EFFECT OF DIFFERENT WATER-SAVING IRRIGATION METHODS ON RICE YIELD, WATER USE AND WATER PRODUCTIVITY IN TYPICAL LOWLAND CONDITIONS IN BAFRA VALLEY, TÜRKİYE

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Abstract

This study primarily focused on the effects of various water-saving irrigation strategies on rice grain yield and water productivity. The case study was carried out in Bafra Experimental Station of the Black Sea Agricultural Research Institute in Turkiye between 2019 and 2020. The experiment conducted on randomized block design with split-plot arrangement with rice as the primary plot and irrigation treatments as subplots with three replications. Two rice varieties ("*Osmancik-97*", and "*Rekor CL*") and 6 irrigation applications (Continuous flooding (CF), Alternate Wetting and Drying (AWD5, AWD10, and AWD15) and Drip Irrigation × 1.75 Epan (DI × 1.75) and Drip irrigation × 2 Epan (DI × 2) were utilized. The effect various irrigation strategies on water input, water productivity, grain yield and grain quality were evaluated. Total water productivities in DI applications were found more efficient than both CF and AWD treatments. The AWD treatments reduced the water input and rice grain yield by 18-33% and 5-25% compared to the CF treatment, respectively. In AWD5, the average grain yield was lessened by just 5-8% compared to CF. AWD5 water-saving rates reached 23% compared to CF. The AWD5 and DI applications were performed similar grain yield values compare to CF. Grain yields were decreased by 11-18% in AWD10 compared to CF. In AWD15, in which flooding events were applied when soil water potential at -15 cm by the soil surface reached 18 to 30 kPa, yield losses were found to be 13-25% compared to CF. The results suggest that DI treatment in rice cultivation might be a useful alternative compared to CF, since it reduced water input while increasing water productivity. Moreover, AWD5

treatments might have a significant potential to water-saving without grain yield loss compared to CF.

Keywords: AWD, irrigation, drip irrigation, rice, water productivity, water saving, yield.

1 Introduction

Rice is one of the most crucial crops for 50% of the global's population. Worldwide rice demand estimated will increase by up to 25% between 2015-2030 years (IRRI 2019). Water shortage in agricultural use is becoming the first-rate problem in many nations of the world day by day, due to the increase in global warming and the overuse of freshwater resources. Around 35% of freshwater use in agriculture is generally for rice production. Most of studies revealed that rice needs 2.500 – 5.000 liters of water to produce 1 kg of grain. Actually , physiological rice production is required less than 1/3 of this amount (IRRI 2019). There is a need of new irrigation practices that reduce water use and increase usage efficiency in rice cultivation. In order to save water, new irrigation technologies and practices have been introduced to increase water efficiency and decrease water usage in rice production. These include keeping soil at saturation, aerobic rice, and AWD (Belder et al. 2005; Bouman et al. 2007). These technology and practices not only save water in rice production, but also help to reduce greenhouse gas emissions. Water-saving irrigation methods and practices such as alternate wetting and drying, drip irrigation, aerobic rice, intermitted drainage and midseason drainage reduce methane emission by increasing oxygen concentration in the soil.

Turkey's rice cultivation areas account for 0.07% (FAOSTAT data for 2018) of rice planting areas of the world. The foremost rice-developing areas in Turkey are the northwestern (Marmara-Thrace) and the northern of the Turkey (Black Sea region). The Marmara-Thrace place has the biggest rice- producing area, followed by the Black Sea region. Marmara-Thrace and the Black Sea region have 109.559 ha of rice cultivation area, and constituiting the 95% of rice cultivation in the country. The average yield in Turkey is 7.8 t ha^{-1}, that is higher than the world average yield. The reason of high yield might be the ecological conditions, the productive rice varieties and used new technologies such as laser leveling, agriculture drone, and semi-autonomous devices.

The aim of this study is to evaluate the results of water-saving irrigation technologies and applied in the MEDWATERICE project on rice yield, rice quality, water productivity and to compare themto those achieved with the traditional irrigation methods in the Bafra Valley.

