Australian Journal of
Crop Science
AJCS
AJCS 4(3):136-141(2010) ISSN:1835-2707

Effects of irrigation water management on yield and water use efficiency of rice in cracked paddy soils

Behrouz Mostafazadeh-Fard[1*], Fatemeh Jafari[2], Sayed-Farhad Mousavi[3] and Mohammad-Reza Yazdani[4]

[1]Irrigation Department, College of Agriculture, Isfahan University of Technology, Isfahan, 84156-83111, Iran
[2]Irrigation Department, College of Agriculture, Isfahan University of Technology, Isfahan, 84156-83111, Iran
[3]Irrigation Department, College of Agriculture, Isfahan University of Technology, Isfahan, 84156-83111, Iran
[4] Researcher, Rice Research Institute, Rasht, 41996-13475, Iran.

***Corresponding author: behrouz@cc.iut.ac.ir**

Abstract

The management of cracking clay soils has important influence on irrigation efficiency. To determine the effects of different irrigation water managements on yield and water use efficiency of rice (*Oryza sativa* L.) in cracked paddy soils, a field experiment was conducted on a silty clay soil, a typical swelling soil of Guilan province, northern part of Iran. The experiment was a randomized complete block design with factorial arrangement of treatments with three replications. The main treatment was crack width (3-4 mm, 1.5 cm and 2.5 cm) which are called C_0, $C_{1.5}$ and $C_{2.5}$, respectively. The sub-treatment was irrigation (D_0, irrigation to fill up the cracks and up to the start of ponding; $D_{2.5}$, irrigation to fill up the cracks and up to 2.5 cm of ponding at the soil surface; D_5, irrigation to fill up the cracks and up to 5 cm of ponding at the soil surface). The results showed that the effects of crack width, depth of irrigation water and their interaction on rice grain yield and water use efficiency were significant at 5% and 1% level, respectively. The highest grain yield (3.279 ton ha^{-1}) belonged to the D_5C_0 and the lowest grain yield (2.04 ton ha^{-1}) belonged to $D_0C_{2.5}$. The reduction of depth of ponding (D_0 vs. D_5) caused 36.5% improvement in water use efficiency. On cracked paddy soils, based on the development of crack width, the irrigation schedule can be planned to save water without considerable reduction of crop yield. The results of this study can be applied to cracked paddy soils of the study area in order to save irrigation water.

Keywords: Deficit irrigation, rice, swelling soils, yield components.

Introduction

More than 90% of the rice in the world is produced and used in Asia. In Asia, more than 80% of the fresh water resources are used in agriculture and half of that is used for rice production (Parsi-Nejad et al., 2003). In Guilan province, north of Iran, the rice cultivation is the main agricultural activity and covers approximately 205,000 ha (0.5 million acres) which is 35.81% of the total paddy fields of Iran (Parsi-Nejad et al., 2003). In this region, the usual irrigation method for paddy fields is flood irrigation which continues from the beginning to the end of the growing season and the conventional method of tillage and planting is wet tillage with manual transplanting (Mousavi et al., 2009). Most agricultural fields in Guilan have cracking clay soils. Cracking clay soils are found worldwide. Asia, Africa and Australia have the largest areas of these soils. The cracks are the main problem for the irrigation of swelling soils. These soils are characterized by swelling and shrinkage as the soil moisture content changes (Mostafazadeh-Fard and Malano, 1996). These soils shrink when they lose their moisture and the cracks will start to develop (Bronswijk, 1990). Infiltration of water into these soils is affected by the swelling and shrinkage phenomena (Liu et al., 2003). When the cracks are formed, water moves downward through the cracks and causes low irrigation efficiency. The management of cracking clay soils has important influence on soil infiltration rate (Islam et al., 2004a). Between 25% and 85% of water applied to the rice fields are lost by seepage and percolation (Hafeez et al., 2007). The study by Liu et al. (2003) showed that in paddy cracking clay soils the infiltration rate increases significantly. They also showed that soil texture, depth of ponded water at the soil surface, crack width, cultivation, suspended minerals in the water and depth of tillage are affecting infiltration rate. Zein El Abedine and Robinson (1971) and Montes (2005) reported that the crack development depends on duration of soil moisture stress, soil type, amount of clay and type of cations. Islam et al. (2003) reported that the soil management practices to reduce crack during irrigation has significant effect on water use efficiency. Bouman and Tuong (2001) showed that the decrease of depth of ponded water on the soil surface can save water about 23%, while the yield reduces about 6%. In transplanted and wet-seeded rice,

Table 1. The calendar dates for various agronomical practices followed in 2006

Agronomical practices	Initial tillage	Puddling	Land leveling	Transplanting	Herbicides	Thinning	Harvest
Date	Mar	May	2-3 days before transplanting	May-mid June	One week after transplanting	At two stages: 15-20 and 25-30 days after transplanting	15 Aug - 15 Sep

keeping the soil continuously around saturation reduced yields on average by 5% and water inputs by 35% and increased water productivity by 45% as compared with flooded conditions (Tabbal et al., 2002).

