J. Trop. Agric. and Fd. Sc. 38(1)(2010): 1–9

Effects of irrigation regime on irrigated rice

(Kesan rejim pengairan pada tanaman padi sawah)

O. Sariam* and A.R. Anuar**

Keywords: irrigation regime, direct seeded rice, saturated soil, growth, yield

Abstract

Field experiments on the effects of irrigation regime on irrigated rice production were carried out in Muda irrigation scheme (MADA) and Kemubu irrigation scheme (KADA) during off season 2004 and main season 2004/05. Five irrigation regimes were imposed on MR 220. Results showed that rice can be grown under saturated conditions without significant effect on the growth and yield when compared with rice grown under normal flooded or partially flooded conditions. However, rice growth and yield were significantly affected when rice was grown under field capacity conditions. Plants and panicles were also shorter whereas aboveground biomass at maturity and grain yield were lower when compared to rice grown under flooded or saturated conditions. Yield reduction in the range of 8–16% was observed in MADA and 40–61% in KADA for rice grown under field capacity conditions. Results from this study suggest that saturated conditions throughout the crop growth period which requires less irrigation water input than flooded conditions has high potential for the growing of direct-seeded rice under minimal water input.

Introduction

In Malaysia, the largest fresh water withdrawal of more than 75% is for irrigation in the agriculture sector and is mainly confined to irrigated rice production. Irrigated rice is normally grown in a flooded environment during most of its growing period, thus, growing rice requires a large amount of water.

Rice is a heavy consumer of water but its water use efficiency is rather low. It is estimated about 3,000 litres of water is used to produce 1 kg of rice and that the water productivity index (WPI) of rice is 0.3 kg grain/m^3 water. Farmers prefer to maintain a relatively high water level during the crop growth period in order to control weeds, as assurance against future water shortages and reduce the frequency of irrigation. This leads to a higher amount of surface runoff, seepage and percolation. Sharma (1989) reported that seepage and percolation accounts for about 50–80% of the total water input to the field.

The present global water crisis, however, threatens the sustainability of irrigated rice production. Climate variability and increase competition for available water from the domestic and industrial sectors have resulted in water scarcity. Water demand from the these sectors is expected to increase and is likely to receive priority over

*Rice and Industrial Crops Research Centre, MARDI Headquarters, Serdang, P.O. Box 12301, 50774 Kuala Lumpur, Malaysia
**Faculty of Agriculture, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia
Authors' full names: Sariam Othman and Anuar Abdul Rahim
E-mail: sariam@mardi.gov.my

irrigation. Thus, rice will be the crop most affected by the water crisis as it depends most heavily on irrigation.

This scenario may necessitate the adoption of rice production practices that reduce water inputs without reducing yield and at the same time increase water use efficiency and eventually save the irrigation water for other uses. This will also help to achieve the 90% self-sufficiency level (SSL) set for rice by 2010 from the present 72% SSL as manifested in the Malaysian Third National Agriculture Policy.

Rice shoot dry weight was moderately affected while tiller production and leaf area index (LAI) was not affected by delayed flood with periodic irrigation to maintain the soil at field capacity until early reproductive stage when compared to normal flooded rice (Beyrouty et al. 1992). They also observed a reduction in plant height when flooding was delayed. This effect of field capacity condition on plant height was observed especially from active tillering through maturity (Sariam 2004). On the other hand, Prasertsak and Fukai (1997) observed that flowering was delayed by 11–15 days when rice was subjected to water stress.

Greater yields and productivity were observed from flooded rice than from rice grown under saturated or drier conditions (Satyanarayana and Ghildyal 1970; Castillo et al. 1992). However, maintaining a saturated soil throughout the growing season can save 25–40% of water in clay loam soil without significant reduction in rice yields (CGIAR 1996; Sariam et al. 2007).

When weed growth is a serious problem, continuous flooding up to the panicle formation and followed by continuous saturation uses 30–35% less water than the traditional practice of continuous flooding and without any increase in weeds or reduction in yield as reported by Tabbal et al. (1992). A 10% yield reduction in direct-seeded rice flooded at early reproductive stage was reported when compared to rice grown with a flood beginning at early tillering (Tanaka et al. 1963). Rice yield was not significantly reduced if water deficit was imposed during vegetative growth, but about 20–70% yield reduction of flooded rice was observed if water deficit was imposed during reproductive period (Lilley and Fukai 1994). Sariam (2004) observed 51–64% yield reduction when rice is grown under field capacity condition throughout the crop growth period as compared to flooded rice. The lower rice yield (58% lower than flooded rice) from alternate wetting and drying practice was mainly due to low LAI at booting and anthesis, less shoot dry weight and lower root length density from booting to harvest as reported by Grigg et al. (2000).

