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**Research Article**

# Thermal Energy Utilization Pattern and Energetics of Short Duration Rice Cultivar in Relation to Age of Nursery

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**ABSTRACT**

Adoption of short duration varieties of rice in Punjab can help to arrest the fall in groundwater table, receding at the rate of 0.4-0.9 m per year at present. A field experiment was conducted for two years to determine the effect of age of seedling at the time of transplanting of short duration variety on the growth and yield of rice, its thermal energy utilization pattern and energetics. Five treatments comprising of 3, 4, 5, 6 and 7 weeks old seedling age at the time of transplanting of rice cultivar PR126 was laid out in randomized complete block design with four replications. Seedlings of 3 weeks age took minimum number of days for attainment of phyiological maturity followed by 4, 5, 6 and 7 weeks old. Reduction in the age of nursery resulted in the shortening of life cycle of crop which resulted in reducing heat requirement. Conversely older seedlings resulted in consumption of the highest number of heat units. Crop raised from 3 weeks old nursery availed minimum heliothermal and photothermal units to attain maturity followed by 4, 5, 6 and 7 weeks old. Maximum heat use efficiency was attained by 3 weeks old nursery followed by 4, 5, 6 and 7 weeks. Three weeks old nursery produced maximum rice yield, statistically at par with 4 and 5 weeks old nursery and significantly higher than 6 and 7 weeks old nurseries. Net energy gain also showed the similar trend but was significant only during second year. Results revealed that in case of short duration cultivar of rice, younger seedlings of 3,4 or 5 weeks age could be transplanted for higher yields and for better thermal energy utilization and energy use efficiency.

**Key words:** Age of nursery, Agro-climatic indices, Energetics, PR126, Rice

## Introduction

Globally, rice (*Oryza sativa* L.) is the dominating food grain feeding half of the population and is also a principal staple food crop of fertile alluvial plains of north-west Indo-Gangetic Plains. More than 90 per cent of the world's rice is grown and consumed in Asia alone. In India, it covered an area of 43.77 million hectares during 2017-18 with a total production of 112.76 million tonnes and productivity of 2.58 t $ha^{-1}$ (Anonymous 2020a) whereas in Punjab, the area was 3.10 million hectares with total production of 12.82 million tonnes and productivity of 4.13 t $ha^{-1}$ during 2018-19 (Anonymous 2020b).

Among the different agro-techniques, timely transplanting and use of seedlings of appropriate age at transplanting are important non-monetary inputs for realizing the higher yield in rice (Pattar *et al.,* 2001). Such techniques are environmentally sound and are cost effective i.e. farmers can easily adopt without changing in input requirement (Rajendran and Ganesa, 2014). The age of seedling is an important criterion in rice production as it has tremendous influence on its growth and development, primarily through the number of tillers per hill and ultimately grain

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formation (Aggarwal *et al.*, 2016). For optimum yield, age of seedlings at transplanting varies with the duration of the variety. With the large scale adoption of short duration high yielding varieties, it becomes imperative to optimize the age of nursery.

Weather plays an important role in influencing rice productivity. Temperature and photoperiod are the key factors influencing growth and development of crops and ultimately yield. The most common weather based agro-indices used to estimate growth and yield of crops are Growing Degree Days (GDD), Heliothermal Units (HTU) and Photothermal Units (PTU) and Heat Use Efficiency (HUE) (Kaur and Dhaliwal, 2014; Chaudhari *et al.,* 2019). Accumulated GDD is an important temperature index which provides an estimate of harvest date as well as development stages of crop (Ketring and Wheless, 1989). The thermal energy utilization also varies with cultivars of different duration (Sandhu *et al.,* 2013). Due to role of photoperiod, both PTU and HTU in addition to GDD are used. HUE, i.e., efficiency of heat utilization in terms of dry matter accumulation, depends on genetic factors, crop type as well as sowing time (Rao *et al.,* 1999). Moreover, age of nursery for transplantation affects the performance of the crop due to variation in duration of crop (Sharma *et al.,* 2013). The productivity is adversely affected when the older seedlings are used at the time of transplanting which results in less tillering due to shortening of vegetative phase on account of reduced accumulation of thermal units (Mobasser *et al*., 2007).

