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# ECONOMICS AND ENERGETICS OF DIRECT SEEDED RICE UNDER DIFFERENT LEVELS OF TILLAGE, SEED RATE AND WEED MANAGEMENT

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## Abstract

A field experiment was conducted at Pandit Jawaharlal Nehru College of Agriculture and Research Institute, Karaikal to study the effect of seed rate, tillage and weed management on the yield of direct seeded rice during *Samba* season (from August 2017 to January 2018). The treatment combination consisted of three levels of tillage (zero, wet and dry tillage), two levels of seed rate (75 and 112.5 Kg $ha^{-1}$) and two levels of weed management practices (weeded and unweeded). The experiment was laid out in Randomized Block Design (RBD) with three replications. The grain yield was not influenced significantly by different tillage methods, though numerically higher grain yield (1992 Kg $ha^{-1}$) was recorded due to wet tillage (puddling), followed by zero tillage (1819 Kg $ha^{-1}$) and dry tillage (1745 Kg $ha^{-1}$) which were all comparable. Significantly higher grain yield (1971 Kg $ha^{-1}$) was recorded due to high seed rate of 112.5 Kg $ha^{-1}$ than low seed rate of 75 Kg $ha^{-1}$ (1732 Kg $ha^{-1}$). Weed management practices significantly influenced the grain yield. The grain yield was 2614 Kg $ha^{-1}$ due to weeding (pendimethalin as pre-emergence herbicide on 3 DAS followed by two hand weedings on 30 and 60 DAS) and it was significantly higher than that of unweeded plots (1090 Kg $ha^{-1}$). The gross return, net return and B:C ratio were higher (Rs. 55859 $ha^{-1}$, Rs. 25702 $ha^{-1}$ and 1.85, respectively) in the treatment combination of zero tillage using glyphosate with higher seed rate of 112.5 Kg $ha^{-1}$ and weed management by application of pendimethalin as pre-emergence herbicide on 3 DAS followed by two hand weedings on 30 and 60 DAS. The highest total energy consumption was 13645 MJ $ha^{-1}$ in the treatment combination of wet tillage (puddling) with high seed rate of 112.5 Kg $ha^{-1}$ and weed management. However, less energy requirement (13377 MJ $ha^{-1}$), high output energy (45643 MJ $ha^{-1}$), high energy use efficiency (3.41) and high energy productivity (0.23 Kg $MJ^{-1}$) were recorded in the treatment combination of zero tillage using glyphosate with high seed rate of 112.5 Kg $ha^{-1}$ and weed management.

***Key words:*** Tillage, seed rate, economics and energetics

## Introduction

Rice (*Oryza sativa* L.) is the prime source of food for nearly half of the world's population (Kumar *et al.*, 2015). In the Union Territory of Puducherry, the area under rice cultivation was 16,263 hectares during the year 2015-2016 which accounted for 63.30 percent of the total cropped area. The increasing scarcity of water threatens the sustainability of the irrigated rice production system (Anwar *et al.*, 2010). It has been reported that ground water table is falling at 0.5 to 2 meter per year in the Indian states of Punjab, Haryana, Gujarat, Tamil Nadu, Rajasthan, Maharashtra and Karnataka (Tuong and Bouman, 2003). It is no longer feasible to flood rice fields to ensure better crop establishment and control weeds as well (Johnson and Mortimer, 2005). In addition to water scarcity, the farmers are facing the problem of acute labour shortage and hike in wage rate. Transplanting takes 240 to 250 man hour $ha^{-1}$, which is 25 percent of the total labour requirement of the rice crop (Ojha and Kwatra, 2014). This led to increased cost of production and reduced profits to farmer. Hence, there has been a shift in crop establishment from transplanting to direct seeded rice in many Asian countries including India.

Direct seeding is a good alternative to transplanting as it is more economical and labour saving. Chatterjee and Maity (1981) reported that rice grain production in India suffered an annual loss of 15 million tonnes due to

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weed competition. Weeds causes heavy damage to direct seeded rice crop which can be to the tune of 5-100 percent.

(Kohle, 1989). Well managed direct seeded rice was almost at par in yield with transplanted crop (Baloch *et al*., 2006). High weed infestation is the major bottleneck in direct seeded rice especially in dry field conditions (Samar *et al*., 2009). Hand weeding is very effective and environment friendly but tedious and highly labour intensive and back breaking one. Unavailability of labour at peak periods, huge time requirement and bad weather conditions force the farmer to adopt alternative measure of weed control. Moreover, morphological similarity between grassy weeds and rice seedlings makes hand weeding difficult at early stages of growth. Considering all these situations an alternative or supplement to hand weeding was increasing crop density especially in low-input systems or when herbicide resistance develops in weeds (Chauhan *et al*., 2012).

