Evaluation For High Water Productivity And Yield Assessment Of Lowland Paddy Rice Under Controlled Drainage And Irrigation Using The System Of Rice Intensification (SRI)

Victoriano Joseph Pascual, Yu-Min Wang

Abstract: The pressure to limit water supply in irrigated agriculture while producing more food with less water is being exacerbated by population growth and climate change. Rice is a very important and valuable crop to Taiwan's economy; but production is being hampered by water shortage. This research was therefore conducted during the rainy season with the intent of saving irrigation and rain water while maintaining a suitable drainage depth for sustaining rice yield under SRI management. Three different drainage depths T_{2cm}, T_{4cm}, T_{6cm} and a control T_{sat} was used alongside irrigation under a complete randomized block design having four replications. Results revealed water reduction after panicle initiation significantly affected plant height in T_{2cm} and T_{4cm}, and grain yield in T_{2cm}. The lowest grain reduction (4.92%) and grain production loss (0.09 kg) was produced by T_{4cm}.The highest total water productivity (0.52kg/m^3) and irrigation water productivity (1.88 kg/m^3) was produced in T_{2cm} followed by T_{4cm} (0.44 kg/m^3) and (1.14kg/m^3) respectively. The draining of excess rainfall at 4cm depth and providing irrigation of the same amount provided the best results under SRI management in terms of yield and irrigation water saving.

Key words: Agriculture, climate change, drainage, irrigation, rice, SRI, water productivity

1 Introduction

Rice is arguably the world's most important food crop as it is a major food grain for more than a third of the global population (Ndiiri et al. 2012). However, it still needs to be increased by 50% or more above the current production level to meet the rising food demand (Mishra and Salokhe 2010). Irrigated rice production is the largest consumer of water in the agricultural sector, and its sustainability is threatened by increasing water shortages (Thakur et al. 2011). The conventional system of irrigating rice is to flood and maintain free water in the field. This system however uses a large amount of water because of high water loss through evaporation, seepage and percolation (Belder et al. 2004). The system of rice intensification (SRI) could potentially become an approach for increasing rice production with decreasing water demand, thus improving both water use efficiency and water productivity. SRI is depicted as a farming system that overturns the conventional norms of rice cultivation since it deviates from the green revolution standards that intends to increase grain yields by either improving genetic potentials of crops, making them more responsive to chemical inputs, and or by increasing the use of external inputs (i.e., water, agrochemicals) (Chapagain et al. 2011). The system proposes the use of single, very young seedlings with wider spacing, intermittent wetting and drying, use of a mechanical weeder for soil aeration, and enhanced soil organic matter.

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All these practices are aimed at improving the productivity of the rice crop grown in paddies through healthier, more productive soil and plants by supporting greater root growth and by nurturing the abundance and diversity of soil organisms (Thakur et al. 2011). SRI has been widely promoted and its management practice has shown yields increase of 50% to 100%. Against this backdrop, a research was conducted to evaluate the performance of lowland paddy rice under SRI management practices. This experiment was performed during the rainy season, utilizing three different water depths under controlled drainage. In keeping with the SRI recommendation of maintaining the paddy soil moist by alternating the wetting and drying days the effects of rainfall, drainage and irrigation will provide a critical assessment on rice development and yield under these conditions. Under controlled drainage conditions, rice may experience fluctuating water level due to the intermittent nature of irrigation system and rainfall pattern causing plants to be frequently exposed to episodes of alternate wetting and drying conditions of various degrees (Shao et al. 2014). By eliminating irrigation that has little impact on yield; unproductive water outflows will be considerably reduced, and irrigation water productivity should increase. This approach takes advantage of the combined effects of rainfall, irrigation and drainage during the different growth stages. It may further, affect rice plants morphology, physiology and ultimately crop yield and water saving. Moreover, such an approach is less documented in literature especially in southern Taiwan where there is high rainfall distribution and variability.

