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# Effects of Irrigation Regimes on Irrigated Rice Production in the Northern Region of Ghana

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***Abstract:*** **The major limiting resource for irrigated rice cultivation is water. As the demand for effective management of water increase due to climate change, future rice production will depend heavily on developing and adopting strategies and practices that use efficient water application regime. The objective was to assess the impacts of different irrigation application on dry season rice yield. Two experiments were conducted using a *randomised complete block design* with 4 replications at On-Station (SARI) and On-Farm (Bontanga Irrigation Scheme) in 2012/2013 and 2013/2014 dry seasons. The treatments were, surface irrigation with applied water equal to: the Field Capacity (FC) moisture content ($W_1$); Saturated soil moisture content (SC) ($W_2$); Continuous flooding (CF) up to 10 cm level, used as control ($W_3$); 10ETc ($W_4$) and 15ETc ($W_5$). A 115 days rice variety, *Gbewaa* rice (Jasmine 85) was used for the experiments. Seedlings were transplanted at spacing of 20 cm × 20 cm and one seedling per stand in 1 m$^2$ micro-plots at On-Station and 7 m $^2$ plots at On-farm. Data was collected on plant height, number of tillers, days to 50 % flowering and maturity, canopy cover, panicle length and fertile spikelets per panicles, weight of 1000 grains, straw, biomass and grain yields and harvest index from four (4) replications. The results showed that plant height at maturity, maximum tiller count, maximum canopy cover, 1000 grain weight, grain and biomass yields of the On-Station and the On-Farm experiments showed significant difference between Field capacity and the rest of the treatments. Results from the experiments therefore suggested that, it is not necessary to flood rice to promote growth characteristics with the aim of obtaining high yield, since maintaining a saturated soil throughout the growing season and 10ETc of irrigation requirement results in comparable rice growth characteristics, yield and above ground biomass.**

*Keywords:* **Dry Season, Irrigated Rice, Northern Region, Water Application Regimes**

## I INTRODUCTION

Irrigated lowland rice is cultivated on leveled and bounded fields with water control, in both dry and wet seasons. Early-maturing varieties dominate dry-season rice production. In general, the productivity of this rice ecosystem is higher than in rainfed lowland rice, due to better water control and higher solar radiation. Where modern technology is used, yields can reach 5 t/ha in the wet season and more than 10 t/ha in the dry season [1], [2]. Some of the world's most productive rice-based irrigation systems are found in arid and semi-arid regions, such as the Indus Valley in Pakistan, the Nile Delta and the Sahel. On the African continent, the most impressive productivity gains are reported from the Office du Niger–a 65 000 ha rice irrigation scheme where yield levels doubled over a period of 10 years from 3 to 6 t/ha following modernization of the system and changes in institutional structures allowing farmers to participate in the management of the scheme. However, water applications during the dry-season rice frequently reach 50 000 m$^3$/ha [1], [2].

As the major contributor of staple food in the world, the rice sector is also the biggest water user. Rice consumes more water than any other irrigated crop and it requires up to 2–3 times more water compared to other crops [3]. Unlike many other cropping systems, where water is mainly used for productive purposes (evapotranspiration), the rice cropping system uses water in numerous ways, both beneficially and non-beneficially. The actual water demand of farmers is often much higher to account for conventional application efficiencies of less than 50 % (taking into consideration seepage and percolation losses) or for special water management practices [1], [2]. [4] reported that rice requires between 700 and 1500 mm of water per growing season. According to [5] water-saving irrigation regimes are needed to deal with a reduced availability of water for rice production. Therefore, increases water productivity with appropriate irrigation management is necessary.

Water availability for agricultural purposes in the world is decreasing due to increasing water scarcity [6]. Although there is no systematic definition, inventory, or quantification of water scarcity in rice-growing areas, it is clear that there is some kind of water scarcity in irrigated lowlands [7]. Current estimates suggest that by 2025, 15–20 million ha of irrigated rice will suffer some degree of water scarcity [7]. Several case studies indicate that there is water scarcity, even in areas generally considered water abundant [8]. Water is becoming scarce both in the quantity and the quality of the water, since degraded water resources become unavailable [9]. Lowland rice is extremely sensitive to water shortage and many effects occur when soil water contents drop below saturation.

[10] compared continuously saturated irrigation with continuous flooded irrigation and interval irrigation in the different depths. There was no significant difference among irrigation treatment for grain yield. [11] compared different irrigation regimes in dry seeded rice production in Australia.

## II Materials And Methods

### A. *Description of the Study Areas*

The study area comprised On-Station research at the Savannah Agricultural Research Institute (SARI) in Tolon District and On-Farm research at Bontanga Irrigation Scheme at Kumbungu District, both in the Northern Region of Ghana. The two districts together used to be one district called the Tolon-Kumbungu District, which lies between latitudes 9º 15′ and 10º 02′ N and Longitudes 0º 53′ and 1º 25′ W.

*Savannah agricultural research Institute (SARI)*

SARI is one of the thirteen (13) research institutes of the Council for scientific and Industrial Research (CSIR). It was originally known as the Nyamkpala Agricultural Experimental Station (NAES) and operated as an outpost of the Crops Research Institute (CRI), Kumasi. In 1994, it gained autonomy and was upgraded to a fully-fledged research institute and renamed Savanna Agricultural Research Institute. SARI is located 16 km west of Tamale at Latitudes 9º 25′ N and Longitudes 1º 00′ W at 183 m above mean sea level, in the Tolon District of the Northern Region of Ghana. The climate is warm, semi-arid with monomodal annual rainfall of 800-1100 mm, which occurs mostly between June and September [12]. This short rainy season is followed by a pronounced dry season between October and May annually. The average daily atmospheric temperature ranges from a minimum of 26 ºC to a maximum of 39ºC with a mean of 32 ºC.

