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Trade-off with different establishment methods in terms of irrigation water requirement and weed pressure of rice (*Oryza sativa* L.)

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Abstract
Rice consumes more water than any other crop, potentially leading to unsustainable water withdrawals in command areas of irrigated rice ecosystem. Rice production in irrigated ecosystem is going through transition due to rising scarcity of land, water and labour. A major adjustment can be expected in the tillage and method of crop establishment. Direct seeding rice (DSR and WSR) has been proposed as one means of achieving these objectives. Therefore a field study was conducted for three seasons on a clay loam soil in Karnataka, India, during *Kharif* Season (2015 and 2016), *Rabi* season (2015) to investigate the trade-off with different establishment methods in terms of crop performance, water saving and weed pressure of rice (*Oryza sativa* L.). The experiment was conducted in Split-split plot design comprising two tillage practices in main plots, two establishment methods in sub plots and three irrigation scheduling practices in sub-sub plots. Tillage treatments were Dry (No puddling) and wet tillage (puddling), Establishment methods were Direct seeding (DSR, WSR) and Transplanting (NPTR, PTR), Irrigation treatments were based on soil water tension (SWT) ranging from continuous flooding/saturation (daily irrigation) to alternate wetting and drying (AWD) with irrigation thresholds of 10 and 40 kPa at 18-20cm soil depth. Rainfall was average and well distributed in 2014 (763.80 mm), and less than average and well distributed in 2015 (384.60).

Pooled three seasons results indicated that with methods of establishment practices, direct seeding crop matures earlier in 115 days in comparison with transplanted delayed crop maturity by 13 d. direct seeding was more affected than transplanting and more so in the drier year. Crop performance in terms of tiller density, leaf area index and growth rate and yield components were also similar in both establishment methods when irrigation was scheduled daily or at 10 kPa, but crop growth and yield parameters were significantly lower at 40 kPa in both direct seeding and transplanting establishment methods.

In each individual season, yield of direct seeding and transplanting were similar when irrigation was scheduled daily or at 10 kPa. Yields of both direct seeding and transplanting declined under higher water deficit stress (40 kPa irrigation threshold), but more so in direct seeding, and more so in drier year. There was a very large and significant decline in irrigation water input with irrigation at 10 kPa compared to daily irrigation in both establishment methods, but only a very small decline in irrigation amount when the threshold was increased from 10 to 40 kPa. Irrigation water use in direct seeding treatments was significantly lower than in respective transplanting treatments (32% water saving in direct seeding compared to transplanting).

The results suggest the feasibility of reducing irrigation amount while maintaining yield by replacing transplanting with DSR with AWD during wet season and WSR with AWD during dry season, provided that soil tension is kept lower than 10 kPa at 20cm depth, but that threshold needs to be tested over wider range of site conditions and varieties.

Keywords: Tillage, establishment method, soil water tension, irrigation scheduling

1. Introduction
Rice (*Oryza sativa* L.) is considered as the “global cereal’ is the most important staple food in Asia, providing 35-80 per cent of the total calorie intake (Kukul *et al.*, 2005) [14]. In India, Irrigated land which covers 40 per cent of total agricultural area significantly contributes in satisfying 55 per cent of total food requirement of the country. However, on the other hand it consumes almost 70 per cent of fresh water resources with limited scope for further expansion. Agriculture has been a forefront agenda at national and international level for food security

and management of natural resources. Thus, from food security point agronomic practices have a pivotal role to play in the present scenario. Most important crop for Asian people, is in the challenge to develop novel technologies and production systems that will allow rice production to be maintained or increased in the face of declining water availability of command areas of irrigated ecosystems.

In irrigated areas, rice is mainly grown by transplanting seedlings into puddle soil. Such a rice production system, however, requires a large amount of water during puddling and transplanting (Chauhan, 2012a, Chauhan, *et al.* 2012) [1, 3, 4]. In general, rice accounts for 34-43 per cent of the world's irrigation water (Bouman, *et al.* 2007). Water, however, is becoming an increasingly scarce resource in India (Kumar and Ladha, 2011, Mahajan, *et al*. 2012) [15, 16]. Therefore, the increasing water scarcity threatens the productivity and sustainability of the irrigated rice system in India.

In Karnataka state of India, rice is cultivated in 1.4 M ha with canal water as the principal source of irrigation in the command areas of Cauvery, Tungabhadra and Upper Krishna. Where, conventional puddle transplanting is the major system of cultivation. (Negalur and Halepyati, 2016) [17]. In this region, rice transplanting mainly depends on the time of release of water from the reservoir. When the water is released late, the rice planting is delayed and there is always labour shortage because of narrow window of transplanting. Also, the availability of the canal water greatly varies with the location of the field. The area located at tail end generally receive water late in the season and sometime also face mid-season water scarcity.

In addition to the water scarcity, labour scarcity is also a concern. In the traditional transplanting nursery raising, puddling and transplanting operations consume a large amount of labour. Because of the increasing demand for labour in non-agricultural sectors and increasing labour costs resulting from the migration of rural labour to the cities, it is difficult to find labour at the critical time of transplanting (Chauhan 2012b) [2]. Reduced labour availability resulted in pushing up the cost of transplanting, which in turn squeezed, the profit margins for farmers (Yadav, 2011) [20]. Alternate crop establishment like direct seeding has a major advantage in this situation due to elimination of labour requirement for nursery preparation and maintenance, pulling out and transport of seedlings and transplanting (Yadav *et al.*, 2014). Furthermore, the total crop cycle is shorter by 10 -15 days because of the absence of transplanting shock. Other resource conservation technologies like reduced tillage can also help in advancing the season (Yadav *et al.*, 2011) [20]. Secondly, proper water management can also helps in increasing the water availability at tail end. Therefore, farmers in some areas are shifting from traditional transplanted rice to mechanized-sown dry-seeded rice (DSR) in response to the rising production costs and shortages of labour and water. Already a section of rice farmers successfully adapted direct seeding (DSR) technologies in these irrigated areas. DSR has several advantages over puddled transplanted rice. However, weeds are the main biological constraint to the production of DSR (Chauhan, 2012b, Chauhan and Johnson, 2010, Chauhan and Opeña, 2012, Chauhan, *et al*. 2012) [2, 6, 4, 3].