Problems related to water scarcity are increasing due to the intensification of agriculture, and increasing water consumption for household and industrial purposes (Janssen and Lennartz, 2007). Traditional transplanted rice with continuous standing water needs relatively high water inputs. By applying appropriate irrigation management during growing season of rice, a large volume of water can be saved which may help to bring more area under irrigation particularly where there are limited water resources (Bouman et al., 2005).

The previous studies showed that using appropriate irrigation management in paddy fields can reduce the amount of applied water for irrigation without considerable reduction in crop yield. However, there is no noticeable study about irrigation of paddy fields, with swelling soils, based on crack development at the soil surface. In this study a new irrigation management based on crack development is introduced to increase irrigation efficiency. Therefore, the main objectives of this study were to irrigate the paddy fields based on development of crack widths at the soil surface using different amounts of irrigation water, and to determine its effects on water use efficiency, crop yield and crop characteristics.

Materials and methods

Site description

The field experiments were conducted on 3×4 m experimental paddy plots at Rice Research Institute, 5 km from the city of Rasht, northern part of Iran, in spring and summer of 2006 for one growing season. Rasht (Longitude $49^{o}36'$E and Latitude $37^{o}16'$N) has elevation of about 7 m below the sea level, mean annual temperature of 15.9 ^{o}C, mean annual rainfall of 1320 mm and mean annual humidity of 78.5%. The climatic factors of mean monthly temperature (°C), humidity (%), rain (mm), and pan evaporation for year 2006 for the study area is shown in Fig. 1. The calendar dates for various agronomical practices followed in 2006 is shown in Table 1. This study was carried out for one year because for the second year the climate conditions might change and this change affects the comparison of the first year with the second year. The weather in this particular year followed the normal trend in the area. To avoid the effects of water and nutrients flowing from neighboring plots, the four sides of each plot were surrounded down to a depth of 50 cm with heavy duty plastic and the distance between every two plots (which was 50 cm) was compacted.

Soil

The soil at the experimental site had a silty clay texture which is a typical swelling soil of Guilan province, northern part of Iran. The clay type of the soil is smectite, which easily expands or shrinks under the influence of soil moisture changes. The selected physical and chemical characteristics of the soil are shown in Table 2.

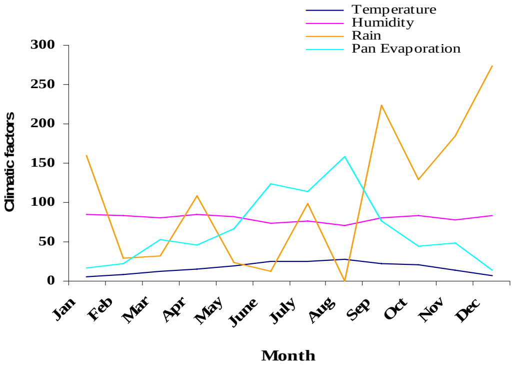

Fig 1. Mean monthly temperature (°C), humidity (%), rain (mm), and pan evaporation for year 2006 for the study area

Treatments

The experiments were a randomized complete block design with factorial arrangement of treatment with three replications. The first treatment was crack width, with crack widths of 3-4 mm, 1.5 cm and 2.5 cm, which are called C_0, $C_{1.5}$ and $C_{2.5}$, respectively. The second treatment was irrigation (D_0, irrigation to fill up the cracks and up to the start of ponding; $D_{2.5}$, irrigation to fill up the cracks and up to 2.5 cm of ponding on the soil surface; D_5, irrigation to fill up the cracks and up to 5 cm of ponding on the soil surface). The treatments and sub-treatments that were used in this study are summarized as follow: D_0C_0, $D_{2.5}C_0$, D_5C_0, $D_0C_{1.5}$, $D_{2.5}C_{1.5}$, $D_5C_{1.5}$, $D_0C_{2.5}$, $D_{2.5}C_{2.5}$ and $D_5C_{2.5}$. Therefore, totally 27 experimental plots were used. From transplanting up to the start of flowering, flood irrigation with depth of ponded water of about 5 cm was applied to all treatments. Then, the above irrigation treatments were applied. The total precipitation during the growing season was 111 mm. For rainy periods, development of cracks started with delay and the irrigation amount was not changed. The characteristics of irrigation water used in this study are shown in Table 3. The irrigation water was pumped from a reservoir and distributed to each experimental plot through the main and sub-main plastic hoses. A valve and a volumetric discharge measurement device was installed at the location where the sub-main hoes enter each plot and they were used to control and measure the exact amount of water needed for each plot. During the growing season, for the C_0, $C_{1.5}$ and $C_{2.5}$ treatments, 32, 27 and 19 irrigations were applied, respectively.