Gill (2008) revealed that seed rate also influenced the weed dry matter effectively as the seed rate increased, the competition exerted by crop increased which shows excellent smothering effect. Increasing the seeding rate of rice from 15 to 125 Kg ha$^{-1}$ decreased weed biomass significantly (Chauhan, 2012). Of late, zero tillage is gaining popularity mainly due to reduced cost of production besides avoiding the delay in planting (Grover and Sharma, 2011). Short to medium term on station studies reported 34-46 per cent savings in machine labour requirement in zero tilled dry direct seeded rice compared with conventional puddled transplanted rice (Saharawat *et al*., 2010). It has been reported that tillage accounts for 25-30 per cent of cost of cultivation (Pradhan *et al*., 2018). In zero tilled direct seeded rice existing weeds are burnt down by using herbicides such as paraquat @ 0.5 Kg a.i ha$^{-1}$ (or) glyphosate @ 1.0 Kg a.i ha$^{-1}$ (Gopal *et al*., 2010). Rice cultivation at Karaikal is also experiencing high cost of cultivation due to increase in cost of labour and water shortage every year which lead to the increased cost of cultivation and threatens the sustainable rice production. From the foregoing facts it is understood that zero tillage, direct seeding and seed rate plays an important role in sustaining the rice production by reducing the cost of cultivation of rice. Therefore, considering these aspects in mind, an investigation on "Economics and energetics of direct seeded rice under different levels of tillage, seed rate and weed management" was carried out at Pandit Jawaharlal Nehru College of Agriculture and Research Institute, Karaikal during *Samba* season (from August 2017 to January 2018).

## Materials and Methods

A field experiment was conducted under low land (wetland) condition in field number $A_2$ in the East farm of Pandit Jawaharlal Nehru College of Agriculture and Research Institute, Karaikal during *Samba* season (August 2017 to January 2018). The experimental site is situated at 10°552 North latitude and 79°492 East longitude and at an altitude of four meters above the mean sea level. The maximum and minimum temperature during the cropping period (August to January) were 31.3 and 23.0°C, respectively. The mean morning and evening relative humidity were 89.9 and 68.8 percent. The normal rainfall during cropping season is 945.3 mm and the normal open pan evaporation is 555.2 mm. The normal total bright sun shine hours received during the cropping season is 716.8. The actual mean maximum temperature, mean minimum temperature and mean relative humidity prevailed during the crop growth period were in normal range, rainfall was higher by 438.9 mm and open pan evaporation was lower by four mm than the normal. The total bright sunshine hours during the crop growth period was more than the normal by 116.07 hours. The soil of the experimental field was sandy clay loam in texture belonging to Sorakudy series (*Fluventic Haplustept*) (SSSO, 1990). The soil was neutral in reaction (pH = 6.72) with an EC of 0.21 dS m$^{-1}$. The fertility status of the soil was low in available nitrogen, high in phosphorus and medium in potassium. The cultivar used for the study was ADT (R) 46 which is a medium duration rice variety (135 days) with long slender grain.

The experiment with different treatments each under different levels was tested in the field in a Randomized Block Design (RBD) with three replications and 12 treatments. The treatment details of the field experiment are as follows with Factor I (Tillage) - 3 levels ($T_1$: Zero Tillage, $T_2$: Wet Tillage, $T_3$ : Dry Tillage (DT); Factor II (Seed rate) - 2 levels ($S_1$ : 75 Kg ha$^{-1}$ (100% RSR), $S_2$ : 112.5 Kg ha$^{-1}$ (150% RSR) and Factor III (Weed management) - 2 levels ($W_1$ : Weeded, $W_2$ : Unweeded)

To create zero tillage, glyphosate was sprayed @ 10 ml L$^{-1}$ of water to knock-out the weeds. To create dry tillage the soil in the plots were dug out at optimum moisture with a spade to 15 cm depth to prepare a seed bed. To create wet tillage, water was impounded in the plot and digging was given by spade to form puddled condition. The entire quantity of phosphorus was applied as basal dose in all the plots. Nitrogen and potassium fertilizers were applied in three equal splits at basal, tillering and panicle initiation stages of crop. The pre-emergence herbicide pendimethalin was sprayed at 3

DAS followed by two hand weedings on 30 DAS and 60 DAS for weeded plots. Neither weeding nor any herbicide was given for the unweeded plots from the date of sowing to till the harvest of crop, as per the treatment schedule. The data on weed population, weed biomass, plant height, number of tillers, crop biomass and numbers of grains/ panicles were recorded. On the basis of existing price of the inputs and outputs, variable cost of cultivation and grass returns was calculated. Benefit : cost ratio was worked out by dividing net returns with variable cost. Using the energy equivalents of various inputs, operations and various energy sources as suggested by Binning *et al*., (1984), the energy requirement for various tillage methods, seed rate and weed management practices pertaining to various treatment combinations were calculated. The energy use efficiency (energy ratio) as suggested by Dazhong and Pimental (1984) and energy productivity as suggested by Singh *et al*., (1997) were worked out. The biometric observations and the analytical data of soil and plant samples, except economics and energy requirements, were subjected to statistical scrutiny as per the statistical procedures given by Gomez and Gomez (1984). The data on weed count and weed dry weight were subjected to square root transformation before statistical scrutiny using the formula $\sqrt{x+0.5}$.