Weeds are the major cause of yield reduction in direct seeded rice. The process of puddling actually consists of primary (pre-puddling) and secondary (puddling) tillage. The pre puddling tillage is mainly aimed at mixing/burying stubbles, levelling the land and reducing weed growth. The effect of puddling (wet tillage) on puddle quality and percolation rate depends on initial soil conditions created by pre-puddling (dry) tillage (Kukal and Sandhu, 2004) [13]. Studies (Gajri *et al*, 1999) [8] have reported a decrease in weed biomass with increase in pre-puddling tillage intensity in sandy loam soils. There is thus, a need to evaluate sustainable tillage, establishment methods and water management practices. Hence, the present investigation was undertaken at Tungabhadra irrigated command area of Karnataka to study the Trade-off with different establishment methods in terms of crop performance, water saving and weed pressure of rice (*Oryza sativa* L.)

2. Materials and Methods

2.1. Experimental site

The study was carried out on the agricultural research station, Gangavathi, India ($15^0 35'$ N, $76^0 15'$ E, 419 m ASL) during 2014 (*wet* and *dry* seasons) and 2015 (*wet* season). The climate is semi arid eco-sub region with a hot summer, wet monsoon season (late June to mid September) and a cool dry winter. Average annual rainfall is 542 mm, 85% of which falls during the monsoon. The soil is medium deep black clay with organic carbon content of 8.25 g kg^{-1} slightly alkaline in reraction (pH 8.62). Soil is low in available nitrogen (198.46 kg ha^{-1}), medium in available phosphorus (59.64 kg ha^{-1}) and high in available potassium content (369.8 kg ha^{-1}). The subsoil is clay and overlying clay loam soils. There is a hardpan around 15-25 cm depth with a bulk density of 1.72 Mg m^{-3}. The depth of groundwater at the site was around 56m and quality of water good for all crops. The site was under a rice-rice cropping system for 5 years prior to establishment of the experiment.

2.2 Experimental design and treatments

The experiment was laid out in three replications in a split-split plot design with two tillage practices *viz.*, dry tillage (unpuddled) and wet tillage (puddle) in main plots, two establishment methods *viz.*, direct seeding (dry direct seeded rice-DSR, wet direct seeded rice-WSR) and Transplanting (non puddle transplanted rice-NPTR, puddle transplanted rice-PTR) in sub plots and three Irrigation schedules *viz.*, (i) Daily (continuous flooding) and intermittent (generally referred to as AWD treatments) irrigation when the soil water tension (SWT) at 20cm depth increased to (ii) 10 kPa, (iii) 40 kPa in sub-sub plots. The daily irrigated treatments were topped up to 50mm standing water depth. The amount of irrigation water applied to all AWD treatments was 50mm at each irrigation.

2.3. Site preparation

The site was cultivated and laser levelled prior to establishment of the experiment. Plot size was 15m × 6.2 m. Each plot was demarcated with a plastic lining to prevent seepage. Plastic lining was done before sowing in all experimental individual plots. Around the bunds of all experimental plots 0.6m depth plastic lining was made using polythene plastic sheet of thickness 0.5mm guage. All the plots were bounded by earthern bunds to prevent lateral movement of water into and through the bunds. There was a 1m wide buffer between all sub-plots and the treatments were placed in the same plots each year. For dry tillage soil puddling was replaced by two shallow dry tillage followed by two harrowings used both for directly sowing (DSR) and non puddled transplanting (NPTR) taken up. For wet cultivation (WSR and PTR), the land was prepared using tractor drawn puddler twice with disc puddler and finally levelled using tractor drawn spike tooth harrow.

2.4 Crop management

The variety used in the investigation was GNV 10-89 (IET-7219) medium slender grain type variety suitable for both *wet* and *dry* seasons, matures early in about 125-130 days. For direct seeding (DSR and WSR) seed rate of 35 kg ha^{-1} was used at a spacing of 20cm between rows, whereas for transplanting (NPTR and PTR) seed rate of 62.5 kg ha^{-1} used. Twenty five day old seedlings were transplanted in PTR and NPTR with 30×10 cm geometry (2-3 seedlings $hill^{-1}$). For non puddle transplanted rice, light irrigation and drainage of excess water before transplanting was followed. In DSR and WSR, pendimethalin 30 EC @ 1 kg.a.i/ha at 3 days after sowing was applied as pre emergent followed by bispyribac sodium (10%) SC @ 35 g.a.i ha^{-1} sprayed at 20 days after sowing (DAS) as early post emergent with the help of hand operated knapsack sprayer. Later two hand weedings at 30 DAS and 50 DAS in DSR and WSR was taken. In PTR and NPTR, six days after transplanting, butachlor 50 EC at the rate of 2.5 lit. ha^{-1} was sand mixed and broadcasted uniformly over the field containing a thin film of water followed by two hand weedings at 20 and 40 days after transplanting (DAT). Fertilizers were applied@ 150:75:75 kg ha^{-1} as per the package recommendations. Fifty per cent N, 100 per cent P and K was applied at the time of transplanting/sowing in different establishment methods, while remaining 50 per cent N applied in two equal doses at the time of maximum tillering and panicle initiation stage in all establishment methods At early stage of crop growth to avoid micro nutrient deficiency $ZnSO_4$ @10 kg ha^{-1} applied through broadcasting method. Need based plant protection measures were followed with dinitofuron, chlorpyriphos, and propiconazole to control brown plan hoppers, stem borer and neck blast respectively.