Crack width

An arbitrary graduated frame was used to measure the crack width (Zein El Abedine and Robinson, 1971). For

Table 2. Some physical and chemical characteristics of soil for the experimental plots

Depth (cm)	Clay (%)	Silt (%)	Sand (%)	Texture	FC (%)	WP (%)	pH	EC (dS/m)
0-30	41	49	10	Silty clay	35.4	22.9	5.89	0.98

The values of soil moisture are based on weight.

Table 3. Irrigation water characteristics

EC_{iw} (dS/m)	pH	Na^+	Ca^{2+}	Mg^{2+}	SO_4^{2-}	CO_3^{2-}	HCO_3^-	SAR
		(meq/l)						
1.352	7.6	7.0	3.3	3.1	5.2	0.3	3.2	3.9

each crack several measurements were made and the average was obtained. To avoid side effects, the measurements were made at the middle of each experimental plot.

Water use efficiency

Water use efficiency (g/m^3) was determined based on the ratio of the yield to the water applied during the irrigation season as follow (Gupta and Acharya, 1993):

$$WUE = \frac{Y}{W}$$

(1) where WUE = water use efficiency, Y= total yield and W= the volume of applied irrigation water.

Cultivation

Cultivation practices including plot preparation, initial tillage, puddling and land leveling were implemented and the usual tillage practices which are wet tillage with manual transplanting was followed. The rice (*Oryza sativa* L.), cultivar Hashemi, seedlings were transplanted into each plot. The fertilizers needed for each plot was calculated based on the amount of 60 kg/ha nitrogen, 100 kg/ha potassium sulfate and 45 kg/ha phosphate and was applied to each plot. Nitrogen was applied at two stages, half during transplanting and the other half during tillering. Potassium was applied at two stages, half during transplanting and the other half after tillering. Phosphate was applied before transplanting.

Data collection and analysis

1000-grain weight

To determine the 1000-grain weight, 1000 grains from the plant samples (at least 5 plants from the middle of each plot) of the experimental plots were selected randomly and weighed.

Plant height, tiller number and ear length

From each plot, some plants were selected by random (at least 5 plants from the middle of each plot) and the average plant height was determined. The number of tillers in each plant was counted and ear length was measured.

Blank grain percentage

From each plot, some plants were selected by random (at least 5 plants from the middle of each plot) and total seeds of each tiller was determined. Blank grains were separated and the percentage was determined.

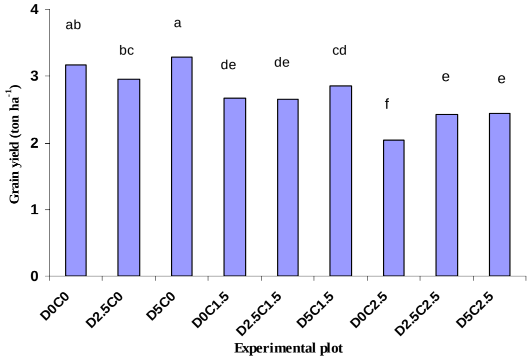

Fig 2. The interaction effect of crack width and depth of irrigation water on grain yield (in each column, the values with at least one common letter are not significantly different at 5% level)

Crop yield

After harvest, the gross yield of each plot was put separately into the plastic bags and they were taken to the laboratory to determine their weight. To reduce the side effects, the middle of each plot was selected for harvesting.
The above collected data were analyzed and plotted using MSTAT-C and EXCEL software.

