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Sürek H., Beser N.

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The effect of water stress on grain and total biological yield and harvest index in rice *(Oryzae sativa L.)*

Halil Sürek and Neemi Beser
Thrace Agricultural Research Institute (Turkey)

Abstract. The objectives of this study were to examine the effects of water stress on grain and total biological yield, and harvest index and to evaluate the water stress tolerance of the rice varieties. Five irrigation treatments were applied to create water stress; (1) irrigation at four-day inteval after tillering initiation, (2) irrigation at eight-day interval after tillering initiation, (3) irrigation at four-day interval after panicle initiation, (4) irrigation at eight-day interval after panicle initiation, (5) continuous flooding irrigation with full water control. All treatment plots were irrigated practising continuous irrigation method until treatment application. Twenty rice cultivars were used in this experiment. Experiment was conducted in a split plot design with two replications in 1995 and 1996. The main plot was irrigation treatment and the subplots were cultivars. Each plot consisted of two 5-m rows and 25 cm apart.

Observation taken includes grain yield, total biological yield, harvest index, and some other agronomic traits. Also, the evaluation was done to determine water stress tolerance of the varieties.

The water stress effected all the characters examined. The lowest values were obtained from irrigation at eight-day interval after tillering initiation, while the highest values were observed at continuous flooding irrigation. The reasons for grain yield reduction with water stress mainly were decreases in the number of filled spikelets per panicle and 1000 grain weight. The cultivars, Sandora, Karmina, HS-96, Krasnodarsky-424, Ana/Mar, HS-1 had good tolerance to water stress, and Altınyazı, TR-648, Meriç, Prometeo, Ergene had moderate tolerance. On the other hand, Sürek-95, Rocca, TR-489, Osmancık-97, TR-475, Trakya, Serhat-92, TR-765, and Lap/PG had poor tolerance.

Key word. Rice (Oryza sativa L.), water stress, grain yield, total biological yield, harvest index.

Introduction

Rice production area changes between 50 000 and 60 000 ha in Turkey, it varies from year to year depending upon available irrigation water and market price. Turkey had more than 70 000 ha rice growing area in early 1980's, it reached to 77 000 ha in 1982. After than, it drastically decreased. Two factors made the big decrease in rice production in Turkey after the mid of 1980's. In the first place, a drought period occurred in this country between 1985 and 1994, therefore, there was shortage of irrigation water. Secondly, there were some limitations on rice import before 1984 such as tax and fund. These were lifted or their amount reduced in 1984. It made easy rice import with low cost. The domestic production cost was higher than imported rice price. Thus, the some farmers left rice cultivation in some regions due to shortage of irrigation water or high production cost. Also, rice cultivation was forbidden in some areas because of drought problem, in order to use available water for other irrigated crops such as cotton, maize and vegetable etc. However, rice growing area started to increase again in 1995. It increased from 41 000 ha in 1994 to 58 000 in 1995.

It was 60 000 ha in 1996. Because, the rainfall increased in the last two years. Therefore, the irrigation water accumulation in the dams and water flowing in the rivers increased.

Rice is cultivated under continuous flooding irrigation with full water control. The sowing is done in 5 to 10 cm depth of water. This water cover is maintained for three to five days and then the plot is drained, leaving the soil saturated with water for a few days. As rice plants appear, the plot is flooded gradually until the water depth reaches 10 to 15 cm. Water is maintained, circulating slowly at that depth until most grains reach the dough stage.

As explained above, irrigation water is the most limiting factor for expanding the area under rice cultivation in Turkey. Although the land structure and climate are suitable for rice growing in many micro and macro climatical regions and the farmers are very eager to produce rice. Due to shortage of irrigation water, it is not possible to expand rice-cultivating area. Therefore, if the available irrigation water is economically used or developed varieties which are cultivated with less water or tolerate to water stress, it will be possible to expand the rice cultivated area.