*Bontanga Irrigation Scheme*

The Bontanga Irrigation Project is a medium scale scheme located in the Northern Region of Ghana, in the Kumbungu District. It lies between latitudes 9˚ 30 ″ and 9˚35″ N and longitudes 1˚ 20″and 1˚04 ″ W and in the Guinea Savannah ecological zone. The water source is the Bontanga River, a tributary of the White Volta with a catchment area of 1600 km$^2$. The Bontanga Irrigation Scheme has a potential irrigable area of 800 ha with only 434 ha presently developed and under cultivation. The cropping area is divided into two, upland and lowland; the upland is a free draining soil and plots are designed for furrow irrigation. The upland area is for vegetables production and the lowland is for rice production because of the nature of the soil, that is heavier textured soil and the irrigation of rice is by flooding. The system consists of an earthen dam that delivers water to the field by gravity and incorporated in the embankment are two (2) off-takes and a spillway, which is set to control the top water level in the reservoir. The reservoir capacity is 25.00Mm$^3$. The dead storage elevation and capacity are 1.52m and 5.00Mm$^3$respectively. The spillway type is drop inlet with a length of 83.7m and a design discharge of 85m$^3$/s. An emergency spillway is also provided. Two (2) main canals and twenty-eight (28) laterals aid in the distribution of water to the farms. Thirteen (13) villages benefit from the dam which include: Tibung, Kumbungu, Kpasogu, Dalun, Wuba, Kukuo, Kpong, Saakuba, Yiplegu, Voggu, Kushibo, Zangbalwe and Bagli [13].

### B. *Methodological Framework for Data Collection Treatments*

Data from two dry season's On-Station experiments in 2012/2013 and 2013/2014 at SARI and On-Farm experiment in 2013/2014 at Bontanga Irrigation Scheme were collected using five (5) treatments comprising of Surface irrigation with applied water equal to:the Field Capacity (FC) moisture content of the soil, ($W_1$)the Saturation soil moisture content (SC), ($W_2$)Continuous flooding (CF) irrigation (up to 10 cm) used as control ($W_3$) 10 ETc, ($W_4$) 15 ETc, ($W_5$).

All treatments were replicated four (4) times.

*Experimental designs for SARI On-Station and the Bontanga Irrigation Scheme (On-Farm)*

The plots for the experiments were permanently created through masonry work using morter and cement blocks. The plots were of equal sizes, one square metre (1 m$^2$) with a lowland soil layer thickness up to 90 cm and 10 cm depth of flooding water above the soil surface. The bottoms of the plots were sealed to serve as a hardpan and prevent seepage. The water for irrigation was taken from an overhead poly-tank that supplied water through piped system by gravity to the plots. However, for these experiments, water was measured to the plots using graduated buckets (10, 15 and 20 litres). For the On-Farm, experiment, the size of each plot was 1m by 7m (7 m$^2$) surrounded by 15 cm high bunds with bottom widths of 20 cm and top widths of 10 cm. The space between plots in each block was 60 cm, while the space between each block was 1m. The water for irrigation was taken from the canal of lateral seven (7) which was diverted through unlined sub-lateral by gravity flow to the experimental site where water was often blocked and collected for irrigation using 20 litre buckets. The experiments were laid out in *randomized complete block design* with four replicates. The treatments (W1 to W5) were distributed randomly and independently in each block (Block 1 to Block 2) using draw lots method.

### C. *Measurement of Soil Physical and Chemical Analysis*

Composite top soil samples (0–30-cm depth) were collected in all the twenty (20) experimental plots of On-Station and On-Farm and analysed for texture and chemical properties at the soil laboratory of SARI before the commencement of the experiments, while other physical parameters such as dry bulk density and infiltration capacity were measured *in situ* before the experiments were conducted in the various plots for both the on-station and on-farm research with results of the analysis shown in Tables 1 and 2.

Data on soil physical properties were measured soil properties such as field capacity, relative saturation and permanent wilting point moisture contents were determined at the SARI Soil Laboratory. In addition, soil dry bulk density and soil water infiltration rate were measured on the plots using core samplers and ring infiltrometer respectively. Soil pH was determined using the glass electrode HT 9017 pH meter in a 1: 2.5 (soil:

Table 1: Soil data for the experimental site at SARI and Bontanga Irrigation Scheme (Lateral 7)

| Horizon (0-30) | SARI | Bontanga (Lateral 7) |
|---|---|---|
| % Sand | 50.4 | 59.76 |
| % Clay | 11.04 | 1.7 |
| % Silt | 38.56 | 38.54 |
| Texture | Loam | Sandy loam |
| Bulk density (g/cm$^3$) | 1.62 | 1.68 |
| Average Infiltration rate (mm/h) | 9.95 | 12.5 |
| Saturation (volumetric %) | 36.6 (31.3-41.9) | 35.7 (30-41.5) |
| Field capacity (volumetric %) | 20.7 (19.9-21.5) | 19.3 (17.5-21) |
| Permanent wilting point (volumetric %) | 4.61 (3.7-5.6) | 1.85 (1.6-2.1) |
| Saturated hydraulic conductivity (cm/h) | 2.7 | 8.2 |

water) soil to distilled water ratio [14]. Organic carbon was determined by following Walkley-Black procedure as described by [15].

The textures of the soils for the two experimental sites are Loam and Sandy loam respectively for SARI and Bontanga. The results support the findings by [16] that, within the drier Savannah agro-ecological zones, lowland soils are relatively low in clay content with most locations showing less than 10% clay content with higher variability (CV > 60%). They occur abundantly and cover a greater part of the lowlands. The soils are generally deep but water retention capacity may be low due to low clay contents.

Table 2a: Results of soil chemical analysis (0-30cm) for the SARI on-station experimental site

| SAMPLE ID | pH(1:2.5 $H_2O$) | % O.C | % N | P (ppm) | K(ppm) | Ca (cmol/kg) | Mg (cmol/kg) | CEC (cmol/kg) |
|---|---|---|---|---|---|---|---|---|
| W1 | 4.81 | 0.47 | 0.043 | 1.88 | 57.00 | 0.98 | 0.35 | 7.13 |
| W2 | 5.50 | 0.90 | 0.078 | 2.42 | 77.75 | 1.20 | 0.40 | 9.05 |
| W3 | 4.98 | 0.67 | 0.063 | 2.43 | 49.00 | 1.05 | 0.30 | 6.20 |
| W4 | 5.06 | 0.65 | 0.058 | 2.55 | 58.50 | 0.98 | 0.38 | 7.20 |
| W5 | 4.94 | 0.64 | 0.06 | 1.77 | 64.50 | 0.98 | 0.38 | 7.80 |
| Average | 5.06 | 0.67 | 0.06 | 2.21 | 61.35 | 1.04 | 0.36 | 7.48 |