2 Materials and methods

2.1 Experimental site description

The study was carried out on the rice field station of the Black Sea Agricultural Research Institute (BSARI) located in Bafra Valley of Samsun, Turkiye, during the rice production seasons between 2019 and 2020 (June-October). The location's climate characterictics are average rainfall of < 760 mm, highest air temperature of 36.1 °C and minimal air temperature of - 6.8 °C. The soil is assessed with silt-clay, Typic Haplustert (Soil Survey 1999). The soil contained 41.02% silt, 40.22% clay, and 18.76% sand (silt clay) in the experiment fields. The field capacity and permanent wilting point moisture content of the experimental soil were fount to be 31.11 and 21.25% percent, respectively. All meterolicigal data was provided from the meteorology station located inside the study area.

2.2 Experimental design and treatments

The research conducted on complete randomized block design with three replications. Two rice cultivars "Osmancik-97" (V1), and "Rekor-CL" (V2) and 6 irrigation methods was utilized. Total 36 plots were established with 5×5 m^2 dimensions in field. Six irrigation treatments were tested in the experiment: T1: Continuous flooding (CF) with a ponding water level maintained at 8-10 cm (control plot), T2: AWD5 – Flooding to a water level of 8-10 cm when the level of water drops to 5 cm under ground level, T3: AWD10– Flooding to a water depth of 8-10 cm when the water level drops to 10 cm below ground level, T4: AWD15 – Flooding to a water depth of 8-10 cm when the water level decreases to 15 cm below ground level, T5: Drip irrigation × 1.75 pan evaporation (Epan), T6: Drip irrigation × 2.0 pan evaporation (Epan).

2.3. Crop management

In the first season, seeds were sown in seedbeds on 24 May 2019 and seedlings were transplanted to 3 seedlings per hill at a spacing of 20 × 20 cm on 15 July 2019 (TPR). In the second season, seeds were sown on 9 July 2020. The seeding rate for dry direct-seeded rice was (DDSR) 170 kg ha^{-1} for *Rekor CL* variety, 160 kg ha^{-1} for *Osmancik-97* rice variety. During the first 21 day after sowing and transplanting in the two experimental years, in order to control weeds, to reduce any water deficiency risk and to to enhance seedling rate, the plots were flood irrigated (the soil was kept saturated); then, the specific irrigation method was applied. In CF plots, water level was kept at 8–10 cm during the whole growing season up to three weeks before harvest time. Timing of irrigation in AWD plots was decided according to the ponding water level inside the water tubes installed in the experimental plots (Bouman et al. 2007). Irrigation was applied to reach a ponding water level of 8-10 cm when the water level inside the water tube decreased to the critical levels of 5, 10, and 15 cm below the soil surface for the three AWD treatments, AWD5, AWD10, and AWD15, respectively. At around flowering, the ponding water level inside the plots for all AWD treatments was kept at 8-10 cm to minimize the risk of panicle sterility because of a lack of water. When flowering stage accomplished, AWD applications were continued till pre-harvesting time (three weeks earlier than harvest).

In drip irrigation treatments (DI 1.75 × Epan, DI 2 × Epan) water was given on alternate days based on open pan evaporation levels of the previous two days. According to infiltration tests performed in the plots, the laterals having drippers with a flow rate of 2.5 L h^{-1} and a distance on the lateral of 40 cm, where installed with an interdistance between laterals of 40 cm. The field was dry-plowed, harrowed and levelled prior to the establishment of the experiment. For each irrigation methods, fertilizer applications were identical. Nitrogen (N) fertilization was splitted in three equal parts of 60 kg ha^{-1} each. (1) Diammonium phosphate applied as basal fertilizer, Ammonium sulfate were applied as top dressing at mid-tillering and panicle initiation. Additionally, 40 kg ha^{-1} phosphorous (P) and potassium (K) were used as basal fertilizer. The post emergence herbicides, Cyhalofop-Butyl, Bentazon and Imazamox (only Recor CL), were applied with advised label rates at 20 days after transplanting/sowing in order to kill weeds which *Echinochloa cruzz galli, Echinochloa oryzoides, Cyperus difformis, and Alisma plantago* etc.

2.4 Measurements and observations

2.4.1 Irrigation

Irrigation water for every plot was measured via a water meter located in the irrigation pipes. Daily ponding water levels above the soil surface and below the soil surface were measured by using a meter stick the water level inside the field water tube located below to 40 cm from the soil surface (Bouman et al. 2007). In CF plots, water levels were measured by using a meter stick. In AWD15 and DI plots, soil moisture tension was measured via tensiometers (produced by Irrometer Company, Inc. USA) installed 15 cm below the soil surface.