Studies on lowland irrigated rice in Southern United States have shown that grain yields may not be reduced when flood is delayed from the four- to five-leaf stage until just prior to or at initiation of reproductive growth (McCauley and Turner 1979). Investigation carried out by Norman et al. (1992) showed that rice grain yields were not reduced when the flood and pre-flood applications were delayed for up to 21 days past the four to five-leaf stage. Too much reduction in water inputs, however, will impose water stress to the crop.

Water stress impairs numerous plant metabolic and physiological processes, decreases plant nutrient uptake due to reduced transpiration (Greenway and Klepper 1969) and impairs active transport and membrane permeability (Hsiao 1973) resulting in reduced root absorbing power which will eventually affect growth and yield of rice. Experiments were conducted to determine the effects of minimum water input on rice growth and yield, and to identify the potential irrigation regime for water saving in direct seeded rice production.

Materials and methods

Field experiments were conducted in the Muda Irrigation Scheme (MADA) and Kemubu Irrigation Scheme (KADA) during off season (OS) 2004 and main season (MS) 2004/05. The soil in MADA is of marine alluvial and has soil texture of silty clay. The top soil layer (0−25 cm) has a pH of 4.33, 1.47% organic C, 0.036% total N and a cation exchange capacity (CEC) of 14.0 $cmol_c\ kg^{-1}$. The soil of experimental site in KADA is a riverine alluvial with a soil texture of silty clay. The pH of the soil in KADA is 4.48 with organic C of 0.95%, total N of 0.046% and CEC of 8.25 $cmol_c\ kg^{-1}$.

The total accumulated rainfall for OS 2004 in MADA (April–July 2004) was 828 mm and in KADA (Jun–September 2004) was 713 mm. For the main season, the total accumulated rainfall in MADA (October 2004 to January 2005) was 594 mm and in KADA (January–April 2005) was 329 mm.

The five irrigation regimes were T1 = Flooded; T2 = Flooding from 7 days after seeding (DAS) up to panicle initiation stage (55 DAS) followed by saturated (F_{55}-saturated); T3 = Flooding from 7 until 30 DAS followed by saturated (F_{30}-saturated); T4 = Saturated (saturated soil conditions throughout the crop growth stage); and T5 = Field capacity condition throughout the growth period.

All plots were puddled and flood was gradually introduced to T1, T2 and T3 at 7 DAS and according to each treatment. On the other hand, the soil was kept wet but there was no standing water throughout the crop growth period for T4 (saturated). The field capacity plot (T5) was flash irrigated with about 3 cm depth of water each time only when the water potential at 15 cm depth fell between –30 and –50 KPa as measured with a tensiometer at the 15 cm soil depth. Field ditch (45 cm wide and 45 cm deep) for supplying water into the plot was constructed on one side of the field and field drain (45 cm wide and 45 cm deep) for removal of water was constructed on the other side of the field which is opposite to the field ditch.

The plot size of each treatment was 10 m x 40 m. Each plot was separated by 1-m bund to prevent water seepage from the adjacent plots. Treatments were arranged in a randomized complete block design and each treatment has four replications. Pre-germinated seeds of rice variety MR 220 (variety was bred for flooded condition) was seeded at the rate of 150 kg/ha on to puddled saturated soil.

Fertilizer was applied at the rate of 150:100:120 kg N, P_2O_5 and K_2O/ha. Nitrogen from urea was applied in four splits at 15, 35, 55 and 75 DAS. All triple super phosphate as the source of P_2O_5 was applied at 15 DAS and K_2O from muriate of potash was applied equally at 15 and 55 DAS. Pre-emergence herbicide was applied at 3 DAS and post emergence herbicide at 12 DAS for weed control. Manual weeding was done when required especially during the later growing stages.

At maturity, the crops from 5 m x 5 m plot of each treatment was harvested for the determination of yield adjusted to 14% moisture content. Plant samples from five 25 cm x 25 cm quadrants per plot were harvested for the determination of yield components. The number of panicles in each sample was counted and the panicle number per square meter was determined.

All spikelets were separated from the panicles, weighed and counted to determine the number of spikelets per panicle. Filled grains were separated from unfilled and partially filled grains by using salt solution with a specific gravity of 1.06. The filled grains were dried, counted and the percentage of filled grains as well as the 1000-grain weight were determined. The straw of each sample was cut at 2 cm above the soil surface, washed, air dried and weighed.

