techniques, reach much higher levels of 0. 349- 0.417 kg m^{-3} (WP_I) and 0.333- 0.39 kg m^{-3} (WP_{I+P}), and 0.322- 0.419 kg m^{-3} (WP_I) and 0.257-0.371 kg m^{-3} (WP_{I+P}), respectively.

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