Original Research Article

Influence of different crop establishment and irrigation methods on growth and growth indices of rice

Abstract

The field experiment was conducted at Zonal Agricultural Research Station, V. C. Farm, Mandya, University of Agricultural Sciences, Bangalore under Cauvery command area of Karnataka to evaluate the influence of different establishment methods and irrigation methods on growth and growth indices of rice during *Kharif* 2018. The experiment was laid out in a split plot design comprised of three main plot irrigation treatments and five sub plot rice establishment treatments. The combination of 15 treatments replicated thrice and the paddy variety used was *'MTU 1001'*. The results revealed that, among irrigation methods continuous flooding recorded significantly higher plant height (80.67 cm) at harvest. Whereas, alternate wetting and drying recorded higher leaf area index (5.06), CGR at 30 to 60 DAS, 60 to 90 DAS and 90 DAS to harvest (1.49, 3.50 and 2.47 g m^{-2} day^{-1}, respectively), NAR at 30 to 60 DAS and 60 to 90 DAS (7.19 and 4.37 mg cm^{-2} day^{-1}, respectively). Among establishment methods, manual transplanting recorded higher plant height (81.82 cm), LAI (5.70), DME (55.77), AGR at 30 DAS (0.36 g day^{-1}), CGR at 30 to 60 DAS and 60 to 90 DAS (1.73 and 3.94 g m^{-2} day^{-1}, respectively) and LAD at 30 to 60 DAS, 60 to 90 DAS and 90DAS to harvest (49.50, 128.70 and 272.80, respectively). However, mechanical transplanting recorded significantly more number of tillers m^{-2} (765.67), NAR at 30 to 60 DAS and 60 to 90 DAS (9.96 and 4.41 mg cm^{-2} day^{-1}, respectively). Among interactions, alternate wetting and drying with manual transplanting (7.39 and 4.94) recorded significantly higher LAI, CGR at 30 to 60 DAS and 60 to 90 DAS (2.01 and 5.23 g m^{-2} day^{-1}, respectively), NAR (5.16 mg cm^{-2} day^{-1}) at 60 to 90 DAS and LAD at 60 to 90 DAS and 90 DAS to harvest (146.10 and 339.08, respectively).

Key words: *Irrigation methods, Leaf area index, Establishment methods, Crop growth rate, Net assimilation rate, Leaf area duration*

1. INTRODUCTION

Food security of world in coming days relies on the sustained accomplishment of rice production in Asia. Since 2002, production of rice has shown a steady increase (Anon., 2019), the road to food security faces major hurdles *viz*., with increasing demand versus declining yield and area harvested; soil fertility and decline in productivity of intensive rice-based cropping systems (Bell et al., 2019); exhaustion and or limitations of natural resources for production; stabilization of yield potential of recently released varieties/hybrids; biotic stresses, abiotic stresses (low temperature, drought and salinity); low income from rice production and changing socio-economic situations (Van and Ferrero, 2006). It is estimated that, by 2025 the rice demand will be 140 million tonnes in India (Hugar et al., 2009). In order to attain this target, the productivity of rice has to be ushered to the level of 3.3 tonnes ha^{-1} (Anjani et al., 2014). In the next two decades, the share of water devoted to irrigation is expected to decline by 10 to 15% (Dhawan, 2017). Rice is one of the highest water demanding crops which consumes about 27% of the world total fresh water resource (Bouman et al., 2007). Water has been taken for granted in irrigated rice production for centuries. The faulty irrigation methods has led to huge loss of water and applied nutrients to the field. Continuous flooding is the commonly used practice in traditional irrigation for rice production, but is now regarded as water consuming. Quite often water is very uneven in distribution, either in excess or not sufficient. The puddling operation in wetland rice production, alone consumes 30 % of the total water consumption by the crop (Chauhan and Opena, 2012). Predictions indicate that by 2025 Asia will face 17–22 M ha of irrigated rice area by water scarcity, demanding water-saving techniques to be practiced widely. After many research studies, different irrigation methods in paddy have been invented to consume less water and produce higher yield. One of the most commonly practiced water saving irrigation (WSI) techniques that has been accepted to trim down water usage in rice cultivating systems is Alternate Wetting and Drying (AWD) (Lampayan et al., 2015), which has been reported to lessen water inputs by 50 to 80 % compared to continuously flooded rice systems (Yadav et al., 2011). In AWD, water is applied to irrigate the field depending on the weather condition or until some fine cracks appear on the soil surface. AWD is an irrigation technique where water is applied to the field a number of days after disappearance of ponded water. Among many cultural practices followed in paddy method of establishment has immense effect on growth and development in paddy (Sanjay et al., 2018). Mechanical transplanting or direct seeded rice enables timely planting/seeding and better crop stand (Malik et al., 2019). Direct seeded rice can lessen the labour requirement by as much as 50 % (Singh et al., 2006) and even the per day water use is 24 % lower in direct seeded rice than other methods (Saharawat et al., 2010). Physiological growth parameters are indicators of increment of crop growth at various crop phenological stages. The growth components have a great importance and its stability governs the dry matter production which is a criterion of yield components and in this regard leaf area index (LAI), crop growth rate (CGR), relative growth rate (RGR), net assimilation rate (NAR), leaf area duration (LAD), are indices which often use for evaluation of plant productivity capability and environmental efficiency (Anzoua et al., 2010; De Sclaux et al., 2000). The yield is mainly dependent on the growth parameters, with increase in leaf area, photosynthesis will be augmented which in order leads to higher production and accumulation of photosynthates into the economic parts of the crop.

2. MATERIAL AND METHODS

The experiment was conducted at Zonal Agricultural Research Station, V. C. Farm, Mandya, University of Agricultural Sciences, Bangalore to study the influence of different establishment methods and irrigation methods on growth and growth indices of rice during *Kharif* 2018. The experiment was laid out in a split plot design with three replications which comprised of three main plot irrigation treatments, viz. Continuous flooding, Maintenance of saturation up to panicle initiation (PI) and flooding after PI and Alternate wetting and drying (AWD) up to panicle initiation (PI) and flooding after PI and five sub plot rice establishment treatments, *viz*. Drum seeded rice, Broadcasting of sprouted rice, Semi-dry rice, Mechanical transplanting and Manual transplanting. Physiological growth parameters used to know the growth and yield of the crop in the experiment are given below with their formulae. The leaf area data was collected from the field at defined crop intervals and the following parameters were calculated.