2.5 Soil water monitoring

2.5.1 Irrigation

Irrigation was applied to each plot measured using greyline flow meter. It measures water level and velocity in partially filled pipes and open channels. The instruments works with water level from 1" to 15 feet. Finally total amount of water used by the crop was calculated based on readings from greyline flow meter and the time taken to irrigate individual plot recorded manually from different irrigation cycles and expressed in mm ha^{-1}. Flow meter measures velocity, water level and finally records Flow volume ($m^3 min^{-1}$). The amount of irrigation water applied to all irrigation scheduling treatments was 50mm at each irrigation cycle. The total amount of irrigation water was calculated from the sum of all irrigations, including pre-tillage and pre-sowing/transplanting irrigations.

In wet season for the first 40 DAS, the direct seeding was irrigated to keep soil water tension below 10–15 kPa at 10cm soil depth to avoid water deficit stress during crop establishment. Thereafter, the irrigation treatments commenced in both transplanting and direct seeding. In dry season the irrigation treatments commenced after 60 DAS. The AWD irrigation treatments were scheduled on the basis of soil water tension measured using irrometers with the ceramic cup at a depth of 18–20 cm. All transplanted treatments were continuously flooded for the first 15 DAT prior to commencement of the irrigation scheduling treatments.

2.5.2 Soil drying pattern

Soil water tension was measured every morning at 09:00 am using Irrometer1 gauge tensiometers with the ceramic cup at a depth of 18-20 cm.

2.6 Observations

2.6.1 Crop growth, yield and yield components

Tiller density (no.m^{-2}) was determined every fortnight by counting the number of tillers in a 1m row (Direct seeding) or 6 hills (equivalent to 0.9 m row length) within a row (Transplanted) at two fixed places in each plot. AccuPAR model LP-80 portable probe was used for fortnightly in-field measurement of leaf area index (LAI), commencing 45 DAS. Measurements were made across five rows, with the probe parallel to the rows, at one fixed location in each plot. Plant samples were collected fortnightly from 0.5mrow length (Direct seeding) or 3 hills (0.45m row length) within a row (Transplanted) at two different places to measure dry matter accumulation after drying the plant samples at 60◦C for 72 h.

Grain yield was determined from an area of $25m^2$ in the centre of each plot, which was harvested and threshed manually. Grain moisture content was measured for each plot using a moisture meter and yield was expressed as t ha^{-1} at 14% grain moisture. The fresh weight of straw was calculated after deducting grain yield from the bundle weight of each plot. Straw moisture content was measured by taking a small sample and oven drying at 60◦C for 72 h and straw yield was expressed as t ha^{-1} at 0% moisture content. Harvest index was derived as the ratio of dry grain yield to total biomass at harvest.

Panicle density was determined in 0.9 and 1m row lengths in transplanted and direct seeded methods, respectively, at the same locations where tiller density was determined. The number of filled florets (grains) and unfilled florets per panicle were determined in 10 randomly selected panicles from each plot at harvest. Floret fertility was calculated as the percentage of filled grain to the total number of florets per panicle. Average grain weight was determined from the weight of 1000 grains from the threshed grain sample for each plot and expressed at 14% moisture content.

2.6.2 Water productivity and water use efficiency

Water productivity (WP_{I+R}) was determined based on the ratio of grain yield to amount of irrigation water plus rainfall during the season and expressed in g grain kg^{-1} water (Yadav *et al.*, 2011) [20]. Water use efficiency (WUE) was determined based on the ratio of the yield to the water applied during the irrigation season (Gupta and Acharya, 1993) [9].

2.6.3 Weed parameters

Weed samples were collected in from 1m x1m quadrate in the net plot area maintained in each plot. Both pre and post emergence herbicides were used as per normal crop management. The population of sedges, grasses and broadleaf weeds were separately counted at 20, 40 and 60 DAS. The collected weed samples were washed with tap water and oven dried at 70ºC for 48 hours and dry weight recorded and expressed in g m^{-2}. The total weed count and total dry matter of weeds was subjected to $\sqrt{}$ x+0.5transformation.

2.7 Weather data

Rainfall was measured at the experimental site each morning at 08:30 am using a standard manual rain gauge. Daily maximum and minimum temperature were recorded at the regional meteorological station of ARS, Gangavathi which was about 500 m from the experimental site.

2.8 Statistical analysis
The data collected from different experiments was analyzed statistically by the procedure prescribed by Gomez and Gomez (1984) [10]**.** Critical difference were calculated at 5% level wherever 'F' test was significant.

3. Results
3.1 Rainfall
The rainfall amount and distribution were quite different during the 2 years of experimentation (Fig. 1). The total receipt of rainfall during year (2014-15) and (2015-16) was 763.80 and 384.60 mm, which is 40.84 per cent higher and 40.99 per cent less than the average rainfall. There was variation in the rainfall during the study years in relation to that of average of past 35 years (Table 1 and Fig. 1). During Wet (2014) season, the rainfall distribution was uniform throught crop growth season and also timely sowing (August first week) resulted in good harvest. During this season more false smut incidence was also observed. Usually false smut believed to be a sign of bumper crop. Whereas, rice yields of Gangavathi regions are severely affected by weather extremes during *dry* season. Single day received 110 mm rainfall during first fortnight of May month coupled with severe hail storm attack resulted in injury to plant organs results in poor rice yields. However, Wet season (2015) received late onset monsoon rains results in late release of canal water resulted to late sowing (last week of August). Sowing dates reconfirms the fact that climate is important, but not sole determinant of planting date. The timing of sowing in a year depends on both economic and climatic conditions. Delayed monsoon also resulted in delayed operations like land preparation, sowing and harvesting. Often continuous dry spells resulted in outbreak of pest incidence such as stem borer, leaf folder, bacterial leaf blight also observed during the season lowering the yield compared to good yielding season of Wet (2014). The temperature and relative humidity existed during the experimentation period were conducive for growth and development of rice.

