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***RESEARCH PAPER***

# Land gradient and configuration effects on yield, irrigation amount and irrigation water productivity in dry direct seeded rice and non-puddle transplanted rice in cauvery delta zone

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**Abstract :** Field experiments were conducted in two different locations in the Cauvery delta zone - *viz*., old delta at Tamil Nadu Rice Research Institute (TRRI) Aduthurai, and new delta at Soil and Water Management Research Institute (SWMRI), Kattuthottam, Thanjavur.Laser levelling with 0% gradient significantly reduced irrigation amount and/or increased irrigation water productivity (WPi) in all crops/systems grown on the flat compared to farmer leveling practice. However, water advancement rate in farmer's field generally very low because of flat configuration and or sub – optimal flow rate, resulting in high rates of drainage below root zone, more so at the head end of the field than tail end because of longer period of flooding of soil surface at the head end.It is hypothesized that formation of a uniform gradient from the head to tail end of the field increase the water advancement rate, reduce irrigation input and increase irrigation water productivity.Experiments were conducted during *Kharif* (*Kuruvai*) 2014, late *Samba* 2014 - 15 and *Kharif* (*Kuruvai*) 2015 at TRRI, Aduthurai and during early *Kuruvai* 2014, *Samba* 2014 - 15 and early *Kuruvai* 2015 at SWMRI, Kattuthottam, Thanjavur to evaluate the effect of land gradient on water and rice crop and water productivity. The experiments were laid out in Randomized Complete Block Design (RCBD) with three land slope treatments in which three observations are taken on each plots (16 m x 50 m) (at the head, middle and tail of the plot) and three replications (blocks) in dry direct seeded rice (DSR) and non – puddle machine transplanted rice (NPTR). The slopes studied are $T_1$ - 0.0 per cent slope, $T_2$ - 0.1 per cent slope (5 cm gradient in 50 m run) and $T_3$ - 0.2 per cent slope (10 cm gradient in 50 m run) with precise leveling. Short duration (100 – 110 d) rice variety ADT (R) 45 was raised as a test variety in the field experiments conducted during early *Kuruvai* and *Kuruvai* seasons in both the experimental sites. For *Samba* / late *Samba* season, long duration (135 – 150 d) rice variety CR 1009 was used in both the experimental sites. With regard to different slope gradients, it was worked out as 2159 litres as water requirement to produce 1 kg of rice under 0.1 per cent slope as against 2566 litres in 0.0 per cent slope across the seasons which indicated a water saving of 407 litres (15.8%) of water per kg of rice at Aduthurai location, whereas it was 661 litres (20.7%) at Thanjavur experimental site. The results further suggested that the effect of land slope gradients was explicitly pronounced more in the sandy loamy soils as compared to clayey loamy soils.

**Key Words :** Precision laser land leveling, Slope, irrigation schedule (stingray flow meter), Soil water tension (tensiometers), Dry direct seeded rice, Non – puddle machine transplanted rice, Grain yield, Total water use, Water use efficiency, Water productivity.

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About half of the total fresh water used for irrigation in Asia is used for rice production. Decreasing water resources and increasing water costs necessitates increasing water use efficiency for rice. However, food security is threatened by yield stagnation and sustainability of rice production is at risk due to groundwater depletion. Efforts are being made to increase rice water use efficiency since rice is an inefficient water user (Bhuiyan *et al.,* 1994) and there is increasing scarcity of water for irrigation and increasing costs of its use. Improved irrigation efficiency is needed to end unsustainable over - exploitation of surface and groundwater resources and increase the amount of water available for non-agricultural purposes (urban, environmental and recreational) (Humphreys *et al.,* 2004). Increasing water use efficiency involves use of less irrigation water to grow a crop with the same or higher rice yield. Water losses in rice can be reduced by lowering seepage and percolation losses through reduced hydrostatic pressure (Kukal and Aggarwal, 2002 and Humphreys *et al.,* 2004).

In agriculture, land development plays a key role because undulating topography of the soil surface has a major impact on the germination, water saving and crop yield. Traditional methods of leveling lands are more cumbersome and time-consuming. A significant (20-25%) amount of irrigation water is lost during its application at the farm due to poor farm design and unevenness of the field (Cook and Peikert, 1960). Unevenness of fields leads to inefficient use of irrigation water and also delays tillage and crop establishment options. Fields that are not level have uneven crop stands, increased weed burdens and uneven maturing of crops. All these factors tend to contribute to reduced yield and grain quality which reduce the potential farm gate income.