2 Materials and Methods

2.1 Site description, treatments and experimental design

The experiment was conducted at the National Pingtung University of Science and Technology experimental and irrigation field in Southern Taiwan. The experimental area is located at 22.39° (N) latitude and 34.95° (E) longitude and 71m above sea level. The soil type is characterized as loamy

(27% of sand and 24% of clay) with a wilting point of 15% volume; field capacity 30.5% volume; saturation 42.9% volume; bulk density 1.40g/cm^3; matric potential 11.09 bar; and hydraulic conductivity at 57mm/hr. The crop cycle was from July to October 2015 and consisted of a randomized complete block design with consisted of 4 management practices and 4 replications, namely:

1. T_{2cm}, draining of excess rain water at 2cm
2. T_{4cm}, draining of excess rain water at 4cm
3. T_{6cm}, draining of excess rain water at 6cm
4. T_{Sat}, plots remained saturated or flooded during the crop cycle

Five days after transplanting, polyvinyl chloride (PVC) pipelines 5cm in diameter were installed at 2, 4, and 6cm above the soil surface representing T_{2cm}, T_{4cm} and T_{6cm} in each plot. The pipelines were connected to surface drains excavated between the 1m blocks. During periods of heavy and continuous rainfall, the excess water was drained from each plot allowing the desired amount of ponded water to remain. Water drained from the same treatments were collected in 3000L farm tanks and recorded throughout the crop period. Plot sizes had a total area of 6m^2, and 0.3m soil bed height. The spacing between plots and between blocks was 1m. To minimize seepage between plots, bunds were covered with plastic film and the plastic film was installed to a depth of 20 cm below soil surface.

2.2 Crop, Irrigation management, Soil water content and soil trend analysis

Twelve days old seedlings were transplanted at hill spacing 25cm between hills and 25cm between rows at one seedling per hill. Fertilizers and pesticides were not incorporated in this experiment and weeds were controlled with a mechanical weeder. After transplanting, crops were subjected to 2-3cm ponded water depth for the first 4 days. Irrigation scheduling was every 5 days, however when crops were subjected to heavy rainfall it was suspended until the following week. T_{sat} was usually saturated throughout the crop cycle, however during periods of heavy and constant rainfall T_{sat} plots were inundated for 1-3days. Water treatments commenced after the drainage pipes were installed. The following equation cited by (Kima et al. 2014b) was used to obtain the desired water volume at required depth.

$$IR = A \times h \times 10x^3$$

IR is the amount of irrigation water (L) for a desired depth above the soil surface, A is the surface of the plot (m^2), and h is the desired water depth above the soil surface (m). The soil water content was measured every 5 days (before irrigation) from 1 month after transplanting to 1 month before harvest using the gravimetric method. Soil samples were collected using an auger, in three different locations within each plot at 20cm depth. The soil was immediately weighed, and dry weight was obtained after oven drying at 105°C for 24 hours. The soil water content per unit was calculated using the following equation:

$$SW = 100 \times (\text{fresh weight-dry weight}) \times \gamma_s / (\text{Dry weight})$$

where SW is the soil water content (mm) soil depth and γ_s is the soil bulk density (g/cm^3). The soil water trend was analyzed by determining the soil water content at saturation level, field capacity, wilting point, and stress threshold using equations 3, 4, 5 and 6 (Allen et al. 1998).

$$SW_{Sat} = 1000\ (SAT) \times Z_r \quad (3)$$
$$SW_{FC} = 1000\ (FC) \times Z_r \quad (4)$$
$$SW_{WP} = 1000\ (WP) \times Z_r \quad (5)$$
$$SW_{ST} = 1000\ (1-P)Sat \times Z_r \quad (6)$$

where SW_{Sat}, SW_{FC}, SW_{WP} and SW_{ST} are soil water content (mm) at saturation, field capacity, wilting point, and stress threshold level, respectively. Sat, FC, and WP are the soil water content at saturation, field capacity and wilting point, respectively in percentage of volume. P is the fraction of water that can be depleted before moisture stress occurs and represent 20% of the saturation for rice crop; Z_r is the sample collection depth (m).