Table 2b: Results of soil chemical analysis (0-30cm) for the Bontanga on-farm experimental site

| ID | pH(1:2.5 H2O) | % O.C | % Total N | P(ppm) | K(ppm) | Ca (ppm) | Mg (ppm) |
|---|---|---|---|---|---|---|---|
| W1 | 5.25 | 0.82 | 0.07 | 2.55 | 81 | 204.50 | 31.75 |
| W2 | 5.40 | 0.43 | 0.03 | 3.44 | 43.00 | 222.00 | 37.00 |
| W3 | 5.41 | 0.39 | 0.03 | 2.86 | 41.00 | 217.25 | 35.50 |
| W4 | 5.69 | 0.43 | 0.04 | 2.84 | 68.00 | 234.25 | 39.50 |
| W5 | 5.60 | 0.59 | 0.05 | 3.21 | 43.00 | 185.25 | 33.25 |
| Mean | 5.47 | 0.53 | 0.04 | 2.98 | 55.20 | 212.25 | 35.40 |

The results from Tables 2a and 2b show that the pH of the soils from both sites were fairly uniform, i.e. slightly acidic with average values of 5.06 and 5.47 for the On-Station and the On-Farm respectively. According to [16], soil pH within the drier Savannah agro-ecological zones, particularly both the Volta and Lima series are strongly acid (mostly < 5.0). Top soil pH ranges from strongly acid to neutral for Lapliki series.

Organic carbon shows much lower levels on both sites just like total nitrogen. [16] state that within the savannah agro-ecology, organic carbon levels are comparatively lower with general mean levels around 6.0 g kg$^{-1}$ with a 50% coefficient of variability across locations.

With regards to total nitrogen, both sites show much lower levels of total Nitrogen with mean levels varied between 0.04 and 0.06. According to [16] the Savannah zones show much lower levels of total nitrogen with much lower variability compared to the forest ecology. Mean levels across locations is lower than 0.7g kg$^{-1}$ as was the case of the two study sites.

Available P is generally very low for the soil of both sites with average values of 2.2 and 2.98 ppm for the On-Station and the On-Farm respectively. This results support the findings by [17], [18] that available P is generally very low for all the soil types and across all agro-ecological zones. Available P is the single most limiting nutrient. Within the Savanna zones, mean available P levels for lowlands is even lower and also varies significantly (CV > 60%). Mean level is about 1.5 mg kg$^{-1}$.

### D. *Land Preparation, Beds Construction and Transplanting of Seedlings for On-Farm Experiment*

*Land preparation:* The weeds on the land were killed by spraying them with *Glyphader* (a non-selective herbicide) and left for two weeks before it was ploughed, harrowed and levelled. The field was then flooded and puddled thoroughly using rotary tiller with rotating blades on the main shaft for cutting the soil when moving downwards and levelled once again. The field was then left undisturbed for about a week to allow the water to drain before it was demarcated into plots. The field was divided into twenty (20) beds of one metre (1 m) width and of seven metres (7 m) lengths with bunds of 10 cm height and 20 cm base width. Four blocks were created with each block comprising five beds. Between two beds, a 60 cm path was kept for easy movement and also to minimise the effect of seepage water interference. The space between one block and another was kept atone metre wide.

*Planting:* The variety of rice that was used for the experiments was "*Gbewaa rice*", (Jasmine 85) a115 days maturing rice variety. Nursing of seeds was done at SARI for both on-station and on-farm experiments for 2012/2013 and 2013/2014 dry seasons. Seedlings were transplanted at 22 days after nursing. Transplanting was done manually at a spacing of 20 cm × 20 cm and one seedling per stand. Plot size was 1 m x 1 m for the on-station experiments and 1m x 7 m for the on-farm experiments.

*E. Irrigation Water Application Regime and Monitoring for Experiments*

After transplanting, all the plots were irrigated to maintain uniform moisture content at saturation for the first week to ensure full establishment of the seedlings. All the plots, after the first week were then irrigated with a management allowable depletion (MAD) of 20 % [19]. Tables 3a and 3b show the water application regimes for the SARI and Bontanga experiments. The soil moisture content was monitored before each water application was done, from transplanting till maturity in the plots by using a Time Domain Reflectometer (TDR) with 30 cm long probe, with Tensiometers installed up to 30 cm depth in some of the treatments (W1, W2, W4 and W5). Field water tubes (35 cm long) were also installed up to 20 cm depth, exposing 15 cm above the soil surface in each of the treatments for two Replications (2 and 4) to measure changes in field water level.

Table 3a: Irrigation Application based on Saturation, Field capacity and Continuous Flooding for SARI and Bontanga Irrigation Scheme

| Moisture content | Volume (cm/m) | TAW at 30 cm RZD | UW at 20 % MAD (cm) | Application (mm) | Irrigation frequency (days) |
|---|---|---|---|---|---|
| Saturation ($W_2$) | 33.6-45.4 | 10.1-13.6 | 2-2.7 | 20-27 | 1 |
| Field Capacity ($W_1$) | 20.5-21.5 | 6.2-6.5 | 1.2-1.5 | 12-15 | 1 |
| Cont. flooding ($W_3$) | Recommended flooding depth of 2-10 cm with initial application of 2 cm one week after transplanting | | | | 1 |

Table 3b: Crop water requirements (ETc) (mm) for rice at 1 day interval

| Month | Decade | Stage | Kc coeff | ETc | 10ETc *(W4)* | 15ETc *(W5)* |
|---|---|---|---|---|---|---|
| | | | | mm/day | mm | mm |
| Dec | 2 | Init | 0.90 | 3.39 | 33.90 | 50.85 |
| Dec | 3 | Init | 0.90 | 3.44 | 34.40 | 51.60 |
| Jan | 1 | Init | 0.90 | 3.49 | 34.90 | 52.35 |
| Jan | 2 | Deve | 0.93 | 3.67 | 36.70 | 55.05 |
| Jan | 3 | Deve | 1.05 | 4.44 | 44.40 | 66.60 |
| Feb | 1 | Deve | 1.17 | 5.29 | 52.90 | 79.35 |
| Feb | 2 | Mid | 1.24 | 5.99 | 59.90 | 89.85 |
| Feb | 3 | Mid | 1.24 | 6.09 | 60.90 | 91.35 |
| Mar | 1 | Late | 1.24 | 6.18 | 61.80 | 92.70 |
| Mar | 2 | Late | 1.22 | 6.15 | 61.50 | 92.25 |
| Mar | 3 | Late | 1.10 | 5.48 | 54.80 | 82.20 |
| Apr | 1 | Late | 0.97 | 4.78 | 47.80 | 71.70 |
| Apr | 2 | Late | 0.89 | 4.34 | 43.40 | 65.10 |
| Total | | | | | 627.30 | 940.95 |