Results and discussion

Plant height and panicle length

The effect of irrigation regime on plant height at maturity was significant in both off and main seasons in MADA and KADA as shown in *Table 1*. The growth of rice under field capacity condition was significantly affected as indicated by shorter plants at maturity regardless of planting season and location as compared with other treatments. Plants were in the range of 9–13% shorter under field capacity than flooded conditions.

Sariam (2004) observed that plants were shorter by 5.5% when rice was grown under field capacity than flooded conditions. Shorter plants can be observed even if the soil is maintained at field capacity up to the early reproductive stage as reported by Beyrouty et al. (1992).

However, maintaining the soil at saturated condition or flooding until 30 or 55 DAS and followed by saturated condition did not significantly affect plant height when compared with the normal flooded rice. In general, rice plant regardless of treatment was taller in MADA than in KADA. This is probably due to the different fertility status of the soil in both the experimental sites.

Besides plant height, the panicle length was also significantly affected by the different irrigation regimes. Panicles was significantly shorter especially when irrigated rice was grown under field capacity condition in all cropping seasons except during MS 2004/05 in KADA (*Table 1*). The panicles under field capacity condition were shorter by 19–23% in MADA and 1.3–13% shorter in KADA than flooded rice. Panicle length was, however, comparable between flooded, F_{55}-saturated, F_{30}-saturated and saturated conditions.

Aboveground biomass

The aboveground biomass (shoot weight) at maturity was significantly affected by the different irrigation regime as shown in *Figure 1*. Results indicated that the aboveground biomass was not significantly different among the flooded, F_{55}-saturated, F_{30}-saturated and saturated conditions except in MADA during MS 2004/05 where F_{30}-saturated produced significantly lower biomass than flooded and F_{55}-saturated conditions. It was observed that in MADA, the aboveground biomass was not significantly different between F_{30}-saturated and field capacity conditions in both OS 2004 and MS 2004/05.

However, this response was not observed in KADA. This could be because of the higher total accumulated rainfall in MADA than KADA regardless of season. The total accumulated rainfall during

Table 1. Plant height and panicle length (cm) at maturity

Treatment	MADA		KADA	
	OS 2004	MS 2004/05	OS 2004	MS 2004/05
Plant height				
Flooded	97.5a	89.0a	87.0a	84.0a
F_{55}-saturated	96.5a	89.8a	88.5a	87.8a
F_{30}-saturated	98.5a	89.0a	87.8a	83.5a
Saturated	98.0a	90.0a	86.3a	85.3a
Field capacity	89.0b	77.5b	78.3b	75.5b
Mean	95.9	87.1	85.6	83.2
Panicle length				
Flooded	25.8a	25.0a	24.8a	22.8a
F_{55}-saturated	24.0a	23.5a	24.5a	24.5a
F_{30}-saturated	25.0a	24.5a	24.0a	23.5a
Saturated	24.5a	23.8a	24.5a	20.3a
Field capacity	20.0b	20.3b	21.5b	22.5a
Mean	23.9	23.4	23.9	22.7

Figures within each column followed by a common letter are not significantly different ($p = 0.05$)

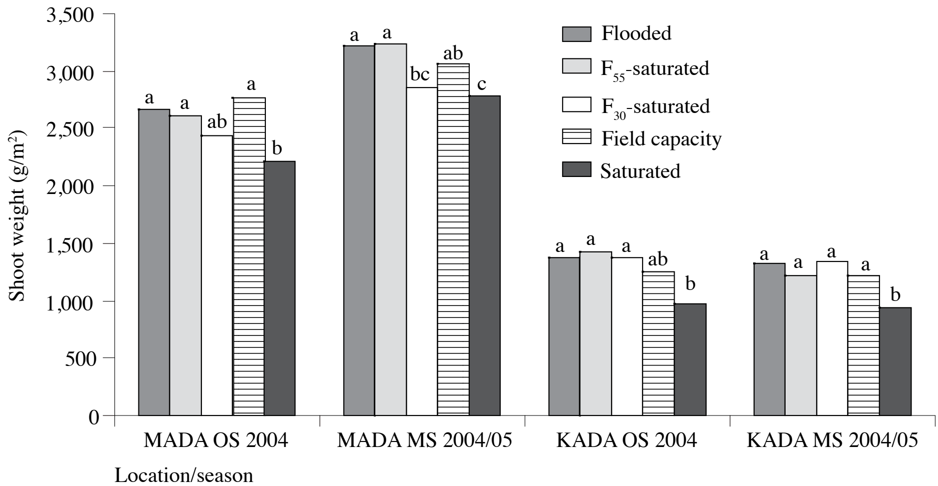

Figure 1. Aboveground biomass in MADA and KADA.
Bars for each season followed by a common letter are not significantly different (p = 0.05)