Rice is a unique crop is that it is adapted to a wide range of climate, soil, and water conditions. It is usually grown under shallow flood or wet paddy conditions, but it is also cultivated where flood water may be several meters deep and, in the extreme, as an upland cereal. Although rice appears to have a high water requirement, it is not much different from that of other field crops. The water requirements of rice for evapotranspiration are between 450 and 700 mm depending on climate and length of growing period, as compared to cotton (700-1300mm), sugar cane (1500-2500 mm) and maize (500-850 mm) (Doorenbos and Kassam, 1979).

It is evident that rice can be grown under unflooded conditions and can even be irrigated like any other upland cereal to obtain good yields. Experiments conducted in the Philippines (De Datta and Williams, 1968) have shown that there was no significant difference in grain yield between continuous flooding and such water-saving treatments as soil saturation and combinations of soil saturation and flooding.

De Datta (1981) classified rice culture according to water regime; upland, with no standing water; lowland, with 50 cm of standing water, and deepwater, with >51 cm to 5-6 meters of standing water.

The effect of water stress on yield decrease of rice is very pronounced during certain period of growth, called the moisture sensitive periods. The most sensitive periods to water deficits are flowering and head development. In an experiment conducted in the Philippines (IRRI, 1973). It has been shown that moisture stress early in the growth of the rice reduced tillering, thereby reduced yield. When moisture stress was extented into reproductive phase, yield loss was significant.

Jana and Ghildyal (1971) examined the effect of varying soil water regime during different growth phases on rice yield. They reported that the soil water stress applied any of the growth phases reduced rice grain yield, compared to the continuous flooding irrigation. The ripening phase appeared to be most sensitive to compared to the other phases. Soil water stress during the earlier growth phases (vegetative) appeared the production of effective tillers resulting in the reduction of grain yield, While stress during the later growth phases (reproductive) appeared to affect the reproductive physiology by interfering with pollination, fertilization and grain filling in the reduction of grain yield.

Kakade and Soner (1983) observed that continuous submergence and submergence upto flowering significantly increased the rice grain yield over alternate submergence and drying, and upland conditions. Submergence upto flowering significantly increased rice straw yields over alternate submergence and drying, and upland condition treatment.

Alvarez (1973) compared 4, 6, and 8-mm seven-day rotational irrigation treatment with 12.5 mm/day continuous flooding irrigation. The continuous flooding irrigation had higher yield than rotational irrigation treatments. Rawgamannar et al., (1978) reported that continuous irrigation in 5 cm depth gave higher grain yield than continuously saturated irrigation.

Raju (1980) observed that the flooded irrigation in reproductive stage and saturated at vegetative stage treatment had higher harvest index than flooded at vegetative stage and saturated at reproductive stage.

On the other hand, continuous irrigation in 5-cm depth gave the highest grain yield, however it had the lowest harvest index.

Yakan and Sürek (1990) compared continuously saturated irrigation with continuous flooded irrigation and interval irrigation in the different depths. There was no significant difference among irrigation treatment for grain yield. Borrell (1991) compared different irrigation regimes in dry seeded rice production in Australia. Flooding irrigation from sowing to maturity gave the highest grain yield, and intermittent irrigation had lowest grain yield. Beser (1997) found out significantly differences for rice grain yield among different irrigation methods. He obtained the highest yield from continuous flooding irrigation, interval and sprinkler irrigation followed it. Also, the highest values of total biological yield and harvest index achieved in continuous flooding irrigation.

Chang et al., (1972) tested the upland and lowland variety groups under upland and lowland conditions to compare their agronomic features and growth characters under severe water stress, most upland varieties are less damaged by drought and have lower panicle sterility than lowland types, but certain lowland types, such as Dular and IR5, tolerate drought as well as the upland varieties. Upland plots produced the lowest harvest index. But the upland varieties generally had higher harvest index than lowland varieties under upland conditions. Pramanik and Gupta (1989) subjected the varieties to moisture stress at different growth stages particularly during seeding stage. They identified some promising lines had tolerance to the water stress. Sing and Sing (1980) reported varietal differences among the cultivar for moisture stress.

The objectives of this study were to examine the effects of water stress on grain and total biological yield, and harvest index and to evaluate the water stress tolerance of the cultivars.