Laser levelling of agricultural land is a recent resource conservation technology in India. Its results are quite encouraging. Precision land levelling may increase the water application efficiency and consequently increase the yield of crops (Ahmed *et al.*, 2001). It has the potential to change the way foodis produced by enhancing resource-use efficiency of critical inputs without any disturbing and harmful effects on the productive resilience of the ecosystem.

Effective land leveling is meant to optimize water - use efficiency, improve crop establishment, reduce the irrigation time and effort required to manage crop. Laser land leveler is intended to enable the users to identify and understand the working of the various components of a laser-controlled land leveling system; undertake a topographic survey using a laser system; set up and use a laser-controlled leveling system. It is hoped that the users (farmers and service providers) could be beneficial by adopting this important resource conserving technology as a precursor to several other improved agronomic, soil and crop management practices. Laser technology can ensure very accurate and precision land leveling to extent of $\pm$2 cm (London, 1995 and Waker, 1989).

Laser land levelling results in saving of 20 to 25 per cent of irrigation water and facilitates field operation and increases yield (Rickman, 2002). Whereas, the efficiency of the irrigation system could be improved easily by adopting proper technologies (Ashraf *et al.,* 1999). However, the water use efficiency along with crop yield could be increased by adopting resource conservation technologies *viz.,* laser leveling.

It has been noted that poor farm design and uneven fields are responsible for 30 per cent water losses (Asif *et al.,* 2003). Precision land leveling facilitated application efficiency through even distribution of water and increased water-use efficiency that resulted in uniform seed germination, better crop growth, higher crop yield and lower labour requirement (Jat *et al.,* 2006). Land Levelling improved the farm income by improving system productivity to 7 per cent and by saving irrigation water upto 14 per cent in rice and upto 13 per cent in wheat (Jat *et al.,* 2009). Thus, laser leveller saves a substantial amount of water as it levelled all the ups and downs in the soil surface for the quick movement of irrigation water in the plot which further resulted in the uniform plant growth and higher yields (Pal, 2005).

The scarcity of canal water supplies coupled with unfit ground water has compelled the farmers to utilize available water resources more wisely and efficiently. Under these circumstances, precision land leveling can help the farmers to utilize the scarce land and water resource more effectively and efficiently towards increased crop production (Abdullaev *et al.,* 2007).

In DSR technique, grain yield and water productivity increased by 2.94 and 14.43 per cent, respectively, with laser leveling compared to transplanted rice (Jat *et al.,* 2006). Therefore, laser land-leveling is a precursor technology and rather an entry point for success of DSR through improved water and crop management.

Manual transplanting is the most popular method in rice cultivation, though transplanting is an effective means of rice cultivation, its tedious, laborious and time consuming, shortage and high cost of labour during peak periods of agricultural operations. Further it is very difficult to cover larger areas within short span by using manual labour. Delay in transplanting from normal date causes considerable reduction in rice yield (Safdar *et al.,* 2008). Under such situation mechanical transplanting is an alternative option as it requires less labour, ensures timely transplanting and also contributes higher yield, (Singh *et al.*, 1985).

Effective energy use is one of the conditions for sustainable agricultural production, since it provides financial savings, fossil resources preservation and air pollution reduction (Uhlin, 1998). Productivity of agriculture depends on adequate inputs such as power (farm machines, human labour and animal draft, electrical), improved seeds, fertilizers and irrigation water. Crop yield is directly proportional to the energy input (Srivastava, 1982). In comparison to conventional cultivation with plough, the fuel consumption could be reduced for cultivation by 2 to 3 fold with a strip tillage system (Islam *et al.,* 2012).

Zero tillage or reduce tillage establishment is used widely for many crops around the world and this technology has potential to allow saving in time, energy, water and labour during rice establishment (Piggin *et al.,* 2002). It has, therefore, growing significance due to receding water table (Humphyreys *et al.,* 2004), rising costs of labour for transplantation of paddy and adverse effects of puddling on the soil health (Singh *et al.,* 2005).