3.2 Effect of establishment method on rate of soil drying
In the wet season, soil water tension at 15 cm in all the treatments almost never exceeded 20 kPa and was less than 10 kPa for most of the season. During dry season, soil moisture tension observed up to 40 kPa. In all three seasons, the degree of soil drying was greater in the puddle soil, occasionally reaching values of 25-40 kPa but was usually less than 15 kPa. There was greater cracking in the puddled soil (WSR and PTR) and at higher water stress situations (40 kPa) which resulted in faster drying this was not reflected well in non puddled soil (DSR, NPTR) and irrigation frequency as irrigation was applied at such a low threshold (10 kPa SWT at 15cm depth and continuous flooding plots).

3.3 Irrigation
The average amount of irrigation water applied was similar among tillage practices during *dry* season. However, during *wet season* dry tillage recorded significantly higher irrigation water savings of 20.0 per cent over wet tillage methods. It was clearly observed that the dry tillage saved substantial amount of irrigation water during wet (*Kharif*) season. Irrigation water was similar in direct seeding and transplanting in requirement did not differ significantly among methods of establishment. Whereas, among scheduling of irrigation practices, continuous flooding recorded significantly higher irrigation water requirement (1747 mm and 1330 mm during pool of two *wet* seasons and *dry season* respectively). Irrigation water requirement declined more with AWD treatments than daily irrigated treatments. Irrigation scheduling at 10 kPa recorded 64.9 and 41.1 per cent water savings during wet and dry seasons, respectively.

3.4 Water productivity (WP_{I+R}) and Water use efficiency (WUE)
Irrigation water productivity was significantly higher in all AWD treatments than in daily irrigated treatments in both Wet and Dry seasons due to large reduction in irrigation amount, which more than offset the reduction in grain yield which occurred when irrigations are scheduled at 40 kPa. Irrigation scheduling with 10 kPa AWD recorded significantly higher water productivity of 0.40 and 0.33 g kg^{-1} during Wet and Dry seasons, respectively.
Irrigation water use efficiency also

3.5 Water use efficiency
Water use efficiency (WUE) differed significantly during the seasons and showed relatively higher WUE during *Wet season* (pooled 2014 and 2015) in comparison to *dry* season.
WUE did not differ significantly among tillage practices during *dry* season whereas, during *wet season* (pooled 2014 and 2015) and data pooled over three seasons among tillage practices dry tillage recorded significantly higher WUE (4.82 and 4.37) over wet tillage (4.44 and 3.97) respectively.
Establishment methods did not cause significant variations on WUE. Among scheduling of irrigation practices, 10 kPa profound significantly higher WUE (5.55, 3.85 and 4.98 during pool of two *wet* seasons, *dry season* and pooled over three seasons, respectively) and the treatment was on par with 40 kPa (5.30, 3.46 and 4.68). Significantly lower WUE observed at continuous flooding irrigation scheduling treatment.
Interaction effects among tillage and mehod of establishment found to be significant only during *dry* season. Dry tillage with transplanting method of establishment recorded significantly higher WUE (3.79) over other treatments. Interaction effects of method of establishment and scheduling of irrigation found non significance influence on WUE. Interaction effects of tillage and scheduling of irrigation was also found non significance influence on WUE. Combined Interaction effects among tillage, method of establishment and scheduling of irrigation also found to be non significant influence on WUE during all three seasons.

3.6 Weed pressure
The pooled results of three seasons indicated that the total weed population and weed biomass differed significantly due to tillage, establishment methods and water management practices. Dry tillage (Unpuddled) recorded significantly higher weed population and weed biomass at 20, 40, 60 DAS over wet tillage (puddled) practices. Among different establishment methods direct seeding (both dry and wet DSR) recorded significantly higher weed population and weed biomass at 20, 40 and 60 DAS over transplanting method (both PTR and NPTR). Among irrigation practices, irrigation scheduling at 40 kPa recorded significantly higher weed population and weed biomass at 20, 40 and 60 DAS over 10 kPa and Continuous flooding treatments. Interaction effect of tillage and method of establishment found significant for total

weed population and weed biomass. Significantly lower weed population and weed biomass was recorded with wet tillage with transplanting compared to all other treatment combination at 20, 40 and 60 DAS. The highest yield and least weed population were in the transplanting treatment. The direct seeded rice (DSR), both dry and wet exhibited severe weed infestation, and compared to transplanting showed reduction in yield both in the presence and absence of weeds. Interaction effects of tillage and scheduling of irrigation also found significant for weed infestation. Weeds, including *Cyperus rotundus* L., *Dactyloctenium aegyptium* (L.) Willd., *Digera arvensis* Forsk., *Phyllanthus niruri* L., *Fimbristylis dichotoma*, *Fimbristylis miliacea*, and *Trianthema portulacastrum* L. which were found in the un-puddled treatments were absent in the puddled plots, particularly the transplanting treatments. Continuous flooding of 5cm irrigation water reduced the emergence of *C. rotundus*, *D. aegyptium*, *T. portulacastrum*, and *Echinochloa crus-galli* compared to 10 kPa and 40 kPa alternate wetting–drying treatments.

3.6.1 Grassy weeds
Grassy weed population (no. m^{-2}) did not differ significantly among tillage practices during the experimental seasons whereas, among methods of establishment direct seeding recorded significantly higher grass weed population (no. m^{-2}) compared to transplanting methods at 20,40DAS and 60DAS. Significantly variable grass weed observed among irrigation scheduling practices also. Irrigation scheduling at 40kPa-AWD recorded significantly higher grass weed population compared to continuous flooding and 10 kPa practices. Grassy weeds observed during the experimental plots were *Echinochloa colona*, *Echinochloa crus-galli*, *Leptochloa chinensis*, *Oryza sativa f. spontanea. Elucine indica*, *Cynodon dactylon* (Fig.2).