Therefore, keeping the foregoing discussion in mind, an experiment was conducted to determine the optimum age of transplanting of short duration variety of rice and to study its energetics and the differential behavior of rice in relation to age of seedlings for thermal energy utilization.

## Materials and Methods

A field experiment was carried out at the research farm of the Department of Agronomy, Punjab Agricultural University, Ludhiana situated at 30°56' N latitude, 75°52' E longitude and at an altitude of 247 m above sea level during *kharif* 2017 and 2018. The site is characterized by sub-tropical type of climate with hot and dry summer, wet monsoon season (July-September) and a cool dry winter with average annual rainfall of about 734 mm, 85 per cent of which falls during the monsoon season. The popular short duration cultivar of rice "PR126" was used as a test crop. Five treatments of age of nursery *viz.,* 3, 4, 5, 6 and 7 weeks old were evaluated in randomized complete block design with 4 replications. The soil of the experimental field was sandy loam in texture, normal in reaction (pH 7.8) with electrical conductivity of 0.13 $dSm^{-1}$. Initial status of the soil was medium for nitrogen (275.0 kg $ha^{-1}$), available phosphorus (19.5 kg $ha^{-1}$) as well as available potassium (197.0 kg $ha^{-1}$). The dates of nursery sowing for 3, 4, 5, 6 and 7 weeks old were 9 June, 2 June, 26 May, 19 May and 12 May, during 2017 and 5 June, 29 May, 22 May, 15 May and 8 May during 2018, respectively. The dates of transplanting were 30 June and 26 June during 2017 and 2018, respectively. Recommended dose of nitrogen @ 105 kg/ha was applied in the form of urea in three equal splits *viz.,* one third each at one, three and five weeks after transplanting. Uniform recommended package of practices were followed for raising the crop. The quantity of irrigation water applied was recorded. Water was kept ponded in the field for 15 days and thereafter irrigation was applied two days after disappearance of the ponded water and irrigation was stopped fortnight before maturity for ease in harvesting.

The growth and yield attributes *viz*., plant height, effective tillers/$m^2$, panicle length, 1000-grain weight, grain yield and straw yield were recorded at harvesting. The grain yield was expressed in q $ha^{-1}$ at 14 per cent moisture content. The collected data was used to perform Analysis of Variance (ANOVA) in a randomized complete block design as per the standard procedure to determine the effect of treatments. Means were compared using least significant difference (LSD) at 5 per cent probability.

Agroclimatic indices namely growing degree days (GDD), heliothermal units (HTU), photothermal units (PTU) and heat use efficiency (HUE) were computed following Sharma *et al.* (2013) as per the following formulae :

GDD (°C days) = $T_{mean} - T_b$

Where, $T_{mean}$ is the daily mean air temperature (°C)= $(T_{max} + T_{min})/2$; $T_b$ is the base temperature (10°C) for rice crop (Aggarwal *et al.*, 2016).

HTU, the product of GDD and corresponding actual sunshine hours for that day were computed on daily basis and summed up:

$$\text{Accumulated HTU} = \sum_{i=1}^{n} \text{GDD} \times \text{Actual sunshine hours}$$

PTU, the product of GDD and corresponding day length for that day were computed on daily basis and summed up:

$$\text{Accumulated PTU} = \sum_{i=1}^{n} \text{GDD} \times \text{Day length}$$

Where day length refers to maximum possible sunshine hours.

GDD, HTU and PTU were accumulated from the date of sowing to date of 50 per cent flowering and date of physiological maturity to give respective accumulated indices.

$$\text{HUE (kg/ha/°C days)} = \frac{\text{Seed yield (kg/ha)}}{\text{AGDD (°C day)}}$$

Where AGDD refers to Accumulated GDD (°C days)

The input and output energies were calculated using energy equivalents given by Singh and Mittal, 1992). Energy use efficiency was calculated by the following formula:

$$\text{Energy use efficiency} = \frac{\text{Output energy (MJ/ha)}}{\text{Input energy (MJ/ha)}}$$

## Results and Discussion

### *Phenological Stages and Growing Degree Days*

Data pertaining to days taken to attain 50% flowering and physiological maturity by rice depicted in Table 1 revealed that there was much variation in number of days required to attain these phases when the crop was transplanted with different age of seedlings. More number of days were taken by older seedlings to complete 50% flowering and maturity as compared to younger seedlings. The maximum duration required by 3 weeks old nursery to achieve 50% flowering was 83 days from sowing in comparison to 89, 92, 98 and 102 days taken by 4, 5, 6 and 7 weeks old, respectively. The physiological maturity of 3 weeks old seedlings was attained in 113- 114 days as compared to 127-128 days taken by 7 weeks old seedlings. Similar trend was observed by Sattar *et al*. (2017) in transplanted rice.