*Fertilization:* Mineral fertilizer at the various rates (120-90-60 kg/ha) was applied using split application with compound fertilizer (15-15-15) as source of N, P and K; urea as N sources and triple super phosphate (TSP) as P source for the remaining rate of P application. Compound fertilizer (15-15-15) was mixed with TSP and applied as basal fertilizer at the rate of (60-90-60 kg/ha) a week after transplanting. Quantity applied based on calculation was approximately 1 kg/m$^2$ of NPK (15-15-15) mixed with 200 g of TSP. At maximum tiller, (30-0-0 kg/ha) was applied using urea as N source. The quantity of fertilizer applied was 200 g/m$^2$. The remaining 30 kg N was applied as top dressing at flowering stage. The quantity of urea applied was 200g/m$^2$. Each time, fertilizer was applied by dibbling and burying in between four (4) hills after draining the field of flood water.

*Weed control:* Weeding was done manually by hand picking and with the use of hand hoe, two weeks after transplanting and as and when weeds reappeared.Weeding and loosening of the soil surface was done four times in the field capacity plots (FC) and two times in the rest of the treatments for both on-station and on-farm experiments. The weeds that were found on the plots were the usual weeds associated with rice valleys as was explained by the farmers. Weeds occurrence in FC was high (50 % coverage of plot area), while that of SC was moderate (30-40 % coverage of plot area) with 10 ETc, CF and 15 ETc recording low occurrence (10-30 coverage of plot area. The common weeds observed were the grasses (*Rottboellia cochichinensis, Oryza barthii and Paspalum orbiculare*); broad leaves (*Ageratum conyzoides, Hibiscus spp and Ipomoea acquatica*) and sedges (*Commelina Africana and Cyperus diformis*).

**F.** *Agronomic Data Collected*

Data was collected on plant height, number of tillers at 21 and 42 days after transplanting and at maturity, days to 50 % flowering and maturity, canopy cover, panicle length and fertile spikelets per panicles, weight of 1000 grains, straw, biomass and grain yields and harvest index from four (4) replications.

## III Results And Discussions

*Plant Height for the On-Station and On-Farm Experiments*

The effect of irrigation regime on average plant height at twenty one days (21), forty two days (42) and at maturity were significantly different for Field Capacity (W1) in the dry season rice production for both On-Station and On-Farm experiment as shown in Tables 4a 4b and 4c. As can be seen from the Tables, FC showed shortest plant height when compared with the rest of the treatments for all the three stages of growth of the rice crop. This phenomenon was the same for the two-year On-Station experiments conducted at SARI and Bontanga as well. Unlike the On-Station experiment, Saturation soil culture (W2) also showed significant difference at 42 DAT for the On-Farm. However, at maturity, the plant height for SC was significantly different from CF for the year two On-Station results and the mean as well as the On-Farm when the LSD values were used to compare the means with the value of continuous flooding. The average plant height at maturity for the two year combined for On-Station is 72.24 cm and ranges between 50.75 and 84.73 cm, while that of On-Farm at maturity was 63.35 cm and ranged from 58.55 to 69.55 cm. The average Plants height at maturity was in the range of 9.32–22.83 % shorter under field capacity than continuous flooding conditions. According to [23] rice is extremely sensitive to water shortage and that, the growth of the plant is prevented and the size of the various plant parts decrease with water shortage below saturated soil moisture content. However, [20] in a similar study indicated that rice plants were in the range of 9–13% shorter under field capacity than flooded conditions at maturity. According to [21] shorter plants can be observed even if the soil is maintained at FC up to the early reproductive stage. According to [22] the tallest plant was observed in the rice grown under flooded condition, with rice growth under saturated and flooded conditions comparable, as was the case for maintaining the soil at saturated condition, continuous flooding and 15ETc for the On-station and On-Farm experiments. These findings are in line with the assertion by [24] and [25] that, application of water at higher regimes promoted growth of rice by increasing plant height. The difference could be attributed to the fact that FC was highly water deficient (18-20 % moisture content) relative to the other treatment (28-40 % moisture content) and therefore was expending more energy to extract water in the soil moisture tension range of 10-15 kPa, while the rest were more or less not stressed as they were growing with sufficient moisture and tension range of 0-5 kPa; as moisture content and soil tension were monitored during the crop growth under the different water application regimes.

Table 4a: Average plant height at 21 DAT for the On-Station and On-Farm Experiment

| Treatment | On-Station Plant Height (cm) | | |
|---|---|---|---|
| | Year One | Year Two | Mean |
| W1 (FC) | 15.48b | 18.50b | 16.99b |
| W2 (SC) | 22.62a | 19.75a | 21.19a |
| W3 (CF) | 19.40a | 25.75a | 22.57a |
| W4(10ETc) | 17.10a | 25.00a | 21.05a |
| W5(15ETc) | 21.65a | 28.50a | 25.07a |
| Mean | 19.25 | 23.50 | 21.38 |
| N= 20 | SED=1.49 | SED = 2.49 | SED = 2.81 |

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

Table 4b: Average plant height at 42 DAT for the On-Station and On-Farm Experiment

| Treatment | On-Station Plant Height (cm) | | |
|---|---|---|---|
| | Year One | Year Two | Mean |
| W1 (FC) | 48.83b | 31.75b | 40.29b |
| W2 (SC) | 59.74a | 39.25a | 49.50a |
| W3 (CF) | 60.64a | 39.25a | 49.94a |
| W4(10ETc) | 56.83a | 41.50a | 49.17a |
| W5(15ETc) | 62.77a | 46.25a | 54.51a |
| Mean | 57.76 | 39.60 | 48.68 |
| N= 20 | SED= 1.70 | SED = 2.61 | SED = 3.15 |