OS 2004 was 828 mm and 713 mm for MADA and KADA respectively. During MS 2004/05, the accumulated rainfall was 594 mm in MADA and 329 mm in KADA. The higher accumulated rainfall in MADA might have increased water content in the lower soil depth (instead of field capacity condition) which was favourable for rice growth. This had resulted in a comparable aboveground biomass to rice grown under flooded condition during the first 30 days and followed by saturated condition.

Results however showed that aboveground biomass was significantly lower when irrigated rice was imposed to field capacity condition throughout the crop growth period as compared to flooded, F_{55}-saturated and saturated conditions in MADA. In KADA field capacity condition significantly reduced aboveground biomass as compared with other irrigation regime tested except saturated condition during OS 2004. Beyrouty et al. (1992) earlier observed that aboveground biomass was moderately affected if the field capacity condition was maintained up to the early reproductive stage.

A higher aboveground biomass was obtained in MADA than KADA irrespective of growing season. As expected, greater reduction in aboveground biomass (about 29%) was also observed in KADA for field capacity as compared with flooded condition.

In MADA, the aboveground biomass was 17% and 14% lower for field capacity than flooded condition during OS 2004 and MS 2004/05 respectively.

Grain yield and yield components

The effects of irrigation regime on grain yield in MADA and KADA areas are shown in *Table 2*. In MADA, grain yield was not significantly different between irrigation regime during OS 2004 but a significantly lower grain yield was observed under field capacity condition during MS 2004/05. Grain yield was even higher under saturated (7.6 t/ha) than flooded condition (7.1 t/ha) in MADA during OS 2004 and equally good during MS 2004/05 with yield of 4.9 t/ha. In KADA, yield from saturated condition (5.1 t/ha) was better than flooded (4.8 t/ ha) during MS 2004/05. Only during OS 2004 grain yield from saturated was significantly lower (2.1 t/ha) than flooded conditions (3.1 t/ha).

Results from MADA and KADA suggest that it is not necessary to flood rice to obtain high grain yield, since maintaining a saturated soil throughout the growing season resulted in a non-significant reduction in rice yield. This result is in agreement with observation as reported in the literature (CGIAR 1996; Sariam 2004). This is however, in contrast to the finding reported by Castillo et al. (1992) where greater rice yield was observed under flooded than saturated condition. The yield performance of F_{55}-saturated and F_{30}-saturated were not significantly different from flooded condition in both seasons.

Yield was significantly lower when rice was grown under field capacity than other irrigation regimes tested. In MADA, a lower yield was observed under field capacity than flooded conditions with yield difference of 8% during OS 2004 (*Table 2*). However, the difference in yield between field capacity and flooded condition was greater and significant (16%) during MS 2004/05.

The greater difference in yield between rice grown under field capacity and flooded conditions in MADA during MS 2004/05 than OS 2004 could have been associated with the soil water status. Higher total accumulated rainfall during OS 2004 would have resulted in wetter soil which favoured crop growth and yield for field capacity condition. However, this effect was not indicated in KADA because of leaf feeders attack during OS 2004.

This difference in yield between field capacity and flooded conditions in MADA is rather low when compared to earlier reports (Lilley and Fukai 1994; Grigg et

Table 2. Yield and yield components (MADA and KADA)

	Yield (t/ha)	Panicles/m^2	Spikelets/ panicle	Filled grains (%)	1000-grain wt (g)
KADA					
OS 2004					
Flooded	7.1a	566b	83a	76.2a	28.4b
F_{55}-saturated	7.3a	731a	72a	70.4a	29.6a
F_{30}-saturated	7.4a	607ab	79a	77.2a	28.1b
Saturated	7.6a	684ab	84a	70.5a	28.2b
Field capacity	6.5a	666ab	69a	75.8a	28.5b
MS 2004/05					
Flooded	4.9a	682a	100a	73.1a	25.9a
F_{55}-saturated	4.5ab	735a	102a	75.8a	26.4a
F_{30}-saturated	4.9a	641a	99a	69.4a	26.6a
Saturated	4.9a	694a	108a	71.3a	25.8a
Field capacity	4.1b	744a	92a	67.2a	26.1a
KADA					
OS 2004					
Flooded	3.1a	497a	87a	51.4a	26.4b
F_{55}-saturated	2.9a	484a	81a	51.1a	27.9a
F_{30}-saturated	3.2a	596a	75a	42.5b	27.2ab
Saturated	2.1b	429a	75a	52.5a	27.1ab
Field capacity	1.2c	508a	68a	42.0b	26.5b
MS 2004/05					
Flooded	4.8a	449a	64a	60.3a	25.7a
F_{55}-saturated	4.2ab	470a	67a	62.4a	26.4a
F_{30}-saturated	3.7ab	479a	58a	55.5a	24.8ab
Saturated	5.1a	441a	64a	59.9a	24.6ab
Field capacity	2.9b	430a	59a	60.1a	23.6b

