Nigerian
Journal of Soil and
Environmental Research

Nig. J. Soil & Env. Res. Vol. 22: 2023 13 - 28
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Determination of Water Requirement of Paddy Rice under the System of Rice Intensification (SRI) Methodology at Kadawa Kano River Irrigation Project

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ABSTRACT

The water requirement of paddy rice under regulated deficit irrigation management through SRI methodology was determined and compared to conventional method in this study. Moisture content at saturation, effective rainfall, crop evapotranspiration and seepage percolation loses were calculated with the aid of aqua-Crop model by keeping track of the differences between incoming and outgoing water fluxes over the concerned time period using daily meteorological data collected from nearby Research Area for determination of irrigation water requirement during pre-saturation and normal growth periods of Rice. The seasonal irrigation water requirement for each treatment was determined by summing up the irrigation water used at different growth stages of the rice throughout the season. At the end of the study, the results showed that, a total of 1696 mm to 2635 mm of water is needed to irrigate one hectare of paddy area in SRI, while 3733.4 mm is needed under conventional farming system. The average mean irrigation water requirement of SRI treatments recorded a convincing water savings of approximately 30 – 60 % over the conventional farming system as a result of SRI treatments. The maximum flow rate was recorded at the initial growth stage and at the beginning of mid-season stages because a shallow water during initial growth stage was kept in order maintain humidity during the first two weeks of transplanted young seedlings. Large volume of water was soaked through the stem of the rice for subsequent use during flowering and grain production at the beginning of the late-season stage. While the least flow rate was recorded at grain filling stage because rice has already taken more water during the mid-season stage, 50% of grains were produced and shading of leaves has occurred.

Keywords: Conventional Farming System, Paddy Rice, Regulated Deficit Irrigation, System of Rice Intensification, Water Requirement

INTRODUCTION

The crop water requirement (WR) for paddy crops can be defined as the total depth of water needed to meet up with the water loss of disease free crop, growing in large fields under non-restricted soil conditions and achieving full production through pre-saturation on the field before cultivation, evaporation from field before and after direct seeding or transplanting, evapotranspiration by paddy during the growth period to maturity, and percolation or infiltration loss (Chong *et al*., 1987).

Deficit or regulated deficit irrigation scheduling is a way of optimizing water use efficiency for higher yields per unit of irrigation water applied. The crop is exposed to a certain level of water stress either during a particular period or throughout the whole growing season (FAO, 2000). The main objective of deficit irrigation is to increase the WUE of a crop by eliminating irrigations that have little impact on yield. The expectation is that any yield reduction will be insignificant compared with the benefits gained through diverting the saved water to irrigate other crops (FAO, 2000) In general, scarce water resources and growing competition for water will reduce its availability for irrigation. At the same time the need to meet the growing demand for food will require increased crop production from less water.

The SRI was developed in the 1980s by a French priest in Madagascar, Father Henri de Laulanie, who spent 20 years learning about rice-growing practices from local farmers (Uphoff, 2007). SRI is a methodology for increasing the productivity of irrigated rice cultivation by changing the management of plants, soil, water, and nutrients, while reducing external inputs. It has been raising yields by 32% to 100%, and sometimes more, with reduced requirements for water, seed, fertilizer, and crop protection (Sato and Uphoff, 2007; Sinha and Talati, 2007). To date, the effects of SRI methodology have been empirically demonstrated in over 30 countries, including most of the rice-producing countries of Asia and many others in Africa and Latin America (Uphoff, 2007). System Rice Intensification is reported to reduce amount of water applied to the field by about 40% to 70% compared to conventional practice of continuous flooding (Sato and Uphoff, 2007; Sinha and Talati, 2007), and reduce labor input by about 8% (Sinha and Talati, 2007). Unlike the conventional method of continuous flooding of paddy fields, SRI involves intermittent wetting and drying of paddies as well as specific soil and agronomic management practices. It is based on six principles: i) transplanting a single seedling, ii) transplanting younger seedlings at a 2– leaf stage (8-12 days old), iii) wide plant spacing of 25 x 25 cm or wider, planted in lines, iv) minimum water applications during vegetative growth period keeping soils moist, but well-drained and aerated, v) frequent weeding with a simple mechanical hand-weeder, and vi) application of organic matter in preference to chemical fertilizer (Laulani´e, 1993; Katambara *et al.,* 2013). Results of SRI practice in many tropical and subtropical countries have shown the significance of SRI methods with respect to increasing grain yield and saving water.

The rapid population growth worldwide and the high demand for water are of great concern. Water is important for plant growth and food production. In arid and semi-arid regions, precipitation is low and therefore water is scarce (Arku *et. al*., 2011). Decline in water resources and increasing food requirements require greater efficiency in water use, both in rain-fed and irrigated agriculture. The major use of water in the agriculture sector is for irrigation, which is affected by decreased water supply. It is estimated that 69% of worldwide water use goes to irrigation with 15-35% of irrigated withdrawals being unsustainable. Within the agricultural sector irrigated rice production is the largest source of demand for fresh water due to its flooding or inundation requirements (Bastiaanssen *et al*., 2000). In arid and semi-arid regions, precipitation is low and therefore water is scarce (Arku *et. al*., 2011). There is the need to conserve the available water resources and increase the efficiency of water use that is available (Arku *et. al*., 2011; Kirda, 2000)

Finally, Achieving greater efficiency of water use will therefore be a primary challenge for the near future (Nega, 2009). In this context, deficit irrigation can play an important role in increasing WUE and enable future expansion of irrigated horticulture in area where water is a limiting factor (Nega, 2009). The determination of water requirement of paddy rice through SRI methodology will ensure rice are grown with less water so that the productivity of the land, labor and capital used in rice production is raised all at the same time while making water more productive (Randriamiharisoa *et al.,* 2006). The different irrigation management strategies employed in SRI methodology, for lowland rice cultivation which includes continuous flooding, alternate wetting and drying and saturated soil conditions significantly affect the growth and yield of crop plants. In conditions of water scarcity, the major foals to be acquired are to save water, increase productivity of water, and most importantly to grow more rice with less water. An analysis of water saving techniques, at the field level, was done by Bouman and Toung (2000). They stated that the reduction of ponding depths to continuous saturation or alternate wetting and drying applied in SRI could be a useful tool for reducing water requirements of rice. Saturated soil conditions saved water by 23 percent with a yield compromise of only 6 percent. Chapagain and Riseman (2011) reported that water applied in the field under SRI can be reduced by about 40 –70 % without a significant yield loss compared with the traditional practice of continuous shallow submergence if a very thin water layer is maintained at saturated soil condition. Keisuke *et al.* (2007) also reported a reduction of irrigation water requirement for non-flooded rice by 20–50 % compared to flooded rice, with the difference being strongly dependent on soil type, rainfall, and water management. According to the outcome of Abdullahi *et al.* (2022), they conclude that, SRI treatments which involved Alternate Wetting and Drying Cycle have substantially improved the rice water productivity by 100–200 %, compared to conventional farming method that involves continuous flooding on the basis of 5-10 cm water application level at interval of 2 to 3-days. Their results agree with that found by Kumar *et al*. (2006) on SRI and traditional farming method. In that research, the researchers found that the water productivity of rice was significantly increased by 91.3 % to 194.9 % by applying SRI with 14-days old seedlings planted at 25-25 cm spacing compared to the conventional method. Generally, Intermittent drying employed in SRI practice, also improves soil, stimulates tiller development and alters sink-source relationships (Boonjung and Fukai, 1996). Drained field during intermitted irrigation in SRI could induce higher root activity by enhancing root respiration and root revitalization, resulting in greater leaf area, higher photosynthesis activity, resulting in higher yield (Tsuno and Wang, 1988). This findings has been complemented by high root activity contributes to a higher photosynthetic rate (Osaki *et al*., 1997) and the growth of shoots is very much dependent on root growth (Nikolaos *et al*., 2000). Super high yielding cultivar has larger root systems compared to other indigenous cultivars therefore, root quantity and root activity both are required for raising yield (Xuan *et al*., 1989).