3.6.2 Sedges weeds
Sedges weed population(No. m^{-2}) did not differ significantly among tillage practices during the experimental seasons whereas, among methods of establishment direct seeding recorded significantly higher sedges weed population (no. m^{-2}) compared to transplanting methods at 20,40DAS and 60DAS. Significantly variable sedges weed observed among irrigation scheduling practices also. Irrigation scheduling at 40kPa-AWD recorded significantly higher sedges weed population compared to continuous flooding and 10 kPa practices. Sedges like *Cyperus iria* L., *Cyperus difformis* L., *Cyperus rotundus*, *Fymbristylis miliaceae* were majorly observed during experimental seasons.

3.6.3 Broad leaved weeds
Broad leaved weed population differed significantly among tillage praces only at 20 DAS. Wet tillage recorded significantly higher broad leaved population at 20 DAS over dry tillage practices. Effect of tillage practices at later 40 and 60 DAS on BLW found significantly not differed. Whereas, among establishment methods direct seeding recorded significantly higher BLW population and among Irrigation Scheduling practices 40 kPa recorded significantly higher BLW population. BLW causing major yield losses are *Eclipta prostrate*, *Ludwigia hyssopifolia*, *Trianthima portulecustrum*, *Amaranthus spinosus*, *Celotia argentia*, *Commelina bengalensis*, *Portulaca Oleracia*, *Marsilea quadrifolia*.

Table 1: Total weed population (No. m^{-2}) of rice as influenced by tillage, crop establishment methods and water management practices over pooled three seasons

Treatments	20 DAS					40 DAS					60DAS				
	T_1		T_2		Mean (S)	T_1		T_2		Mean (S)	T_1		T_2		Mean (S)
	M_1	M_2	M_1	M_2		M_1	M_2	M_1	M_2		M_1	M_2	M_1	M_2	
S_1	3.48 (11.6)	3.45 (11.4)	3.79 (13.9)	3.02 (8.6)	3.43	5.26 (23.3)	5.06 (21.8)	6.11 (31.2)	4.65 (18.4)	5.27	5.32 (27.9)	5.25 (27.2)	5.60 (30.9)	5.36 (28.2)	5.38
S_2	3.99 (15.4)	4.37 (18.6)	4.17 (16.9)	3.51 (11.8)	4.01	6.31 (34.0)	6.41 (34.7)	7.04 (42.2)	5.59 (26.4)	6.34	6.38 (40.3)	6.44 (41.1)	6.73 (44.9)	5.91 (34.6)	6.37
S_3	5.30 (27.9)	5.87 (34.3)	4.89 (23.5)	4.35 (18.5)	5.10	8.12 (55.4)	8.41 (59.5)	7.84 (53.4)	6.47 (35.6)	7.71	7.76 (59.7)	8.10 (65.2)	7.82 (60.8)	6.61 (43.2)	7.57
Mean	4.26	4.56	4.28	3.63	4.18	6.56	6.63	7.00	5.57	6.44	6.49	6.60	6.72	5.96	6.44
Mean (M)	M_1 :	4.27	M_2 :	4.09	4.18	M_1 :	6.78	M_2 :	6.10	6.44	M_1 :	6.60	M_2 :	6.28	6.44
Mean (T)	4.41		3.95		4.18	6.59		6.28		6.44	6.54		6.34		6.44
	S.Em ±		CD at 5%			S.Em ±		CD at 5%			S.Em ±		CD at 5%		
T	0.05		0.15			0.05		0.17			0.05		NS		
M	0.05		0.15			0.10		0.30			0.04		0.16		
S	0.06		0.20			0.09		0.29			0.05		0.16		
T × M	0.05		0.16			0.10		0.32			0.05		0.17		
M × S	0.09		NS			0.13		NS			0.07		NS		
T × S	0.09		0.28			0.13		0.41			0.07		0.22		
T × M× S	0.13		NS			0.19		NS			0.10		0.32		

NS - Non significant Data in $\sqrt{x+0.5}$ transformation

Main plot treatments: Tillage (T) Sub plot treatments: Method of establishment (M) Sub-sub plot treatments: Scheduling of irrigation (S)

T_1 - Dry tillage (No puddling) M_1 - Direct seeding (DSR, WSR) S_1 - Continuous flooding

T_2 - Wet tillage (Puddling) M_2 - Transplanting (NPTR, PTR) S_2 - 10 kPa

S_3 - 40 kPa

*Values in parenthesis indicate original values

Table 2: Total weed dry weight (g m-2) of rice as influenced by tillage, crop establishment methods and water management practices over pooled three seasons

Treatments	20 DAS					40 DAS					60DAS				
	T_1		T_2		Mean (S)	T_1		T_2		Mean (S)	T_1		T_2		Mean (S)
	M_1	M_2	M_1	M_2		M_1	M_2	M_1	M_2		M_1	M_2	M_1	M_2	
S_1	1.87 (2.9)	1.97 (3.4)	1.98 (3.4)	1.56 (1.9)	1.84	2.69 (6.7)	2.69 (6.7)	2.89 (7.8)	2.42 (5.3)	2.67	3.12 (9.2)	3.11 (9.1)	3.22 (9.8)	3.06 (8.9)	3.13
S_2	2.10 (3.9)	2.49 (5.7)	2.18 (4.2)	1.81 (2.7)	2.14	3.09 (9.0)	3.33 (10.6)	3.30 (10.3)	2.78 (7.2)	3.12	3.60 (12.4)	3.72 (13.3)	3.72 (13.3)	3.36 (10.8)	3.60
S_3	2.85 (7.7)	3.42 (11.2)	2.58 (6.2)	2.28 (4.7)	2.78	3.92 (14.9)	4.36 (18.5)	3.78 (13.8)	3.30 (10.3)	3.84	4.32 (18.1)	4.64 (21.1)	4.29 (17.9)	3.80 (13.9)	4.26
Mean	2.27	2.63	2.25	1.88	2.26	3.23	3.46	3.32	2.83	3.21	3.68	3.82	3.74	3.41	3.66
Mean (M)	M_1 :	2.26	M_2 :	2.26	2.26	M_1 :	3.28	M_2 :	3.14	3.21	M_1 :	3.71	M_2 :	3.62	3.66
Mean (T)	2.45		2.06		2.26	3.34		3.08		3.21	3.75		3.57		3.66
	S.Em ±		CD at 5%			S.Em ±		CD at 5%			S.Em ±		CD at 5%		
T	0.03		0.10			0.04		0.14			0.02		0.07		
M	0.01		NS			0.02		0.07			0.02		0.06		
S	0.04		0.13			0.04		0.13			0.02		0.08		
T × M	0.02		0.07			0.02		0.07			0.02		0.06		
M × S	0.06		NS			0.06		NS			0.04		NS		
T × S	0.06		0.19			0.06		0.19			0.04		0.12		
T × M× S	0.08		NS			0.09		NS			0.05		0.17		