## Result and Discussion

### Effect of tillage, seed rate and weed management practices on total weed density (No. m$^{-2}$) and weed dry matter production (g m$^{-2}$)

#### Weed analysis

The total density of weeds (number of grasses + sedges + broad leaved weeds m$^{-2}$) were not influenced significantly by the various tillage methods and seed rates, whereas, the weed management practices significantly affected the total weed density at all stages of crop. The total weed density (number m$^{-2}$) was significantly lower in weeded plots at all the stages of crop *viz.,* at 30 DAS (104.4 m$^{-2}$), 60 DAS (122.2 m$^{-2}$) and at 90 DAS (18.7 m$^{-2}$) than that of unweeded plots which recorded 260.3, 414.0 and 141.3 numbers m$^{-2}$, respectively on 30, 60 and 90 DAS table. 1. In general, the total population of weeds increased upto 60 DAS and declined thereafter as reflected on 90 DAS in both weeded and unweeded plots. None of the interaction effects had any significant effect on the total weeds density. This only indicated that the weed density was not affected by tillage methods, seed rate and weed management practices.

As far as the total DMP of weed is concerned, neither the tillage nor the seed rate or their interaction effect had any significant effect on 30, 60 and 90 DAS. However, the total weed DMP was significantly influenced by the weed management practices at all the stages. The unweeded plots registered significantly the maximum total DMP as compared to weeded plots at all crop growth stages. The total DMP of weeds were 12.6 and 30.0 g m$^{-2}$, respectively for weeded and unweeded plots on 30 DAS. It was 64.2 and 202.2; 11.1 and 127.5 g m$^{-2}$, respectively for weeded and unweeded plots on 60 and 90 DAS, respectively. The total weed DMP was the lowest in weeded plots under all the three methods of tillage and they were on par with each other, whereas the total weed DMP was the highest in unweeded plots under various tillage methods. However, the DMP of weeds in unweeded plots under dry tillage was the highest (253.4 g m$^{-2}$) but it was on par with that of wet tillage (184.4 g m$^{-2}$). In the unweeded plots, the lowest DMP of

**Table 1:** Total weed density (No. m$^{-2}$) and weed dry matter production (g m$^{-2}$) as influenced by tillage, seed rate and weed management practices.

| Treatments | Total weed density(No. m$^{-2}$) | | | Total weed dry matter production (g m$^{-2}$) | | |
|---|---|---|---|---|---|---|
| | 30 DAS | 60 DAS | 90 DAS | 30 DAS | 60 DAS | 90 DAS |
| T1: Zero tillage | 11.4 (147.9) | 14.5 (229.2) | 7.4 (69.4) | 3.8 (15.6) | 10.8 (125.8) | 6.6 (58.3) |
| T2 : Wet tillage | 12.9 (198.5) | 16.7 (311.5) | 8.6 (91.0) | 4.7 (23.4) | 10.4 (121.0) | 7.9 (82.5) |
| T3 : Dry tillage | 12.7 (200.8) | 15.0 (263.5) | 7.8 (79.6) | 4.6 (25.0) | 11.4 (152.8) | 7.1 (67.2) |
| S Ed | 1.9 | 1.0 | 0.8 | 0.5 | 0.8 | 0.5 |
| CD (P=0.05) | NS | NS | NS | NS | NS | NS |
| $S_1$ : 75 Kg ha$^{-1}$ | 11.7 (171.8) | 15.2 (259.7) | 8.0 (78.9) | 4.2 (19.2) | 11.0 (135.2) | 7.1 (69.9) |
| $S_2$ : 112.5 Kg ha$^{-1}$ | 13.0 (193.0) | 15.7 (276.5) | 7.9 (81.2) | 4.6 (23.4) | 10.8 (131.2) | 7.2 (68.7) |
| S Ed | 1.5 | 0.8 | 0.6 | 0.4 | 0.6 | 0.4 |
| CD (P=0.05) | NS | NS | NS | NS | NS | NS |
| $W_1$ : Weeded | 9.5 (104.4) | 10.8 (122.2) | 4.2 (18.7) | 3.5 (12.6) | 7.8 (64.2) | 3.2 (11.1) |
| $W_2$ : Unweeded | 15.2 (260.3) | 20.1 (414.0) | 11.6 (141.3) | 5.3 (30.0) | 14.0 (202.2) | 11.2 (127.5) |
| S Ed | 1.5 | 0.8 | 0.6 | 0.4 | 0.6 | 0.4 |
| CD (P=0.05) | 3.2 | 1.8 | 1.4 | 0.8 | 1.3 | 0.9 |

weeds was recorded due to zero tillage (168.8 g $m^{-2}$) but it was on par with that of unweeded plot under wet tillage (184.4 g $m^{-2}$). As far as the effect of tillage on the DMP of weeds was concerned, there was some variations in the DMP of specific group of weeds *viz*., grasses, sedges and BLWs especially at specific stages of crop (30, 60 and 90 DAS). However, when the overall total DMP of all the weeds (DMP of grasses + sedges + broad leaved weeds) was considered, there was no significant difference between tillage methods at all stages of crop *viz*., 30, 60 and 90 DAS. This has clearly shown that zero tillage (chemical tillage using glyphosate) is comparable with conventional tillage practices such as wet and dry tillages in respect of weed control in direct seeded rice.