Leaf area index (LAI): Leaf area index (LAI) is defined as an assimilatory surface per unit area of land (Sestak et al., 1971).

$$\mathrm{LAI} = \frac{\text{Total leaf area of a plant}}{\text{Ground area occupied by the plant}}$$

Absolute growth rate (AGR): It refers to the total growth of a plant per unit time. For various growth periods it was worked out from the below mentioned formula of Watson (1952) and expressed in g per day (g day^{-1}).

$$\mathrm{AGR} = \frac{W_2 - W_1}{t_2 - t_1}$$

Where, AGR = Absolute growth rate expressed in gram day^{-1}, W_1 = Dry weight of hill at time t_1 and W_2= Dry weight of hill at time t_2

Relative growth rate (RGR): Relative Growth Rate (RGR) expresses the total plant dry weight increase in a time interval in relation to the initial weight or Dry matter increment per unit biomass per unit time or grams of dry weight increase per gram of dry weight and expressed as unit dry weight / unit dry weight / unit time (g g^{-1} day^{-1}).

$$\mathrm{RGR} = \frac{(\log_e W_2 - \log_e W_1)}{(t_2 - t_1)}$$

Where,
W_1 and W_2 are the plant dry weigh at time t_1 and t_2, respectively.

Crop growth rate (CGR): Crop growth rate (CGR) for various growth periods was worked out from the below given formula of Watson (1952) and expressed in g per m^2 per day.

$$\mathrm{CGR} = \left(\frac{1}{P}\right) \times \frac{W_2 - W_1}{t_2 - t_1}$$

Where, W_1 = Dry weight of hill at time t_1, W_2 = Dry weight of hill at time t_2 & P = Land area in cm^2

Net Assimilation Rate (NAR): It is defined as the rate of increase of dry weight per unit of leaf area. NAR for various growth periods was worked out from the below given formula of Gregory (1926) and expressed in g per dm^2per day.

$$\mathrm{NAR} = \frac{W_2 - W_1}{t_2 - t_1} \times \frac{\log_e L_2 - \log_e L_1}{L_2 - L_1}$$

Where,
$W_1$and W_2 = dry weight of whole plant at time t_1 and $t_{2,}$ respectively
L_1 and L_2 = leaf weights or leaf area at t_1 and t_2 respectively

Dry matter efficiency (DME): It is defined as the percent of dry matter accumulated in the grain from the total dry matter produced over the crop growth period.

$$\mathrm{DME} = \frac{\text{Harvest index}}{\text{Duration of genotype}}$$

Leaf area duration (LAD): LAD takes into account, both the duration and extent of photosynthetic tissue of the crop canopy. The LAD is expressed in days.

$$\mathrm{LAD} = \frac{\mathrm{L_1} + \mathrm{L_2}}{2} \times \mathrm{t_2} - \mathrm{t_1}$$

Where,

L_1 = LAI at the first stage, L_2 = LAI at the second stage, t_2 & t_1= Time interval in days

3. RESULTS AND DISCUSSION

3.1 Plant height (cm)

Plant height varied significantly among different rice establishment methods, but it shown on par results with different irrigation methods (Table 1). Among irrigation methods, irrigating the crop with continuous flooding recorded higher plant height (80.67 cm) whereas it was on par with maintenance of saturation up to panicle initiation (PI) followed by flooding after PI method (76.89 cm) and alternate wetting and drying (AWD) up to PI followed by flooding after PI method of irrigation (79.49 cm). Among establishment methods (Table 1), manual transplanting recorded higher plant height (81.82 cm) which was closely followed by mechanical transplanting (79.97 cm) and semi dry rice (79.20 cm) which were at par with each other and significantly superior over other methods (76.47 to 77.61 cm). Manual transplanting, semi dry rice and drum seeded rice recorded higher plant height due to the closer plant spacing (20 x 10 cm) which increased the competition among nearby plants and forced the plants to grow vertically (Krishna and Biradar, 2009). AWD strengthens the air exchange between soil and the atmosphere, thus sufficient oxygen is supplied to the root system to accelerate soil organic matter mineralization and inhibit soil N mobilization, all of which should increase soil fertility and produce more essential plant-available nutrients to favour rice growth (Tan et al., 2013).

3.2 Number of tillers m^{-2}

Effect of irrigation methods on number of tillers m^{-2} was non-significant (Table 1). However, more number of tillers m^{-2} was recorded in maintenance of saturation up to panicle initiation (PI) followed by flooding after PI method (577.48) over rest of the irrigation methods (555.87 to 563.72). Effective utilization of resources was favored by the aeration of soil in maintaining saturated condition which resulted in higher number of tillers m^{-2} (Christine et al., 2007). Among establishment methods, mechanical transplanting recorded more number of tillers m^{-2} (765.67) followed by broadcasting of sprouted rice (656.67) and were significantly superior over rest of the methods (439.28 to 484.36). In semi dry rice, there was no submergence of panicle initiation buds up to 40 DAS, hence the number of tillers produced per m^{-2} were more up to 60 DAS. However, in mechanical transplanting, seedlings were transplanted at uniform depth in puddled field at wider spacing (25 cm x 15 cm). This helped in optimal utilization of available resources like water and nutrients which led to early growth and prolonged tiller initiation due to the formation of more tillering buds (Manjunatha et al., 2009a and Subhash et al., 2013). Among interaction between irrigation and rice establishment methods, continuous flooding with mechanical transplanting recorded significantly a greater number of tillers m^{-2} (790.67) followed by alternate wetting and drying with mechanical transplanting (782.67) over rest of the interactions (398.17 to 723.67).

3.3 Leaf area index (LAI)

Effect of irrigation methods was significant (Table 1). Alternate wetting and drying up to PI followed by flooding after PI recorded significantly higher LAI (5.06) than other methods (4.28 to 4.67) Nguyen et al. (2009). It might be due to more plant dry matter which resulted in greater LAI at tillering and heading stages as recorded in this study. The increased LAI would be due to the effect of water on activation of the cell division and elongation (Abul-El-Ezz, 2014). Reduction in LAI might be due to reduced turgor pressure under moisture stress conditions which affected the leaf cell expansion (Bouman et al., 2005). Among establishment methods, manual transplanting recorded higher LAI (5.70) and was statistically superior over rest of the methods (4.05 to 4.93). Among interactions, alternate wetting and drying up to PI followed by flooding after PI with manual transplanting (7.39 and 4.94) recorded significantly higher LAI than rest of the interactions. This was owing to the fact that, younger seedlings planted at proper spacing enhanced the root growth which facilitated improved cell division and cell enlargement and more number of tillers with more leaves and subsequently, higher photosynthetic rate for increased LAI (Kukal et al., 2014).