2.3 Assessment of agronomic parameters and water productivity

The measurements for plant height and tillers number were taken from fifteen selected hills throughout the diagonals and median. Plant height was measured from the base of the plant to the tip of the highest leaf at panicle initiation and heading stage. Tillers were counted individually, and the numbers were determined at the above mentioned stages. Five (5) hills from each replicate were randomly selected for root assessment at panicle initiation. This was done using an auger 10cm diameter to remove soil of 20cm depth from selected hills. A uniform soil volume of 1570cm^3 was excavated to collect root samples for all treatment. Roots were carefully washed and removed from uprooted plants. Root volume was measured by water displacement method by putting all the roots in a measuring cylinder and getting the displaced water volume (Ndiiri et al. 2012). Root depth was obtained by direct manual measurements of top root using a ruler against a millimeter paper. Roots dry biomass per hill was obtained after oven drying at 70°C for 24hours. At harvest, yield components (panicle number per hill, panicle length, and panicle weight, grain number per panicle, grain weight per panicle and filled grain per panicle) were obtained from the fifteen sampled hills. Panicles length and number of grain per panicles were determined according to the methods of (Kima et al. 2014b). On each plot, all remaining plants in the area (6m^2) were harvested for grain yield determination per unit area (tha^{-1}). Three samples of harvested grains were randomly picked from each replicate and the dry weight was determined. Grains weight per panicle, and grain yield was obtained at a constant weight after oven drying at 70°C for 72hours. The grain yield for unit area was then adjusted at the standard moisture content of 14%. Five samples of 1000 grains were taken from the total grains production of each plot and weighted for 1000 grains weight determination. Filled spikelet's from these samples were separated from unfilled spikelet's using a seed blower for 2mm. The percentage of filled grain was calculated, mass basis, as the ratio of filled grains weight out of the total grains weight multiplied by 100. Fifteen samples were considered per treatment. The dry biomass per hill from the harvested plants was determined after oven drying at 70°C for 24hours, and the total straw weight (tha^{-1}) was calculated accordingly. The total water productivity (TWP) and irrigation water productivity (IWP) were calculated according to equations (9) - (10) (Pereira et al. 2012):

$$TWP = Y/TWU$$
$$IWP = Y/IWU$$

Where TWP and IWP are the total water productivity (rain + irrigation) and irrigation water productivity, expressed in kg m^{-3}; Y is the grain yield (kg ha^{-1}), TWU and IWU are the total water and irrigation water used expressed in m^3 ha^{-1}.

Data Analysis: The statistical analysis applied on the data includes analysis of variance using SPSS 22 software. The significance of the treatment effect was determined using F-test and means were separated through Duncan's test at 0.05.

3 Results and Discussion

3.1 Agrohydrological condition and soil trend analysis

The monthly rainfall data and the mean maximum and minimum temperatures recorded during the crop season are presented in Table 1. The soil moisture trend analysis is presented in Figure 1. Agro-hydrological data were recorded at the National Pingtung University of Science and Technology Agro-Meteorological station during the crop cycle. The highest mean maximum temperature was recorded in July whereas the mean minimum temperature was in October. The maximum total monthly rainfall (536mm) was recorded in September, followed by July (189mm), August (103mm) and October (55mm). Rainfall was more frequent in the month of July compared to other months registering 17, 12, 13 and 13 rainy days for the months of July, August September and October respectively. According to the growth stages 2490m^3/ha of rainfall was registered during the vegetative stage (July 1st to August 9th), 4780m^3/ha during panicle initiation (August 10th to September 12th), 1560m^3/ha from heading to harvest (September 13th to October 31st). When heading to harvest. When comparing the three rice development stages (i.e. vegetative, panicle initiation and heading), the maximum amount of water drained was during panicle initiation. In T_{2cm}, T_{4cm} and T_{6cm}, the amount drained was respectively 4310m^3/ha, 3660m^3/ha, and 3390m^3/ha. The fluctuation of soil moisture trend which is caused by the intermittent nature of irrigation and rainfall pattern indicate that up to panicle initiation soil moisture was frequently above the soil saturation level in all treatments. Maximum soil moisture was observed in T_{sat} throughout the crop cycle; however, after panicle initiation soil moisture decreased in all other treatments and was even below the soil stress threshold level in T_{2cm}. Low soil moisture recorded after panicle initiation was 68.6, 77.1, and 84.0, for T_{2cm}, T_{4cm} and T_{6cm} respectively.