Accumulated growing degree days as shown in Table 2, depicted that among the different age of seedlings transplanted at the same time, the highest number of growing degree days were accumulated by 7 weeks old seedlings followed by 6, 5, 4 and 3 weeks old nursery for both 50 per cent flowering and physiological maturity, during both the years. Since anthesis in rice crop is advanced with higher temperature and incident radiation thus the variation in different phenophase duration changes with sowing dates of nursery, which results in early or delayed

**Table 1.** Number of days taken by rice cultivar PR 126 to attain different phenological stages

| Age of seedling | 50 % flowering | | | | Physiological maturity | | | |
|---|---|---|---|---|---|---|---|---|
| | After sowing | | After transplanting | | After sowing | | After transplanting | |
| | 2017 | 2018 | 2017 | 2018 | 2017 | 2018 | 2017 | 2018 |
| 3 weeks | 81 | 83 | 60 | 62 | 114 | 113 | 93 | 92 |
| 4 weeks | 87 | 89 | 59 | 61 | 119 | 118 | 91 | 90 |
| 5 weeks | 91 | 92 | 56 | 57 | 124 | 122 | 89 | 87 |
| 6 weeks | 95 | 98 | 53 | 56 | 125 | 124 | 83 | 82 |
| 7 weeks | 100 | 102 | 51 | 53 | 128 | 127 | 79 | 78 |

**Table 2.** Agroclimatic indices of rice at different phenological stages as affected by age of seedlings at the time of transplanting

| Age of seedling | Growing degree days (°C days) | | Helio thermal units (°C day hours) | | Photo thermal units (°C day hours) | |
|---|---|---|---|---|---|---|
| | 2017 | 2018 | 2017 | 2018 | 2017 | 2018 |
| | | | 50% flowering stage | | | |
| 3 weeks | 1712 | 1766 | 12479 | 10749 | 23289 | 24117 |
| 4 weeks | 1859 | 1916 | 13844 | 11774 | 25375 | 26230 |
| 5 weeks | 1950 | 1998 | 14832 | 12876 | 26693 | 27395 |
| 6 weeks | 2047 | 2126 | 15956 | 13983 | 28029 | 29121 |
| 7 weeks | 2164 | 2207 | 17281 | 14703 | 29610 | 30228 |
| | | | Physiological maturity stage | | | |
| 3 weeks | 2336 | 2324 | 17628 | 14449 | 30871 | 30977 |
| 4 weeks | 2462 | 2465 | 18598 | 15344 | 32741 | 32990 |
| 5 weeks | 2574 | 2593 | 19897 | 17021 | 34350 | 34782 |
| 6 weeks | 2621 | 2650 | 20569 | 17156 | 35157 | 35664 |
| 7 weeks | 2702 | 2718 | 21384 | 17579 | 36335 | 36660 |

fulfillment of thermal requirements to attain a particular phenophase (Kobayasi *et al.*, 2010). In transplanted rice, requirement of higher thermal time in early sown crop for attaining 50 per cent flowering and maturity corroborates the findings of Sattar *et al.* (2017). In other words, younger seedlings required less degree days to reach 50 per cent flowering and physiological maturity as compared to older seedlings. This might be because of the reduction in the age of nursery resulted in the shortening of life cycle of crop which resulted in reducing heat requirement.

### *Heliothermal units*

The HTU accumulated to attain 50 per cent flowering and physiological maturity by rice transplanted under different age of seedlings are given in Table 2. During both the years, less HTU to attain 50 per cent flowering were required by 3 weeks old nursery, followed by 4, 5, 6 and 7 weeks old nursery. Similar trend was found in HTU requirement for maturity. For different age of seedling, the HTU requirement for maturity varied from 17628 to 21384°C day hours during first year and 14449 to 17579°C day hours during second year. Early sown seedlings i.e. 7 weeks nursery in our study took more time than late sown seedlings i.e. 3 weeks old nursery, thus accumulated more heliothermal units.