3.4 Dry Matter Efficiency (DME)

The relationship of total biological yield to economic yield helps to visualize the performance or efficiency of genotypes (Table 1). The ratio of biological yield and economic yield in conjunction with duration is considered as DME. Among irrigation methods, continuous flooding recorded significantly higher DME (52.68) followed by maintenance of saturation up to PI followed by flooding after PI (52.07) than alternate wetting and drying up to PI followed by flooding after PI (47.22). Establishment methods showed significant difference with respect to DME. Manual transplanting recorded significantly higher DME (55.77) than rest of the methods (45.43 to 51.76). Among interactions, continuous flooding with manual transplanting recorded significantly higher DME (65.64) than rest of the methods (43.00 to 65.64). DME was higher under conventional method. The increase in total dry matter with increasing plant population indicates the favourable response of biomass produced to plant population. It is possibly related to hastening the photosynthesis activity that increased dry matter accumulation (Shao-hua et al., 2002, Sridevi and Chellamuthu, 2015). The increased cell division and elongation of plant parts will enhance leaf area which will synthesize higher photo-assimilates and yield higher dry matter due to available nutrients coupled with available moisture (Swarup and Yaduvanshi, (2000), and Yadana et al., 2009).

3.5 Absolute growth rate (AGR):

Rate of increase of biomass between two intervals varied significantly among different irrigation and crop establishment methods at different growth stages (Fig.1) and Table 2.

Among irrigation methods, irrigating the crop with continuous flooding recorded significantly higher AGR (0.36 g day^{-1}) at 30-60DAS followed by maintenance of saturation up to panicle initiation (PI) followed by flooding after PI method (0.36 g day^{-1}) than alternate wetting and drying (0.33 g day^{-1}). At 60 to 90 DAS and 90 DAS to harvest, alternate wetting and drying recorded significantly higher AGR (0.90 and 0.59 g day^{-1}, respectively) than rest of the methods.

Mechanical transplanting recorded significantly higher AGR (0.49 and 1.09 g day^{-1}, respectively) at 30 to 60 DAS and 60 to 90 DAS than rest of the treatments. However, at 90 DAS to harvest, Drum seeded rice recorded significantly higher AGR (0.59 g day^{-1}) which was closely followed by Semi dry rice (0.58 g day^{-1}). Among interactions, alternate wetting and drying with mechanical transplanting recorded higher AGR at 30 to 60 DAS (0.47 g day^{-1}). At 60 to 90DAS, continuous flooding with mechanical transplanting recorded significantly higher AGR (1.15 g day^{-1}) followed by alternate wetting and drying with mechanical transplanting (1.12 g day^{-1}). However, at 90 DAS to harvest, alternate wetting and drying with mechanical transplanting recorded higher AGR (0.67 g day^{-1}) than rest of the methods. Mechanical transplanting recorded higher AGR due to wider spacing and large root volume which reduced the Intra species competition and helped in absorption of available resources compared to conventional method and other methods of rice cultivation (Uphoff, 2003, Takeshihorie et al., 2003, Nataraja et al., 2006 and Makarim et al., 2007). The dry matter production and LAI both influence the growth indices like absolute growth rate, crop growth rate, relative growth rate and net assimilation rate.

3.6 Relative growth rate (RGR):

Rate of increase in dry matter per unit per unit dry matter already present in the plant over period of time varied significantly with different irrigation and establishment methods (Fig.2) and Table 2.

Among irrigation methods, maintenance of saturation up to panicle initiation (PI) followed by flooding after PI method recorded significantly higher RGR (368.47 and 158.63 mg g^{-1} day^{-1}, respectively) at 30 to 60 DAS and at 60 to 90 DAS. However, at 90 DAS to harvest, continuous flooding recorded significantly higher RGR (53.99 mg g^{-1} day^{-1}). Among establishment methods, broadcasting of sprouted rice (381.71 mg g^{-1} day^{-1}) at 30 to 60 DAS, mechanical transplanting (166.80 mg g^{-1} day^{-1}) at 60 to 90 DAS and drum seeded rice (56.55 mg g^{-1} day^{-1}) closely followed by broadcasting of sprouted rice (55.83 mg g^{-1} day^{-1}) recorded significantly higher RGR. RGR was high in the early stages and it started declining progressively with the aging of the crop. The reason of declining in RGR at the final stage can be associated to increasing of the dead and woody tissues than the alive and active tissues and decrease of leaf area index (Shukla et al. (2002) in Indian mustard, Sridevi and Chellamuthu (2015) in rice and Jeffrey et al. (2005) in corn.

3.7 Crop growth rate (CGR):

Dry matter accumulated per unit land area per unit time showed significant difference among the treatments (Fig.3) and Table 2.

Among irrigation methods, at 30 to 60 DAS, 60 to 90 DAS and 90 DAS to harvest, alternate wetting and drying recorded significantly higher CGR (1.49, 3.50 and 2.47 g m^{-2} day^{-1}, respectively) than rest of the treatments. Among establishment methods, manual transplanting (1.73 g m^{-2} day^{-1}) followed by drum seeded rice (1.69 g m^{-2} day^{-1}) recorded significantly higher CGR at 30 to 60DAS. At 60 to 90 DAS manual transplanting recorded significantly higher CGR (3.94 g m^{-2} day^{-1}). However, at 90 DAS to harvest, drum seeded rice recorded significantly higher CGR (2.95 g m^{-2} day^{-1}) followed by manual transplanting (2.66 g m^{-2} day^{-1}) than any other treatments. Among interactions, at 30 to 60 DAS and 60 to 90 DAS, alternate wetting and drying with manual transplanting recorded significantly higher CGR (2.01 and 5.23 g m^{-2} day^{-1}, respectively). While at 90 DAS to harvest, continuous flooding with drum seeded rice (3.27 g m^{-2} day^{-1}) which was closely followed by alternate wetting and drying with drum seeded rice (3.26 g m^{-2} day^{-1}) recorded significantly higher CGR. The CGR increased up to flowering thereafter it started declining, irrespective of treatments. It could be attributed to better soil aeration, less competition which favoured more root growth and photosynthetic activity (Sridevi and Chellamuthu, 2015). The increase in CGR with the increasing rate of plant population in manual transplanting than other methods may be due to hastening the photosynthesis activity and the positive response of crop growth rate to plant population (Jeffrey et al., 2005). The reduction in crop growth rate to time of harvesting is due to leaf senescence and decrease of leaf area index (Egly and Guffy, 1997). Significantly inferior treatments could not compete with best treatments due to reduction in soil moisture content below the field capacity in the necessary period (Das et al., 2001 and Shekara et al. (2010).

3.8 Net Assimilation Rate (NAR):

Dry matter increment per unit leaf area or per unit leaf dry weight per unit of time (mg cm^{-2} day^{-1}) varied significantly over the treatments (Fig.4) and Table 3.