Mechanical transplanting into zero tilled plots (zero tilled transplanted) has been shown to be a promising technology for establishing rice in Haryana with large energy and labour saving and regular plant spacing (Malik and Yadav, 2008 and Sharma *et al.,* 2005).

Under these back ground, the present study was taken up to evaluate the effect of land configuration (slope) on water use, water productivity and the productivity of DSR and NPTR as a whole.

## MATERIAL AND METHODS

The soil of the experimental site at TRRI, Aduthurai was clay in texture and moderately drained. The soil was low in available nitrogen, high in available phosphorus and medium in available potassium. At SWMRI, Thanjavur the soil was sandy loam with good drainage with low available nitrogen, high available phosphorus and medium available potassium.

The first site was located at Tamil Nadu Rice Research Institute (TRRI), Aduthurai in old Cauvery delta zone (CDZ) of Tamil Nadu at 11$^{o}$ North latitude and 79 $^{o}$ East longitude at an altitude of 19.5 m above Mean Sea Level (MSL) while the second site was in the new CDZ at SWMRI, Kattuthottam, Thanjavur at 10$^{o}$45' North latitude and 79$^{o}$ East longitude at an altitude of 50 m above MSL.

Though rice crop is being grown in both *Kuruvai* and *Samba* seasons under irrigated condition, the prevailing weather parameters differ between these two seasons. Comprehensively during *Kuruvai* season, the total rainfall received would be around 465 and 233 mm, while the average values for maximum temperature would be 34.3 and 36.2 $^{o}$C, minimum temperature 25.1 and 26.7 $^{o}$C, relative humidity (RH) 83.6 and 79.1 per cent and bright sunshine 5.8 and 6.7 hours, respectively in Aduthurai and Thanjavur locations.

In respect of *Samba* season, the values for total rainfall 189.2 and 433.1 mm, maximum temperature 30.7 and 30.1$^{o}$C, minimum temperature 20.6 and 22.9$^{o}$C, morning RH 93.5 and 87.4 per cent, evening RH and bright sunshine 6.5 and 4.5 hours, respectively in Aduthurai and Thanjavur locations. It is inferred that the total quantity of rainfall received is relatively higher during *Samba* over *Kuruvai* season.

The region is characterized by a sub-tropicalclimate with a hot dry summer (March-June), and extended wet period from September to February. The annual rainfall in old CDZ is 1237.2 mm in 2014 and 1292.4 mm in 2015 while the same was 1014.4 mm and 1169.7 mm during 2014 and 2015, respectively in new CDZ.

The study includes three land configuration sloping treatments with larger plot size to facilitate land sloping with laser land leveler. The reduced levels of grid points Gross plot: (50.0 m × 16.0 m = 800 m$^2$) were taken prior to and after the leveling operation, following standard surveying and leveling procedures.

After dry tillage, the layout of the experiment was marked before laser leveling of each plot. A commercial unit of laser guided land leveller (Spectra Precision ® Laser Model GL612 and GL622) was used for the study. The gradient was set as per treatment while doing the laser leveling. In the first year, there was significant shifting of soil while in second year; a fine touch was given to maintain the gradient as per treatments.

The plots were laid out with irrigation and drainage channels all around the experimental field. Buffer channels were formed at a spacing of 0.5 m, between the plots horizontally. Irrigation channels are formed vertically at a spacing of 0.70 m. A buffer spacing of 1 m was kept between the replications.

The periodical biometric observation on irrigation water productivity and yield attributes were recorded and used the appropriate statistical model for a RCBD with 'k' treatments (3 in our case) and 'b' blocks (3 reps in our case) in which's' observations are taken on each block (the three measurements at the head, middle and tail of the plot in our case) is:

$$\gamma_{ijs} = \mu + \tau_i + \beta_j + \varepsilon_{ij} + \vartheta_{ijs}$$

$\gamma_{ijs}$ is the observation at the $s^{th}$ subsample of the $i^{th}$ treatment in the $j^{th}$ block.

$\mu$ is the overall mean

$\tau_i$ is the effect of $i^{th}$ treatment,

$\beta_j$ is the effect of the $j^{th}$ block,

$\varepsilon_{ij}$ is the effect of $i^{th}$ treatment in the $j^{th}$ block

$\vartheta_{ijs}$ is the residue of the $s^{th}$ subsample of the $i^{th}$ treatment in the $j^{th}$ block.

