Water productivity and yield of Paddy Rice cultivation under AWD irrigation management in Pingtung, southern Taiwan

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Abstract— *Decreasing water input while maintaining grain yield remains a challenge for World to produce rice sustainably. In recent years, the Alternate wetting and Drying Irrigation(AWD)has been developed toward Asian' farmers. However, the gap observed is the low assessment of its performances, particularly in Taiwan.*

The aim of this study is to determine whether AWDI management could maintain grain yield with reduced water input.

AWD approach experiment field was conducted in National Pingtung University, in Southern Taiwan. A two leaves old rice seedling, TAINAN11 was arranged in a randomized complete block design with five water treatments: AWD_{2cm}, AWD_{3cm}, $AWD_{3cm/w}$, AWD_{4cm} *and* AWD_{5cm} *with respectively 2cm and 3 cm water depth monitoring by soil hairline cracks; 3cm, 4 cm, and 5cm weekly irrigation. The irrigation regimes were done by AWD technics. The plant water status was assessed through soil water content. Crop growth, grain yield, and water productivity were measured.*

The results showed that grain yields under AWD_{3cm}, AWD_{2cm} *and* $AWD_{3cm/w}$ *presented the high yield and irrigation water productivity about 0.211, 0.208 and 0.205 respectively. The* AWD_{4cm} *and* AWD_{5cm} *despite the high-water depth presented low yield with respectively 3081 Kg/ha and 2604 Kg/ha.*

The results confirmed also that AWD3cm and more precisely $AWD_{3cm/w}$ *could obtain comparable grain yield close to farmers practices with fewer irrigations. These findings suggested that AWD with 3 cm water depth (*AWD_{3cm} *and* $AWD_{3cm/w}$*) could be used for water-saving while maintaining grain yield in paddy rice production.*

Keywords—Grain yield, Water productivity, Alternate Wetting and Drying, AWD.

I. INTRODUCTION

The 2017's edition of The State of Food Security and Nutrition in the World reveled that in 2016, the number of undernourished people in the world increased to an estimated 815 million, up from 777 million in 2015 but still down from about 900 million in the year 2000[1]. It's well known that rice (*Oryza sativa L.*) is a staple food for nearly half of the world's seven billion people particularly in Asia, and this alimentary need must be satisfy by doubling the present production over 2030 [2].

The fresh water, one the indispensable input in rice production, is a finite resource which is faced to the increasing large demand of Agriculture. The per capita available water resources in Asia are expected to decline by 15-54 % compared with 1990 [3] and already 12 million hectares of south Asia's irrigated rice are at risk of severe water shortage. In Taiwan were rice is a very important and valuable crop, with a total yield of more than 1.73 million tons[4], the possibilities of sustainable production are welcome. Indeed, Rice is grown from February to July, and August to December [5], but according to Kuo andal., (2006) [6] the amount of water available for agricultural use has recently become critical.

Agriculture is now faced with the challenge of securely delivering sufficient food to meet the projected demands of population growth and overcoming issues such as climate change and water scarcity through sustainable agricultural intensification ([7]. This poses major challenges for scientists, extension workers, and farmers.

Numerous technologies have been developed with the aim to reduce water use and help the farmers in rice production with higher water productivity ([8] and [9]). One of these technologies is the Alternate Wetting and Drying (AWD) which has been developed since the 1970s [10]- [9]. The concept of AWD technology is based on the fact that rice high yields can be obtained by just providing the only need water to the crop.

In 2015 and 2016 a field experiment was conducted in southern of Taiwan by KIMA andal., (2015) [11] and Pascual andal., (2016) [12] respectively, to determine the most suitable ponded water depth for enhancing water saving in paddy rice irrigation. The firsts found that lowest water reduced yield component between 15-32%. They mentioned that weekly application of 3cm water depth combined with rainfall improved AWD effectiveness and yielded the highest beneficial water productivity with less yield expenses. The seconds showed that the highest total water productivity, (0.75 kg/m^3) and irrigation water productivity (1.40 Kg/m^3) was achieved in T_2 cm. They also found that weekly application of T_4 cm ponded water depth produced the lowest yield reduction (1.57%) and grain production loss (0.06 kg), having no significant impact on yield loss compared to T_5 cm.