2.4.2 Yield, yield components and water productivity

The grain yield was obtained from 12 m^2 area in each plots. The grain moisture was measured using a digital tester and the grain yield in each plot was determined by converting it to 14% moisture content. At maturity, ten plant samples were taken for the determination of the yield contributing components such as plant height, length of the panicle, etc. Water productivity (kg m^{-3}) was defined as grain yields divided by the total water inputs including irrigations and rainfall for each plot.

2.4.3 Data analysis

Data was analysed by Analysis of Variance (ANOVA). Randomized block for a split-plot design was carried out with variety as the main factor, and irrigations as the sub-factor. Mean comparison among treatments was based on the Least Significant Difference (LSD) test at the 5% probability level.

3. Results and Discussions

3.1 Soil moisture content during the drying periods

In both years, T1 (CF) plots, field water depth maintained from 8 to 10 cm until three weeks at harverst. There were more AWD cycles (wetting and drying) in T2(AWD5) treatments, however, AWD cycle was least in T4 (AWD15) treatments. T2 (AWD5) cycles were 15 to 22 days (2019-2020, respectively) and number of day between irrigations events were 1 to 2 days (the days between irrigation period), T3 (AWD10) cycles were 12 to 17 days and number of day between irrigations event were 3 days, T4 (AWD15) cycles were 10 to 13 days and the number of days between irrigations varies between 4 and 5 days.

In AWD15 and DI plots, soil moisture tension was measured via tensiometers (produced by Irrometer Company, Inc. USA) installed 15 cm below the soil surface. When the ponded water in T4 (AWD15) plots reached the expected threshold level, the soil water potential was changed between 18-30 kpa. In T4 treatments, it was determined that the soil moisture content varies between field capacity and wilting point before irrigation. In T5 (DI 1.75) and T6 (DI 2) treatments, the soil water potential before irrigation was changed between 5-15 kpa except for a few warmer days. Soil drying event should be at least 3 days long according to the soil moisture contents before irrigation were examined in T5 and T6 treatments, it was seen that the soil moisture before irrigation was close to and slightly above the field capacity but it was below the field capacity during a few warmer days. The Intergovernmental Panel on Climate

Change (IPCC) suggested that each soil drying event should be at least 3 days long (IPCC, 2006). Some research reported decreases in rice grain yields under AWD (Lagomarsino et al., 2016; Linquist et al., 2015; Xu et al., 2015; Feng et al., 2021), whereas in other research, it was shown that AWD caused no yield reduction (Liu et al., 2013; Ullah et al., 2018). Carrijo et al. (2017) conducted meta-analysis to interpret 56 research studies and stated that the grain yield does not decrease when the soil moisture tension is higher than -20 kPa under AWD irrigation, but it can decrease to an average value of 23%, if soil water potential reached is lower than -20 kPa.

3.2 Water input and water productivity

The total rainfall and evaporation during each growing season were 135.9 mm and 467.1 mm in 2019, 16.2 mm and 571 mm in 2020, respectively. The 2020 experimental year was a dry year (rainfall above the regional average). Significant differences were observed in the amount of irrigation water applied among irrigation treatments. The amount of irrigation total water input in CF was higher than in AWD and drip irrigation treatments. According to the two experimental years' results, AWD treatments saved between 18% and 33% irrigation water, compared with continuous flooding. However, drip irrigation treatments provided a water saving between 69% and 77%. Total water productivity across irrigation treatments ranged from 0.20 to 0.80 kg m^{-3} in experimental seasons. The highest irrigation water productivity was obtained from T5 (0.72-0.80 kg m^{-3}) treatments followed by T6 (0.65-0.71 kg m^{-3}). The lowest irrigation water productivity was obtained from T1 (0.20 kg m^{-3}) treatments. The water productivity in T5 and T6 treatments were higher than in T1, because of the lower water input and closer grain yield than in T1.