Figures within each column followed by a common letter are not significantly different ($p = 0.05$)

al. 2000; Sariam 2004). On the other hand, greater yield differences (61% during OS 2004 and 40% during MS 2004/05) were observed between field capacity and flooded conditions in KADA. The lower yield for rice grown under field capacity condition or alternate wetting and drying practice was mainly due to low LAI at booting and anthesis, less shoot dry weight and lower root length density from booting to harvest as reported by Grigg et al. (2000).

Total root length and root length density were significantly lower for rice grown under field capacity condition (Sariam 2009). Since the capacity of rice plant to absorb nutrients is closely related to the total root length of the root system (Teo et al. 1995), the lower total root length and root length density under field capacity condition has reduced nutrient uptake and eventually reduced growth and grain yield. The field capacity condition also might have affected some physiological processes such as transpiration rate which would decrease plant nutrient uptake, growth and yield (Tanguilig et al. 1987).

In general, yield from MS 2004/05 in MADA was very much lower than OS 2004. This is mainly due to dry weather during the grain filling stage in MS 2004/05 (December 2004 to January 2005). On the other hand, the poor performance of the OS 2004 crop for KADA was due to serious attack by leaf feeders even during the reproductive stage.

In MADA, the relatively few spikelets per panicle (69 and 92 spikelets during OS 2004 and MS 2004/05 respectively) and lower percentage of filled grains especially during MS 2004/05 had attributed to the low grain yield for rice subjected to field capacity condition (*Table 2*). There was some effects of irrigation regime on the number of panicles per square meter in MADA. The number of panicles per square meter was not significantly different between irrigation regime in both seasons except between flooded and F_{55}-saturated during OS 2004. There was no significant effect of irrigation regime on the 1,000-grain weight.

In KADA, the percentage of filled grain was significantly lower under F_{30}-saturated and field capacity conditions during OS 2004. However, the 1,000-grain weight was significantly lower under field capacity than F_{55}-saturated conditions during OS 2004 and lower than flooded and F_{55}-saturated conditions during MS 2004/05 (*Table 2*). There was no clear trend of other yield components contribution on yield.

Conclusion

Maintaining irrigation regime at saturated condition had no significant effect on the growth and yield of rice variety MR 220 in MADA and KADA areas. Results suggest that irrigated rice can be grown in irrigated schemes with minimum water input under continuous saturated condition without significant reduction in yield. However, rice yield was significantly low when irrigated rice was grown under field capacity condition throughout the crop growth period. Yield reduction in the range of 8–16% in MADA and 40–61% in KADA was observed.

Acknowledgement

The authors gratefully acknowledged the technical assistance of Mr Radzman Fariq Rohan in MADA, Mr Mazudi Mohamad and Mr Mohd Hamni Mohammad in KADA.

References

Beyrouty, C.A., Norman, R.J., Wells, B.R., Gbur, E.E., Grigg, B.C. and Teo, Y.H. (1992). Water management and location effects on root and shoot growth of irrigated lowland rice. *J. Plant Nutr.* 15: 737–752

Castillo, E.G., Buresh, R.J. and Ingram, K.T. (1992). Lowland rice yield as affected by timing of water deficit and nitrogen fertilization. *Agron. J.* 84: 152–159

CGIAR (1996). IRRI working to increase rice plant yield by using water more efficiently, Consultative Group on Int. Agricultural Research. Retrieved on 23 May 2001 from http://www.worldbank.org/html/cgiar/newsletter/May96/5rice.html

Greenway, H. and Klepper, B. (1969). Relation between anion transport and water flow in tomato plants. *Physiol. Plant* 22: 208–219