At 30 to 60 DAS and 60 to 90 DAS, alternate wetting and drying recorded significantly higher NAR (7.19 and 4.37 mg cm^{-2} day^{-1}, respectively). While at 90 DAS to harvest, continuous flooding recorded significantly higher NAR (2.70 mg cm^{-2} day^{-1}). Among establishment methods, at 30 to 60 DAS and 60 to 90 DAS, mechanical transplanting recorded significantly higher NAR (9.96 and 4.41 mg cm^{-2} day^{-1}, respectively). However, at 90 DAS to harvest, drum seeded rice recorded significantly higher NAR (2.83 mg cm^{-2} day^{-1}) followed by broadcasting of sprouted rice (2.79 mg cm^{-2} day^{-1}).

Among interactions, at 30 to 60 DAS alternate wetting and drying with mechanical transplanting recorded significantly higher NAR (11.16 mg cm^{-2} day^{-1}), alternate wetting and drying with manual transplanting (5.16 mg cm^{-2} day^{-1}) at 60 to 90 DAS and continuous flooding with broadcasting of sprouted rice (3.11 mg cm^{-2} day^{-1}) followed by alternate wetting and drying with drum seeded rice (3.04 mg cm^{-2} day^{-1}) at 90 DAS to harvest. NAR was high in the early stages between active tillering and panicle initiation and thereafter the rate of increase was slow with advancement in the age of the crop. Reduction in NAR could be attributed to less leaf area and shortage of other growth factors like nutrient, space, water etc. (Sridevi and Chellamuthu, 2015). NAR was found higher in mechanical transplanting and manual transplanting may be due to double tillering and ability of leaves to absorb solar radiation (Nadim et al., 2012). Horie (2003) showed that increase in the NAR causes increase in leaf area and grain yield. Number of factors such as temperature, light, CO2 content, water, leaf age, mineral nutrients, chlorophyll content and genotype influence net assimilation rate. The erect leaves have a higher leaf area index that increases photosynthetic carbon assimilation rate through light capture and nitrogen use efficiency (Sakamoto et al., 2006). Leaves are the predominant photosynthetic organ and thus, are critical targets for maximizing carbon assimilation by improving morphological traits (Zhu et al., 2010).

3.9 Leaf area duration (LAD):

Integration of LAI with time is called as Leaf Area Duration. LAD varied significantly among the treatments (Fig.5) and Table 3.

Among irrigation methods, maintenance of saturation up to panicle initiation (PI) followed by flooding after PI method recorded significantly higher LAD (43.65) which was on par with continuous flooding (43.50) at 30 to 60 DAS. At 60 to 90 DAS, alternate wetting and drying (109.35) followed by maintenance of saturation up to panicle initiation (PI) followed by flooding after PI method recorded significantly higher LAD (108.15). However, at 90 DAS to harvest, alternate wetting and drying recorded significantly higher LAD (244.20) than rest of the treatments. Among establishment methods, manual transplanting recorded significantly higher LAD at 30 to 60 DAS, 60 to 90 DAS and 90DAS to harvest (49.50, 128.70 and 272.80, respectively). Among interactions, at 30 to 60 DAS, continuous flooding with manual transplanting (54.60) was on par with maintenance of saturation up to panicle initiation (PI) followed by flooding after PI with drum seeded rice (53.85) and continuous flooding with broadcasting of sprouted rice (53.70) recorded significantly higher LAD. While, at 60 to 90 DAS and 90 DAS to harvest, alternate wetting and drying with manual transplanting recorded significantly higher LAD (146.10 and 339.08, respectively) than rest of the methods.

LAD increased with the age of the crop, with maximum LAD at flowering stage. LAD expresses the magnitude and persistence of leaf area of leafiness during the period of crop growth. It reflects the extent or seasonal integral of light interception and correlates with yield (Deepika et al. 2017).

4. CONCLUSION

The Irrigation and establishment method has immense effect on the growth and development of the rice crop. Among the irrigation methods alternate wetting and drying method of irrigation will save irrigation water and also enhance the growth and yield. The availability of moisture with efficient root aeration will help roots go grow and penetrate deeper and will help in moisture supply to crops. Alternate wetting and drying recorded higher leaf area index (5.06), CGR (2.47 g m^{-2} day^{-1}), NAR

(4.37 mg cm^{-2} day^{-1},). The manual transplanting will help for better establishment of the crop with increased growth and development. Among establishment methods, manual transplanting recorded higher plant height (81.82 cm), LAI (5.70), DME (55.77), AGR (0.36 g day^{-1}), CGR (3.94 g m^{-2} day^{-1}, respectively) and LAD (272.80 days). The mechanical transplanting has proved to be efficient in increasing the number of tillers in the paddy crop. The alternate wetting and drying in hand with manual transplanting will help to save water and to produce more yields. Alternate wetting and drying with manual transplanting (7.39 and 4.94) recorded significantly higher LAI, CGR (5.23 g m^{-2} day^{-1}), NAR (5.16 mg cm^{-2} day^{-1}) and LAD (339.08, days).

Table 1: Growth parameters as influenced by irrigation management practices and establishment methods in rice

Treatment	Plant height (cm)	Number of tillers m^{-2}	LAI	DME
Main plot: Irrigation methods				
I_1: Continuous flooding	80.67	563.72	4.28	52.68
I_2: Maintenance of saturation up to PI and flooding after PI	76.89	577.48	4.67	52.07
I_3: Alternate wetting and drying	79.49	555.87	5.06	47.22
S.Em$\pm$	3.09	6.00	0.09	1.23
P= 0.05	NS	NS	0.34	4.83
Sub plot: rice establishment methods				
E_1: Drum seeding	77.61	482.47	4.93	51.76
E_2: Broadcasting of sprouted rice	76.47	656.67	4.05	50.47
E_3: Semi-dry rice	79.20	484.36	4.59	50.40
E_4: Mechanical transplanting	79.97	765.67	4.08	45.43
E_5: Manual transplanting	81.82	439.28	5.70	55.77
S.Em$\pm$	1.30	10.79	0.08	1.21
P= 0.05	3.80	31.48	0.24	3.54
Interaction				
T_1: I_1E_1	81.20	496.33	5.26	49.39
T_2: I_1E_2	77.50	658.33	4.50	45.78
T_3: I_1E_3	80.77	469.33	3.91	57.40
T_4: I_1E_4	81.33	790.67	4.15	46.62
T_5: I_1E_5	82.53	398.17	3.56	71.17
T_6: I_2E_1	76.57	501.67	4.55	65.64
T_7: I_2E_2	74.63	658.33	3.64	54.97
T_8: I_2E_3	76.93	519.73	5.31	48.32
T_9: I_2E_4	76.60	723.67	3.71	46.03
T_{10}: I_2E_5	79.70	450.67	6.17	49.69
T_{11}: I_3E_1	75.07	443.67	4.98	43.00
T_{12}: I_3E_2	77.27	653.33	4.02	52.25
T_{13}: I_3E_3	79.90	464.00	4.55	46.24
T_{14}: I_3E_4	81.97	782.67	4.37	43.93
T_{15}: I_3E_5	83.23	435.67	7.39	52.10
S.Em$\pm$	3.69	17.75	0.15	2.25
P= 0.05	NS	54.53	0.41	6.14