I – Materials and methods

The cultivars used in the experiment are, Serhat-92, Sürek-95, Meriç, TR-765, Sandora, Rocca, TR-489, Osmancık-97, Altınyazı, Karmina, TR-475, TR-468, Prometeo, Ergrene, Ana/Mar, Krasnodarsky-424, HS-1, Trakya, Lap/PG, HS-96.

Five irrigation treatments were applied to create water stress:

❏ irrigation at four-day interval after tillering initiation,

❏ irrigation at eight-day interval after tillering initiation,

❏ irrigation at four-day interval after panicle initiation,

❏ irrigation at eight-day interval after panicle initiation,

❏ continuous flooding irrigation with full water control.

In the interval irrigation treatments; every four or eight day, the plots were fulled with water without draining, and then water flowing into the plots stopped. All treatment plots were irrigated practising continuous irritation method till treatment application.

The experiment was conducted in a split plot design with two replications at Thrace Agricultural Research Institute in 1995 and 1996. The main plot was irrigation treatment and the subplots were cultivars. Each subplot consisted of two 5-m rows and 25 cm apart. Harvesting area was 4x0.5= 2 $m^{2.}$. 450 seeds per squarmetter were planted in dry conditions. The soil was sandy clay silt with 1.1% organic matter and pH 6.8 and sand clay silt with 0.6% organic matter and pH 7.4 in 1995 and 1996, respectively.

Observation taken includes grain yield, total biological yield, harvest index and some other agronomic characters. Also, the evaluation was done to determine water stress tolerance of the varieties. This evaluation was conducted according to 1-9 scale, as phenotypic acceptability at reproductive stage (1) Excellent (continuous irrigation treatment considered excellent), (3) good, (5) moderate, (7) poor, and (9) very poor.

II – Results and discussion

The water stress effected all the characters examined. The treatment (2), irrigation at eight-day interval after tillering initiation created the highest water stress than the other treatments, and treatment (1) followed it. There was no more difference between treatment (3) and treatment (4) in terms of water stress effectiveness.

As it seen in Table 1, the lowest grain yield obtained from the treatment (2), irrigation at eight-day interval after tillering initiation both in 1995 and 1996. It followed by treatment (1). There were significantly differences among the irrigation treatments in both years. However, the treatment (3) and the treatment (4) gave the similar results, there was no significant difference between these treatments. The highest grain yield was achieved in continuous flooding irrigation with full water control.

The variance analysis of two year's pooled data also showed significant difference for grain yield (table-2). These results are in agreement with those found by other researchers (Jana and Ghildyal, 1971; Kakade and Soner, 1985; Alvarez, 1973; Rawgannar et al., 1978; Borrell, 1991; and Beser, 1997). On the contrary, De Datta, and Williams, (1968), and Yakan and Sürek, (1990) reported that there was no significant difference in grain yield between continuous flooding and such water-saving treatments.

The effect of water stress on total biological yield was similar to grain yield. The lowest total biological yield obtained from treatment (2) and the highest total biological yield achieved in continuous irrigation. There was no significant difference for total biological yield among the treatments in 1995, however the significant difference observed in 1996. Also, the variance analysis of two year's pooled data showed significant difference among irrigation treatments (Table 2). The similar results were reported by Kakada and Soner (1985) and Beser (1997).

The effect of water stress on harvest index was similar to grain and total biological yield. There were significant difference for harvest index among irrigation treatments in 1995 and no difference in 1996. The continuous flood irrigation had the highest harvest index, whereas, the treatment (2) had the lowest value. These results were in agreement with Chang et al., (1972) and Beser (1997).

As it seen in table 3, the water stress also effected some other agronomic trait as well, such as day to flowering, plant height, the number of panicles per squarmetter, the number of filled spikelets per panicle and 1000 grain weight depending upon water stress. The reasons for grain yield reduction with water stress mainly were decreases in the number of filled spikelets per panicle and 1000 grain weight. The similar results were reported by Jana and Ghildyal (1971) and Beser (1997).

The variance analysis indicated that there were significant differences for the characters among the cultivars used in this experiment (Table 4). However, there was no cultivar x irrigation treatment interaction for grain and biological yield, and harvest index.