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

Table 4c: Average plant height at Maturity for the On-Station and On-Farm Experiments

| Treatment | Plant Height for On-Station (cm) | | |
|---|---|---|---|
| | Year One | Year Two | Mean |
| W1 (FC) | 79.10b | 50.75b | 64.93b |
| W2 (SC) | 80.68a | 59.25c | 69.96c |
| W3 (CF) | 87.23a | 65.75a | 76.49a |
| W4(10ETc) | 82.18a | 65.00a | 73.59a |
| W5(15ETc) | 84.73a | 67.75a | 76.24a |
| Mean | 82.78 | 61.70 | 72.24 |
| N= 20 | SED = 3.13 | SED = 2.23 | SED = 3.40 |

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

*B. Tiller Count at Maximum tiller for On-Station and On-Farm Experiments*

Table 5 shows the analysis of tiller count at the maximum tiller for the two-year On-Station and On-Farm experiments. The effect of irrigation regime on maximum tiller count of rice grown under FC, 10 ETc and 15 ETc for year one and two On-Station experiments showed significant difference when their means were compared, with the LSD values. However, the On-Farm showed significant difference for FC and 15 ETc with both showing low tiller number when the difference between their means were compared with their LSDs using CF as a check. The lower value of tiller count for 15 ETc could be attributed to the effects of high water depth that results in hindering the production of more tillers. As can be seen from the Table, except Field capacity (FC) which showed lowest tiller count, the rest did not show any significant difference at maximum tiller for the mean of the two On-Station results. The mean maximum number of tillers is 14.5 and varied between 6 and 23 numbers of tillers for On-Station, while that of On-Farm is 17.7. The reduced number of tillers as observed in Field capacity could be attributed to the deficit irrigation, since rice is extremely sensitive to water shortage, which result to changes in assimilate partitioning, i.e., more roots growth at the expense of the shoot during vegetative development. While the FC suffered from water deficit (18-20 % moisture content) resulting in reduced number of tillers and smaller leaf area, the SC was able to produce more tillers due to the optimum moisture content (28-40 % moisture content) which enhance tillering, where as CF, 10 ETc and 15ETc had sufficient depth of water (5-15 cm) to ensure vigorous growth and development of expanded leaf area as well as number of tillers. The results for FC is in line with the results obtained by [26] that, tiller numbers decreased with increasing water deficit, on investigating the effects of water deficit on days to maturity and yield development in rice. In a similar vein [22] indicated that more tillers were observed under CF (W3) and SC (W2) conditions than FC condition, which is also in line with the findings of this research. According to [27], irrigating rice at saturation during tillering and panicle initiation stages gave better results than irrigating at saturation during other stages; this could probably be due to adequate circulation of oxygen around the root zone depth.

Table 5: Average tiller count at Maximum Tiller for the On-Station and On-Farm Experiments

| Treatment | Maximum No. of Tiller for On-Station | | |
|---|---|---|---|
| | Year One | Year Two | Mean |
| W1 (FC) | 17.11d | 06.89d | 12.00b |
| W2 (SC) | 21.31a | 10.78a | 16.05a |
| W3 (CF) | 22.61a | 12.10a | 17.36a |
| W4(10ETc) | 18.22c | 09.62b | 13.92a |
| W5(15ETc) | 18.44b | 08.15c | 13.29a |
| Mean | 19.54 | 09.51 | 14.52 |
| N= 20 | SED = 2.71 | SED = 1.49 | SED = 2.37 |

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

*C. Maximum Canopy Cover for the On-Station and On-Farm Experiments*

Table 6 shows the analysis of canopy cover for the two-year On-Station and the On-Farm experiments. The canopy cover showed significant difference for (FC) when compared with the rest of the treatments for not only the mean analysis of the two On-Station experiments, but also for each On-Station and On-Farm experiments as well. The mean value of maximum canopy cover was 80.06 % and ranges between 48 and 90 % for the On-Station, while that of the On-Farm experiment was 85.84 %. From the Table, it could be realised that the value for canopy cover was lowest for FC and highest for 15 ETc. This could be attributed to the fact that, rice crop grown under flooded conditions developed bigger leaves, and hence extended CC, while those under water stress conditions produced smaller leaves resulting in smaller CC. [28] indicated that the reduction in leaf area (by reduced leaf expansion, rolling, and senescence) results in reduced light interception, which reduces total crop photosynthesis and hence total biomass production. [29] and [30] indicate that leaf and canopy expansion are reduced soon after the soil dries below saturation in most cultivars; even in upland cultivars, expansion begins to be inhibited when only a small fraction of the total available water (TAW) has been depleted. According to [31] and [32], when the soil water content drops below saturation, growth and yield formation of rice are affected, mainly through reduced leaf surface area, photosynthesis rate, and sink size and hence reduction in total biomass production. These assertions have reflections on the values recorded for yields and biomass from the field capacity water application as compared to the other water application regimes at both experimental sites.

Table 6: Maximum Canopy Cover for the On-Station and On-Farm Experiments

| Treatment | Maximum CC for On-Station (%) | | |
|---|---|---|---|
| | Year One | Year Two | Mean |
| W1 (FC) | 87.9b | 48.4b | 68.2b |
| W2 (SC) | 90.8a | 68.4c | 79.6a |
| W3 (CF) | 93.8a | 76.5a | 85.6a |
| W4(10ETc) | 89.8a | 68.8d | 79.3a |
| W5(15ETc) | 94.6a | 80.5a | 87.6a |
| Mean | 91.4 | 68.5 | 80.06 |
| N= 20 | SED =0.03 | SED=0.01 | SED =0.02 |

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

*D. Time of 50% flowering (days) and Days to Maturity after Transplanting for the On-Station and On-Farm Experiments*

From the Two-Year analysis of On-Station and that of On-Farm results, Time of 50% flowering and days to maturity after transplanting indicated significant difference between FC and the rest of the treatment (CF, SC, 10ETc and 15ETc) when their means were compared using LSD values. From Table 7a and 7b, it could be seen that FC gave on the average, the highest value for both days to 50 % flowering (88 days) and maturity (118), while 15ETc gave the lowest values, 79 and 109 days respectively for days to 50 % flowering and maturity for the On-Station experiment. For the On-Farm experiment, the average number of days spent at 50 % flowering was 85 days, while on an average 115 days were spent at maturity, with FC spending the highest number of days to 50 % flowering (93 days) and days to maturity (123 days), which could be attributed to delay in pollination as a results of the deficit irrigation. The days to 50 % flowering of *Gbewaa rice* therefore ranges from 77.5-90.5 days with a mean of 82 days, while the maturity period also ranges from 107.5-120.5 days with a mean of 112 days. The results therefore suggested that water application regimes have significant effects in determining days to 50 % flowering and maturity period, since under deficit irrigation conditions the flowering and maturity periods of rice crop are increased by six (6) days while that of high water application regime decreased by 3 days. This finding is in line with the results obtained by [26] on investigating the effects of water deficit on days to maturity and yield development of three recently developed rainfed rice varieties that is, New Rice for Africa (NERICA). The plants that were daily watered (control) took the least days to attain 50% flowering, while the most water stressed plants took the longest number of days to reach 50 % flowering and to maturity. According [33] water stress decreased yield and increased the delay of 50% flowering in day at mid-tillering and booting stages as compared to well-watered plants.