**Sowing :**

Sowing was done dry seeding using seed drill during *Kuruvai* season. In *Samba* season, because of wet conditions, rice crop was mechanically transplanted under non-puddled conditions. The rice variety ADT (R) 45 was sown during *Kuruvai* season with a seed rate of 35 - 40 kg ha$^{-1}$. The seeds were first treated with carbendazim @ 2.0 g kg$^{-1}$ of seed and sowing was taken up with tractor drawn seed drill with a row to row spacing of 20 cm. Rice variety CR 1009 was sown in mat nursery for mechanical transplanting under non puddled condition during *Samba* season with a seed rate of 18-25 kg ha$^{-1}$. The seeds were first treated with carbendazim @ 2.0 g kg$^{-1}$ of seed.

**Fertilizer application:**

For DSR, recommended dose of nutrients *viz*., 150:50:50 kg NPK ha$^{-1}$ was applied uniformly for all treatments. The entire P fertilizer was applied as basal in the form of single super phosphate (16 % $P_2O_5$), in addition, zinc sulphate was applied @ 25 kg ha$^{-1}$. Nitrogen (as urea) and potassium (as muriate of potash – 60 % $K_2O$) were applied in four equal splits at basal, active tillering, panicle initiation and heading stages of rice crop.

For NPTR, recommended dose of nutrients *viz.,* 150:50:50 kg NPK ha$^{-1}$ was applied uniformly for all treatments as per the schedule. Entire dose of phosphorus was applied as basal in addition to zinc sulphate @ 25 kg ha$^{-1}$ and gypsum @ 500 kg ha$^{-1}$. The fertilizer N was applied in 4 split doses at basal, active tillering, panicle initiation and heading stages. The K fertilizer was applied in the form of muriate of potash (60 % $K_2$ O) in two equal splits one at basal and another at panicle initiation stage.

**After cultivation practices:**

Thinning and gap filling were done within 15 days after sowing (DAS) in case of DSR and gap filling alone was done on 7 days after transplanting (DAT) in case of NPTR. Plant population was maintained uniformly in all the experimental plots.

For DSR, pre-emergence application of the recommended herbicide, pendimethalin @ 1.0 kg a.i. ha$^{-1}$ on 3 DAS keeping a thin film of water in the field, post emergence herbicide, bispyribac Na @ 50 g a.i.ha$^{-1}$ on 20 DAS mixed with water at the rate of 500 litres ha$^{-1}$. which was followed by one hand weeding at 35 DAS.

For NPTR, butachloar @ 1.25 kg a.i. ha$^{-1}$ was applied as pre-emergence application on 3 DAT. Inter cultivation was given with cono weeder on 45 DAT and one hand weeding on 60-70 DAT. Need based plant protection measures were taken up to control pest and diseases as per the Crop Production Guide (TNAU, 2012).

**Soil drying patterndry direct seeded rice (DSR):**

Soil water tension was used as indicator for soil drying pattern. To measure soil water tension, Irrometer® gauge tensiometers were installed with the ceramic cup at a depth of 15 cm. Three tensiometers were installed in each plot to represent head, middle and tail end of the plot. The tensiometer installed at head end was 9 m away from the water inlet. Soil water tension was measured every morning at 9:00 am.

**Soil drying pattern non – puddle machine transplanted rice (NPTR) :**

AWD can be managed based on visual or measured observations. Visual observations include irrigation scheduling when hairline cracks start to appear on the soil surface.

**Irrigation management :**

Irrigation water applied to each plot was measured individually using Greylineul trasonic Doppler Flow Meter. For the first three weeks in order to get proper crop establishment, rice crop was irrigated based on visual observation of rooting depth and soil moisture condition for both *Kuruvai* and *Samba* season crops. After 3 weeks, irrigation water was applied to each plot based on average soil moisture tension reading of 3 tensiometers installed at head end, middle end and tail end of the plot at 10 kPa and 15 cm soil depth for *Kuruvai* season DSR crop. The samba season, being a wet North East monsoon period, after 3 weeks, irrigation water applied based on AWD principles by visual observation. The cut off time for irrigation was 45 m for the first irrigation (to ensure proper germination / establishment) and 40 m for rest of the irrigation cycles.