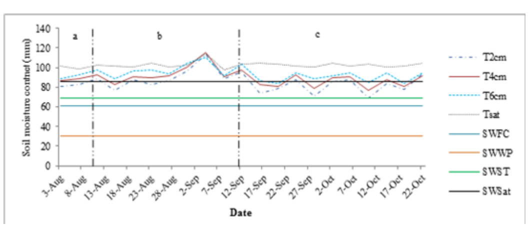

Figure 1. *Soil moisture content under different irrigation regimes during the crop production cycle.*

3.2 Rice growth

The result shows that soil moisture was frequently within soil saturation level from vegetative to panicle initiation stages. Frequent rain falls during this period occasionally led to ponding even after the excess water was drained. Ponding was more common in T_{6cm}, T_{4cm} and T_{sat}, whereas most of the ponded water in T_{2cm} was lost due to its lower drainage depths; however, soil moisture inT_{2cm} remained within soil saturation. Plant height at panicle initiation was unaffected by irrigation and drainage management however significant difference was observed at heading (Figure 2a). Height reduction rate was calculated by the ratio of height difference between the two lower water treatments and T_{sat} (considering T_{sat} as the reference). At heading plant height reduced by 6.03% and 6.69% in T_{2cm} and T_{4cm} respectively, with no comparable differences observed in T_{sat} and T_{6cm}. Tiller numbers showed no significant differences and were similar at panicle initiation and heading stages (Figure 2b). Water supplied proved adequate for maintaining plant height up to panicle initiation; on the contrary the sensitivity of rice to water reduction was shown at heading as plant height was reduced. The occurrence of ponding followed by subsequent soil drying (T_{2cm}, T_{4cm}, T_{6cm}) was frequently observed during the early growth stages and may have contributed to good plant performance in terms of plant height and tiller numbers when compared with T_{sat}. Such observation continues to reinforce the findings of (Hameed et al. 2013) among others who explains that rice does not necessarily requires continuous submergence, however adequate water must be provided for proper plant development during critical growth stages. Plant height in T_{2cm} and T_{4cm} were significantly shorter at heading and may be as a consequence of lower rainfall after panicle initiation, however 6cm ponded water depth during this time provided adequate soil moisture until the next irrigation. Plant height reduction after panicle initiation suggests that rice may be very sensitive to a small loss of available water since soil moisture then was at or between soil stress threshold and soil saturation for T_{2cm} and T_{4cm}. Rainfall during this period was 1560m^3/ha and irrigation water supplied was not sufficient to maintain plant height comparable to T_{6cm} and T_{sat}. T_{6cm}, however was able to yield similar height to T_{sat} but showed no significant difference when compared to other treatments. Differences were not observed in tiller numbers per hill among treatments, this is supported by (Chapagain et al., 2011) indicating that SRI management enhances tillering due to efficient utilization of resources as a result of less inter and intra space competition.

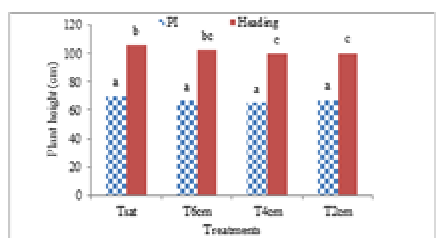

***Figure 2a**. Effects of water management on plant height at panicle initiation and heading.*

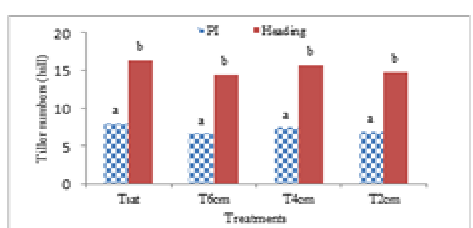

Figure 2b. *Effects of water management on tiller numbers at panicle initiation and heading.*