Table 7a: Days to 50 % flowering for the On-Station and O-Farm Experiments

| Treatment | Days to 50 % Flowering for On-Station | Days to 50 % Flowering for On-Farm | |
|---|---|---|---|
| | Year One | Year Two | Mean |
| W1 (FC) | 90.50b | 84.50b | 87.50b |
| W2 (SC) | 81.50a | 84.50c | 83.00c |
| W3 (CF) | 82.00a | 78.25a | 80.12a |
| W4(10ETc) | 82.75a | 77.75a | 80.25a |
| W5(15ETc) | 80.50c | 77.50a | 79.00a |
| Mean | 83.45 | 80.50 | 81.97 |
| N= 20 | SED= 0.86 | SED= 0.83 | SED = 0.92 |

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

Table 7b: Days to Maturity for the On-Station and O-Farm Experiments

| Treatment | Days to Maturity for On-Station | | |
|---|---|---|---|
| | Year One | Year Two | Mean |
| W1 (FC) | 120.50b | 114.50b | 117.50b |
| W2 (SC) | 111.50a | 114.50c | 113.00c |
| W3 (CF) | 112.00a | 108.25a | 110.12a |
| W4(10ETc) | 112.75a | 107.75a | 110.25a |

| | | | |
|---|---|---|---|
| W5(15ETc) | 110.50c | 107.50a | 109.00a |
| Mean | 113.45 | 110.50 | 111.97 |
| N= 20 | SED=0.86 | SED= 0.83 | SED=0.92 |

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

### *E. Yield Components for the On-Station and On-Farm Experiments*

The yield components considered in this analysis were panicle length, percent fertile per panicle and weight of 1000 grains. However, only weight of 1000 grains showed significant difference between FC and the rest of the treatments for both On-Farm and On-Station experiments, as shown in Table 8. From the Table, it could also be observed that FC and SC for year two On-Station results and FC and 10 ETc of the On-Farm experiment gave the lowest value for 1000 grains weight when compared with the rest of the treatments with LSD values of 1.375, 0.870, and 1.644 respectively for Year one, two and the mean results and 0.74 for the On-Farm results. The results suggested that the *Gbewaa rice* is sensitive to water shortage. The nature of the results of the 1000-grain mass are in line with the assertion by [25], that, application of water at higher regimes promoted growth of rice by increasing higher 1000 grain weight. The field capacity moisture content produced the lowest mass of 1000 grain compared with the other treatments. This could be attributed to water stress condition suffered by that treatment which resulted in the reduction of biomass partitioning to the yield components.

Table 8: Average Mass of 1000-grain (g) for the On-Station and On-Farm Experiments

| Treatment | 1000 Grain Mass (g) for On-Station | | |
|---|---|---|---|
| | Year One | Year Two | Mean |
| W1 (FC) | 23.20b | 20.50b | 21.85b |
| W2 (SC) | 25.34a | 20.50c | 23.55a |
| W3 (CF) | 25.36a | 21.80a | 23.58a |
| W4(10ETc) | 26.12a | 22.15a | 24.14a |
| W5(15ETc) | 23.34a | 21.30a | 22.32a |
| Mean | 24.67 | 21.50 | 23.09 |
| N= 20 | SED=0.67 | SED= 0.42 | SED =0.95 |

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

### *F. Grain and Biomass Yields for the On-Station and On-Farm Experiments*

Table 9a and 9b show the results of analyses for grain yield and above ground biomass for both On-Station and On-Farm. From the Table, it could be observed that, grain yield and above ground biomass showed significant difference only between FC (W1) and the rest of the treatments when the means were compared using LSD values for both parameters. The FC indicated the lowest while SC the highest value for grain, and biomass yields as compared with the rest of the treatments. The results therefore suggested that, maintaining rice plants at a saturated condition throughout the growing period has resulted in a significant increase of the total biomass (Table 9b). It could be observed that increase in canopy cover and number of tillers resulted in increase in photosynthetic rate of saturated soil culture, continuous flooding, 10ETc and 15ETc water application regime thereby producing high biomass, 1000 grain weight and hence increase in grain yield. The lower yield for rice grown under field capacity condition was therefore mainly due to low CC at booting and anthesis, less shoot dry weight and lower root length density from booting to harvest as reported by [34]. Also the slightly lower yield of 15 ETc as compared with CF could be attributed to the assertion by [35] that, while comparable rice yields are obtained with water ponding of 5 and 10 cm, increasing the ponding depth to 15 and 20 cm causes progressive water requirement, as was the case of yield obtained for 15ETc. The yield obtained by the FC water application regime therefore suggested that "Gbewaa rice" (Jasmine 85) rice variety is drought tolerant like any other drought tolerant rice varieties as it can be cultivated as aerobic rice variety; and since it has the ability to maintain rapid growth in soils with moisture content at or below field capacity, and can produce yields of 4-6 t/ha with a moderate application of fertilizers under such soil water conditions as was also observed by [36]. The lower grain yields as was observed under FC conditions were also in consonance with the results obtained for the yield components such as 1000 grain weight, number of tillers and maximum canopy cover. Grain yield was even higher (3-4 %) under SC (7.12 t/ha) than CF condition (6.85 t/ha) for the mean of the On-station results. The 10ETc, which is a sandwich between SC and CF in terms of total irrigation application, yielded 6.43 t/ha. This yield is 6 % lower than that of CF, but had saved about 10 % water relative to CF. The results from the experiments therefore suggested that it is not necessary to flood rice to obtain high grain yield, since irrigating at 10 ETc and also maintaining saturated soil moisture conditions throughout the growing season resulted in a non-significant reduction in rice yield, but rather an increment on yield in the case of SC. Experiments conducted in the Philippines, [37] have shown that there was no significant difference in grain yield between continuous flooding and such water-saving treatments as soil saturation and combinations of soil saturation and flooding. [38] and [22] reported that it is not necessary to flood rice to obtain grain at high yield and of high quality and that, the efficiency of water use for grain production was higher in saturated soil culture than in flooded rice production. But under the unsaturated soil moisture conditions, dry matter production and grain yield decreased significantly in some earlier reports [38]; [39]; [40]; [41]; [42] as was the case of field capacity in these experiments.