To determine the water stress tolerance of the cultivars, the evaluations were done according to 1-9 scale as phenotypic acceptance at reproductive stage. The averages of two year's results are given in Table 5. These results showed that the cultivars, Sandora, Karmina, HS-96, Krasnodarsky-424, Ana/Mar, and HS-1 appeared to have good tolerance to water stress and Altınyazı, TR-648, Meriç, Prometeo, and Ergene seemed to have moderate tolerance, while Sürek-95, TR-765, Serhat-92, Rocca, TR-489, Osmancık-97, TR-475, Trakya, and Lap/PG had poor tolerance.

Conclusion

The water stress applied after tillering initiation stage, either four or eight day interval, were more effective on grain yield and the other characters than the water stress applied after panicle initiation stage. The irrigation at eight-day interval after tillering initiation created the most effective water stress on the cultivars. It can be used to evaluate the breeding material for the water stress in our region.

The reasons for grain yield reduction with water stress mainly were the decreases in the number of filled grain per panicle and 1000 grain weight depending on water stress.

Some cultivars tested in this experiment have good water stress tolerance, such as Sandora, Karmina, HS-96, Krasnodarsky-424, Ana/Mar and HS-1. These varieties may be used to develop the cultivars to be cultivated under water stress conditions or water limiting area.

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Table 1. the results of the irrigation treatment for grain and total biological yield, and harvest index in 1995 and 1996

Treatment	1995 Grain yield (t/ha)	1995 Total biological yield (t/ha)	1995 Harvest index (%)	1996 Grain yield (t/ha)	1996 Total biological yield (t/ha)	1996 Harvest index (%)
(1) Irrigation at four-day interval after tillering initiation	5.59**b**	14.54	39.00**b**	4.93**bc**	13.93**bc**	35.10
(2) Irrigation at eight-day interval after tillering initiation	4.45**c**	12.65	35.80**c**	4.14**c**	13.26**c**	31.80
(3) Irrigation at four-day interval after panicle initiation	5.68**b**	14.32	39.80**b**	5.72**ab**	15.56**ab**	36.60
(4) Irrigation at eight-day interval after panicle initiation	5.60**b**	13.88	40.30**ab**	5.46**ab**	15.47**ab**	33.90
(5) Continuous flooding irrigation with full water control	6.58**a**	15.96	41.40**a**	6.28**a**	16.08	39.50
F Values	24.24**	4.98	34.95**	6.44*	7.29*	1.95
LSD (0.05)	0.60	NS	1.41	1.25	1.75	NS
CV (%)	11.48	10.78	8.31	12.91	9.86	11.11

Table 2. Averages of data obtained in 1995 and 1996 for grain and total biological yield and harvest index

Treatment	Grain yield (t/ha)	Total biological yield (t/ha)	Harvest index %
(2) Irrigation at four-day interval after tillering initiation	5.26**b**	14.24**bc**	36.00**ab**
(2) Irrigation at eight-day interval after tillering initiation	4.30**c**	12.95**c**	33.80**b**
(3) Irrigation at four-day interval after panicle initiation	5.70**b**	14.95**ab**	38.20**a**
(4) Irrigation at eight-day interval after panicle initiation	5.53**b**	14.68**ab**	37.10**ab**
(5) Continuous flooding irrigation with full water control	6.43**a**	16.02**a**	40.50**a**
F Values	13.04**	10.27**	5.22**
LSD (0.05)	0.69	1.36	4.14
CV (%)	12.19	10.31	9.68

Table 3. Averages of data obtained in 1995 and 1996 for some agronomic characters

Treatment	**Day to flowering**	**Plant height** (cm)	**The number of panicles** (per squarmetter)	**The number of filled spikelets per panicle**	**1000 Grain weight** (g)
(3) Irrigation at four-day interval after tillering initiation	76.3**ab**	87.2**ab**	348	50.7**b**	30.6**b**
(2) Irrigation at eight-day interval after tillering initiation	77.8	80.1**b**	354	41.9**c**	29.4**c**
(3) Irrigation at four-day interval after panicle initiation	75.4**abc**	93.3**a**	325	57.7**ab**	31.0**ab**
(4) Irrigation at eight-day interval after panicle initiation	75.0**bc**	88.1**a**	331	55.5**ab**	31.0**ab**
(5) Continuous flooding irrigation with full water control	73.7**c**	92.6**a**	344	60.1**a**	31.8**a**
F Values	5.91**	7.34**	1.23	8.78**	10.96**
LSD (0.05)	2.41	7.7	NS	7.9	1.0
CV (%)	2.61	6.16	13.23	17.14	5.07