## Results and Discussion

The results obtained from the present investigation as well as relevant discussion have been summarized under following heads :

**Grain yield (kg / ha):**

The perusal of mean data on grain yield (Table 1) revealed that difference in grain yield among the different land slope treatments was significant in both the locations across all the seasons.

Among the different land slope treatments tried, land slope of 0.1 per cent ($S_2$) registered significantly higher grain yield of 5110 and 4760 kg / haacross the three seasons at Aduthurai and Thanjavur, respectively as compared to land slope of 0.0 per cent (4719 and 4343 kg/ha, respectively in Aduthurai and Thanjavur sites). The enhanced yield achieved under 0.1 per cent slope was in addition to the water savings realized in the same treatment.

Significant yield difference between the seasons in both the experimental sites was also observed higher yield of 6083 and 6511 kg / hawas obtained under NPTR raised during the *Samba* season at Aduthurai and Thanjavur, respectively.

Enhanced yields recorded during *Samba* season in both the sites was mainly attributed to the potential long duration variety (CR 1009) grown during this season and not because of the seasonal influence.

A common finding has been that irrigation rates can indeed be reduced without lowering grain yield (Yang *et al.,*2004 and Zhang *et al.,*2009). When biomass and yield components were higher for a particular treatment especially under 0.1 per cent slope gradient in the present investigation, certainly that treatment must be with higher yield. In respect of rice, because of higher dry matter production, higher grain yield was reported by Kumar *et al.* (2013).

Tuong and Bouman (2003) documented that soil water lower than saturated condition reduced rice yield. Similarly, Sharma (1989) found no effect on rice yield and water saving of 843 mm (23 %) by allowing the soil to dry to -10 kPa at 10 cm depth prior to reflooding for periods of 1-3 weeks.

Similar to biomass production, the highest grain yield was observed during *Samba* season (wet) as compared to *Kuruvai* season (dry). It is an established fact that the rice yield of winter season is low. According to Subrahmaniyan *et al.* (2004), when compared to summer season, the RTD (Relative temperature disparity) values in winter season were very low especially during the months of October and November.

Laser land leveling results in saving of 20 -25 per cent of irrigation water apart from several other benefits (Rickman 2002). Hence DSR yield is correlated with precision of land leveling (Lantican *et al.,* 1999). Though the benefit of land leveling with 0.0 per cent slope was already established in the above experiments, in order to

**Table 1 and 2 : Effect of land gradient treatments on Grain yield (kg / ha) and total water use (mm) of DSR and NPTR**

| Treatments | Grain yield (kg / ha) and total water use (mm) | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Grain yield (kg / ha) | | | | | | | | Total water use (mm) | | | | | | | |
| | Aduthurai | | | | Thanjavur | | | | Aduthurai | | | | Thanjavur | | | |
| | K* | K** | LS* | Mean | EK* | EK** | S* | Mean | K* | K** | LS* | Mean | EK* | EK** | S* | Mean |
| $S_1$ | 4008b | 4240b | 5909a | 4719 | 3508c | 3197a | 6323a | 4343 | 1376a | 1128a | 1129a | 1211 | 1343a | 1379a | 1428a | 1383 |
| $S_2$ | 4410a | 4639a | 6281a | 5110 | 4074a | 3537a | 6670a | 4760 | 1227b | 1092a | 990b | 1103 | 1161b | 1198b | 1245b | 1201 |
| $S_3$ | 4172ba | 4391ba | 6060a | 4874 | 3815b | 3160a | 6540a | 4505 | 1250b | 1103a | 1004b | 1119 | 1145b | 1240b | 1289b | 1225 |
| Mean | 4197 | 4423 | 6083 | | 3799 | 3298 | 6511 | | 1284 | 1108 | 1041 | | 1216 | 1272 | 1321 | |

$S_1$: 0.0 per cent slope, $S_2$: 0.1 per cent slope and $S_3$: 0.2 per cent slope: Means with the same letters are not significantly different at P = 0.05.
Aduthurai - K* - *Kuruvai* DSR (2014), K**- *Kuruvai* DSR (2015) and LS*- late *Samba* NPTR (2014 – 15) and Thanjavur - EK* - early *Kuruvai* DSR (2014), EK** - Early *Kuruvai* DSR (2015) and S* - *Samba* NPTR (2014 – 15). DSR – Dry direct seeded rice and NPTR – Non- puddle transplanted rice

refine the land leveling technology with an aim to reduce the water use further besides achieving an yield improvement, the slope gradients was hypothesized in the present study and as a result higher water productivity was attained under 0.1 per cent slope through higher crop productivity.