Due to some uncertainties from the two previous studies, in 2017, Kissou and al.,[13] conducted a similar experiment during the dry season. Their results shown that 3 cm water depth gave the best results in terms of water saving, high yield, but some uncertainties underlined were the closeness of these results with the 4 cm water depth. Therefore, the present experiment was conducted applying the AWDto more clarify these findings.

The objective of this study was to determine whether the AWD irrigation management could maintain grain yield with less water use. It was specifically expected to determine the water input (quantity and frequency) and the water productivity;and its effect on agronomic traits and grain yield.

II. MATERIALS AND METHODS

2.1 Study area description and field experiment

The experimentation was conductedfrom 21st November 2017 to 20th of May 2018, in the irrigation experimental field of the National Pingtung University of Science and Technology (NPUST) in Southern of Taiwanlocated at 71 m above sea level; at 22.39° (N) latitude and 34.95° (E) longitude. Previous analysis of the soil physical properties[11]-[12], concluded that the textural class of the soil in the experimental field was loamy soil(27% of sand and 24% of clay).

The experimental field was a randomized complete block design with four replications and five water treatmentsAWD_2, AWD_3, $AWD_{3cm/w}$, AWD_4 and AWD_5. Irrigation water depths were applied at 2 cm, 3 cm (biweekly) and 3 cm, 4 cm and 5cm (per week) representing respectively treatments. Each plot was 4 m long and 1.5 m wide with total area of 6 m^2 and 0.3 m hardpain. The spacing between blocks was 1 m. Water depth was kept constant and the soil hairline cracks occurring in the concerned plotswere monitored.The experimental site is equipped with irrigation pipes and drainage systems.

Two leaves age (25 days-old) seedlingsof the Tainan 11 (TN11) varietywere manually transplanted on 5th December 2017. Seedling was transplanted, lined up with 25 cm hills spacing between rows and 25 cm between hills (75 hills per plot). Each hill received one seedling. Plants gap's filling was done with the same seedlings, one week after transplanting due to young plant attacks by snails and insects in some plots of the blocks 2 and 3.

To ensure plants nutrients need, some fertilizers was applied. The Organic Fertilizer (NPKS) with a ratio of 5-2.5-2.5-81, was applied at the rate of 270Kg/ha as basal fertilizer before rice transplanting. Chemical fertilizer N-P2O5-K2O at the ratio of 15-15-15-4-50 was applied once during the development stage at the dose of 270 kg/ha.Urea was applied in split doses at the rate of 150 kg/ha.Liquide containing Probiotic bacteria were applied on 17, 21, 70, and 105 DAT at a concentration of 12*10^8 cells.Weed management were done manually at 20, 40, and 76DAT.

The frequency of irrigation was initiated according to the irrigation interval of each treatment. The use of previous approach [11], allowed to precise the desired water depth to reach the amount of each plot need as shown in the equation 1 below :

$$R = A \times h \times 10^3 \quad [1]$$

Where ***R*** is the amount of irrigation water (liters) for a desired depth above the soil surface (m); ***A*** is the surface area of the plot (m^2), and ***h*** is the desired water depth above the soil surface.

The irrigation water was applied using a water pipe, after measured its discharge. The duration of irrigation to reach the required water depth corresponding to each treatment was computed through the following equation 2 :

$$Q \times t = d \times A \quad [2]$$

Q is the flexible link discharge expressed in liter per second (l/s); ***t*** is the set time of irrigation (second); ***d*** is the depth of irrigation water applied (millimeters) and ***A*** is the area irrigated (m^2).

Irrigation water depth in the field was kept to 50 mm during the first 2 weeks (16 days) after transplanting (from 6th to 21stDecember 2017), all plots were irrigated daily applying (50 mm) per day to maintain soil near saturation and facilitate the seedling rooting (semi-tillering stage). During the panicle initiation (from 1st April), irrigation date of all the plots were reduce one day due to the higher water demand by crop and the increase temperature during this period.