Results and discussion

Grain yield

The analysis of variance in Table 4 shows the effects of crack width on grain yield are significant at 1% level and the effects of depth of irrigation water and their interaction on grain yield are significant at 5% level. Comparison of average grain yields in different irrigation treatments indicate that the C_0 treatment has the highest grain yield (3.134 ton ha^{-1}) and the $C_{2.5}$ treatment has the lowest grain yield (2.3 ton ha^{-1}) and the difference is significant (Table 5). Among the irrigation treatments, the highest grain yield (2.86 ton ha^{-1}) was belonged to the D_5 treatment and the lowest grain yield (2.628 ton ha^{-1}) was belonged to the D_0 treatment. The difference in grain yield between D_0 and $D_{2.5}$ treatments was not significant and the increase in yield was just 1.79%. In Fig. 2 the interaction effect of crack width and depth of irrigation

Table 4. Analysis of variance for parameters

	Yield parameters						
Source of variations	Grain yield (ton ha^{-1})	Blank grain percentage	1000-grain weight (g)	Ear length (cm)	Plant height (cm)	Number of tillers	Water use efficiency (g/m^3)
Crack width	71.1699**	0.9267^{ns}	9.5656**	6.8729**	2.8341^{ns}	9.9814**	94.8314**
Depth of irrigation water	6.1931*	7.9288**	8.8866**	7.9668**	4.9919*	4.0552*	51.0044**
Depth of irrigation water × crack width	3.2034*	0.1782^{ns}	1.3717^{ns}	2.6527^{ns}	1.0460^{ns}	2.7599^{ns}	7.2823**

ns, * and ** not significant, significant at 5 and 1 percent levels, respectively.

water on grain yield is shown. Fig. 2 shows that D_5C_0 has the highest grain yield and $D_0C_{2.5}$ has the lowest grain yield. In C_0 treatment, the difference in grain yield between D_0 and $D_{2.5}$ is not significant. In $C_{1.5}$ treatment, the differences in grain yield among the different irrigation treatments are not significant. In $C_{2.5}$ treatment, the differences in grain yield for depth of irrigation water of 2.5 and 5 cm are not significant. The results of other researchers (e.g., Alizadeh and Eisivand, 2006) have shown that the growth of rice could be better even under low depth of irrigation water as compared to the flood irrigation (which consumes high amounts of water). The lower depth of irrigation water for rice causes higher day-time temperature and lower night-time temperature which causes better growth. The non-significant difference in grain yield between D_0 and $D_{2.5}$ treatments might be related to the above statement.

Blank grain percentage

The crack width and the interaction effect of crack width and depth of irrigation water on blank grain percentage was not significant but the effect of depth of irrigation water on blank grain percentage was significant at 1% level (Table 4). The comparison of average blank grain percentages shows that the D_5 treatment has the highest (23.9%) and the D_0 treatment has the lowest (15.91%) blank grain percentage (Table 5). Islam and Mondal (1992) observed that Percent filled grains is seriously affected by moisture stress at the later part of crop growth.

1000-grain weight

Table 4 shows that effect of crack width and depth of irrigation water on 1000-grain weight is significant at 1% level. The interaction effect of crack width and depth of irrigation water on 1000-grain weight is not significant. The comparison of the mean values of the 1000-grain weight (Table 5) shows that C_0 treatment has the highest (22.17 g) 1000-grain weight. There is no significant difference in 1000-grain weight between $C_{1.5}$ and $C_{2.5}$ treatments. The D_0 treatment has the lowest value of 1000-grain weight and there is no significant difference in 1000-grain weight between $D_{2.5}$ and D_5 treatments. Similar results were obtained by Thomas et al. (2003) which showed that as the applied irrigation water increases, 1000-grain weight increases significantly.

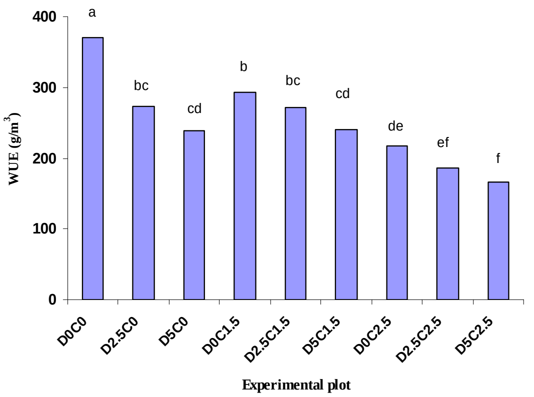

Fig 3. The interaction effect of crack width and depth of irrigation water on water use efficiency (in each column, the values with at least one common letter are not significantly different at 1% level)

Ear length

Table 4 shows the effect of crack width and depth of irrigation water on ear length is significant at 1% level. The comparison of the mean values of ear length shows that there is no significant difference between C_0 and $C_{1.5}$ treatments, and between $C_{1.5}$ and $C_{2.5}$ treatments (Table 5). The lowest and the highest ear length are belonged to D_0 and D_5 treatments, respectively. There is no significant difference between the D_0 and $D_{2.5}$ treatments and $D_{2.5}$ and D_5 treatments. But from the D_0 to $D_{2.5}$ treatment, the ear length increased 3.36%. The increase in ear length from $D_{2.5}$ to D_5 treatment was 5.6%.