**Total water use (mm):**

In general, there was no significant difference in total water use (mm) among the three seasons studied at both the experimental sites (Table 2).

The mean total water use (mm) was higher at Thanjavur location as compared to Aduthurai which was due to the light textured sandy loam soil type of Thanjavur site. The overall mean total water use was the highest at Thanajvur location (1269 mm) as compared to Aduthurai (1144 mm).

The highest water use of 1383 mm was recorded at Thanjavur under 0.0 per cent slope across the seasons, whereas the lowest water use of 1103 mm was recorded in Aduthurai site at 0.1 per cent slope across the seasons.

Land gradient with 0.1 per cent slope had significantly lower water use of 1103 and 1201 mm at Aduthurai and Thanjavur centres, respectively which was followed by 0.2 per cent slope (1119 mm and 1225 mm) and 0.0 per cent slope (1211 mm and 1383 mm).

Among the three seasons studied, the total water use was the highest during *Samba* season at Thanjavur location (1428 mm) which was obviously due to the longer duration variety used in that season. In contrary, the highest water use was observed during *Kuruvai* 2014 at Aduthurai location (1284 mm) which may be due to more frequent irrigation because of scanty rainfall and high evaporation demand.

In the present study also, total water use was higher at Thanjavur site than Aduthurai which might be due to the light textured sandy loam soil type. The sandy loamy soil is normally known for higher infiltration rate and poor water holding capacity. As a result the highest water use of 1383 mm was observed at Thanjavur under 0.0 per cent slope across the seasons. The lowest water use of 1103 mm was observed in Aduthurai site under 0.1 per cent slope across the seasons.

Bhushan *et al.* (2007) also observed irrigation water saving of 25 – 26 per cent with zero till DSR compared with PTR when irrigation for both establishment methods was scheduled on the appearance of hairline cracks, whereas Yadav *et al.* (2011) found a large reduction of 50 per cent in irrigation input in the first year in dry seeded rice on a clay loam (non-puddled) and Mandal *et al.* (2009) reported 60 per cent irrigation water saving with DSR compared with PTR on a silty loam soil. Hence, in addition to soil types, the water input in paddy-fields depends on the rates of the outflow processes and on the duration of land preparation and crop growth and as a result, the method of land preparation would have also contributed in water saving during both the seasons.

As far as land slope gradient concerned, in the clayey soils of Aduthurai, a water saving of 8.9 and 7.6 per cent was observed with 0.1 and 0.2 % slopes, respectively as compared with zero slope. Whereas, it was 13.1 and 11.4 per cent higher irrigation water saving in 0.1 and 0.2 % slopes, respectively than zero slope at Thanjavur under sandy loamy condition. Higher amount of irrigation water use under zero per cent slope might be due to the poor advancement rate in the flat condition which would have ultimately resulted in higher drainage losses. On the other hand, formation of a uniform slope from the head to the tail end of the field in 0.1 and 0.2 per cent slope had increased the water advance rate and reduced the water losses. The present results are in accordance with the findings of Campbell (1989) who reported irrigation advance was substantially affected by inflow rate and surface roughness, whilst recession