Grigg, B.C., Beyrouty, C.A., Norman, R.J., Gbur, E.E., Hanson, M.G. and Wells, B.R. (2000). Rice responses to changes in floodwater and N timing in southern USA. *Field Crop Res.* 66: 73–79

Hsiao, T.C. (1973). Plant responses to water stress. *Ann. Rev. Plant Physiol.* 24: 519–570

Lilley, J.M. and Fukai, S. (1994). Effects of timing and severity of water deficit on four diverse rice cultivars. III. Phenological development, crop growth and grain yield. *Field Crop Res.* 37(3): 225–234

McCauley, G.N. and Turner, F.T. (1979). Rice production and water use efficiency in relation to flood period. In: *Agronomy Abstracts,*105 p. Madison, WI: ASA

Norman, R.J., Helms, R.S. and Wells, B.R. (1992). Effects of delayed flood and nitrogen fertilization on dry seeded rice. *Fert. Res.* 32: 55–59

Prasertsak, A. and Fukai, S. (1997). Nitrogen availability and water stress interaction on rice growth and yield. *Field Crop Res.* 52: 249–260

Sariam, O. (2004). Growth response of rice under different water and nitrogen management. PhD Thesis, p. 60–115, Faculty of Agriculture, Universiti Putra Malaysia

—— (2009). Effect of irrigation practices on root growth and yield of rice. *J. Trop. Agric. and Fd. Sc.* 37(1): 1–8

Sariam, O., Asiah, A. and Anuar, A.R. (2007). Water-saving irrigated rice production. Poster presentation in International Trade Fair "Ideas – Inventions – Innovations", IENA 2007, Nuremberg, Germany

Satyanarayana, T. and Ghildyal, B.P. (1970). Influence of water regimes on growth and nutrient uptake by rice (*Oryza sativa*). *Indian Soc. Soil Sci. J.* 18: 51–55

Sharma, P.K. (1989). Effect of periodic moisture stress on water use efficiency in wetland rice. *Oryza* 26(3): 252–257

Tabbal, D.F., Lampayan, R.M. and Bhuiyan, S.I. (1992). Water-efficient irrigation technique for rice. In: *Soil and water engineering for paddy field management*. (Proc. of the Int. workshop on soil and water engineering for paddy field management), 28–30 Jan. 1992, Bangkok, Thailand, (Murty, V.V.N. and Koga, K., eds.), p. 146–159. Bangkok: Asian Inst. of Tech.

Tanaka, I., Nojima, K. and Yoshimasa, U. (1963). Influence of drainage on the growth of rice plant in rice field. II. Relation between irrigation methods and the growth and yield of rice at various levels of nitrogen fertilization and sowing density. *Proc. Crop Sci. Soc. Jpn.* 32: 89–93

Tanguilig, V.C., Yambao, E.B., O'Toole, J.C. and De Datta, S.K. (1987). Water stress effects on leaf elongation, leaf water potential and nutrient uptake of rice, maize and soybean. *Plant and Soil* 103: 155–168

Teo, Y.H., Beyrouty, C.A., Norman, R.J. and Gbur, E.E. (1995). Nutrient uptake relationship to root characteristics of rice. *Plant and Soil* 171: 297–302

Abstrak

Kesan rejim pengairan terhadap hasil tanaman padi sawah telah dikaji di Skim Pengairan Muda (MADA) dan Skim Pengairan Kemubu (KADA) pada musim luar 2004 dan musim utama 2004/05. Sebanyak lima rejim pengairan telah diuji terhadap varieti MR 220. Kajian mendapati padi sawah boleh ditanam dalam keadaan tanah tepu tanpa memberi kesan ketara kepada pertumbuhan dan hasil berbanding dengan padi yang ditanam dalam keadaan pembanjiran atau separa pembanjiran. Walau bagaimanapun, pertumbuhan dan hasil padi nyata terjejas apabila padi sawah ditanam di tanah berkeupayaan ladang. Pokok dan tangkai padi didapati lebih pendek manakala biomas pokok dan hasil lebih rendah daripada padi yang ditanam dalam keadaan pembanjiran atau keadaan tanah tepu. Penurunan hasil tanaman padi di tanah berkeupayaan ladang adalah sebanyak 8–16% dan 40–61% masing-masing di MADA dan di KADA. Hasil kajian menunjukkan bahawa keadaan tanah tepu yang memerlukan input pengairan yang kurang berbanding dengan sistem pembanjiran berpotensi untuk tanaman padi tabur terus menggunakan input air yang minimum.

Accepted for publication on 15 June 2009