**Effect of tillage, seed rate and weed management practices on growth attributes**

**Plant height (cm)**

On 30 DAS, zero tillage registered significantly taller plants (34.5 cm) than under wet tillage (30.5 cm) and dry tillage (30.4 cm) table. 2 and the latter two were on par with each other. The seed rates did not influence the plant height significantly throughout the crop growth. The plant height was not influenced significantly by the weed management practices in the early (30 DAS) and mid stage (60 DAS) of crop but significantly influenced plant height at latter. The plant height was 95.2 cm in weeded plots and 85.6 cm in unweeded plots, respectively on 90 DAS. The improvement in plant height in zero tillage at early stage of crop seems to be due to better soil physical conditions (aeration, improved water holding capacity of soil, etc.), better root growth and its proliferation, which might have promoted the plant height by enhanced cell division. Stanzen *et al*., (2017) were also of similar opinion. Similarly, the seed rate also did not influence the plant height at all the growth stages of observation. The plant height was not influenced by weed management practices up to 60 DAS. However at 90 DAS weed management practices influenced the height of rice. Controlling the weeds by weeding (pendimethalin *fb* two hand weedings) resulted in significantly taller plants than unweeded plots at 90 DAS. This could be attributed to the increased availability of nutrients and effective utilization of natural resources *viz*., light, space, nutrients etc., which in turn would have reduced crop-weed competition at growth period. Several workers (Mandal *et al*., 2011 and Chadachanakar *et al*., 2017) have reported that the plant height was affected when weeds were allowed to compete with rice.

**Leaf Area Index (LAI)**

The LAI in weeded plots were 5.3 and 4.8 on 60 and 90 DAS, respectively which was significantly higher than that of unweeded plots which recorded LAI of 3.6 and 3.0 respectively on 60 and 90 DAS table. 2. Due to weeding, the plants could produce more number of leaves. Controlling the weeds not only increased the number of leaves $plant^{-1}$, but also increased the length and width of the leaves. All these factors led to increase in the size of the photosynthetic area as indicated by higher leaf area index in those treatments, where weed growth was effectively checked due to application of pendimethalin as pre-emergence herbicide on 3 DAS followed by two hand weedings on 30 and 60 DAS. This is attributed to effective weed control. On the contrary, unweeded plots recorded the lowest leaf area index throughout the crop growth period due to reduction in number of leaves, their width and length. Dubey *et al.,* (2017) also reported that the LAI of rice was reduced due to weed competition

**Table 2:** Effect of tillage, seed rate and weed management practices on growth attributes.

| Treatments | Plant height (cm) | | | Leaf Area Index | | | Number of tillers $hill^{-1}$ | | |
|---|---|---|---|---|---|---|---|---|---|
| | 30 DAS | 60 DAS | 90 DAS | 30 DAS | 60 DAS | 90 DAS | 30 DAS | 60 DAS | 90 DAS |
| T1: Zero tillage | 34.5 | 79.7 | 93.0 | 1.2 | 4.5 | 3.9 | 4.3 | 11.5 | 14.2 |
| T2 : Wet tillage | 30.5 | 75.4 | 88.6 | 0.9 | 4.5 | 4.0 | 4.0 | 9.5 | 14.0 |
| T3 : Dry tillage | 30.4 | 73.5 | 89.6 | 0.9 | 4.3 | 3.7 | 3.7 | 9.1 | 12.9 |
| S Ed | 1.5 | 2.7 | 3.0 | 0.1 | 0.3 | 0.3 | 0.4 | 0.7 | 1.1 |
| CD (P=0.05) | 3.1 | NS | NS | NS | NS | NS | NS | 1.6 | NS |
| $S_1$ : 75 Kg $ha^{-1}$ | 32.4 | 77.6 | 91.0 | 0.9 | 4.5 | 3.7 | 3.8 | 10.5 | 13.9 |
| $S_2$ : 112.5 Kg $ha^{-1}$ | 31.2 | 74.8 | 89.8 | 1.0 | 4.6 | 4.0 | 4.3 | 9.6 | 13.5 |
| S Ed | 1.2 | 2.2 | 2.5 | 0.1 | 0.2 | 0.2 | 0.3 | 0.6 | 0.9 |
| CD (P=0.05) | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| $W_1$ : Weeded | 31.6 | 76.7 | 95.2 | 1.0 | 5.3 | 4.8 | 4.0 | 11.6 | 17.2 |
| $W_2$ : Unweeded | 32.1 | 75.7 | 85.6 | 0.9 | 3.6 | 3.0 | 4.0 | 8.5 | 10.2 |
| S Ed | 1.2 | 2.2 | 2.5 | 0.1 | 0.2 | 0.2 | 0.3 | 0.6 | 0.9 |
| CD (P=0.05) | NS | NS | 5.2 | NS | 0.5 | 0.5 | NS | 1.3 | 1.8 |

that resulted in resource depletion by weeds.

### Number of tillers hill$^{-1}$

On 60 DAS, the highest number of tillers hill$^{-1}$ were recorded due to zero tillage (11.5), followed by wet tillage (9.5) and the lowest no. of tillers were recorded due to dry tillage (9.1) table 2 but they were significantly different from each other. The number of tillers were not significantly influenced by seed rate at all the stages of observation. As far as weed management practices were concerned, except on 30 DAS, significant differences were observed in respect of number of tillers hill$^{-1}$ on 60 and 90 DAS. At these two stages, the weeded plots recorded significantly higher number of tillers (11.6 and 17.2 respectively on 60 DAS and 90 DAS) than in unweeded plots (8.5 and 10.2 respectively on 60 DAS and 90 DAS.