Hence the main objective for this study was to determine the irrigation water requirement (IWR) for paddy rice under regulated deficit irrigation (DI) management through SRI practices and compared to conventional farming system in order to evaluate the impact of SRI methodology.

MATERIALS AND METHODS

The Study Area

The experiment was conducted during 2017/2018 and 2018/2019 irrigation farming season at the Irrigation Research Station, Kadawa, situated at about 50 km from Kano along the Kano - Zaria high way of Nigeria. Kadawa is enclosed between latitude 11°30' to 12°03' N, longitude 8° 30' E to 09°40' E and 486 m above sea level within the Hadeja Jama're River Basin. The climatic condition is typical of the Sudan savannah ecological zone which divides the years into three distinct periods; the warm rainy season from June to September, the cool dry season from November to February and the hot dry season from March to June. The average annual rainfall is 884.4 mm with 60% of which falls in July and August. The daily mean air temperature is 26°C with the maximum value at 42°C occurring in the month of April/May and minimum of 19°C in December. The geology of the project area is belongs to the Northern Nigerian complex (NADECO, 1976) which is heterogeneous complex of rocks. The dominant rock types are granitic gneisses and schists. In many places the original material is overlain by alluvial and *Aeolia*n material which resulted into different land forms. Generally, the soils of the project area belong to Eutric Gambisol in FAO/UNESCO system (NADECO, 1976). They are moderately deep and well drained with sandy loam textured surface and sandy clay loam textured subsoil

Soil Sampling

Undisturbed soil samples were taken randomly from different spots within the experimental research field at 0 to 15 cm, 15 - 30 cm and 30 - 45 cm depth using tube auger to record the initial soil physical and chemical properties. Soil sample was air dried, grounded and sieved through 2 mm sieve to test their properties. Standard laboratory methods were used to determine the soil chemical and physical properties. The soil physical properties include: soil texture, bulk density, saturated hydraulic conductivity soil moisture content at field capacity, permanent wilting point and at saturation. Another soil samples were collected immediately after land preparation for the determination of the following soil chemical properties such as: pH, electrical conductivity (EC), organic carbon, Nitrogen, Phosphorus and Potassium.

Experimental Design

The experiment was laid out in a split-plot design in randomized complete block design (RCBD) arrangement and replicated three times into 12 treatment combinations. The treatments include four SRI water application levels

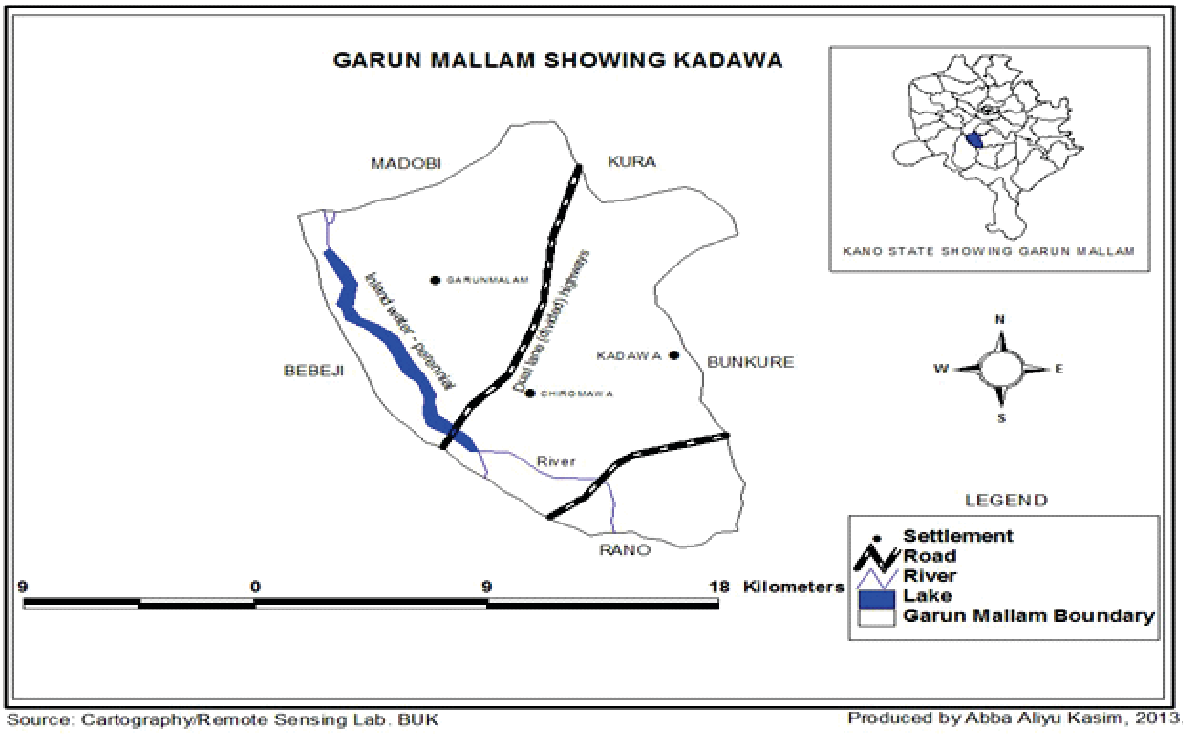


Figure 1. Kadawa, within the Kano River Irrigation Project

(WAL) at sub-plot, i.e.: 0.5 cm (25 %), 1 cm (50 %), 1.5 cm (75 %) and 2 cm (100 %) above the soil surface (Factor A); and three levels of irrigation intervals at 2-days, 3-days and 4-days, at main-plot (at different growth stages of the rice, Factor B) given a total of 12 treatments and thirty six (36) plots units. The total field area was 1,023 m^2 (46.5 m x 22 m) at two different locations. The dimension of the individual plots was 5 m by 3 m (15 m^2). There was a bund accounting to 0.5 m width between main plot and sub-plot. Each replication was separated by 1.5 m bund. The crop geometry of rice was 25 × 25 cm^2 (hill to hill and row to row spacing) with one seedling per hill (Figure 2).