Table 2: Growth indices at different growth stages and at harvest as influenced by irrigation management practices and establishment methods in rice

Treatment	AGR (g day^{-1})			CGR (g m^{-2} day^{-1})			RGR (mg g^{-1} day^{-1})		
	DAS			DAS			DAS		
	30-60	60-90	90-harvest	30-60	60-90	90-harvest	30-60	60-90	90-harvest
Main plot									
I_1	0.36	0.68	0.57	1.42	2.83	2.43	326.47	148.01	53.99
I_2	0.36	0.77	0.52	1.46	3.24	2.20	368.47	158.63	47.38
I_3	0.33	0.90	0.59	1.49	3.50	2.47	273.58	157.61	49.46
S.Em$\pm$	0.01	0.02	0.02	0.04	0.10	0.07	6.74	4.09	1.26
P= 0.05	0.04	0.09	0.06	0.17	0.39	0.27	26.40	16.01	4.93
Sub plot									
E_1	0.31	0.68	0.59	1.69	3.26	2.95	365.58	146.54	56.55
E_2	0.37	0.50	0.53	1.40	2.69	2.39	381.71	148.15	55.83
E_3	0.23	0.86	0.58	1.38	3.18	2.32	286.05	157.72	50.75
E_4	0.49	1.09	0.56	1.08	2.90	1.49	238.08	166.80	39.12
E_5	0.35	0.79	0.53	1.73	3.94	2.66	342.76	154.54	49.14
S.Em$\pm$	0.01	0.02	0.01	0.04	0.08	0.07	8.41	3.55	1.34
P= 0.05	0.02	0.05	0.04	0.11	0.22	0.20	24.55	10.37	3.92
Interaction									
T_1: I_1E_1	0.37	0.67	0.65	1.85	3.36	3.27	300.69	137.69	58.45
T_2: I_1E_2	0.37	0.62	0.68	1.67	2.81	3.05	313.20	132.30	61.91
T_3: I_1E_3	0.31	0.66	0.58	1.22	2.65	2.31	284.02	152.28	56.32
T_4: I_1E_4	0.37	1.15	0.49	0.99	3.05	1.30	219.06	177.57	34.76
T_5: I_1E_5	0.27	0.46	0.44	1.37	2.30	2.22	515.38	140.20	58.48
T_6: I_2E_1	0.32	0.62	0.46	1.58	3.11	2.32	500.10	154.09	50.59
T_7: I_2E_2	0.30	0.54	0.44	1.33	2.42	1.99	515.48	146.89	53.33
T_8: I_2E_3	0.39	0.94	0.56	1.54	3.75	2.23	290.98	163.91	43.69
T_9: I_2E_4	0.38	1.00	0.52	1.01	2.66	1.38	267.46	169.66	39.79
T_{10}: I_2E_5	0.36	0.86	0.61	1.81	4.28	3.06	268.30	158.63	49.53
T_{11}: I_3E_1	0.33	0.66	0.65	1.63	3.32	3.26	295.95	147.85	60.60
T_{12}: I_3E_2	0.26	0.63	0.48	1.19	2.85	2.14	316.46	165.25	52.26
T_{13}: I_3E_3	0.34	0.78	0.61	1.38	3.14	2.42	283.15	156.98	52.24
T_{14}: I_3E_4	0.47	1.12	0.67	1.25	2.97	1.79	227.72	153.17	42.80
T_{15}: I_3E_5	0.40	1.05	0.54	2.01	5.23	2.72	244.60	164.80	39.41
S.Em$\pm$	0.02	0.04	0.03	0.07	0.15	0.12	14.67	6.86	2.43
P= 0.05	0.04	0.08	0.07	0.19	0.38	0.34	42.51	17.97	6.79

Table 3: Growth indices at different growth stages and at harvest as influenced by irrigation management practices and establishment methods in rice

Treatment	NAR (mg cm^{-2} day^{-1})			LAD (Days)		
	DAS			DAS		
	30-60	60-90	90-harvest	30-60	60-90	90-harvest
Main plot						
I_1	6.00	3.81	2.70	43.50	101.40	213.12
I_2	6.42	4.07	2.35	43.65	108.15	223.85
I_3	7.19	4.37	2.46	38.85	109.35	244.20
S.Em±	0.20	0.12	0.06	1.04	3.05	6.89
P= 0.05	0.80	0.46	0.24	4.09	11.95	26.97
Sub plot						
E_1	6.97	3.99	2.83	42.75	111.60	248.60
E_2	4.62	3.45	2.79	49.20	103.05	203.78
E_3	5.07	4.48	2.53	39.00	97.95	223.03
E_4	9.96	4.41	1.92	29.40	90.00	187.00
E_5	6.05	4.10	2.44	49.50	128.70	272.80
S.Em±	0.16	0.10	0.07	1.04	2.58	5.70
P= 0.05	0.47	0.28	0.20	3.04	7.54	16.64
Interaction						
T_1: I_1E_1	7.78	4.16	2.93	38.70	111.90	267.85
T_2: I_1E_2	5.10	3.26	3.11	53.70	113.70	234.03
T_3: I_1E_3	4.65	4.43	2.82	35.85	82.95	196.63
T_4: I_1E_4	8.12	4.25	1.70	34.65	96.45	186.18
T_5: I_1E_5	4.33	2.94	2.93	54.60	101.85	181.23
T_6: I_2E_1	5.21	3.51	2.52	53.85	116.40	221.65
T_7: I_2E_2	4.64	3.29	2.66	48.15	96.45	179.85
T_8: I_2E_3	5.81	4.75	2.16	39.30	110.40	249.15
T_9: I_2E_4	10.59	4.61	1.96	24.60	79.65	170.50
T_{10}: I_2E_5	5.84	4.20	2.46	52.20	138.15	298.65
T_{11}: I_3E_1	7.92	4.29	3.04	36.00	106.80	256.85
T_{12}: I_3E_2	4.12	3.80	2.60	46.05	99.30	197.45
T_{13}: I_3E_3	4.76	4.25	2.60	42.00	100.50	223.58
T_{14}: I_3E_4	11.16	4.36	2.11	28.95	93.90	204.05
T_{15}: I_3E_5	7.98	5.16	1.94	41.10	146.10	339.08
S.Em±	0.32	0.19	0.12	1.92	5.03	11.20
P= 0.05	0.81	0.48	0.34	5.27	13.05	28.82