## Effect of tillage, seed rate and weed management practices on yield attributes and yield

### Yield attributes

Zero tillage recorded significantly the highest panicle length (27.9 cm), followed by wet tillage (26.6 cm) and dry tillage (26.6 cm) table 3 and the latter two were on par with each other. As far as seed rate is concerned, none of the yield parameter *viz*., (no. of panicles m$^{-2}$, panicle length, panicle weight and test weight etc.) were influenced significantly by the seed rate. However, high seed rate of 112.5 Kg ha$^{-1}$ recorded numerically higher number of panicles m$^{-2}$ (404.2) than that of low seed rate of 75 Kg ha$^{-1}$ (370 panicles m$^{-2}$) table. 3. The weed management practices significantly influenced all yield parameters except test weight. The weeded plots recorded significantly more number of panicles (446 m$^{-2}$), panicle length (28.1 cm) and panicle weight (3.2 g) than unweeded plots. The number of panicles m$^{-2}$, panicle length and panicle weight of unweeded plots were 328 m$^{-2}$, 25.5 cm and 2.2 g, respectively. The unweeded plots registered lesser number of panicles (94.2), filled grains per panicle (77.1) and low filling percentage (80.9). Zero tillage recorded significantly the longest panicles, followed by wet and dry tillage and the latter two were on par with each other. With regard to other yield parameters, zero tillage was comparable with wet and dry tillage methods.

The superiority of yield parameters in zero tillage could be attributed to the improvement in growth attributes of rice due to better soil physical condition and better utilization of natural resources (light, space, moisture etc.). Further, early control of the weeds was achieved by use of pendimethalin as PEH on 3 DAS, followed by two hand weeding on 30 and 60 DAS. Because of better control of weeds in the early stage, the rice crop was able to grow free of weed competition and hence the growth and yield attributes were better in zero tillage than that of wet and dry tillage methods. Otherwise, it is inferred that zero tillage is comparable with wet and dry tillage methods, in respect of yield attributes.

The weed management practices significantly influenced all the yield parameters, except test weight. The weeded plots recorded significantly more number of panicles m$^{-2}$, longer panicles and higher panicle weight than unweeded plots. Jabran *et al*., (2011) also reported higher percentage of yield contributing parameters like panicle bearing tillers, grains per panicle and 1000 grain weight in weeded plots as compared to unweeded plots. Controlling weeds by pendimethalin as PEH followed by two hand weeding significantly increased the length and weight of panicle as compared to unweeded plots. The increase in length and weight of panicle could be attributed to the increase in availability of nutrients besides other natural resources, particularly at the time of panicle initiation which in turn could be attributed to reduced weed competition. Further, due to higher availability of nutrients and soil moisture, the translocation of assimulates to the spikelets was also higher as evident by higher filling percentage in weeded plots where weeds were effectively controlled. Due to these reasons, the weed control treatments recorded higher number of grains panicle$^{-1}$ and higher test weight. In

**Table 3:** Effect of tillage, seed rate and weed management practices on yield attributes and yield.

| Treatments | No. of panicles m$^{-2}$ | Panicle length (cm) | Panicle weight | Test weight (g) | Grain yield (Kg ha$^{-1}$) | Straw yield (Kg ha$^{-1}$) | Harvest index |
|---|---|---|---|---|---|---|---|
| T1: Zero tillage | 392.7 | 27.9 | 2.7 | 24.0 | 1819 | 6769 | 0.25 |
| T2 : Wet tillage | 396.0 | 26.6 | 2.8 | 24.2 | 1992 | 7386 | 0.27 |
| T3 : Dry tillage | 372.0 | 26.0 | 2.7 | 24.6 | 1745 | 7862 | 0.22 |
| S Ed | 30.0 | 0.6 | 0.1 | 0.4 | 138 | 461 | 0.02 |
| CD (P=0.05) | NS | 1.4 | NS | NS | NS | NS | NS |
| $S_1$ : 75 Kg ha$^{-1}$ | 370.0 | 27.1 | 2.8 | 24.2 | 1732 | 7183 | 0.24 |
| $S_2$ : 112.5 Kg ha$^{-1}$ | 404.2 | 26.5 | 2.6 | 24.3 | 1971 | 7495 | 0.26 |
| S Ed | 24.0 | 0.5 | 0.1 | 0.4 | 113 | 376 | 0.02 |
| CD (P=0.05) | NS | NS | NS | NS | 233 | NS | NS |
| $W_1$ : Weeded | 446.0 | 28.1 | 3.2 | 24.6 | 2614 | 9396 | 0.28 |
| $W_2$ : Unweeded | 328.0 | 25.5 | 2.2 | 23.9 | 1090 | 5281 | 0.22 |
| S Ed | 24.0 | 0.5 | 0.1 | 0.4 | 113 | 376 | 0.02 |
| CD (P=0.05) | 51.0 | 1.1 | 0.2 | NS | 233 | 781 | 0.04 |

general, studies elsewhere indicated that weed management treatment combinations involving pendimethalin @ 1000 g ha$^{-1}$ could register higher yield attributes. Walia *et al*., (2012) and Chakraborti *et al*., (2015) were also of similar opinion.