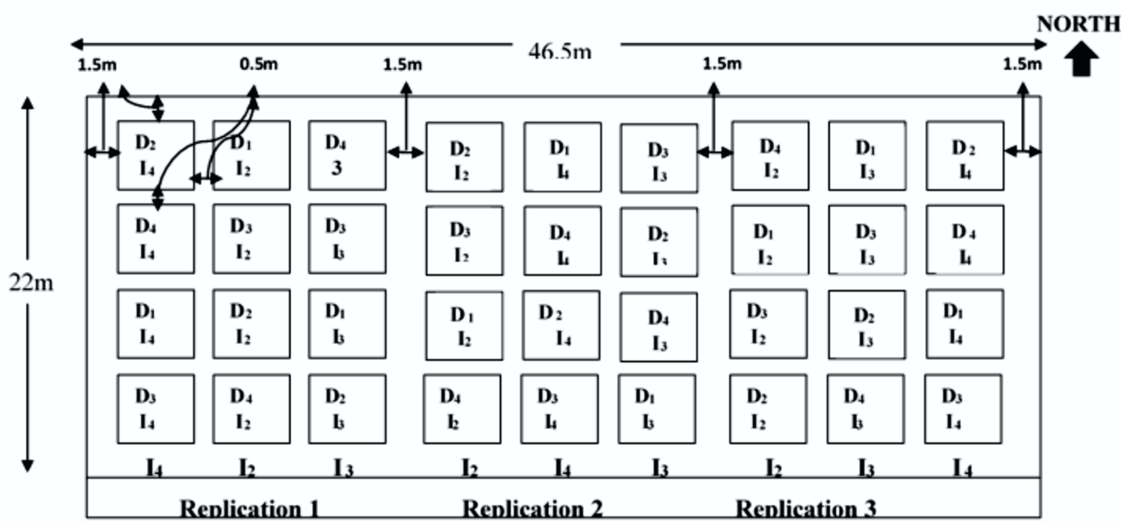
Field Preparation, Layout and other Agronomic practices

Experimental crop used was faro 44 (SIPII) rice varieties. It is a long grained high yielding and an average duration rice variety with growth duration of 100-115 days. During the land preparation, 20 cm of the top soil was well loosened. One month later, ploughing, muddying, and leveling activities were conducted. Five (5) tones of organic fertilizer were initially applied before ploughing. N, P and K as well as Zn were applied at 120:80:80:25 kg/ha respectively (from Urea, DAP, MOP and $ZnSO_4$). Full doses of N, P, K and Zn were applied before the final land preparation as basal fertilizer. Urea was applied in three equal installments, i.e. 60 kg N/ha after seedling recovery (i.e. after the transplanted plant re-germinated) the remaining half dose of 60 kg N/ha was applied in two split doses, 30 kg N/ha at active tillering stage and 30 kg N/ha at panicle initiation stage for all treatments. Nursery was designed exactly like a vegetable plot, i.e. 5 m long and 1 m wide. The seedbed was covered with very loose and light soil with a depth of 15 cm. 1.5 kg of seed was used to sow the seedbed for use in transplanting in the experimental field. Transplanting activities was followed after one week of soil preparation. The transplanting work in SRI starts when the seedlings have two leaves (8-12 DAS) and seedlings were transplanted singly. The young seedlings were transplanted in a square grid pattern at 25 x 25 cm spacing. The seedlings were lightly placed in the basin gently (at 1-2 cm depth within the mud), in the form of the letter «L». After transplanting, the plot was lightly irrigated to maintain humidity during the first two weeks

Irrigation

In this research work, Safe Alternate Wetting and Drying (AWD) irrigation method was used. AWD is a technology for water saving in rice production. Under this practice the rice paddies are irrigated intermittently during the vegetative growth stage in order to keep the soil moist under aerobic conditions in contrast to the conventional method where the soil is continuously flooded.

In AWD an access tube was installed at the center of each basin and the next irrigation was applied when the water within the access tube fell below 15 cm from a ponding depth of 2 cm. In this study, the irrigation intervals were determined based on this principle, and it was discovered that the water level fell within 10-15 cm, 15-25 and 25-30 cm after two, three and four days after irrigation respectively. Therefore, the irrigation intervals of 2, 3, and 4 days were chosen for this study and during each



D_1 ($I_{D100\%}$) = 0 % deficit irrigation depth or irrigation at 100 % SRI Water Application Level (WAL), D_2 ($I_{D75\%}$) = 25 % deficit irrigation depth or irrigation at 75% SRI WAL, D_3 ($I_{D50\%}$) = 50% deficit irrigation depth or irrigation at 50 % SRI WAL, D_4 ($I_{D25\%}$) = 75 % deficit irrigation depth or irrigation at 25 % SRI WAL. L_2 = Irrigation interval @ 2-days, L_3 = Irrigation interval @ 3-days, L_4 (@4-days) = Irrigation interval @ 4-days.

irrigation interval, four SRI water application levels (WAL) was applied at a depth of 0.5 cm (25 %), 1 cm (50 %), 1.5 cm (75 %) and 2 cm (100 %) above the soil surface. The initial soil water content at the top of soil during transplanting was assumed to be close to field capacity as a result of pre-irrigation a day before transplanting. However, each treatment was irrigated to a ponding depth of 2 cm throughout the establishment stage in order to maintain humidity during the first two weeks (since small vegetable seedlings are extremely very sensitive to moisture stress). After two weeks the deficit irrigation treatments were applied to each plot according to the treatments specification (as described in Table 1) from panicle initiation (PI) to grain filling stage. However, during flowering stage, a thin layer of water (2cm) was kept on the entire plots and the normal AWD was continue during grain filling growth stage

Data Collection and Statistical Analysis

Data collection from the experimental research field was commenced from the day of pre-irrigation to the end of grain filling growth stage. Meteorological data such as rainfall, temperature, humidity, wind speed and sunshine hours, obtained from local meteorological station within the experimental site, were used to determine the irrigation water requirement through FAO Penman Monteith using Cropwat 8.0 software, embedded in the Aqua-crop model

Finally, all data collected and recorded ware subjected to statistical analysis of variance using Microsoft Excel. Means and significant differences was evaluate using Duncan's new multiple range test (DMRT) at 1 and 5 % significant level.

Determination of Irrigation Water Requirement (IWR)

$$IWR = ETc - Pe \qquad 1$$

Where,

IWR = Irrigation Water Requirement,

Etc = Crop water need and

Pe = Effective Rainfall

The irrigation water requirement of rice (IWR) is determined as follows:

Step 1: Determine the reference crop evapotranspiration: Eto

$$ETo = \frac{0.408\,\Delta\,(Rn - G) + \gamma \frac{900}{T+273}\, u_2\,(es - ea)}{\Delta + \gamma\,(1 + 0.34u_2)}$$

Et*o* is reference evapotranspiration (mm/day), Δ is slope of saturated vapour pressure per temperature curve (kPa/ ºC), γ is psychrometric constant (kPa/ ºC), u_2 is wind speed at 2m height (m/s), R*n* is total net radiation at the crop surface (MJ/m^2day), G is soil heat flux density (MJ/m^2day), T is mean daily air temperature at 2m height (ºC), e*s* is saturation vapour pressure (kPa) and e*a* is actual

Table 1. Description of Treatments Details and Symbols

Treatment	Treatment Description
T_1 ($I_{D100\%}$ @ 2Days)	Irrigation at 100% SRI Water Application Level (WAL) after every 2 days.
T_2 ($I_{D75\%}$ @ 2Days)	Irrigation at 75% SRI WAL after every 2 days.
T_3 ($I_{D50\%}$ @ 2Days)	Irrigation at 50% SRI WAL after every 2 days.
T_4 ($I_{D25\%}$ @ 2Days)	Irrigation at 25% SRI WAL after every 2 days.
T_5 ($I_{D100\%}$ @ 3Days)	Irrigation at 100% SRI WAL after every 3 days.
T_6 ($I_{D75\%}$ @ 3Days)	Irrigation at 75% SRI WAL after every 3 days.
T_7 ($I_{D50\%}$ @ 3Days)	Irrigation at 50% SRI WAL after every 3 days.
T_8 ($I_{D25\%}$ @ 3Days)	Irrigation at 25% SRI WAL after every 3 days.
T_9 ($I_{D100\%}$ @ 4Days)	Irrigation at 100% SRI WAL after every 4 days.
T_{10} ($I_{D75\%}$ @ 4Days)	Irrigation at 75% SRI WAL after e very 4 days.
T_{11} ($I_{D50\%}$ @ 4Days)	Irrigation at 50% SRI WAL after every 4 days.
T_{12} ($I_{D25\%}$ @ 4Days)	Irrigation at 25% SRI WAL after every 4 days.