**Table 3 and 4 : Effect of land gradient treatments on WUE (kg / ha mm) and WP (kg / m$^3$) of DSR and NPTR**

| Treatments | Water use efficiency (kg / ha mm) and water productivity (kg / m$^3$) | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | WUE (kg / ha mm) | | | | | | | | WP (kg / m$^3$) | | | | | | | |
| | Aduthurai | | | | Thanjavur | | | | Aduthurai | | | | Thanjavur | | | |
| | K* | K** | LS* | Mean | EK* | EK** | S* | Mean | K* | K** | LS* | Mean | EK* | EK** | S* | Mean |
| $S_1$ | 3.52c | 9.92b | 6.30b | 6.58 | 2.90b | 3.06c | 6.37b | 4.11 | 2.91c | 3.76b | 5.24b | 3.97 | 2.61b | 2.31b | 4.39c | 3.10 |
| $S_2$ | 4.46a | 11.61a | 7.84a | 7.97 | 3.97a | 4.13a | 8.29a | 5.46 | 3.59a | 4.24a | 6.33a | 4.72 | 3.40a | 2.96a | 5.33a | 3.90 |
| $S_3$ | 4.12b | 10.71ba | 7.44a | 7.42 | 3.79a | 3.46b | 7.67a | 4.97 | 3.33b | 3.98b | 6.04a | 4.45 | 3.34a | 2.53b | 5.04b | 3.64 |
| Mean | 4.03 | 10.75 | 7.19 | | 3.55 | 3.55 | 7.44 | | 3.28 | 3.99 | 5.58 | | 3.12 | 2.60 | 4.92 | |

$S_1$: 0.0 per cent slope, $S_2$: 0.1 per cent slope and $S_3$: 0.2 per cent slope: Means with the same letters are not significantly different at P = 0.05.
Aduthurai - K* - *Kuruvai* DSR (2014), K** - *Kuruvai* DSR (2015) and LS* - late *Samba* NPTR (2014 – 15) and Thanjavur - EK* - Early *Kuruvai* DSR (2014), EK** - early *Kuruvai* DSR (2015) and S* - *Samba* NPTR (2014 – 15). DSR – Dry direct seeded rice and NPTR – Non-puddle transplanted rice

was affected by slope and surface roughness.

The flow rates of seepage and percolation and the resistance to movement of water in the soil was less in the case of both 0.1 and 0.2 per cent slope and this would have resulted in lesser water use as compared to zero per cent slope (flat condition). In additionthe irrigation was stopped when the advance has travelled 90 % of the length of the plot in both 0.1 and 0.2 per cent slope which might have reduced the total water requirement and ultimately resulted in lesser water use. However, these results differed from the earlier reports of Yadav *et al.* (2014) which indicated that lower water saving on the sandy loam with 0.2 % was because of the inverted "U" shape of the water advance front compared with a


**Fig. 1: Soil water tension 10 kPa at 15 cm soil depth for different land gradient treatments on DSR kuruvai and early kuruvai season vertical bars are ± standard error the mean the old CDZ Clay soil at TRRI, Aduthurai and New CDZ Sandy loam SWMRI, Thanjavur in 2014**

flatter advance with 0.1 % slope which needs further study.

**Water use efficiency (kg/ha/mm):**

Similar to total water use, the water use efficiency (kg/ha/mm) was also significantly influenced by the land slope treatments across the seasons studied in both the experimental sites (Table 3).

Land configuration with 0.1 per cent slope ($S_2$) significantly registered higher water use efficiency of 7.97 kg/ha/mm and 5.46 kg/ha/mm across the three seasons at Aduthurai and Thanjavur centres respectively. The lowest water use efficiency was recorded with 0.0 per cent slope in both Aduthurai (6.58 kg/ha/mm) and Thanjavur (4.11 kg/ha/mm) centres. The enhanced water use efficiency achieved under 0.1 per cent land slope eventually led to higher rice productivity at both the sites.

Significant difference in water productivity was observed among the three seasons studied at both the sites. The non- puddle machine transplanted rice raised during samba season resulted in higher water use efficiency of 7.19 kg/ha/mm and 7.44 kg/ha/mm at Aduthurai and Thanjavur locations respectively. The enhanced water productivity realized during samba season might be due to high yielding longer duration variety (CR 1009) grown during that season.

In the present study, land slope gradients significantly varied for water use efficiency across the seasons studied in both the experimental sites. Because of a great reduction in seepage and percolation due to greater advancement rate, land slope gradient of 0.1 per cent allows for greater WUE and high water saving as compared with 0.2 and 0.0 per cent slope gradients. The increased WUE was mainly due to the increased grain yield as well as reduced water consumption observed in the respective treatments. This result is in conformity with the findings of Wang *et al.* (2004).