2.2 Parameters Observed

2.2.1 Leaves Chlorophyll Content

The Chlorophyll meter (model SPAD-502, MINOLTA, Japan) provides an easy, quickly, safe and low-cost method as an approach supported by[14]. At 60 days after transplanting, three randomized samples in plots were selected for their chlorophyll content measurement. Five uppermost fully expanded leaves were randomly selected from each sampled hill to analyze the variability of leaves chlorophyll amount treatments. The collection area on each leaf is located between 40% and 70% along the length from the leaf base and three different points for readings were done and the average data recorded. Analysis of leaves sampling patterns follows the approach of [15].

2.2.2 Leaf Area Index measurement

The total leaf area of a rice population is a factor closely related to grain production because the total leaf area at flowering greatly affects the amount of photosynthates available to the panicle [16].

LAI was measured using the approach of LAI with leaves not removed from plants.The two hills x two hill sample approach was applied. The tillers for each sample hill in each plot is counted, thus, for each measurement session, the length and maximum width of each leaf on the middle tiller was measured and the area of each leaf based on the length-width method (Tilahun-Tadesse andal., 2013; Yoshida, 1981) was computed as equation 3 and equation 4 below:

$$Leaf\ area\ (cm^2) = L \times W \times K \quad [3]$$

Where L is leaf length, W is maximum width of the leaf and K is a correction factor of 0.75

Then the LAI was obtained by:

$$LAI = \frac{sum\ of\ the\ leaf\ area\ of\ all\ leaves}{ground\ \ area\ cover\ by\ 4\ hills} \quad [4]$$

FIGURE 1 : Chlorophyll meter (SPAD-50MINOLTA)

FIGURE 2 : View of the plant growth measurement

2.3 Yield and Water productivity assessment

At harvest, ten panicles randomly sampled from hills of the plot center square meter were cut at the base, separated from the straw and grain handly threshed. The amount of grain collected was dried at 14% humidity. Marketable yield was gotten after unfilled spikelets were separated using a seed blower for 2 mm.

Productivity is a ratio between a unit of output (yield) and input (water). The total amount of water applied (Twu) is the sumof irrigation water (Irw) and rain water (Rw). Thus,Total water productivity (TWP), Irrigation water productivity (IWP) and Rain water productivity (RWP) were calculated through thefollowing equationsof [17] :

$$TWP = \frac{Yact}{TWU} \quad [5]$$

$$IWP = \frac{Yact}{Irw} \quad [6]$$

$$RWP = \frac{Yact}{Rw} \quad [7]$$

TWP, IWP and RWP are expressed in kg.m^{-3}. Y_{act} is the actual markable yield (Kg. ha^{-1}), Twu, Irw and Rw are expressed in m^{3}. ha^{-1}.

2.4 Statistical analysis of Data

Field Observation data were compiled using Microsoft Excel software.The collecting data of each sample was analyzed separately using Statistical Analysis System (SAS) to evaluate the variance of treatment effects. The significance of the treatment effect was determined using F-test. When ANOVA indicated that there was a significant difference, multiple comparisons of means were performed using the Least Significant Difference method (LSD) at 0.05 probability level. The student's t-test was employed to test the significance of difference between the two water management treatments.

III. RESULTS AND DISCUSSIONS

3.1 Climate characteristic during the experimental period

Data collected from the Agro-Meteorological station of the NPUST and computed gave some pieces of information about the weather evolution during the cropping period. The Figure 3 below, shows the occurrence of rainfalls from December 2017 to May 2018, considered as dry season in Taiwan. However, the repartition of the rainfall was irregular during the cropping period. The maximum cumulative rainfall was 85.4 mm with a minimum of 4.5 mm. The effective rainfalls represented around 11% of the water applied to treatment (11.84% of AWD_2, 10.36 of AWD_3, 12.03% of $AWD_{3/w}$, 11.02% of AWD_4 and 10.17% of AWD_5) during the cycle of production. The average temperature was high with 27.79 and 19.7 ^{o}Crespectively for maximum and minimum.