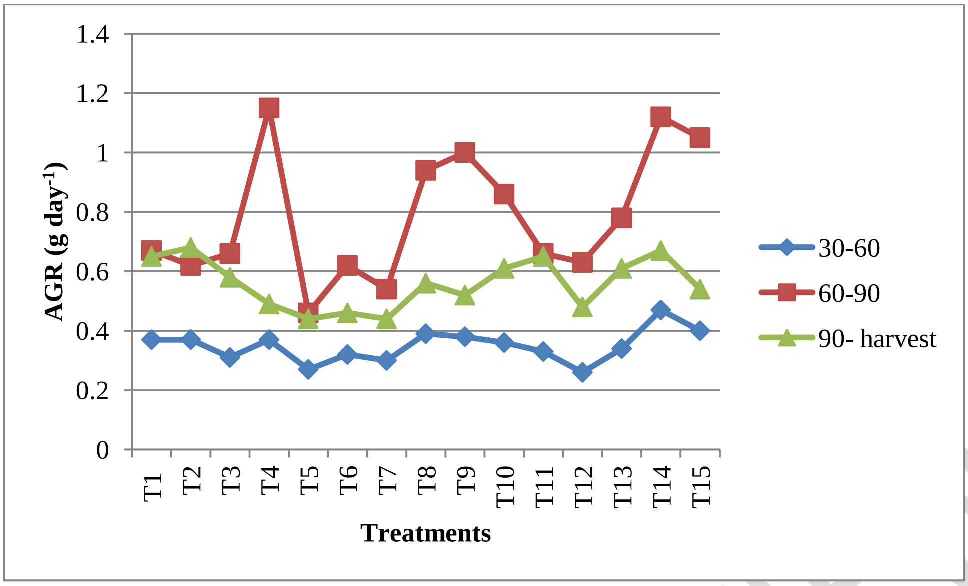

Fig. 1: Absolute Growth Rate of paddy as influenced by different establishment methods and irrigation methods

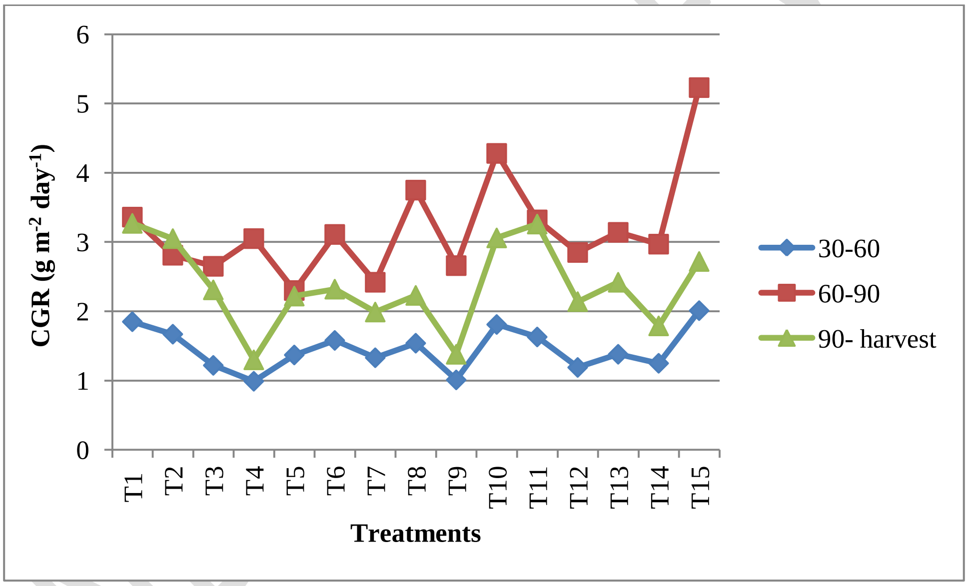

Fig. 2: Crop Growth Rate of paddy as influenced by different establishment methods and irrigation methods

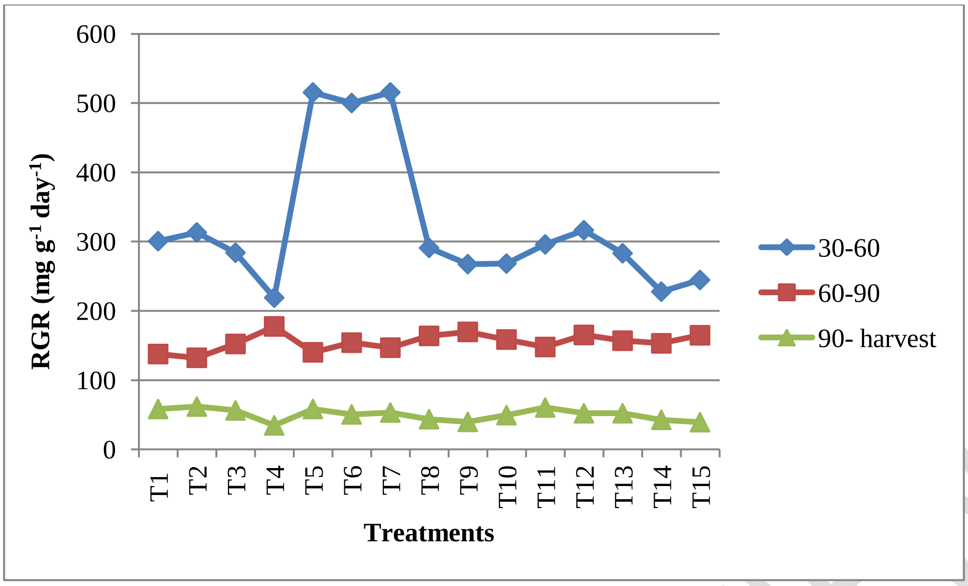

Fig. 3: Relative Growth Rate of paddy as influenced by different establishment methods and irrigation methods