**Water productivity (kg /m$^3$) :**

The water productivity (kg/m$^3$) was significantly influenced by the land slope treatments across the seasons studied in both the experimental sites and the mean data on water productivity are presented in (Table 4).

In succession of lower water use and higher water use efficiency, land configuration with 0.1 per cent slope significantly recorded higher water productivity of 4.72 kg/m$^3$ and 3.90 kg/m$^3$ across the three seasons at Aduthurai and Thanjavur, respectively. The lowest water productivity was recorded with 0.0 per cent land slope at both the sites of Aduthurai (3.97 kg/m$^3$) and Thanjavur (3.10 kg/m$^3$).

The effect of slope treatments on water productivity was significant in all the three seasons studied. The higher water productivity of 5.58 kg/m$^3$ and 4.92 kg/m$^3$ at Aduthurai and Thanjavur centres, respectively was observed during samba season raised with non puddle machine transplanted rice. Similar to the trend of water use and water use efficiency, the higher water productivity realized during samba season might be due to higher grain yield attained with the longer duration variety (CR 1009) grown during that season.

Large reductions in water input can be potentially realized by reducing the unproductive evaporation and seepage and percolation flows during land preparation and during the crop growth period (Tuong, 1999; Bouman and Tuong, 2001). The water productivity can be increased either by increasing the yield or by maintaining the yield level and reducing the quantity of water input (Anitha Malar, 2013).

In accordance to the above findings, the highest water productivity has been achieved in 0.1 per cent slope gradient by arresting the seepage and percolation losses through greater advancement rate. Since the water productivity is the derivative of total water used and grain yield, by virtue of lesser water use and higher grain yield obtained under 0. 1 per cent slope, the higher water productivity was accomplished across all the three seasons in both the locations.

Furthermore, because DSR establishes deeper roots and is more efficient at using soil moisture, less frequent irrigation is required during the growing season (Joshi *et al.,* 2013). Similarly the unpuddle rice also saves nearly 300 mm of water in land preparation (Rahman and Mahbub, 2012). Hence in addition to the land slope gradients in water saving, adopting either non puddle transplanted rice cultivation or direct sown rice cultivation would be viable technological option to mitigate GHG emission from rice and to grow rice with less water.

**Soil drying pattern:**

Performance of tensiometers the site specific as in case of the Dry direct seeded rice (DSR) as tensiometers measured the soil water tension and show the irrigation need when it is required. Hence, in sandy loam soil it may show more number of irrigations while in heavy textured it may show requirement of less number of irrigations as macro - pores of light textured soil are not able to hold water at a higher suction while micro - pores of heavy textured soil could hold water up to a higher level of suction Fig.1. Increased grain yield coupled with reduced water intake was due to the conducive soil water movement created by 0.1 slope owing to optimal rate of water advancement. Similar results are reported by Grabham (2012) also observed a wide range in furrow discharge and advance times within each Bay in these systems.

Dry direct seeded rice reduce irrigation input and increase irrigation water productivity, under safe irrigation water management guided by the threshold level of soil water tension (10 - 15 kPa) ata depth of 15 cm. (Wopereis *et al.,* 1996; Bouman and Tuong, 2001; Belder *et al.,* 2004; Singh *et al*., 2017a; Singh *et al*., 2017b; Singh *et al.,* 2017c; Singh *et al*., 2018; Tiwari *et al.,* 2018; Tiwari *et al.,* 2019a; Tiwari *et al.,* 2019b; Kour *et al.,* 2019; Singh *et al.,* 2019). Yadav *et al.,* 2011). The irrigation water requirement for rice fields measurement of soil matric potential with locally fabricated, low cost tensiometers (Hira, 1993). The feasibility scheduling of irrigation to rice on the basis of soil matric potential and deciding on the optimum level of the same to save irrigation water without adverse effects on rice yield.

## Conclusion :

An irrigation threshold of 12 kPa DSR and NPTR irrigation scheduling when hairline cracks start to appear on the soil surface was the optimum in terms of maximizing grain yield, land gradient slope of 0.1 per cent uses lesser water with higher water productivity $WP_I$, $WP_{I+R}$ than other slope studied in both the locations and seasons. This should include studies on the level of water deficit stress to which DSR and NPTR can be safely exposed at different growth stages.

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