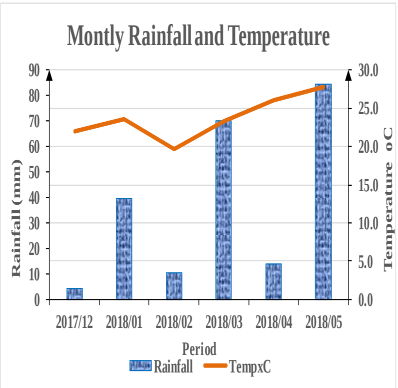

FIGURE 3 : Evolution of the monthly rainfall and temperature during the rice cropping

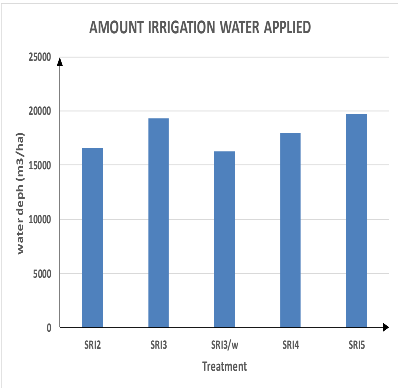

FIGURE 4 : View of the amount of irrigation water applied in AWD rice crop

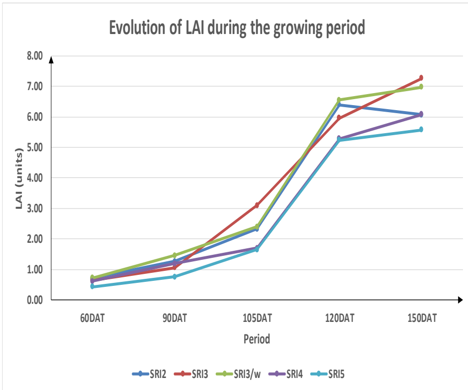

FIGURE 5 : Evolution of Leaf Area Index during the from 60 DAT to 150 DAT

These values hid the real daily influence of temperature during the growing period. Indeed, in 2018 low temperatures were recorded and the minimum reached 6.8^{o}C. These low temperatures might affect the rice plants growth at this period.

3.2 AWD irrigation managementand water used efficiency

3.2.1 Irrigation applied and total water received

The principle of the irrigation is to supply water required by rice plant to satisfy its need and compensate the water lost due to evapotranspiration. Each of the five treatments received the irrigation water following the planning of irrigation. The Fig. 4 above presented the amount of water consumed (irrigation and rainfall) during the survey.

The irrigation by AWD technic for treatments started at 17 DAT, due to the interval of water application and reduction of the quantity, some hairline cracks appeared on soil and help for monitoring visually the interaction soil-plantduring all growing stages of rice plants.

3.2.2 LAI response to irrigation

Leaves are plants organs consideredas the regulators of plants face to climate factors in particular due to their stomates functions. In this survey, water was applied for each treatment and the leaves morphological status was observed through the leaf area index. The Fig. 5 above presents the evolution of the leaf area index from the tillering to the maturity stage.

The LAI increase during the plant growth stages. At maturity (150 DAT), rice leave area was maximum and the treatment AWD_3 presented the highest surface, followed by $AWD_{3/w}$, AWD_4, AWD_2, and AWD_5. The water treatment was a factor that influenced these values. Indeed, the ANOVA test of the variance shown that there is no significant difference between treatment $AWD_{3/w}$, AWD_3, and AWD_2; also, AWD_4, and AWD_5 are not significantly different.

3.2.3 Effect of water application on plant chlorophyll content

During the present study, chlorophyll content was measured to monitor rice plant health status and his response to the AWD water application.The measurement results shown that chlorophyll content varied with vegetation growth of the plant. During the cropping season, chlorophyll increased from 60 DAT to 120 DAT and the values stagnated or decreased in the late phase. The comparison of different stages by t-Test using the LSD (at p= 0.8787) also revealed that AWD_4, AWD_5, and $AWD_{3/w}$ presented the same means from 105 DAT until maturity (44.96, 44.69 and 44.44 respectively); but the first and second stages are significantly different.

The analysis of the means value through ANOVA showed that there is no difference between AWD_2, AWD_3, and AWD_4. $AWD_{3/w}$ presented a significant difference from the three and also different from AWD_5.