3.3 Root Parameters:

The results of the root parameters are displayed in Table 2. When compared to the other treatments maximum root volume and root biomass was achieved in T_{sat} with significant differences between T_{sat} and T_{2cm}, whereas comparable root weight was seen in T_{2cm}, T_{4cm} and T_{6cm}. Root volume decreased by 39.17 in T_{2cm} whilst root biomass decreased by 47.51%, 35.74% and 38.09% in T_{2cm}, T_{4cm} and T_{6cm} respectively. Irrigation and drainage management did not affect root depth. Root characteristics were superior in T_{sat} and produced thicker and heavier roots when compared with the other treatments. Root depth at panicle inanition produced comparable results however deeper roots were observed in T_{2cm} expressing the adoption mechanism developed by plants for extracting water in depths. Root dry biomass and root volume were significantly higher for T_{sat}, with no significant differences expressed inT_{2cm}, T_{4cm} and T_{6cm}. The root dry biomass accumulation expressed in T_{sat} is one of the main growth factors of rice as large root dry biomass implies high root activity and strong water and nutrient absorption capacity, which tends to favor high grain Kato and Okami, 2010. Further observation also revealed that roots were thicker and fuller in 0-8cm soil depth and healthy roots were observed in all treatments. Thakur et al (2009) demonstrated that a moderate AWD could enhance root growth, facilitate the remobilization of carbon reserve to grains, accelerate grain filling and improve grain yield.

3.4 Yield and grain components

Average panicle length and average panicle weight were similar among all treatments with significant difference observed between average panicle number per hill and grain number per panicle Table 3. Average panicle number per hill was similar in T_{sat}, T_{6cm} and T_{4cm} however grain number per panicle was reduced in T_6 compared to the other treatments. Average panicle number decreased by 24.32% in T_{2cm} while grain number per panicle decreased by 9.24% in T_{6cm}. Grain filling was reduced by 14.46% in T_{2cm} while 1000 grain weight decreased by 25.06% and 13.20% in T_{2cm} and T_{6cm}, respectively (Table 4). Overall, the lowest grain yield and maximum yield loss was produced in T_{2cm} and the least yield reduction was achieved in T_{4cm}. Average grain number per panicle, grain filling rate, 1000 grain weight and grain yield were also affected by irrigation and drainage management. Despite showing no difference in tiller numbers the decrease in panicle number per hill in T_{2cm} showed that effective tillers were affected. Yang et al. (2007) explained that in contrast with other crops, rice is particularly more sensitive to water especially at the critical growth stages such as panicle initiation, anthesis and grain filling. Water deficit at any of these critical stages may affect flowering and interrupt floret initiation causing spikelet sterility and grain filling resulting in lower grain weight and ultimately poor paddy yield. This is likely because, based on water deficit and its severity; carbohydrate synthesis slowed down and weakens the sink strength at reproductive stages causing the abortion of fertilized ovaries (Rahman et al. 2002). As a result, this may have induced spikelet sterility and caused grain filling delay ultimately leading to highest unfilled grain percentage in T_{2cm}. In this study however, the critical line was the stress threshold which shows that T_{2cm} encountered a certain level of stress which may have contributed to a reduction of overall grain yield. Nevertheless, T_{4cm}, performed as well as T_{sat} and T_{6cm} indicating and the application of 4cm ponded water depth after panicle initiation may have allowed for an efficient use of water by plants.

3.5 Water use efficiency

Maximum irrigation water used was recorded in T_{sat} whilst the maximum amount of water drained was recorded in T_{2cm} Table 5. The highest overall water saving performance, (0.52 kg/m^3) for total water productivity, (1.88 kg/m^3) for irrigation water productivity and water saving (3600 m^3/ha) was produced in T_{2cm}. However, T_{4cm} exhibited the lowest production loss (0.09 kg/m^3) due to saving one unit of water. Controlled irrigation and drainage alongside AWD-SRI proved that appropriate soil moisture can be maintained while efficiently utilizing rainfall and saving irrigation water. The most water drained was produced from T_{2cm} and therefore may have contributed to certain depression in crop performance. Overall a total of 11810m^3 of rainwater was drained during the crop cycle. The study also showed that T_{sat} consumed highest amount of water 14030m^3/ha which is greater than the combined amount of water drained. The lowest yield reduction (4.92%) and grain production loss (0.09kg) due to the saving of 1m^3 of water was produced by T_{4cm}. This result can be compared with (Bouman and Tuong 2001) and (Kima et al. 2014a) who explained that in Asia water savings under saturated soil conditions were on average 23% with yield reductions of 6%. There are at present no generally accepted design criteria for managed irrigation and drainage systems in humid areas. Thus, there is a need to develop new management methods for irrigation and drainage to meet the challenges of irrigated agriculture and save irrigation water while minimizing the effect of environmental impact.