Irrigation at 100% SRI WAL = Irrigation at 20mm ponding depth (0% deficit irrigation depth)

Irrigation at 75% SRI WAL = Irrigation at 15 mm ponding depth (25% deficit irrigation depth)

Irrigation at 50% SRI WAL = Irrigation at 10mm ponding depth (50% deficit irrigation depth)

Irrigation at 25% SRI WAL = Irrigation at 5mm ponding depth (75% deficit irrigation depth)

vapour pressure (kPa).
The meteorological data for computing reference evapotranspiration include maximum and minimum temperature (ºC), maximum and minimum relative humidity (%), wind speed at 2m height (m/s), height above mean sea level at a particular altitude (m), solar radiation (MJ/m^2), and latitude. The daily values of all components to calculate reference evapotranspiration were taken from Kadawa Irrigation Research Station (IRS).
Step 2: Determine the crop factors: Kc (Table 2)
The total growing season of the experimental rice variety Faro 44 (SIPII) under the dry climate and light wind of "Kadawa Station" was = 115 days with the following Kc values at the different growth stages:
Kc at day 0 to 60: 1.1
Kc at day 60 to 95: 1.2
Kc at day 95 to 120: 1.0
Step 3: Calculate the crop water need: ET crop = ETo × Kc 3
Step 4: Determine the effective rainfall: Pe
Step 5: Calculate the irrigation water requirement: IWR = ET crop – Pe

Paddy rice, growing with "its feet in the water", is an exception. Not only has the crop water need (ET crop) to be supplied by irrigation or rainfall, but also water is needed for: saturation of the soil before planting, percolation and seepage losses and establishment of a water layer. In summary, the determination of the irrigation water need for paddy rice requires the following steps:
Step 1: Determine the reference crop evapotranspiration: ETo

Step 2: Determine the crop factors: Kc

Step 3: Calculate the crop water need: ET crop = ETo × Kc

Step 4: Determine the amount of water needed to saturate the soil for land preparation by puddling: SAT
In the month before sowing or transplanting, water is needed to saturate the root zone. The amount of water needed depends on the soil type and rooting depth. For the purpose of this research it is however determine that the amount of water needed to saturate the root zone (30 cm) is 158.5mm.

Table 2: Kc Values for Paddy Rice

Climate	Little wind		Strong wind	
Growth stage (days)	dry	humid	Dry	Humid
0-60 days after transplant or direct sowing	1.1	1.1	1.1	1.1
Mid-season	1.2	1.05	1.35	1.3
last 30 days before harvest	1.0	1.0	1.0	1.0

Source: (Brouwer and Heibloem 1987)

Step 5: Determine the amount of percolation and seepage losses: PERC
The percolation and seepage losses depend on the type of soil. They will be low in very heavy, well-puddled clay soils and high in the case of sandy soils. The percolation and seepage losses vary between 4 and 8 mm/day.
For heavy clay: PERC = 4 mm/day
For sandy soils: PERC = 8 mm/day
On average: PERC = 6 mm/day
Step 6: Determine the amount of water needed to establish a water layer: WL
A water layer was established during transplanting and maintained throughout the growing season.
Various approaches are being used with respect to the depth of the water layer. In SRI a water layer of 20 mm was established after transplanting and maintained throughout during establishment and flowering stage. In other cases, the water layer was applied intermittently during vegetative growth stage in order to keep the soil moist with mostly aerobic conditions rather than continuously flooding the soil as in contrast to conventional method.
Step 7: Determine the effective rainfall: Pe
The effective rainfall was calculated using the following formulae:
Pe = 0.8 P - 25 if P > 75 mm/month
Pe = 0.6 P - 10 if p < 75 mm/month
Step 8: Calculate the irrigation water requirement (IWR)
The irrigation water requirement was calculated using the following formula;
IWR = ET crop + SAT + PERC + WL – Pe 4
However, in case of ground water contribution as a result of capillary rise (CR) of water from a shallow water table of the site; equation 3.4 has been adjusted to:
IWR = ET crop + SAT + WL + PERC – Pe – CR 5

Determination of Total Volume (V) of Irrigation Water Requirement

$V = d_g x A + SAT + WL + SDP - Pe - CR$ 6
Where,
V = volume of water delivered in m^3
d_g = depth of irrigation, m
A = Total area of treatment plot in m^2
SAT = amount of water needed to saturate the soil at the root zone of rice in m^3
WL = the amount of water needed to establish a water layer in m^3

The Irrigation Depth (Dr)

$D_r = W_{rFC-} W_{rt+n}$. 7

Where,

D_r = Irrigation Depth or root zone depletion (it referred to the amount of irrigation water that need to be applied to soil in order to bring it back to field capacity)

W_{rFC} = the water content in the root zone at the field capacity

W_{rt+n} = the water content in the root zone at the n^{th} day

Where n = 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13 … etc.

W_{rt} = the water content in the root zone at the instance of sampling i.e. at t = 0

W_{rt+1} = the water content in the root zone at the next day (at t = 1)

W_{rt+2} = the water content in the root zone at the second day (at t = 2)

etc.

$W_{rFC} = 1000 * \theta_{FC} * Z$ 8

$W_{rt} = 1000 * \theta * Z$ 9

$W_{rt+1} = W_{rt} + (I+P–RO) +CR –ET–SDP$ 10

$W_{rt+2} = W_{rt+1} + (I+P–RO) +CR –ET–SDP$ 11

$W_{rt+n} = W_{rt+n} + (I+P–RO) +CR –ET–SDP$ 12

P = amount of water added by rainfall

RO = water which was lost by runoff (which is 0 for basin irrigation)

CR = Capillary Rise

ET = Evapotranspiration

SDP = Seepage and Deep Percolation ($W_{rt+n} – W_{rFC}$)

θ = Volumetric water content of soil in its natural state

θ_{FC} = Volumetric water content of soil at field capacity

Z = rooting depth

2.9. Application Time (t)

$$t = \frac{(\bar{dg} \times A + SAT + WL + SDP - Pe - CR)}{q_s} \quad 13$$

Where,

$q_{s=}$ The estimated volume of water delivered into the basin.

Ground Water Monitoring and Contribution

36 PVC piezometer tubes were installed deep enough to meet the water table in each and every plot to facilitate water table level monitoring in order to find out the actual water contribution to the experimental plots by capillary rise. Water table levels in the tubes were measured with the aid of meter rule. Water table measurements were taken every 2 days. The water contribution by capillary rise was determined with the aid of Aqua-crop model. Aqua-crop model use the ground water table fluctuation information to determined exactly the amount of water that enter the root zone of the rice which might in one way or the other utilized by the rice crop through evapotranspiration.

RESULTS AND DISCUSSION

In this section, the results and discussions of seasonal water requirement of rice through SRI under regulated deficit irrigation (DI) management at different irrigation levels and intervals in Kadawa Irrigation Research Station (IRS) were made.

Ground Water Table Monitoring and Contribution

Figure 3 shows the water table fluctuations across the twelve SRI treatment combinations while Figure 4 shows the water capillary rise at different piezometer points across all the treatments in the study area. It can be seen that, both the initial and final water table depth were not uniform across all the piezometer points. The depth of water table at the end of the irrigation was lower than at beginning of the study. This was, as a result of water contribution by capillary rise from the ground water table to the rooting depth of the crops following irrigation, which was manifested from the differences between the initial and final depth of the water table across the piezometers.