TABLE 1
DUNCAN'S MULTIPLE RANGE TEST FOR CHLOROPHYLL

Duncan Grouping		Mean	N	TRT
	A	43.3535	20	$AWD_{3/w}$
B	A	42.8050	20	AWD_4
B	A	42.6135	20	AWD_2
B	A	42.4050	20	AWD_3
B		42.0620	20	AWD_5

These means comparison to show that plant under water treatment tend to use the resources from soil to express his potential and this is not easily detectable without analysis of the chlorophyll.

Previous studies underlined that the water stress in AWD did not change the relationship between leaf N and SPAD readings and the SPAD values can contribute to the prediction of leaf N of rice under AWD.[18] supported that apart from irrigation treatment, the PAD value ranged to 38 could be used as the critical value for fertilizer application. This approach could offer to the farmer location-specific critical information ideal and time for assisting decision makers in monitoring their crops and managing farming activities to achieve maximum production.

3.2.4 Effect of irrigation water on yield and water productivity

The application of AWD irrigation in the different plots leads to the yield that the range is presented in the Table 2 below. The table contains the assessment of the water productivities calculated based on the approach of [17].

TABLE 2
WATER PRODUCTIVITY

Treatment	Yield ($Kg.\ ha^{-1}$)	Irrigation Water ($m^3.ha^{-1}$)	Effective Rain Water ($m^3.ha^{-1}$)	TWP ($Kg.m^{-3}$)	RWP ($Kg.m^{-3}$)	IWP ($Kg.m^{-3}$)
AWD_2	3448	16600	2230	0.183	1.546	0.208
AWD_3	4072	19300	2230	0.189	1.826	0.211
$AWD_{3/w}$	3340	16300	2230	0.180	1.498	0.205
AWD_4	3081	18000	2230	0.152	1.382	0.171
AWD_5	2604	19700	2230	0.119	1.168	0.132

Where TWP, IWP, and RWP arerespectively the total, irrigation, and rainwater productivities.

The results showed that even if the grain yields are important, they were relatively low than expected. This situation may partially imputable to the climate parameters as low temperature during the tillering, but also to other parameters as reseeding after nails and insect's attacks and others no identify. The results showed that the low grain yield was borne by the plots which received the lowest water treatment. Kima*andal.*,[11], followed by Pascual and Wang[12]observed that the lowest water treatment resulted in the lowest values of panicle weight. The AWD with 2cm contradicted these results but can be explained by the fact that water application frequency is short (biweekly irrigation).

IV. CONCLUSION

The present survey was conducted during a dry season with the aim to improve the AWD capacities as water-saver for yield improvement. Five irrigation treatment were design and realized in NPUST irrigation experiment station.

The applying of twice-weekly irrigation water depth of about 2 cm and 3cm and the monitoring of the soil hairline cracks as an indicator of water status known in farmer practice, showed good results. The yield result was good correlated to the water treatment with a probability ofabout 0.825. The treatment $AWD_{3/w}$, a weekly single irrigation underlined as the optimum irrigation depth by previous studies, presented some results closed to AWD_2 and AWD_3 with high grain yield.

The marketable yield obtained tend to be low than those presented in other studies. The possible effects of the climatic parameters throughout the rice cycle may explain this yield value. From nursery to seedling and tillering ages, rice plant suffered about temperature fluctuation, specifically the cold. The daily variation of temperature largely influenced the growth of rice plants leading to lengthening of rice reproduction cycle and then a more consumption of water and other resources. One of the consequence is also the reduction of the water productivity even if the rate found was positive (0.208 to 0.132 respectively from SR_{2cm} to SR_{5cm}).

Despite of the weather influence, the irrigation management ensured a good productivity of yield and water. The IWP and the RWP registered an average of 0.208 and 1.623 respectively for AWD_2, AWD_3, and $AWD_{3/w}$. AWD_4, and AWD_5 have an average of 0.152 and 1.275 of irrigation and rainwater productivity.

Regarding to the yield performance and the water used efficiency, rice grown with AWD methods reveals a lot of opportunities in rice farming system. Under drought condition, adaptation capacity of rice plant can give good yields and water productivity. The results of this study open some perspectives forricecultivation performing on different periods.

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