Table 9a: Grain yields for the On-Station and On-Farm Experiments

| Treatment | Grain yield (t $ha^{-1}$) for On-Station | | |
|---|---|---|---|
| | Year One | Year Two | Mean |
| W1 (FC) | 6.41b | 3.26b | 4.83b |
| W2 (SC) | 9.67a | 4.56a | 7.12a |
| W3 (CF) | 9.28a | 4.42a | 6.85a |
| W4(10ETc) | 8.60a | 3.87a | 6.24a |
| W5(15ETc) | 9.17a | 4.27a | 6.72a |
| Mean | 8.62 | 4.08 | 6.35 |
| N= 20 | SED=1.22 | SED=0.46 | SED=1.04 |

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

Table 9b: Biomass yields for the On-Station and On-Farm Experiments

| Treatment | Biomass yield (t $ha^{-1}$) for On-Station | | |
|---|---|---|---|
| | Year One | Year Two | Mean |
| W1 (FC) | 13.17b | 9.51b | 11.34b |
| W2 (SC) | 17.95a | 13.39a | 15.67a |
| W3 (CF) | 17.22a | 12.92a | 15.07a |
| W4(10ETc) | 16.52a | 12.79a | 14.66a |
| W5(15ETc) | 17.32a | 12.77a | 15.04a |
| Mean | 16.44 | 12.28 | 14.36 |
| N= 20 | SED =1.69 | SED =0.68 | SED =1.51 |

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

## IV Conclusions

The effect of irrigation regime on rice growth parameters such as plant height at maturity, maximum tiller count, maximum canopy cover, days to 50 % and maturity were significantly different for Field Capacity (FC) in the dry season rice production for the two-year individual and the mean On-Station experiments conducted at SARI, as well as the On-Farm results from Bontanga. With respect to yield components and yield, mass of 1000 grains, grain yield and above ground biomass showed significant difference between W1 (FC) and the rest of the treatments for not only the Two-Year mean analysis, but also the two individual On-Stations as well as the On-Farm experimental results. Results from the experiments therefore suggested that, it is not necessary to flood rice to promote growth characteristics with the aim of obtaining high yield, since maintaining a saturated soil throughout the growing season and 10ETc of irrigation requirement results in comparable rice growth characteristics, yield and above ground biomass.

Since saturation culture and 10 ETc water application regimes had the same number of weeding and also gave comparable yield to continouos flooding but showed to be economically water productive for dry season irrigated rice production in the Northern Region, rice farmers could be educated to adopt these water saving regimes in view of the experience of reducing water availability due to climate change phenomenon for dry season rice Production

## V References


[1] L.C. Guerra, S.I. Bhuiyan, T.P. Tuong, and R. Barker, .*Producing more rice with less water from irrigated systems*. SWIM Paper No. 5, Colombo, International Water Management Institute. Colombo, Sri Lanka, 1998.

[2] T. Watanabe, Irrigation water requirement.*In* Mizutani, M., Hasegawa, S., Koga, S., Goto, A. & Murty, V.V.N. *Advanced paddy field engineering*. Tokyo, Japan, The Japanese Society of Irrigation, Drainage and Reclamation Engineering (1999).

[3] T.P. Tuong, B.A.M. Bouman, and M. Mortimer, *More rice, less water: integrated approaches for increasing water productivity in irrigated rice-based systems in Asia.* Plant Prod. Sci. 8 (2005): 231-241.

[4] S. I. Bhuiyan, Water management in relation to crop production: Case study on rice. Outlook Agric. 21(4): 1992, 293–299.

[5] P. Belder, B.A.M. Bouman, and J.H.J. Spiertz, *Exploring options for water savings in lowland rice using a modeling approach.* Agricultural Systems 92 (2007) 91-114. www.elsevier.com/locate/agsy

[6] RF. Rijsberman, *Water scarcity: fact or fiction?* Agric. Water Manage. 80, 2006: 5-22

[7] T.P. Tuong and B.A.M. Bouman, *Rice production in water scarce environments.* In: ed. Kijne, JW, Barker, R, Molden, D. Water productivity in agriculture: limits and opportunities for improvement. Ch. 4, (2003). 53-67. CABI Publishing, Wallingford, UK.

[8] B. Dong, D. Molden, R. Loeve, Y.H. Li, C.D. Chen, and J.Z. Wang, *Farm level practices and water productivity in Zanghe Irrigation System*. Rice Field Water Environ. 2 ( 2004): 217-226.

[9] L. S. Pereira, T. Oweis, and A. Zairi, *Irrigation management under water scarcity.* Agricultural Water Management, 57 (2002), 175–206.

[10] H. Yakan, and H. Sürek, *Edirne yöresinde çeltik sulaması. Köyhizmetleri Genel Müdürlüsü, Kırklareli Atatürk Aras.* Ens.Müd.