NS - Non significant Data in $\sqrt{x+0.5}$ transformation

Main plot treatments: Tillage (T) Sub plot treatments: Method of establishment (M) Sub-sub plot treatments: Scheduling of irrigation (S)

T_1 - Dry tillage (No puddling) M_1 - Direct seeding (DSR, WSR) S_1 - Continuous flooding

T_2 - Wet tillage (Puddling) M_2 - Transplanting (NPTR, PTR) S_2 - 10 kPa

S_3 - 40 kPa

*Values in parenthesis indicate original values

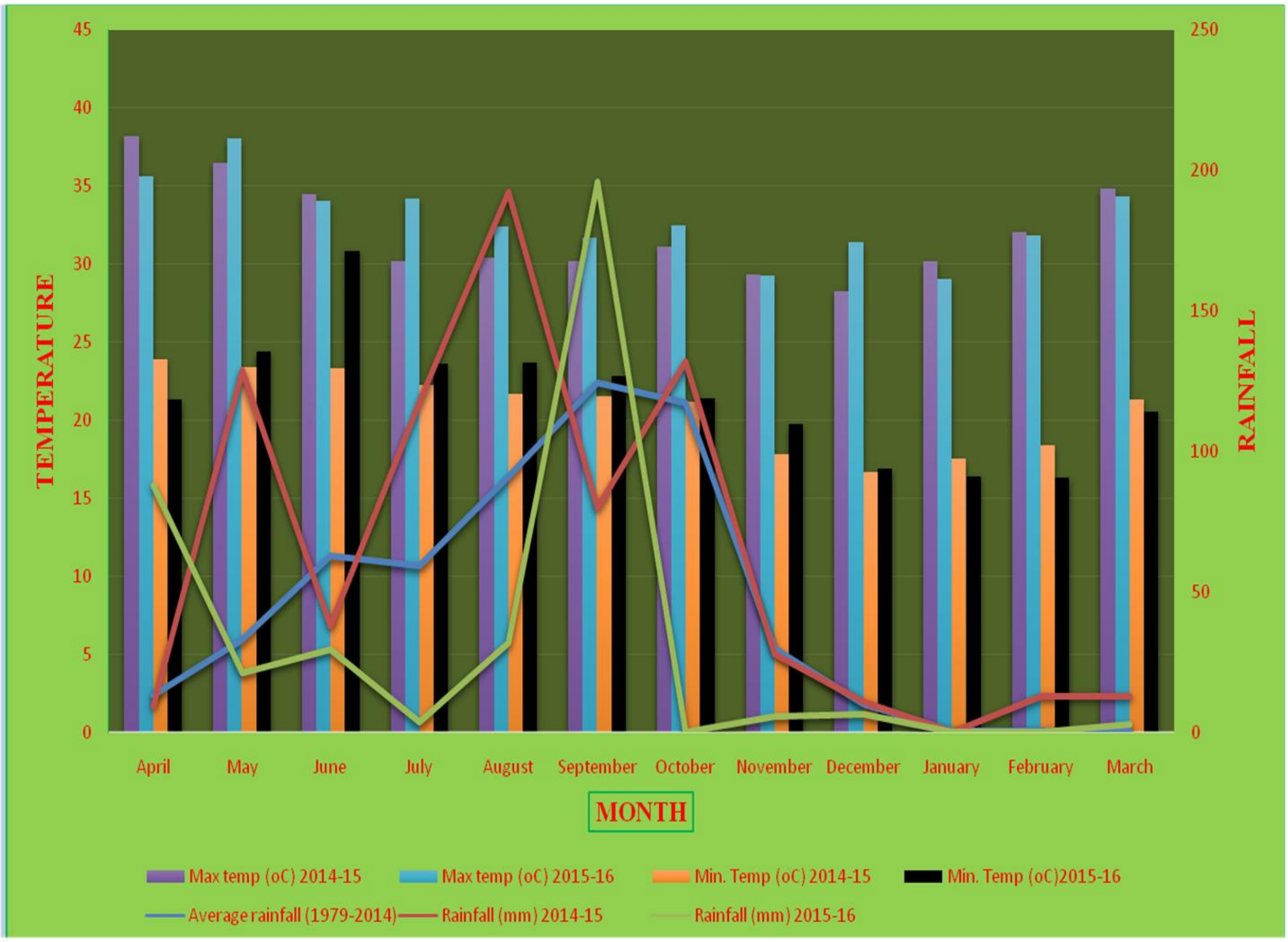
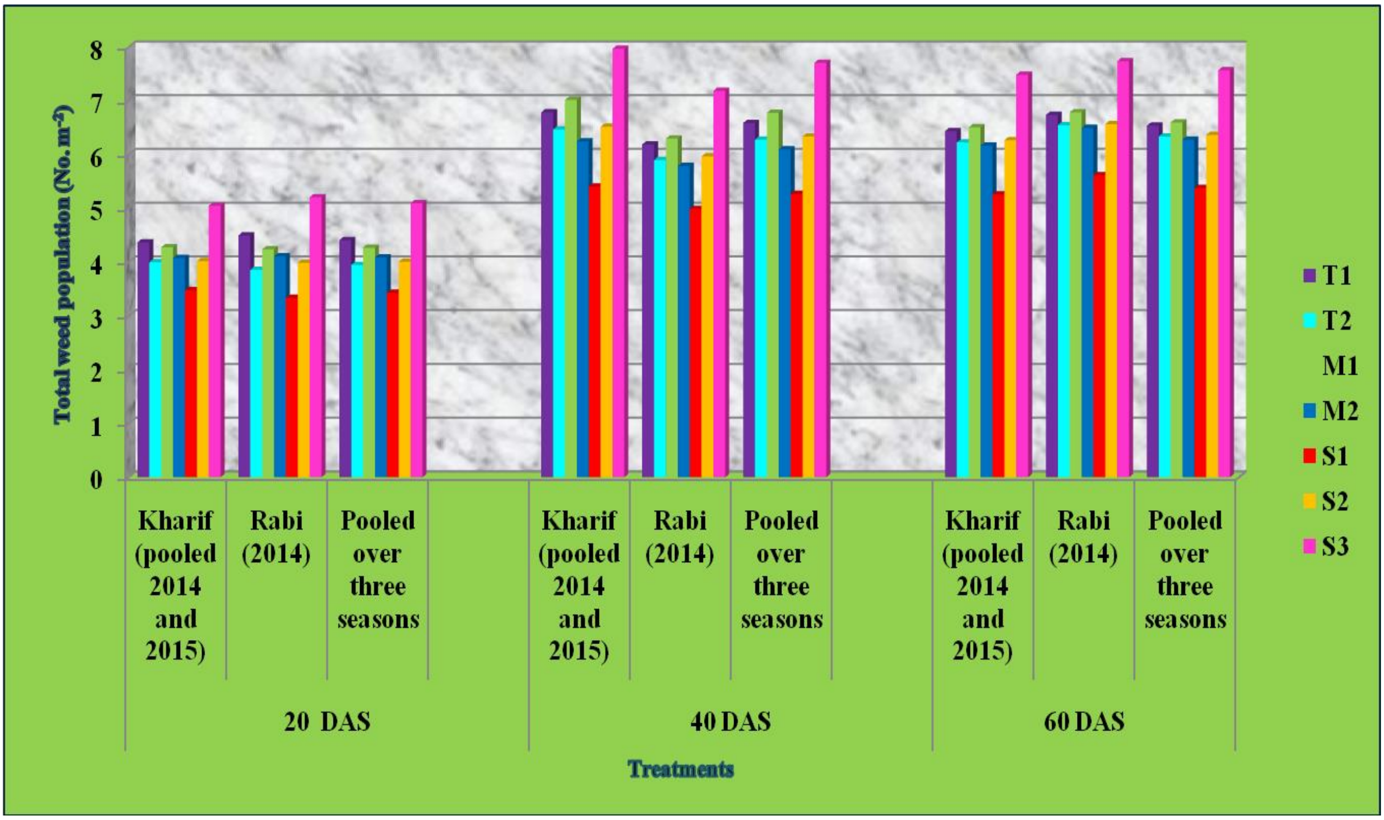
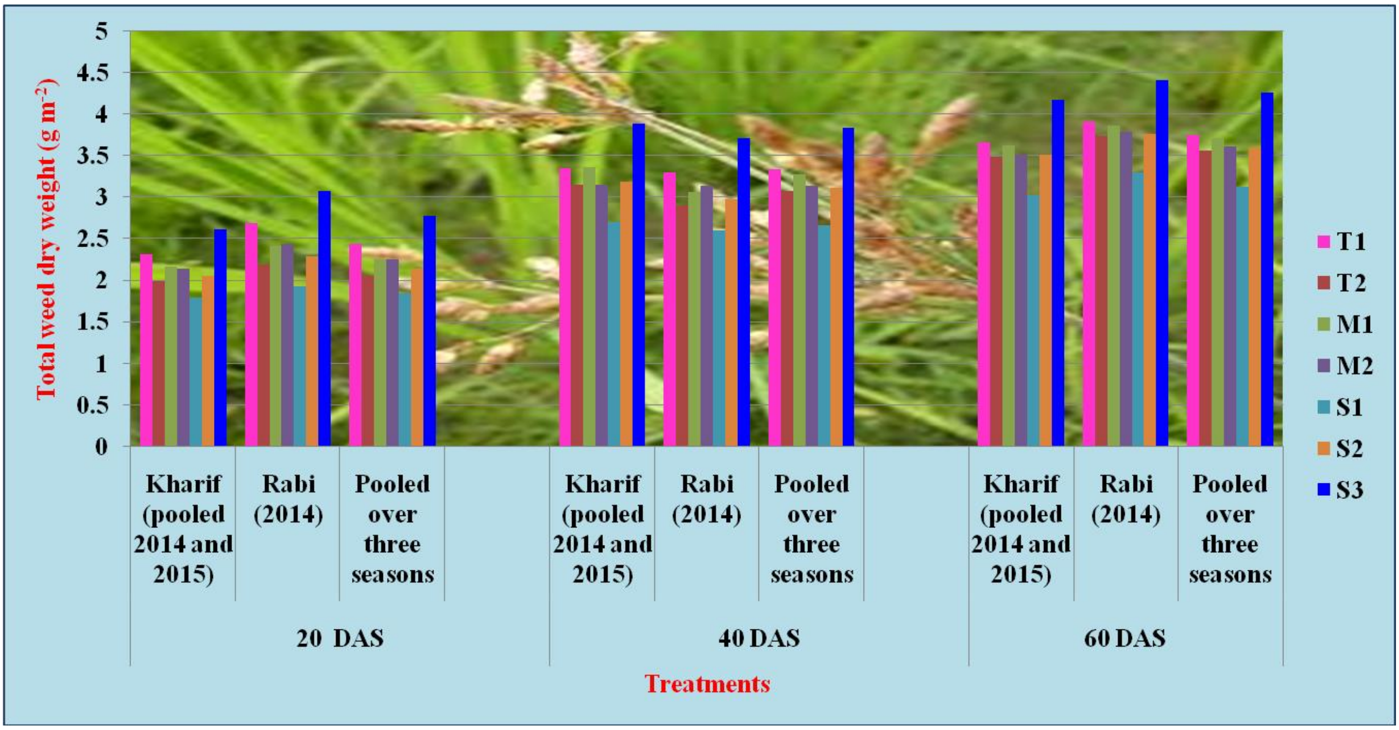