Moreover, the amount of water contributed was determined by measuring the amount of water rise by capillary to the crops rooting depth with the aid of aqua-crop model. Figure 5 shows that, the highest mean average seasonal water contribution by capillary was achieved from treatment T_{12} (99 mm), T_8 (85 mm) and T_4 (81 mm) irrigated at 75% deficit levels at 4-days, 3-days and 2-days irrigation interval respectively while the least water contribution by capillary was recorded at treatments T_1 (33 mm), T_5 (36 mm) and T_9 (39 mm) irrigated at 0% deficit irrigation level respectively, at the same order of irrigation interval of 2-days, 3-days and 4-days. In conclusion, the average seasonal water contribution across the twelve treatment combination was 52 mm and the highest water contribution by capillary was achieved when irrigation was done at maximum deficit levels while the minimum water contribution by capillary was recorded as a result of minimum deficit levels of irrigation.

Effective Rainfall

The daily value of rainfall event was collected from the nearby meteorological irrigation research station of Kadawa. The effective value was then calculated throughout the growing season of the rice and used directly into equation 5 (figure 5) in order to determine the average seasonal irrigation water requirement of the paddy rice. Figure 5 shows that, the effective rainfall (Pe) was not recorded from the beginning of the research i.e. during the first up to the fourth week of March and the first (5^{th}) week of April as a result of absent of rainfall event. Some rainfall was observed during the second (6^{th}) and third (7^{th}) week of April which contributed the average weekly Pe of 21.4 mm. In the Month of May, rainfall was observed at the first (9^{th}), third (11^{th}) and the fourth (12^{th}) week, and contributed the average weekly Pe of 22.4 mm. In the month of June, rainfall event was observed in the second (14^{th}), third (15^{th}) and the fourth (\`16^{th}) week which

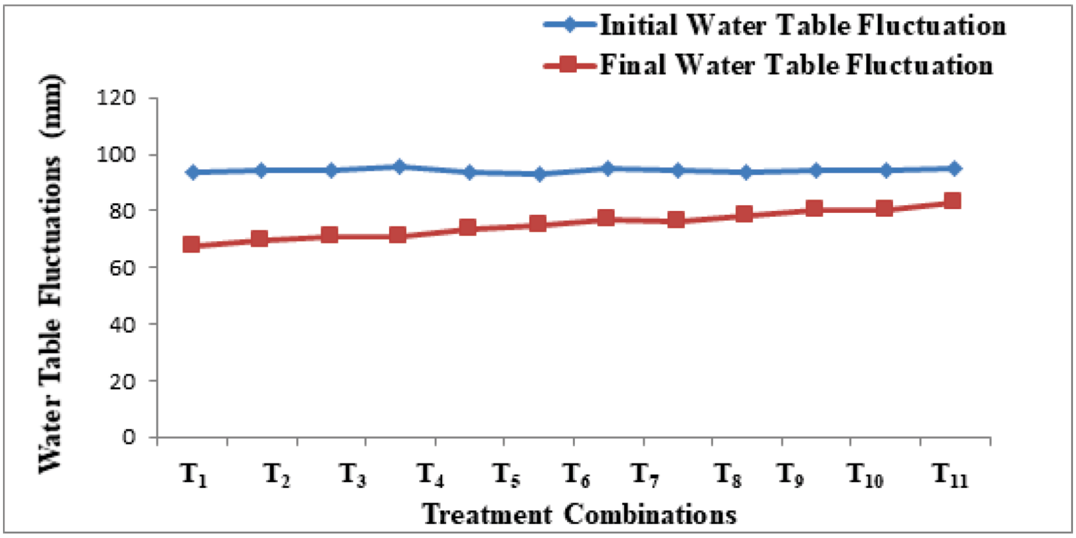


Figure 3: Initial and Final Water Fluctuations across the 12 Treatment Combinations

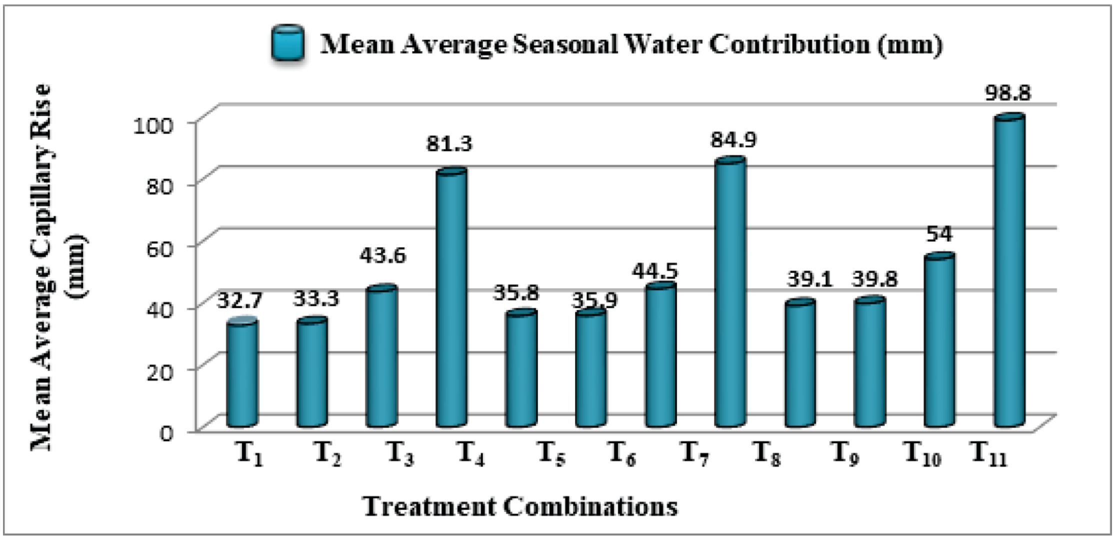


Figure 4. Mean Average Seasonal Water Contribution by Capillary Rise across the 12 SRI Treatments

contributed an average weekly Pe of 16 mm. Finally, only the first weeks (17^{th}) of July fell within the period of the study and the average weekly Pe of 31.2 mm was received across the two seasons. Therefore, the highest average weekly effective rainfall (Pe) of 31.2 mm was received in the first week of July (17^{th}) while the lowest average Pe of 16, 21.4 and 22.4 mm was recorded in the month of June, April and May respectively. Generally, the total value of average seasonal effective rainfall calculated in the study area during the period of this study was equal to 189.2 mm

Determination of Crop Water Requirement

Irrigation water requirement was determined using equation 5 with the aid of Aqua-Crop model. The seasonal irrigation water requirement for each treatment was determined by summing up the irrigation water used at different growth stages of the rice throughout the season (i.e. at Free-irrigation, initial, vegetative, flowering and at, grain filling stages, Table 3)

Table 5 shows the results of average mean seasonal irrigation water requirement for the 12 SRI plots and the estimated value of conventional farming method. The conventional farming method which was irrigated on the basis of continuous flooding throughout the crop growing season, received the highest mean average of 3733.4 mm for both seasons. While, the average seasonal irrigation water requirement in SRI which involved Alternate Wetting and Drying (AWD) cycle at different deficit water level varied from 2635 mm to 1696 mm with an average of 2071 mm. The highest seasonal water requirement of 2635 mm was achieved at 2-days interval when irrigation was made at 100 % water application depth (i.e. at 0 %

deficit irrigation level) and the least mean average seasonal water requirement of 1696 mm was obtained at 4-days interval when irrigation was made at 25 % water application depth (75% deficit irrigation level)

Relationship between Average Means Irrigation Water Requirement (IWR) and Flow Rate at Different Crop Growth Stages in the Study Area

Table 4 shows the average mean irrigation water requirement of the rice and the corresponding flow rate at different growth stages. The average mean irrigation water requirement at each crop growth stage is proportional to the flow rate amount. The growth stage with maximum flow rate received the highest average mean irrigation water requirement. However, Conventional farming system received the maximum flow rate across the rice growth stages as a results of haphazard water application and lower productivity in the used of water. Generally, the flow rate across all the growths stages for both conventional and SRI practice varied from 5.3 and 3.0 litre/sec to 1.4 and 0. litre/sec with an average of 3.7 and 2.1 litre/sec onds respectively.