**Grain yield**

The grain yield was not influenced significantly by different tillage methods. However numerically higher grain yield (1992 Kg ha$^{-1}$) was recorded due to wet tillage (puddling), followed by zero tillage (1819 Kg ha$^{-1}$) and dry tillage (1745 Kg ha$^{-1}$) which were all comparable table 3. The grain yield was significantly influenced by different seed rates. Significantly higher grain yield (1971 Kg ha$^{-1}$) was recorded due to high seed rate of 112.5 Kg ha$^{-1}$ than low seed rate of 75 Kg ha$^{-1}$ (1732 Kg ha$^{-1}$). Weed management practices significantly influenced the grain yield. The grain yield was 2614 Kg ha$^{-1}$ due to weeding and it was significantly higher than that of unweeded plots (1090 Kg ha$^{-1}$). The straw yield was not influenced significantly by different tillage methods. However numerically higher straw yield was recorded under dry tillage (7862 Kg ha$^{-1}$), followed by wet tillage (7386 Kg ha$^{-1}$) and zero tillage (6769 Kg ha$^{-1}$). The seed rate did not influence the straw yield significantly. However, numerically higher straw yield (7495 Kg ha$^{-1}$) was recorded at high seed rate of 112.5 Kg ha$^{-1}$ than that of low seed rate of 75 Kg ha$^{-1}$ (7183 Kg ha$^{-1}$). The weed management practices had significantly influenced the straw yield. The straw yield was higher in weeded plots (9396 Kg ha$^{-1}$) than unweeded plots (5281 Kg ha$^{-1}$).

Weed management practices alone significantly influenced the harvest index, whereas, the HI was not affected significantly by seed rate and tillage methods. The harvest index was higher in weeded plots (0.28) than in unweeded plots (0.22). Among the tillage methods, there was no significant difference in respect of grain yield, straw yield and HI. This indicated that zero tillage is no way inferior to wet and dry tillage methods and it was comparable with wet and dry tillage as far as the yield and HI were considered. Higher seed rate of 112.5 Kg ha$^{-1}$ recorded higher grain yield than that of low seed rate of 75 Kg ha$^{-1}$. This was due to more number of tillers hill$^{-1}$, number of panicle per unit area, panicle length and panicle weight. Yadav *et al*., (2017) also reported that the highest seeding rate recorded the highest number of panicles accompanied by highest number of filled grains and 1000 grain weight resulting in the highest grain yield. The results of the present investigation also closely corroborate with the findings of Zhao *et al*., (2007). Studies at Maharashtra by Dongarwar *et al*. (2018) with different seed rates (50, 75, 100, 125 and 150 Kg ha$^{-1}$) indicated that increasing the seed rate by 50 per cent (75 Kg ha$^{-1}$) in direct seeded rice variety (Sye-2001) gave higher grain yield than recommended seed rate of 50 Kg seeds ha$^{-1}$. The weed management practices significantly influenced both grain yield and straw as well as the harvest index. Controlling the weeds in direct seeded rice using pendimethalin as PEH *fb* two HW on 30 and 60 DAS substantially increased the grain and straw yields. This is attributed to effective control of weeds that might have paved way for enhanced availability of nutrients, soil moisture and other resources for improving the growth and yield attributes of rice which ultimately enhanced the grain and straw yield. The increase in grain and straw yields due to effective control of weeds was also reported by Devi and Singh (2018). The overall increase in grain yield was 153 and 129 percent, respectively due to weeding as compared to unweeding, for low and high seed rates, across various tillage methods. Similarly, the overall increase in grain yield due to weeding was 140 percent as against unweeding, irrespective of seed rates and tillage methods. Otherwise, it may be stated that the yield reduction was ranging from 29 to 53 percent due to unweeding (unweeded plots). Yield reduction to the tune of 60.5 and 70 percent in wheat has been reported due to weedy condition (unweeded condition) under conventional tillage and zero tillage, respectively (Singh *et al*., 2015). Irrespective of seed rate, under weeded condition, the yield due to zero tillage was 3.4 percent lesser than wet tillage and 15.8 percent higher than dry tillage. This has pointed out that the yield under zero tillage is fairly comparable with wet tillage but better than dry tillage, under weeded condition. Under unweeded condition the yield differences were amplified, i.e., as compared to zero tillage, the yield was 27.3 and 23.8 percent higher, respectively due to wet and dry tillage methods, irrespective of seed rate. This has indicated that if weeding was not done (*i.e.,* under unweeded condition), the yield penalty was high in zero tillage to the tune of 23 to 27 per cent as compared to wet and dry tillage methods. This finding has emphasized the importance of tillage and weeding in rice production, especially in direct sown rice. Rani and Yakadri (2017) reported that grain yield of rice obtained from zero tillage was comparable with conventional tillage.