Table 4. Average of data observed for the cultivars in 1995 and 1996

Cultivars	**Grain yield** (t/ha)	**Total biological yield** (t/ha)	**Harvest index** (%)
Serhat-92	5.85 bcd	15.31 abc	38.2efg
Sürek-95	5.82 bcd	15.21 abc	38.0efg
Meriç	5.87 bc	16.17 a	36.3gh
TR-765	5.56 bcdef	15.91 a	35.2 h
Sandora	5.58 bcde	13.12 h	42.6 abc
Rocca	4.04 I	14.02 defgh	28.7 J
TR-489	4.17 I	14.81 bcd	27.7 J
Osmancık-97	5.12 fgh	15.44 ab	32.8 I
Altınyazı	4.71 h	16.04 a	29.2 J
Karmina	5.63 bcd	14.33 defg	38.8 ef
TR-475	5.09 gh	13.51 gh	37.9 efg
TR-648	5.61 bcd	15.92 a	35.0 hI
Prometeo	5.93 b	13.98 defgh	41.2 cd
Ergene	5.47 defg	14.05 defgh	38.8 ef
Ana/Mar	5.80 bcd	13.50 gh	42.3bc
Krasnodarsky-424	6.41 a	14.60 bcde	43.7 ab
HS-1	5.42 defg	13.65 efgh	39.5 de
Trakya	5.70 bcd	14.58 bcdef	38.9 def
Lap/PG	5.16 efg	13.59 fgh	37.0 fgh
HS-96	5.96 b	13.58 gh	44.7a
F Values :			
Cultivar	15.87**	8.50**	35.75**
Cultivar x irrigation treatment	0.95	0.96	1.06
LSD (0.05) (for cultivar)	0.41	0.93	2.24
CV (%)	12.19	10.31	9.68

Table 5. The averages of reaction to water stress observed for the cultivars in 1995 and 1996

	Irrigation treatment (a)				
Cultivar	1	2	3	4	5
Serhat-92	5.5(b)	7.5	4.0	4.5	1
Sürek-95	6.0	7.0	5.0	4.5	1
Meriç	4.0	6.0	4.0	3.0	1
TR-765	6.0	7.0	4.0	4.5	1
Sandora	3.0	3.0	2.0	2.0	1
Rocca	7.5	8.0	5.5	7.0	1
TR-489	6.5	8.5	6.0	7.0	1
Osmancık-97	5.5	7.0	5.5	5.0	1
Altınyazı	5.5	5.5	5.5	4.5	1
Karmina	3.0	4.0	2.5	3.0	1
TR-475	6.0	7.5	4.5	5.5	1
TR-648	5.0	6.0	4.0	5.0	1
Prometeo	4.0	5.5	3.0	4.0	1
Ergene	4.0	5.0	3.5	4.5	1
Ana/Mar	4.5	4.0	2.5	3.0	1
Krasnodarsky-424	4.0	4.5	3.0	4.0	1
HS-1	3.0	4.0	3.0	3.0	1
Trakya	5.5	7.5	6.5	5.5	1
Lap/PG	5.5	7.0	3.5	5.0	1
HS-96	3.0	4.5	3.0	3.0	1
Mean	4.9b	6.0a	4.0b	4.4b	1.0c

LSD (0.05) = 0.9

(a): 1) Irrigation at four-day interval after tillering initiation, (2) Irrigation at eight-day interval after tillering initiation, (3) Irrigation at four-day interval after panicle initiation, (4) Irrigation at eight-day interval after panicle initiation, (5) Continuous flooding irrigation.

(b): At reproductive stage; (1) Excellent (Contiuous irrigation considered excellent), (3) good, (5) moderate,(7) poor, and (9) very poor.