The maximum flow rate of 5.3 and 3.0 litre/sec for both conventional and SRI practice respectively was recorded at the initial growth stages because each treatment was irrigated to a ponding depth of 2 cm in SRI and 10 cm in Conventional method throughout the initial growth stage in order to maintain humidity during the first two weeks (since small vegetable seedlings are extremely very sensitive to moisture stress). The flow rate drop at vegetative growth stages to 3.9 and 2.2 litre/sec for conventional and SRI practice respectively. This is because, the treatments specification of intermittent irrigation were imposed in SRI plots and the ponding depth in conventional was reduced and maintained between 5 to10 cm. Moreover, the flow rate seemed to be increased for both conventional and SRI practice from stem elongation, heading and flowering growth stages with a flow rate of 2.5 and 4.5, 2.6 and 4.7 and 2.3 and 4.2 litre/sec respectively with a maximum flow rate received at heading growth stages. This is because during the stem elongation the rice water requirement increases in proportion to the size of the crop while at heading i.e. the beginning of late-season stage, rice water requirement heavily increases because at this stage water was absorbed through the stem of the rice for use during the flowering and the subsequent use during the grain production of the rice. Finally, the least flow rate of 0.7 and 1.4 litre/sec. was received at the final rice growth stages i.e. during grain filling stages. At this stage, rice has already taken more water into its stem during heading and flowering growth stages and the rice has already produce 50 % of its grains, shading of leaves occurred, thereby required less amount of water. Table 4. The Average Water Requirement and Flow rate of Rice at Different Growth Stages

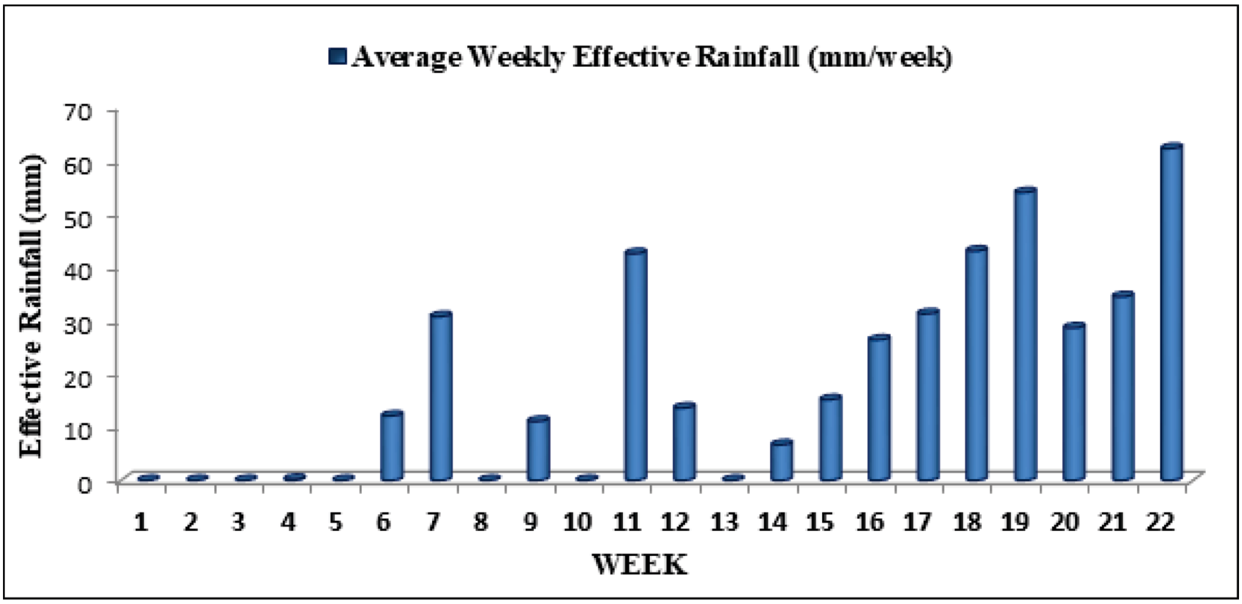


Figure 5: Average Weekly Effective Rainfall (mm/week)

Effect of SRI Practices on the Average Means Irrigation Water Requirement (IWR) Relative to Convectional Farming Method in the Study Area

Table 5 shows the results on the average means irrigation water requirement (IWR) across SRI treatments and the average estimated value of conventional farming method in the 2017/2018 and 2018/2019 irrigation seasons.

The average means irrigation water requirement of SRI treatments T_1, T_2, T_3, T_4, T_5, T_6, T_7, T_8, T_9, T_{10}, T_{11}, and T_{12} relative to conventional farming method recorded a

Table 3. The Average Mean Results of Season 2017/2018 and 2018/2019 Irrigation Water Requirement per Growth Stages at Different Deficit Irrigation Level

Treatments	Free irrigation (mm)	Initial Growth Stage (0-13 DAT) (mm)	Vegetative Growth Stage			Flowering (72-85 DAT) (mm)	Grain Filling (86-102 DAT) (mm)	Seasonal Irrigation Water Requirement (mm)
			Tillering (14-40 DAT) (mm)	Stem elongation (41-61 DAT) (mm)	Heading (62-71 DAT) (mm)			
To (Conventional)	**290.20**	**642.3**	**867.50**	**809.10**	**409.80**	**509.30**	**205.20**	**3733.4**
T1 ($I_{D100\%}$ @ 2Days)	158.50	360.35	698.45	632.90	274.45	349.45	171.70	2634.6
T2 ($I_{D75\%}$ @ 2Days)	158.50	360.35	638.08	576.20	255.60	326.90	148.33	2450.8
T3 ($I_{D50\%}$ @ 2Days)	158.50	360.35	577.53	518.83	238.15	302.55	120.13	2260.0
T4 ($I_{D25\%}$ @ 2Days)	158.50	360.35	516.75	461.58	221.38	280.33	91.880	2069.6
T1 ($I_{D100\%}$ @ 3Days)	158.50	360.35	531.23	469.73	257.05	304.65	136.05	2207.5
T2 ($I_{D75\%}$ @ 3Days)	158.50	360.35	491.25	434.28	243.93	290.98	117.78	2085.2
T3 ($I_{D50\%}$ @ 3Days)	158.50	360.35	451.28	398.30	230.28	276.25	98.780	1960.3
T4 ($I_{D25\%}$ @ 3Days)	158.50	360.35	411.30	362.43	216.68	261.50	79.880	1835.4
T1 ($I_{D100\%}$ @ 4Days)	158.50	360.35	434.70	451.36	209.05	267.15	107.88	1977.1
T2 ($I_{D75\%}$ @ 4Days)	158.50	360.35	404.70	421.03	201.10	258.85	94.950	1886.0
T3 ($I_{D50\%}$ @ 4Days)	158.50	360.35	374.63	388.03	192.95	249.95	81.650	1788.4
T4 ($I_{D25\%}$ @ 4Days)	158.50	360.35	344.58	357.53	184.73	241.15	68.400	1696.0
Average SRI at DGS	**158.50**	**360.40**	**489.50**	**456.00**	**227.10**	**284.10**	**109.80**	**2070.9**