4. Conclusion

The draining of rain water at 4cm depths during periods of heavy rain and re-irrigation of the same amount provided best results in terms of yield, water saving, and grain production loss. Since rain water is free and water saving is important, eliminating the use of excess water that has insignificant impact on yield can considerably increase water saving. High rainfall during the vegetative stage allowed for water to be drained without having any significant impact on plant development. The drained water from T_{2cm} and T_{4cm} during the crop cycle was more than the irrigation water applied and therefore could have been used for irrigating the said treatments if collected. We argue that, rather than keeping soil saturated by applying small amounts of water every one or two days; keeping drainage pipes set at 4cm during the rainy season and re-irrigating at the same amount every 5 days can contribute to water saving with no significant reduction in yield in this study area. Such research is critical and of high priority as the sustainability of world's rice production under limited fresh water conditions is threatened by irrigation scarcity.

Appendices

Table 1: *Temperature and rainfall during the crop cycle.*

Months	Temperature(°C)		Rainfall (mm)
	Mean maximum	Mean minimum	Total Monthly
July	33.68	26.28	189
August	31.77	24.21	102
September	31.64	26.12	536
October	30.04	25.20	55

Table 2: *Effects on water management on average root volume average root length and average root dry biomass.*

Treatments	Root volume (cm^3)	Root length (cm)	Root dry biomass (g/hill)
T_{sat}	18.65^{a}	18.27	12.76^{a}
T_{6cm}	14.95^{ab}	18.75	9.24^{b}
T_{4cm}	16.50^{ab}	18.50	9.40^{b}
T_{2cm}	13.40^{b}	19.75	8.65^{b}
P	**	ns	**

Notes: ***: Means within the same columns not followed by the same letter are significantly different at p< 0.05 level by Duncan's tests; ns: not significantly different.*

Table 3: *Water treatments effects on panicle number, panicle length, panicle weight and grain number per panicle.*

Treatments	Average panicle number hill	Average panicle length (cm)	Average panicle weight (g)	Grain number per panicle
Tsat	7.87a	20.91	2.10	81.88ab
T6	7.69a	21.22	2.03	76.78b
T4	7.31ab	20.42	2.01	83.87a
T2	6.33b	20.47	1.98	79.31ab
P	**	Ns	ns	**

Notes: ***: Means within the same columns not followed by the same letter are significantly different at p< 0.05 level by Duncan's tests; ns: not significantly different.*

Table 4: *Water treatments effects on grain filling rate, 1000 grain weight, grain yield, biomass.*

Treatments	Grain filling rate (%)	1000 grain weight (g)	Grain yield (ton/ha)	Yield loss (kg/ha)	Yield reduction (%)	Above ground biomass
Tsat	84.30^{a}	24.60^{a}	3.86^{a}			8.41^{a}
T6	78.56^{ab}	21.73^{bc}	3.54^{a}	320	8.29	8.27^{a}
T4	82.55^{a}	23.41^{ab}	3.67^{a}	190	4.92	8.07^{a}
T2	73.65^{b}	19.67^{bc}	3.01^{b}	850	22.02	7.32^{b}
P	**	**	**	-	-	

Notes: ***: Means within the same columns not followed by the same letter are significantly different at p< 0.05 level by Duncan's tests; ns: not significantly different.*

Table 5: *Effects of water management on water use efficiency.*

Treatments	Rain (m^3 /ha)	Water drained (m^3 /ha)	Irrigation (m^3 /ha)	TWP (kg /m^3)	IWP (kg/m^3)	Irrigation Water saving (m^3 /ha)	Water saving impact (kg/m^3)
T_{Sat}	8830	0	5200	0.27	0.74		
$T6_{cm}$	8830	3390	4800	0.25	0.73	400	0.81
$T4_{cm}$	8830	3730	3200	0.44	1.14	2000	0.09
$T2_{cm}$	8830	4690	1600	0.52	1.88	3600	0.23

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