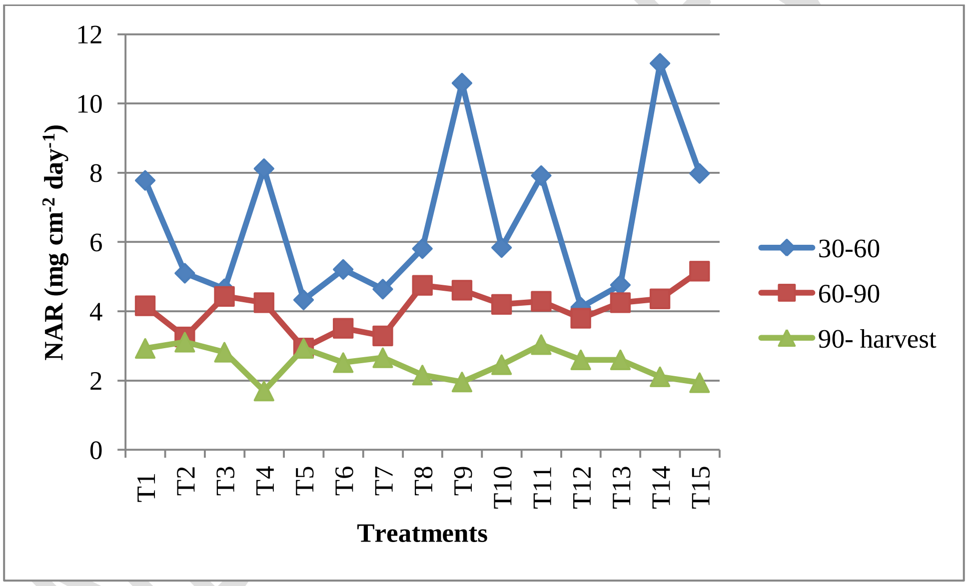

Fig. 4: Net Assimilation Rate of paddy as influenced by different establishment methods and irrigation methods

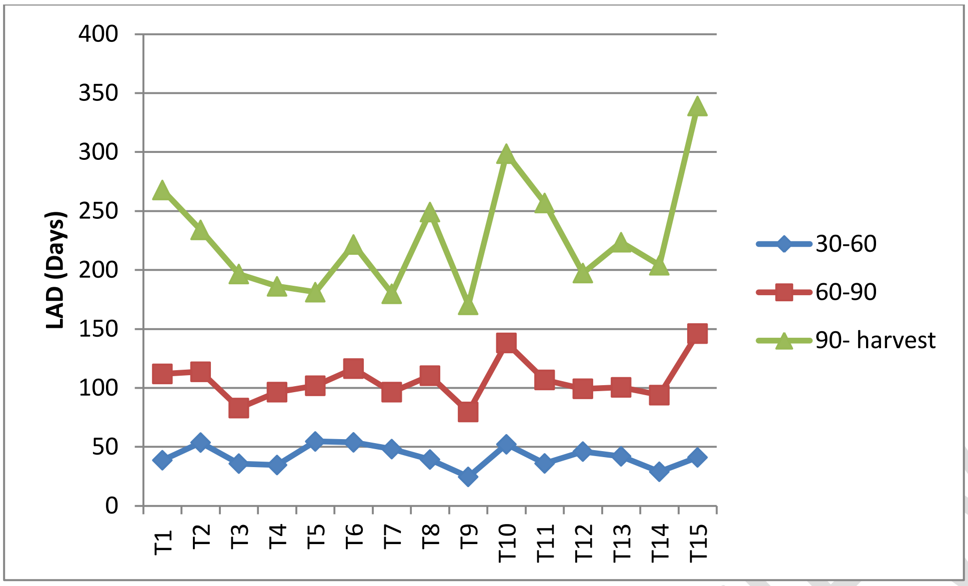

Fig. 5: Leaf Area Duration of paddy as influenced by different establishment methods and irrigation methods

REFERENCES

1. Abu El-Ezz A E 2014. Evaluating of some rice cultivars under different water regimes and Tillage systems. PhD Thesis. Tanta University, Egypt. Pp 100.

2. Anjan, K, Dasgupta Pragnakumar and Rakesh. 2014. Emerging opportunities and challenges in rice production. *Popular Kheti* **2**(2): 6-11.

3. Anzoua K G, Junichi, K, Toshihiro, H, Kazuto I, and Yutaka J 2010. Genetic improvements for high yield and low soil nitrogen tolerance in rice (*Oryza Sativa* L.) under a cold environment. *Field Crops Res.,* **116**, 38-45.

4. Bell R W, Haque M E, Jahiruddin M, Rahman M M, Begum M, Miah M A M, Islam M A, Hossen M A, Salahin N and Zahan T. 2019. Conservation agriculture for rice-based intensive cropping by smallholders in the eastern Gangetic plain. Agriculture **9**: 5.

5. Bouman B A M, Lampayan R M, and Tuong T P 2007. Water management in irrigated rice: coping with water scarcity; International Rice Research Institute: Los Baños, Philippines, pp. 1-54.

6. Bouman B A M, Peng S, Castaneda A R and Visperas R M 2005. Yield and water use of irrigated tropical aerobic rice systems. *Agril. Water Manag.*, **74**: 87-105.

7. Chauhan B S and Opena J 2012. Effect of tillage systems and herbicides on weed emergence, weed growth, and grain yield in dry-seeded rice systems. *Field Crops Res.,* **137**: 56-69.

8. Christine K, Klaus D, Xunhua Z, Zhang X, Shan L, Hongbin T and Burkhard S 2007. Fluxes of methane and nitrous oxide in water-saving rice production in north China. *Nutrient Cycling in Agroecosystems* **77**: 293-304.

9. Das J C, Barkakoty P K and Sarmah N N 2001. Performance of direct seeded rice under different irrigation regimes and sowing methods. *J. Agril. Sci.,* **14**: 126-28.

10 De Sclaux D, Huynh T T and Roumet, P 2000. Identification of soybean plant characteristics that indicate the timing of drought stress. *Crop Sci.,* **40**: 716-722.

11. Deepika V, Ompal S, Anita D and Gontia A S 2017. Study on crop growth rate and relative growth rate of growth analytical parameters in wheat, barley and oat. *Int. J. Current Microbiol. Applied Sci.,* **6**(9): 1341-1347.

12. Dhawan V 2017. Water and Agriculture in India. Presented in: *Global Forum of Food and Agriculture*, pp. 17-24.

13. Egl D B and Guffy R D 1997. Factors associated with reduced yields of delayed planting of soybean. *J. Agron. Crop Sci.,* **159:** 176-185.

14. FAOSTAT 2019. Statistics Division Food and Agriculture Organization of the United Nations; Viale delle Terme di Caracalla: Rome, Italy.

15. Horie T 2003. Increasing yield potential in irrigated rice: Breaking the yield barrier. International Rice Research Institute Press, Manila, Philippines.