Source: Field Survey, 2017/2018 and 2018/2019; DGS = Different Growth Stages, I_{D100}= 0 % deficit irrigation depth, I_{D75}= 25 % deficit irrigation depth, I_{D50}= 50 % deficit irrigation depth, I_{D25}= 75 % deficit irrigation depth. @ 2days = irrigation interval at 2 days, @ 3-days = irrigation interval at 3-days and @ 4-days = irrigation interval 4-days.

convincing water savings of 29.5, 34.4, 39.5, 44.6, 40.9, 44.1, 47.5, 50.8, 47.0, 49.5, 52.1 and 54.6 % respectively. The approximate average means irrigation water savings of 30 – 60 % over the conventional farming system were achieved as a result of SRI treatments. This range was in agreement with the findings reported by Sato and Uphoff (2007) under SRI management in eastern Indonesia. The results also agreed well with the findings reported by Keisuke *et al.* (2007). They reported a reduction of irrigation water requirement for non-flooded rice (SRI) by 20–50 % compared to flooded rice, with the difference being strongly dependent on soil type, rainfall, and water management. More so, Chapagain and Riseman (2011) reported that water applied in the field under SRI can be

Table 4: The Average Water Requirement and Flow rate of Rice at Different Growth Stages

Growth Stages	**Average Water Requirement in SRI (mm)**	**Average Water Requirement in Conventional (mm)**	**Growth Duration (days)**	**Flow Rate in SRI** litre/sec ( )	**Flow Rate in Conventional** (litre/sec)
Free Irrigation	158.50	290.20	–	–	–
Initial	360.40	642.30	14	3.0	5.3
Tillering	489.50	867.50	26	2.2	3.9
Stem Elongation	456.00	809.10	21	2.5	4.5
Heading	227.10	409.80	10	2.6	4.7
Flowering	284.10	509.30	14	2.3	4.2
Grain Filling	109.80	205.20	17	0.7	1.4
SIWR	2071.0	3733.4	–	–	–

Source: Field Survey 2017/2018 and 2018/2019; SIWR = Seasonal Irrigation Water Requirement

Table 5: Percentage Difference of Seasonal Irrigation Water Savings (SIWS) of SRI Relative to Conventional Farming Method during 2017/2018 and 2018/2019 Irrigation Season

Treatment	**Seasonal Irrigation Water Requirement (mm)**	**% Difference of SIWS Relative to Conventional (%)**
To (Conventional)	3733.4	-
T1 ($I_{D100\%}$ @ 2Days)	2634.6	29.5
T2 ($I_{D75\%}$ @ 2Days)	2450.8	34.4
T3 ($I_{D50\%}$ @ 2Days)	2260.0	39.5
T4 ($I_{D25\%}$ @ 2Days)	2069.6	44.6
T5 ($I_{D100\%}$ @ 3Days)	2207.5	40.9
T6 ($I_{D75\%}$ @ 3Days)	2085.2	44.1
T7 ($I_{D50\%}$ @ 3Days)	1960.3	47.5
T8 ($I_{D25\%}$ @ 3Days)	1835.4	50.8
T9 ($I_{D100\%}$ @ 4Days)	1977.1	47.0
T10 ($I_{D75\%}$ @ 4Days)	1886.0	49.5
T11 ($I_{D50\%}$ @ 4Days)	1788.4	52.1
T12 ($I_{D25\%}$ @ 4Days)	1696.0	54.6

Source: Field Survey, 2017/2018 and 2018/2019; SIWS = Seasonal Irrigation Water Savings, I_{D100} = 0 % deficit irrigation depth, I_{D75}= 25 % deficit irrigation depth, I_{D50}= 50 % deficit irrigation depth, I_{D25}= 75 % deficit irrigation depth. @ 2days = irrigation interval at 2 days, @ 3-days = irrigation interval at 3-days and @ 4-days = irrigation interval 4-days.

reduced by about 40 –70 % without a significant yield loss compared with the traditional practice of continuous shallow submergence if a very thin water layer is maintained at saturated soil condition. An analysis of water saving techniques, at the field level, was done by Bouman and Toung (2000). They stated that the reduction of ponding depths to continuous saturation or alternate wetting and drying applied in SRI could be a useful tool for reducing water requirements of rice.

The Effects of Deficit Irrigation Level and Irrigation Intervals on Seasonal Irrigation Water Requirement (IWR) under SRI Practice at Kadawa in 2017/2018 and 2018/2019 Irrigation season.

Table 6 shows the statistical analyses on the results of means seasonal irrigation water requirement in SRI practice as affected by deficit irrigation depth and intervals during 2017/2018 and 2018/2019 irrigation seasons. A significant variation at 5 % and 1 % probability level was recorded with respect to deficit irrigation level

Table 6. Statistical Means of Seasonal Irrigation Water Requirement (SIWR) as Affected by Deficit Irrigation Level and Irrigation Interval at Kadawa in 2017/2018 and 2018/2019 Irrigation season.

Treatment	Mean Seasonal Irrigation Water Requirement (mm/season)	
	2017/2018	2018/2019
Deficit Irrigation Level		
$I_{D100\%}$	2257.067a	2289.067a
$I_{D75\%}$	2122.717b	2158.617b
$I_{D50\%}$	1980.100c	2025.700c
$I_{D25\%}$	1839.042d	1894.958d
CV (%)	2.246309	1.933759
Significance	**	**
Irrigation Interval		
2-Days	2332.519a	2374.981a
3-Days	2004.250b	2039.950b
4-Days	1812.425c	1861.325c
CV (%)	3.43343	2.019104
Significance	**	**
Interaction (Irr. Level × Irr. Interval)		
$I_{D100\%}$ @2Days	2618.2500a	2650.9500a
$I_{D100\%}$ @3Days	2194.450cd	2220.550cd
$I_{D100\%}$ @4Days	1958.500ef	1995.700ef
$I_{D75\%}$ @2Days	2434.7000b	2466.9000b
$I_{D75\%}$ @3Days	2069.025de	2101.3750e
$I_{D75\%}$ @4Days	1864.4250f	1907.575fg
$I_{D50\%}$ @2Days	2238.225bc	2281.7750c
$I_{D50\%}$ @3Days	1940.875ef	1979.7250f
$I_{D50\%}$ @4Days	1761.2000g	1815.600gh
$I_{D25\%}$ @2Days	2038.9000e	2100.3000e
$I_{D25\%}$ @3Days	1812.650fg	1858.1500g
$I_{D25\%}$ @4Days	1665.575gh	1726.425hi
CV (%)	2.246309	1.933759
Significance	*	*

Source: Field Survey, 2017/2018 and 2018/2019; Means followed by the same letter (s) in a column of any treatment group are not statistically different at 5% probability level using DMRT. ** = significant at 1% level, * = significant at 5% level difference, NS = not significant, cv = coefficient of variation, SIWR = Seasonal Irrigation water Requirement, Irr = irrigation. I_{D100} = 0% deficit, I_{D75} = 25% deficit, I_{D50} = 50% deficit, I_{D25} = 75% deficit.

and irrigation interval.