Fig 1: Monthly meteorological data for the year 2014-15, 2015-16 and average of past 35 years rainfall data of Agricultural Research Station, Gangavathi



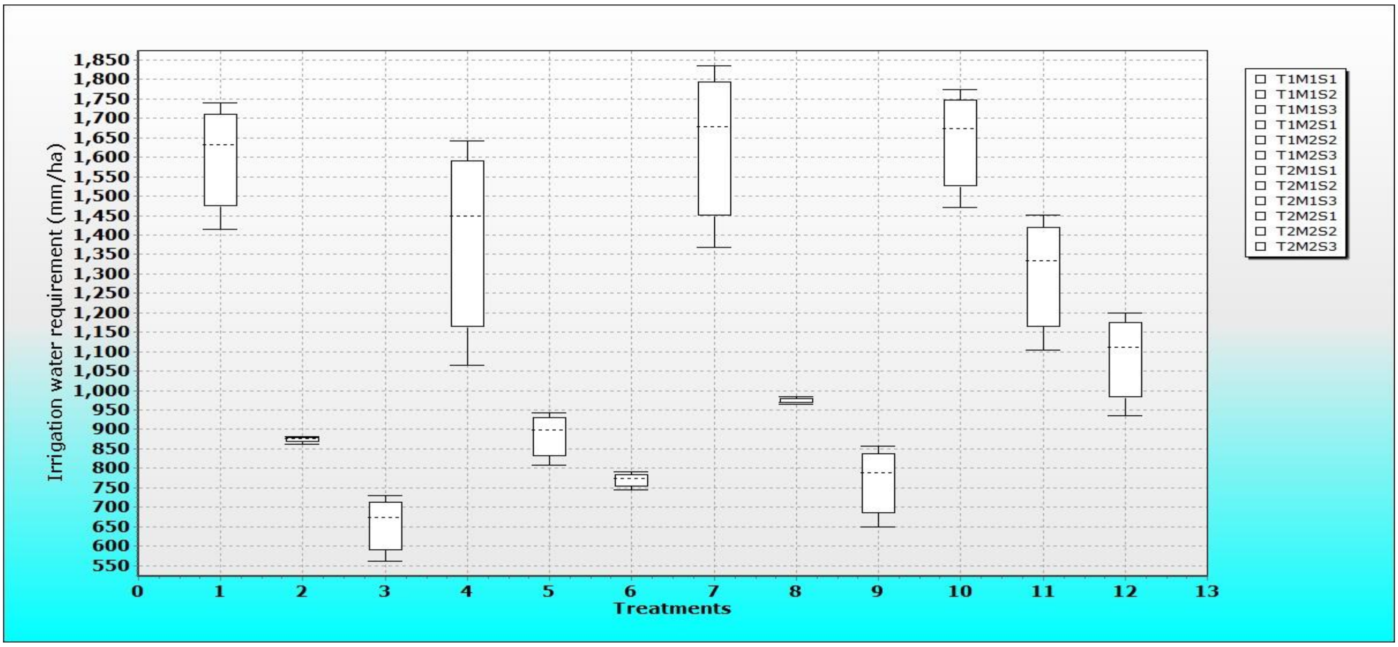
Main plot treatments: Tillage (T) :T_1 - Dry tillage (No puddling) T_2 - Wet tillage (puddling)
Sub plot treatments: Method of establishment (M) : M_1 - Direct seeding (DSR, WSR) M_2 - Transplanting (NPTR, PTR)
Sub-sub plot treatments: Scheduling of irrigation (S) : S_1 - Continuous flooding S_2 - 10 kPa S_3 - 40 kPa

Fig 2: Total weed population (No. m^{-2}) at different growth stages of rice as influenced by tillage, crop establishment methods and water management practices during *kharif* (pooled 2014 and 2015), *rabi* (2014) and data pooled over three season



Main plot treatments: Tillage (T) :T_1 - Dry tillage (No puddling) T_2 - Wet tillage (puddling)
Sub plot treatments: Method of establishment (M) : M_1 - Direct seeding (DSR, WSR) M_2 - Transplanting (NPTR, PTR)
Sub-sub plot treatments: Scheduling of irrigation (S) : S_1 - Continuous flooding S_2 - 10 kPa S_3 - 40 kPa

Fig 3: Total weed dry weight (g m^{-2}) at different growth stages of rice as influenced by tillage, crop establishment methods and water management practices during *kharif* (pooled 2014 and 2015), *rabi* (2014) and data pooled over three seasons



$T_1M_1S_1$: Dry tillage DSR + CF $T_1M_2S_1$: Dry tillage NPTR + CF $T_2M_1S_1$: Wet tillage WSR + CF $T_2M_2S_1$: Wer tillage PTR + CF
$T_1M_1S_2$: Dry tillage DSR + 10 kPa $T_1M_2S_2$: Dry tillage NPTR + 10 kPa $T_2M_1S_2$: Wet tillage WSR + 10 kPa $T_2M_2S_2$: Wet tillage PTR + 10 kPa
$T_1M_1S_3$: Dry tillage DSR + 40 kPa $T_1M_2S_3$: Dry tillage NPTR + 40 kPa $T_2M_1S_3$: Wet tillage WSR + 40 kPa $T_2M_2S_3$: Wet tillage PTR + 40 kPa

Fig 4: Irrigation water requirement (mm ha^{-1}) of rice as influenced by tillage, crop establishment methods and water management practices during *kharif* (pooled 2014 and 2015), *rabi* (2014) and data pooled over three seasons

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