16. Hugar A Y, Chandrappa H, Jayadeva H M, Salish A and Mallikarjun G B 2009. Comparitive performance of different rice establishment methods in Bhadra command area. *Karnataka J. Agril. Sci.,* **22**(5): 992-994.

17. Jeffrey T, Edwards C, Purcell E and Earl D 2005. Light interception and yield potential of short season maize (*Zea mays* L.) hybrids in the mid-south. *Agron. J.,* **9(7):** 225-234.

18. Krishna A and Biradar N K 2009. Influence of seedling age and spacing on seed yield and quality of short duration rice under system of rice intensification. *Karnataka J. Agril. Sci.,* **22**(1): 53-55.

19. Kukal S, Bhatt R, Gupta N and Singh M C 2014. Effect of crop establishment methods on performance of rice (*Oryza sativa* L.) and irrigation water productivity in sandy-loam soil. *J. Res.,* 51:326-328.

20. Lampayan R M, Rejesus R M, Singleton G R and Bouman B A M 2015. Adoption and economics of alternate wetting and drying water management for irrigated lowland rice. *Field Crops Res.,* **170**: 95–108.

21. Makarim A K, Zain Z, Gani A and Syamsiah I 2007. Water management practices in philippine. In: *Water Wise Rice Production*, *IRRI,* Manila, pp 129-141.

22. Malik R K, Kamboj B R, Jat M L, Sidhu H S, Bana A, Singh V, Saharawat Y S, Pundir A, Sahnawaz R D, Anuradha T and Kumaran N 2019. No-till and unpuddled mechanical transplanting of rice-operational manual. *Gates Open Res.,* 3.

23. Manjunatha M V, Masthana reddy B G, Shashidhar S D and Joshi V R 2009a. Studies on the performance of self-propelled rice transplanter and its effect on crop yield. *Karnataka J. Agril. Sci.,* **22**(2): 385-387.

24. Nadim M A, Awan I U, Baloch M S, Khan E A, Naveed K and Khan M A 2012. Response of wheat (*Triticumaestivum* L.) to different micronutrients and their application methods. *J. Animal Plant Sci.,* **22**(1): 113-119.

25. Nataraja T H, Halepyati A S, Desai B K and Pajani B T 2006. Response of wheat to zinc and iron fertilization. *Karnataka J. Agril. Sci.,* **19**(1):1-4.

26. Nguyen H T, Fischer K S and Fukai S 2009. Physiological responses to various water saving systems in rice. *Field Crops Res.,* 112: 189-198.

27. Saharawat Y S, Singh B, Malik R K, Ladha J K, Gathala M, Jat M L and Kumar V 2010. Evaluation of alternative tillage and crop establishment methods in a rice-wheat rotation in North Western IGP. *Field Crops Res.,* **116**: 260-267.

28. Sakamoto T, Morinaka Y, Ohnish T, Sunohara H, Fujioka S, Ueguchi-Tanaka M, Mizutani M and Sakata K 2006. Erect leaves caused by brassinosteroid deficiency increase biomass production and grain yield in rice. *Nat. Biotechnol.* 24: 105-109.

29. Sanjay K, Ashok K S, Singh G, Nareshmani P, Ajit K and Dinesh, K 2018. Effect of establishment methods and weed management practices on the growth and yield of direct seeded rice (*Oryza sativa* L.). *J. Pharmacogn. Phytochem.,* **7**(1): 164-168.

30. Shao-Hua W, Weixing C, Dong J, Tingbo Dai T and Yan Z 2002. Physiological characteristics and high yield techniques with SRI rice. *In Proceeding of International Conference* on Assessments of the System of Rice Intensification (SRI), Sanya, China. 1-4 Apr, pp 116-125.

31. Shekara B G, Sharnappa and Krishnamurthy N 2010. Effect of irrigation schedules on growth and yield of aerobic rice (*Oryza sativa* L.) under varied levels of farmyard manure in Cauvery command area. *Indian J. Agron.,* **55**: 35-39.

32. Shukla R K, Arvind K B, Mahapatra S and Basanth K 2002. Integrated nutrient management practices in relation to morphological and physiological determination of seed yield in Indian mustard (*Brassica juncea*). *Indian J. Agril. Sci.,* **72:** 670-672.

33. Singh Y P Singh G Singh S P, Kumar A, Sharma G, Singh M K, Mortin M and Johnson D E 2006. Effect of weed management and crop establishment methods on weed dynamics and grain yield of rice. *Indian J. Weed Sci.,* **38**(1-2): 20-24.

34. Sridevi V and Chellamuthu V 2015. Growth analysis and yield of rice as affected by different system of rice intensification (SRI) practices. *Int. Res. Applied Nat. Social Sci.,* **3**(4): 29-36.

35. Subhash C, Sanjay K and Vishal K. 2013. Comparative performance evaluation of self-propelled paddy transplanters in calcareous soil. *Agricultural Mechanization in Asia, Africa and Latin America* **44**(2): 33-38.

36. Swarup A and Yaduvanshi N P S 2000. Effect of Integrated nutrient management for plant hopper in East Asia, 13-15 November, 2002. Guilintelluric microflora. Ph.D. Thesis. University, Paris, XII Val de Marn. pp 187.

37. Takeshihorie Koki H and Hiroe Y 2003. SRI practices in Japan. *Proc. Crop Sci., Japan* **40**: 90-94.

38. Tan X, Shao, D, Liu H, Yang F, Xaio C and Yang H. 2013. Effects of alternate wetting and drying irrigation on percolation and nitrogen leaching in paddy fields. *Paddy Water Environ.,* **11**:1-15.

39. Uphoff N 2003. Biological approach to sustainable soil system. *Int. J. Agril. Sustain.,* **1**: 38-50.

40. Van Nguyen N and Ferrero A 2006. Meeting the challenges of global rice production. *Paddy Water Environ.,* 4: 1–9.

41. Yadana K L, Aung K M, Takeo Y and Kazuo O 2009. The effects of green manure (Sesbania rostrata) on the growth and yield of rice. *J. Faculty Agric.*, Kyushu University 54(2): 313-319.

42. Yadav S, Humphreys E, Kukal S S, Gill G and Rangarajan R 2011. Effect of water management on dry seeded and puddled transplanted rice part 2: Water balance and water productivity. *Field Crops Res.,* **120**: 123-32.

43. Zhu X G, Long S P, Ort D R, Eizenga G, McCling A, Kovach M, Tyagi, W, Ali M L, Tung C W and Reynold A 2010. Improving photosynthetic efficiency for greater yield. *Ann. Revised Plant Biol.,* 61: 235-261.