Yayınları. No: 18. (1990).
[11] A. K. Borell, S. Fukai, and A.L. Garside, *Irrigation methods for rice in tropical Australia.,* International Rice Research Newsletter. 16 (3): 1991, 28.
[12] J.M. Kombiok, E.Y. Safo, and C. Quansah, *Yield and nitrogen fixation of cowpea as affected by tillage and cropping systems in the northern savannah zone of Ghana.* West African Journal of applied ecology, vol.7. (2005).
[13] S. Abdul-Ganiyu, M.K.. Amaanatu, and J. K.. Korese, *Crop water use and productivity for pepper (Capsicum Frutescens) production in the Bontanga irrigation scheme of northern region of Ghana*. International Journal of Agricultural Science and Bioresource Engineering Research Vol. 1 (2), pp. 43-50, Mar-Apr 2012. Available online at http://www.ijasber.com
[14] IITA, *Selected Methods for Soil and Plant Analysis.Manual Series No. 1*. IITA, Ibadan, Nigeria, 1979.
[15] D. W. Nelson, and L. E. Sommers, Total carbon, organic carbon, and organic matter. In D. L. Sparks (ed.). Methods of Soil Analysis, Chemical Methods, Part 3. Soil Science Soc. Am. Madison, WI, 1996.
[16] J. K. Senayah, R. N. Issaka, and C. D. Dedzoe, *Characteristics of Major Lowland Rice- growing Soils in the Guinea Savanna Voltaian Basin of Ghana.* Ghana Journal of Agricultural Sciences: Agricultural and Food Science Journal of Ghana, 2009.
[17] M. M. Buri J. Oppong F. M. Tetteh and E. Aidoo, *Soil Fertility Survey of Selected Lowlands within the Mankran Watershed in the Ashanti region of Ghana*. CSIR – Soil Research Institute Technical Report No. 274, 2008a.
[18] M. M. Buri, E. Aidoo and H. Fujii, *Soil Fertility Survey of Selected Lowlands within the Jolo Kwaha Watershed near Tamale in the Northern region of Ghana*. CSIR – Soil Research Institute Technical Report No. 279, 2008b.
[19] R.G. Allen, L.S. Pereira, D. Raes, and M. Smith, *Crop Evapotranspiration Guidelines for Computing Crop Water Requirements.*FAO Irrigation and Drainage Paper 56. Rome, 1998.
[20] O. Sariam, and A.R. Anuar, *Effects of irrigation regime on irrigated rice (Kesan rejim pengairan pada tanaman padi sawah).* J. Trop. Agric. and Fd. Sc. 38(1)(2010): 1–9
[21] C.A. Beyrouty, R.J. Norman, B.R. Wells, E.E. Gbur, B.C. Grigg, and Y.H. Teo, *Water management and location effects on root and shoot growth of irrigated lowland rice*. J. Plant Nutr. 15: 1992, 737–752
[22] W.M. Zulkarnain, M.R. Ismail, M. Ashrafuzzaman, H.M. Saud, and I.C. Haroun, *Rice growth and yield under rain shelter house as influenced by different water regimes*. Int. J. Agric. Biol., 11(2009): 566–570
[23] R.S. Zeigler, S.A. Leong, and P.S. Teng, *Rice blast disease.* IRRI, Manila Philippines. (1994), pp. 7-10.
[24] S.K. De Datta, *Principles and practices of rice production*. John Wiley & Sons, New York, 1981, p: 618.
[25] H.S. Uppal, Indian J. Agric. Sci., 61(1991): 634-636.
[26] P. A. Sikuku, G. W. Netondo, D. M. Musyimi, and J. C. Onyango, *Effects of water deficit on days to maturity and yield of three Nerica rainfed rice varieties.* ARPN Journal of Agricultural and Biological Science.VOL. 5, NO. 3. (2010). Pp 1-9
[27] S.K. Surajbhan, Indian J. Agric. Res., 21 (1987): 207-212.
[28] N. C. Turner, J. C. O'Toole, R.T. Cruz, E.B. Yambao, S. Ahmad, O. S. Namuco, and M. Dingkuhn, *Responses of seven diverse rice cultivars to water deficits: II. Osmotic adjustment, leaf elasticity, leaf extension, leaf death, stomatal conductance and photosynthesis.* Field Crops Res. 13, (1986), 273–286.
[29] J.M. Lilley, and S. Fukai, *Effect of timing and severity of water deficit on four diverse rice cultivars. II*. Physiological responses to soil water deficit. Field Crops Research 37, ((1994). 215-223.
[30] M.C.S. Wopereis, M.J. Kropff, A.R. Maligaya, and T.P. Tuong, *Drought-stress responses of two lowland rice cultivars to soil water status.* Field Crops Res. 46, (1996), 21-39.
[31] B. A. M. Bouman, and T. P. Tuong, *Field water management to save water and increase its productivity in irrigated rice*. Agric. Water Manage. 49, 2001, 11–30.
[32] S. Yoshida, *Fundamentals of Rice Crop Science.* IRRI, Los BanÄos, Philippines, (1981). p. 269.
[33] N. Davatgara, M.R. Neishabouria, A.R. Sepaskhah, and A. Soltani, *Physiological and morphological responses of rice (Oryza sativa L.) to varying water stress management strategies.* International Journal of Plant Production (2009) 3(4): 19-32
[34] B.C. Grigg, C.A. Beyrouty, R.J. Norman, E.E. Gbur, M.G. Hanson and B.R. Wells, *Rice responses to changes in flood water and N timing in southern USA.* Field Crop Res., 66 (2000): 73–79
[35] R. Singh, D.K. Kundu, and K.K. Bandyopadhyay, *Enhancing Agricultural Productivity through Enhanced Water Use Efficiency.* Journal of Agricultural Physics, Vol. 10, (2010). pp. 1-15. http://www.agrophysics.in
[36] T. Parthasarathi, K.. Vanitha, P. Lakshamanakumar, and D. Kalaiyarasi, *Aerobic rice-mitigating water stress for the future climate change*. International Journal of Agronomy and Plant Production. 3(7) (2012): 241-254.
[37] S.K.. De Datta, H.K.. Krupp, E.I. Alvarez and S.C. Modgal, *Water management practices in flooded tropical rice*. In: Water Management in Philippine Irrigation Systems: Research and Operations, IRRI, Los Banos, Philippines, 1973 pp. 1–18.
[38] A.K. Borrell A.L. Garside and S. Fukai, *Improving efficiency of water use for irrigated rice in a semi-arid tropical environment.* Field Crop Res. 52, 1997, 231–248.
[39] E. G. Castillo, R. J. Buresh, and K. T. Ingram, *Lowland rice yield as affected by timing of water deficit and nitrogen fertilization.* Agron. J. 84, 1992, 152–159.
[40] S. M. Dabney, and B. J. Hoff, *Influence of water management on growth and yield of no-till planted rice.* Crop Sci. 29, 1989, 746–752.
[41] G. N. McCauley, *Sprinkler vs. flood irrigation in traditional rice production regions of southeast Texas.Agron*. J. 82, 1990, 677–683.
[42] H. S. Mishra, T. R Rathore and R. C. Pant. Root growth, water potential and yield of irrigated rice. Irrig. Sci. 17, (1997), 69–75.

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