Plant height

Table 4 shows the effect of depth of irrigation water on plant height is significant at 5% level. The effect of crack width and the interaction effect of crack width and depth of irrigation water on plant height are not significant. The comparison of the mean values of plant height shows that the lowest and the highest plant height is belonged to D_0 and D_5 treatments, respectively (Table 5). There is no significant difference between D_0 and $D_{2.5}$ treatments and $D_{2.5}$ and D_5 treatments.

Table 5. The comparison of the measured average parameters as influenced by crack width and depth of irrigation water

Parameter	Crack width				Depth of irrigation			
	C_0	$C_{1.5}$	$C_{2.5}$	LSD Value	D_0	$D_{2.5}$	D_5	LSD Value
Grain yield (ton ha^{-1})	3.134a	2.729b	2.300c	0.2042	2.628b	2.675b	2.860a	0.1482
Blank grain percentage	18.33a	19.47a	21.07a	4.282	15.91b	19.06ab	23.90a	5.900
1000-Grain weight (g)	22.17a	21.02b	20.89b	0.9399	20.58b	21.77a	21.73a	0.9399
Ear length (cm)	29.52a	28.55ab	27.24b	1.797	27.35b	28.19ab	29.77a	1.797
Plant height (cm)	144.1a	145.2a	149.1a	4.645	142.6b	146.2ab	149.5a	4.645
Number of tillers	17.45 a	15.22 b	14.07 b	2.242	14.48b	15.59ab	16.67 a	1.627
Water use efficiency (g/m^3)	293.8 a	268.0 b	189.9 c	22.95	293.2a	243.7 b	214.8 c	22.95

The values that have at least one common character are not significant at 5% level. Each value in the table is an average of three replications.

Number of tillers

The effect of crack width on number of tillers was significant at 1% level and the effect of depth of irrigation water on number of tiller was significant at 5% level but their interaction effect was not significant (Table 4). The comparison of the mean values of number of tillers shows that the highest and the lowest number of tillers is belonged to the C_0 and $C_{2.5}$ treatments, respectively (Table 5). The highest number of tillers is belonged to D_5 and the difference between D_5 and $D_{2.5}$ is not significant.

Water use efficiency

The effect of crack width, depth of irrigation water and their interaction on water use efficiency is significant at 1% level (Table 4). The comparison of the mean values of water use efficiencies shows that the highest and the lowest water use efficiency is belonged to C_0 and $C_{2.5}$ treatments, respectively (Table 5). The interaction effect of crack width and depth of irrigation water on water use efficiency is shown in Fig. 3. This figure shows that for C_0, $C_{1.5}$ and $C_{2.5}$ treatments, there is no significant difference between $D_{2.5}$ and D_5 treatments. Therefore, to save water, it is better to use $D_{2.5}$ treatment instead of D_5 treatment, because $D_{2.5}$ consumes less water as compared to the D_5. The reduction of depth of ponding (D_0 vs. D_5) caused 36.5% improvement in water use efficiency (Table 5). At the present time, the farmers apply flooding irrigation to the paddy fields with low irrigation efficiency. Based on the results of this research, paddy fields could be irrigated with much less water than the amount that farmers are using traditionally. Arora (2006) reported that mean yield and ET in continuous submergence regime were the same for the two irrigation depths of 50 and 75mm, thereby leading to same values of ET-based water productivity. Islam et al. (2004b) reported that the main cause of reduction of water use efficiency in cracking clay soils is the preferential flow. In cracking clay soils, as the irrigation time increases, the irrigation water loss increases too. To increase the water use efficiency of these soils it is necessary to reduce deep percolation and lateral water losses. The study by Kukal and Aggarwal (2002) showed that reduction in depth of ponded water decreases the deep percolation substantially.

Conclusions

The findings of the present research showed that in cracked paddy soils, based on the development of crack width, the irrigation schedule can be planned to save water without considerable reduction of the crop yield. The reduction of depth of irrigation water caused 36.5% increase in water use efficiency. Paddy fields with cracking clay soils are found worldwide. The irrigation of paddy fields based on crack development is a new idea. Similar experiment can be conducted in paddy fields with cracking clay soils in order to have better irrigation management and to save irrigation water.

Acknowledgements

This research was funded and supported by the Isfahan University of Technology and Rice Research Institute of Iran which is gratefully acknowledged.

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