**Economics**

The total cost of cultivation of various treatments ranged from Rs.22388 to 33677 ha$^{-1}$. The total cost of cultivation was the lowest due to zero tillage (Rs. 22388 ha$^{-1}$) with 75 Kg seed ha$^{-1}$ under unweeded condition. The highest total cost of cultivation was Rs. 33677 ha$^{-1}$ due to wet tillage with high seed rate of 112.5 Kg ha$^{-1}$

**Table 4:** Effect of different treatments on the economics*.

| Sl. No. | Treat-ments | General cost of cultiva-tion | Treatment cost | | | | Total cost of cultiva-tion | Gross income | | Gross return (Rs. $ha^{-1}$) | Net income (Rs. $ha^{-1}$) | B:C ratio |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Sow-ing | Seed | Land prepa-ration | Weed mana-gement | | Grain (Rs. $ha^{-1}$) | Straw (Rs. $ha^{-1}$) | | | |
| 1 | ZT $S_1W_1$ | 16863 | 1200 | 2475 | 1850 | 6532 | 28920 | 34620 | 8541 | 43161 | 14241 | 1.49 |
| 2 | ZT $S_1W_2$ | 16863 | 1200 | 2475 | 1850 | 0 | 22388 | 14565 | 4447 | 19012 | -3376 | 0.85 |
| 3 | WT $S_1W_1$ | 16863 | 3270 | 2475 | 3300 | 6532 | 32440 | 43290 | 9818 | 53108 | 20668 | 1.64 |
| 4 | WT $S_1W_2$ | 16863 | 3270 | 2475 | 3300 | 0 | 25908 | 13999 | 3417 | 17416 | -8492 | 0.67 |
| 5 | DT $S_1W_1$ | 16863 | 1200 | 2475 | 2800 | 6532 | 29870 | 33849 | 9489 | 43338 | 13468 | 1.45 |
| 6 | DT $S_1W_2$ | 16863 | 1200 | 2475 | 2800 | 0 | 23338 | 15600 | 7385 | 22985 | -353 | 0.98 |
| 7 | ZT $S_2W_1$ | 16863 | 1200 | 3712 | 1850 | 6532 | 30157 | 46575 | 9284 | 55859 | 25702 | 1.85 |
| 8 | ZT $S_2W_2$ | 16863 | 1200 | 3712 | 1850 | 0 | 23625 | 13374 | 4804 | 18178 | -5447 | 0.77 |
| 9 | WT $S_2W_1$ | 16863 | 3270 | 3712 | 3300 | 6532 | 33677 | 40665 | 10149 | 50814 | 17137 | 1.51 |
| 10 | WT $S_2W_2$ | 16863 | 3270 | 3712 | 3300 | 0 | 27145 | 21574 | 6158 | 27732 | 587 | 1.02 |
| 11 | DT $S_2W_1$ | 16863 | 1200 | 3712 | 2800 | 6532 | 31107 | 36249 | 9096 | 45345 | 14238 | 1.46 |
| 12 | DT $S_2W_2$ | 16863 | 1200 | 3712 | 2800 | 0 | 24575 | 19000 | 5476 | 24476 | -99 | 1.00 |

*Data not analysed statistically
ZT - Zero tillage (Chemical tillage), WT - Wet tillage, DT- Dry tillage, $S_1$ - 75 Kg $ha^{-1}$ (100% RSD), $S_2$ - 112.5 Kg $ha^{-1}$ (150 % RSD), $W_1$ - Weeded, $W_2$ - Unweeded

under weeded condition. It was followed by wet tillage with 75 Kg seed rate $ha^{-1}$ under weeded condition (Rs. 32440 $ha^{-1}$) and dry tillage with 112.5 Kg seed rate $ha^{-1}$ under weeded condition (Rs. 31107 $ha^{-1}$). The highest gross returns (Rs. 55859 $ha^{-1}$), net income (Rs. 25702 $ha^{-1}$) and B:C ratio (1.85) were obtained in the treatment combination of zero tillage with high seed rate of 112.5 Kg $ha^{-1}$ under weeded condition table 4. It was followed by the treatment combination of wet tillage with 75 Kg seed $ha^{-1}$ under weeded condition which registered gross returns of Rs. 53108 $ha^{-1}$, net income of Rs. 20668 $ha^{-1}$, with B:C ratio of 1.64. However, zero tillage with low seed rate of 75 Kg $ha^{-1}$ under weeded condition gave net income of Rs. 14241 $ha^{-1}$ with a B:C ratio of 1.49. The highest gross income (Rs. 55859 $ha^{-1}$), net income (Rs. 25702 $ha^{-1}$) and B:C ratio (1.85) were obtained in the treatment combination of zero tillage with high seed rate (112.5 Kg $ha^{-1}$) under weeded condition (using pendimethalin as PEH *fb* two hand weedings on 30 and 60 DAS). This was due to less cost involved for land preparation and comparable output (yield) under zero tillage as compared to other tillage methods as well as other treatment combinations. Weeding was very important aspect for enhancing the yield and net income as compared to tillage and seed rate. Among the tillage methods and seed rate, the impact of tillage is more effective than seed rate. However, the appropriate combination of these three factors (*i.e.,* zero tillage + weed control using pendimethalin as PEH *fb* two Hand weedings on 30 and 60 DAS + high seed rate) could result in the highest net income.