3.2 Grain yield and yield components

The rice variety was shown to have a significant effect on grain yield and yield components in the 2019 and 2020 experimental years. The highest average grain yield (7.42 t ha^{-1}) was obtained for Rekor rice variety, the lowest grain yield (7.18 t ha^{-1}) for Osmancik-97 variety. In both years, the statistical analysis determined significant differences in the effects on yield and yield characteristics of the six different irrigation treatments. Considering the two-year average grain yield, the highest grain yield was obtained for the T1(7.33-8,60 t ha^{-1}) treatment, while the lowest was for T4 (5,48-7,49 t ha^{-1}) treatment. In terms of both treatments and years, T2 (6.75-8,18 t ha^{-1}), T5 (6.86-8,10 t ha^{-1}), and T6 (6.98-8,24 t ha^{-1}), irrigation treatments were in the same statistical group and showed close grain yield values compare to

CF. The reason why similar grain yield values were obtained is due to the soil moisture that takes values close to and slightly above the field capacity during the rice season. In both years, there were non-significant interactions between the varieties and the irrigation treatments on yield and yield components.

4. Conclusions

This study revealed that DI treatments have high water-saving potential and water productivity when compared to both CF and AWD treatments. According to the experimental result, the highest water productivity (0.72-0.80 kg m^{-3}) was obtained in treatment (DI 1.75) followed by treatments (DI 2) (0.65-0.71 kg m^{-3}). Despite the slight decrease of the grain yield in drip irrigation treatments, it was achieved a huge water saving (69-77%). This was occured due to the soil moisture content in drip irrigation treatments, which was maintained at the field capacity and above, except for a few days when the weather was very warm. The study revealed that the AWD threshold level had a significant effect on yield. The grain yields might be maintained at moderate AWD. Despite the fact that AWD5 provided a reduction in water use between 18-22%, it illustrated similar grain yield values to CF. Although AWD10 and AWD15 irrigation applications showed lower yield values compared to CF, they provided 25-28% and 32-33% water savings, respectively. It is thought that the reason for the decrease in grain yields of AWD 10 and AWD 15 irrigation applications compared to the conventional irrigation is affected by the climatic conditions of the region and especially the high depth of the groundwater level. Therefore, it is necessary to know the soil characteristics of the field and the groundwater level in order to be able to recommend the appropriate AWD threshold level to the farmers.

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References

Belder, P., Spiertz, J. H. J., Bouman, B. A. M., Lu, G., & Tuong, T. P. (2005). Nitrogen economy and water productivity of lowland rice under water-saving irrigation. *Field Crops Research*, *93*(2-3), 169-185.

Bouman, B. A. M. (2007). Water management in irrigated rice: coping with water scarcity. Int. Rice Res. Inst..

Carrijo, D. R., Lundy, M. E., & Linquist, B. A. (2017). Rice yields and water use under alternate wetting and drying irrigation: A meta-analysis. *Field Crops Research*, *203*, 173-180.

Feng, Z. Y., Qin, T., Du, X. Z., Sheng, F., & Li, C. F. (2021). Effects of irrigation regime and rice variety on greenhouse gas emissions and grain yields from paddy fields in central China. *Agricultural Water Management*, *250*, 106830.

International Rice Research Institute (IRRI), 2019. Annual Report for 2019. Los Baños, Philippines

IPCC, 2006. International Panel for Climate Change Guidelines for National Greenhouse Gas Inventories. https://www.ipcc-nggip.iges.or.jp/public/2006gl/

Lagomarsino, A., Agnelli, A. E., Linquist, B., Adviento-Borbe, M. A., Agnelli, A., Gavina, G., ... & Ferrara, R. M. (2016). Alternate wetting and drying of rice reduced CH_4 emissions but triggered N_2O peaks in a clayey soil of central Italy. *Pedosphere*, *26*(4), 533-548.

Linquist, B. A., Anders, M. M., Adviento□Borbe, M. A. A., Chaney, R. L., Nalley, L. L., Da Rosa, E. F., & Van Kessel, C. (2015). Reducing greenhouse gas emissions, water use, and grain arsenic levels in rice systems. *Global change biology*, *21*(1), 407-417.

Ullah, H., Mohammadi, A., & Datta, A. (2018). Growth, yield and water productivity of selected lowland Thai rice varieties under different cultivation methods and alternate wetting and drying irrigation. *Annals of Applied Biology*, *173*(3), 302-312.

Xu, Y., Ge, J., Tian, S., Li, S., Nguy-Robertson, A. L., Zhan, M., & Cao, C. (2015). Effects of water-saving irrigation practices and drought resistant rice variety on greenhouse gas emissions from a no-till paddy in the central lowlands of China. Science of the Total Environment, 505, 1043-1052.