When the means seasonal irrigation water requirement was analyzed with respect to irrigation intervals, the highest mean seasonal irrigation water requirement of 2332.519 mm was recorded at irrigation interval of 2-days while the lowest mean seasonal irrigation water requirement of 1812.425 mm was recorded at irrigation interval of 4-days during 2017/2018 irrigation season. However, during 2018/2019 irrigation season, a statistically similar mean result of seasonal irrigation water requirement of 2374.98 mm was recorded at irrigation interval of 2-days while the lowest mean value of 1861.325 mm was recorded at irrigation interval of 4-days. On average, the highest average means seasonal irrigation water requirement of 2353.75 mm was recorded at irrigation intervals of 2, while the lowest average mean of 1836.875 mm was recorded at irrigation interval of 4-days.

Moreover, when analyses was made with respect to deficit irrigation level during 2017/2018 irrigation season, treatments $I_{D100\%}$ (0 % deficit irrigation level) recorded the highest means seasonal irrigation water requirement of 2257.067 mm, while the least mean value of 1839.042 mm was received in treatment $I_{D25\%.}$(75 % deficit irrigation level). Moreover, statistically similar results of seasonal irrigation water requirement were recorded during 2018/2019 irrigation seasons, where the same treatments $I_{D100\%}$ recorded the highest means values of 2374.981, while the least mean value of seasonal irrigation water requirement of 1861.325 mm was also recorded in treatment $I_{D25\%}$.On average, the highest average means seasonal irrigation water requirement of 2316.024 mm was recorded at 0 % deficit irrigation level ($I_{D100\%}$), while the lowest average mean of 1850.184 mmwas recorded at 75 % deficit irrigation depth ($I_{D25\%}$).

The interactions among the treatments factors, i.e. deficit irrigation level x irrigation interval were found significant at 5 % probability level. In the irrigation season 2017/2018, the mean seasonal irrigation water requirement in the study area varied from 2618.250 mm to 1665.575 mm with an average value of 2141.913 mm. Treatment T_1 irrigated at 0 % deficit irrigation level at 2-days irrigation interval recorded the highest mean value of 2618.250 mm of seasonal irrigation water requirement, while the least mean value of 1665.575 mm of seasonal irrigation water requirement was recorded in treatment T_{12} irrigated at 75 % deficit irrigation level at 4-days irrigation interval. Similarly, during 2018/2019 irrigation season, the mean seasonal irrigation water requirement varied from 2650.950 mm to 1726.425 mm with a mean value of 2188.688 mm. Also, treatment T_1 irrigated at 0% deficit irrigation level at 2-days irrigation interval recorded the highest mean value of 2650.950 mm of seasonal irrigation water requirement, while the least mean value of 1726.425 mm of seasonal irrigation water requirement was recorded in treatment T_{12} irrigated at 75 % deficit irrigation level at 4-days irrigation interval. On average, the mean seasonal irrigation water requirement in the study area varied from 2635 mm to 1696.0 mm with an average value of 2071 mm**.** Treatment T_1 irrigated at 0 % deficit irrigation level at 2-days irrigation interval recorded the highest mean value of 2635 mm of seasonal irrigation water requirement, while the least mean value of 1696.0 mm of seasonal irrigation water requirement was recorded in treatment T_{12} irrigated at 75 % deficit irrigation level at 4-days irrigation interval.

In summary, the highest mean seasonal water requirement was achieved at 2-days interval when irrigation was made at 100 % water application depth (i.e. at 0 % deficit irrigation level) while the least mean seasonal water requirement was obtained at 4-days interval when irrigation was made at 25 % water application depth (75 % deficit irrigation level). This study, well agreed with the finding of Habib (2014). He reported that, the highest water was applied to irrigation with 100 % water application depth at 7-days irrigation interval due to the frequent irrigation adopted with a full irrigation (0 % deficit irrigation level). While the least water was applied to irrigation with 25 % deficit irrigation level at 21-days irrigation interval because the crop was irrigated at a longer period with large deficit irrigation (75 % deficit irrigation level). Another study on the effect of deficit irrigation and mulch on water use and yield of drip irrigated onion conducted by Nega *et al.,* (2009) reported that, the highest mean crop water use was recorded at 100 % irrigation water depth (0 % deficit irrigation level) and the lowest mean irrigation water application was received at 75% deficit irrigation level.

CONCLUSION

The main objective of this study is to determine the Water Requirement of Paddy Rice under Regulated Deficit Irrigation (DI) regime through the SRI Practices and compare with conventional farming system in order to evaluate the impact of SRI methodology.

The conventional farming method which was irrigated on the basis of continuous flooding throughout the crop growing season, received the highest mean average of 3733.4 mm for both seasons. While, the average seasonal irrigation water requirement in SRI which involved Alternate Wetting and Drying (AWD) cycle at different deficit water level varied from 2635 mm to 1696 mm with an average of 2071 mm. The highest seasonal water requirement of 2635 mm was achieved at 2days interval when irrigation was made at 100 % water application level (i.e. at 0 % deficit) and the least seasonal water requirement of 1696 mm was obtained at 4-days interval when irrigation was made at 25 % water application depth (75 % deficit)

The average means irrigation water requirement of SRI treatments T_1, T_2, T_3, T_4, T_5, T_6, T_7, T_8, T_9, T_{10}, T_{11}, and T_{12}

relative to conventional farming method recorded a convincing water savings of 29.5, 34.4, 39.5, 44.6, 40.9, 44.1, 47.5, 50.8, 47.0, 49.5, 52.1 and 54.6 % respectively. The approximate average means irrigation water savings of 30 – 60 % over the conventional farming system were achieved as a result of SRI treatments.

The flow rate across the rice growths stages for both conventional and SRI practice varied from 5.3 and 3.0 litre/seconds to 1.4 and 0.7 litre/seconds with an average of 3.7 and 2.1 litre/seconds respectively. The maximum flow rate was recorded at the initial growth stage and at the beginning of mid-season stage (i.e. at heading) because irrigation at a ponding depth of 2 cm in SRI and 10cm in Conventional were made at initial growth stage in order to maintain humidity during the first two weeks while at the beginning of late-season stage, rice water requirement heavily increases because at this stage water was absorbed through the stem of the rice for use during the flowering and the subsequent use during the grain production of the rice. While the least flow rate was recorded at grain filling stages because at this stage, rice has already taken more water into its stem during heading and flowering growth stages and the rice has already produce 50% of its grains, shading of leaves occurred, thereby required less amount of water.

The effects of deficit irrigation level and irrigation interval on seasonal irrigation water requirement (IWR) under SRI practice during 2017/2018 and 2018/2019 irrigation seasons shows a significant variation at 5% and 1% probability level.

when analyses was made with respect to deficit irrigation level, on average, the highest average means seasonal irrigation water requirement of 2316.024 mm was recorded at 0 % deficit irrigation level ($I_{D100\%}$), while the lowest average mean of 1850.184 mm was recorded at 75% deficit irrigation depth ($I_{D25\%}$).

When the average means seasonal irrigation water requirement was analyzed with respect to irrigation intervals, the highest average means seasonal irrigation water requirement of 2353.75 mm was recorded at irrigation intervals of 2-days, while the lowest average mean of 1836.875 mm was recorded at irrigation interval of 4-days.

ACKNOWLEDGEMENT

The authors wish to express their special thanks to late Prof. A. A. Ramalan and Prof. O. J. Mudiare for their encouragement, constructive critism, and proper supervision to the completion and success of this research. We wish the soul of prof. A. A. Ramalan rest in eternal peace and Jannatu Firdausi be his final abode.

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