### Energy requirement

The total energy requirement of various treatments ranged from 12069 MJ $ha^{-1}$ to 13645 MJ $ha^{-1}$. The total energy requirement was the lowest (12069 MJ $ha^{-1}$) due to zero tillage with low seed rate of 75 Kg $ha^{-1}$ under unweeded condition. The highest total energy requirement was 13645 MJ $ha^{-1}$ due to wet tillage with high seed rate

**Table 5:** Effect of different treatments on the energy requirement*.

| Sl. No. | Treat-ments | General energy requi-rement MJ $ha^{-1}$ | Treatment cost | | | | Total energy requi-rement MJ $ha^{-1}$ |
|---|---|---|---|---|---|---|---|
| | | | Sow-ing | Seed | Land prepa-ration | Weed manag-ement | |
| 1 | ZT $S_1W_1$ | 10527 | 120.61 | 1103 | 318.92 | 757.32 | 12826 |
| 2 | ZT $S_1W_2$ | 10527 | 120.61 | 1103 | 318.92 | 0 | 12069 |
| 3 | WT $S_1W_1$ | 10527 | 115.26 | 1103 | 591.52 | 757.32 | 13093 |
| 4 | WT $S_1W_2$ | 10527 | 115.26 | 1103 | 591.52 | 0 | 12336 |
| 5 | DT $S_1W_1$ | 10527 | 120.61 | 1103 | 421.61 | 757.32 | 12929 |
| 6 | DT $S_1W_2$ | 10527 | 120.61 | 1103 | 421.61 | 0 | 12172 |
| 7 | ZT $S_2W_1$ | 10527 | 120.61 | 1654 | 318.92 | 757.32 | 13377 |
| 8 | ZT $S_2W_2$ | 10527 | 120.61 | 1654 | 318.92 | 0 | 12620 |
| 9 | WT $S_2W_1$ | 10527 | 115.26 | 1654 | 591.52 | 757.32 | 13645 |
| 10 | WT $S_2W_2$ | 10527 | 115.26 | 1654 | 591.52 | 0 | 12887 |
| 11 | DT $S_2W_1$ | 10527 | 120.61 | 1654 | 421.61 | 757.32 | 13480 |
| 12 | DT $S_2W_2$ | 10527 | 120.61 | 1654 | 421.61 | 0 | 12723 |

*Data not analysed statistically
ZT - Zero tillage (Chemical tillage), WT - Wet tillage, DT- Dry tillage, $S_1$ - 75 Kg $ha^{-1}$ (100% RSD), $S_2$ - 112.5 Kg $ha^{-1}$ (150 % RSD), $W_1$ - Weeded, $W_2$ - Unweeded.

of 112.5 Kg ha$^{-1}$ under weeded condition. It was followed by dry tillage with the seed rate of 112.5 Kg ha$^{-1}$ under weeded condition (13480 MJ ha$^{-1}$) and zero tillage with high seed rate of 112.5 Kg ha$^{-1}$ under weeded condition (13377 MJ ha$^{-1}$) table 5. The highest total energy requirement was 13645 MJ ha$^{-1}$ needed for wet tillage with high seed rate of 112.5 Kg ha$^{-1}$ under weeded condition. This was due to higher energy spent for land preparation and high seed rate. This is in line with the findings of Jain *et al*., (2007). Among the tillage methods, zero tillage was requiring the lowest energy. This was due to the reason that there was physical absence of tillage for land preparation. Only the non-selective herbicide (glyphosate) was used to kill the weeds. Similar results of zero tillage requiring low energy input was reported by Bohra and Kumar *et al*., (2015) and Pandey *et al*., (2018).

In terms of total energy output, the combination of zero tillage using Glyphosate with higher seed rate of 112.5 Kg ha$^{-1}$ under weeded condition (using pendimethalin as PEH *fb* two HW on 30 and 60 DAS) registered the higher energy output (45644 MJ ha$^{-1}$), energy use efficiency (3.41) and energy productivity (0.23 Kg MJ$^{-1}$) as compared to other treatments. High energy output, energy use efficiency and energy productivity in this treatment was due to increased crop productivity and also energy value of grain output. Abhishek *et al*., (2017) reported that zero tillage recorded the higher energy use efficiency (5.79), energy productivity (0.11 Kg MJ$^{-1}$) as compared to conventional tillage which recorded (4.90) energy use efficiency and (0.10 Kg MJ$^{-1}$) energy productivity in chickpea. This is in line with the findings of present investigation.

## Conclusion

From the foregoing discussion, it is concluded that zero tillage is comparable to the wet and dry tillage in respect of crop yield output, besides saving in cost of cultivation. For direct seeding of rice in the coastal region of Karaikal, zero tillage using glyphosate with 50 per cent high seed rate of 112.5 Kg ha$^{-1}$ and weed control using pendimethalin as pre-emergence herbicide followed by two hand weeding on 30 and 60 DAS is recommended for getting high yield and net income. This package of practices was very economical with higher energy output, energy use efficiency and energy productivity.

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