### *Photothermal units*

Persual of data as depicted in Table 2 showed that the trend of PTU accumulated by rice under different age of seedling was in line with the trend observed in the HTU. It might be because both these indices are based on time period required to attain 50 per cent flowering and physiological maturity. The PTU for 50% flowering ranged from 23289 to 29610 and 24117 to 30228°C day hours whereas for maturity it varied from 30871 to 36335 and 30977 to 36660°C day hours during first and second year, respectively.

### *Heat use efficiency*

It was observed that the heat use efficiency improved with reduction in the age of nursery. Heat use efficiency for grain production was maximum when 3 weeks old nursery was transplanted, followed by 4,5,6 and 7 weeks (Table 3). Younger nursery also showed its superiority over older nursery in terms of heat use efficiency for straw production. The index increased from 2.68 to 3.45 kg/ha/°C days with reduction in the age of nursery from 7 to 3 weeks for grain production and the corresponding increase was 4.84 to 5.94 kg/ha/°C days for straw production, during first year. Thus, younger seedlings use the thermal energy more efficiently

**Table 3.** Heat use efficiency (kg/ha/°C days) of rice for grain and straw production as affected by age of seedlings at the time of transplanting

| Age of seedling | Grain (HUE) | | Straw (HUE) | |
|---|---|---|---|---|
| | 2017 | 2018 | 2017 | 2018 |
| 3 weeks | 3.45 | 3.41 | 5.94 | 5.89 |
| 4 weeks | 3.21 | 3.14 | 5.55 | 5.46 |
| 5 weeks | 2.99 | 2.91 | 5.27 | 5.12 |
| 6 weeks | 2.92 | 2.82 | 5.12 | 4.91 |
| 7 weeks | 2.68 | 2.61 | 4.84 | 4.56 |

as compared to older ones. Similar results were obtained during the second year. Delayed transplanting of seedlings reduced the heat use efficiency was also reported by Abhilash *et al.* (2017).

### *Rice growth and yield attributes*

The data in Table 4 depicted that plant height was not affected significantly by different age of seedlings in both the seasons. The number of effective tillers varied significantly due to seedling age. Maximum effective tillers were produced by 3 weeks old nursery, statistically at par with 4 and 5 weeks old nursery and significantly higher than 6 and 7 weeks old nursery. Other yield parameters *viz.,* panicle length and thousand grain weight were not affected significantly. Rajendran and Ganesa (2014) and Ali *et al.* (2013) also reported that seedling age at transplanting influenced the number of panicles at harvest. Younger seedlings produced more effective tillers as compared to older ones (Singh *et al*., 2018) which might be due to the reduction in rice tiller number, pre-anthesis dry matter accumulation, remobilization efficiency and contribution to grain yield, as well as reduction in post-anthesis photosynthesis amount causing reductions in the number of effective panicles Liu *et al.* (2017).

### *Rice yield*

The persual of the data in Table 5 showed that rice cultivar PR 126 produced highest yield

**Table 4.** Effect of age of seedlings at the time of transplanting on growth and yield attributes of rice cultivar PR 126

| Age of seedling | Plant height (cm) | | Effective tillers/m$^2$ | | Panicle length (cm) | | 1000- grain weight (g) | |
|---|---|---|---|---|---|---|---|---|
| | 2017 | 2018 | 2017 | 2018 | 2017 | 2018 | 2017 | 2018 |
| 3 weeks | 97.7 | 104.0 | 318.0 | 313.2 | 27.3 | 26.5 | 23.3 | 22.8 |
| 4 weeks | 97.1 | 103.5 | 302.3 | 301.7 | 27.2 | 27.4 | 23.0 | 22.1 |
| 5 weeks | 96.3 | 103.3 | 290.0 | 292.5 | 27.1 | 26.2 | 21.3 | 21.6 |
| 6 weeks | 98.7 | 104.4 | 276.0 | 268.0 | 27.0 | 26.7 | 21.2 | 20.8 |
| 7 weeks | 98.4 | 104.9 | 259.0 | 249.5 | 26.9 | 26.5 | 20.3 | 20.4 |
| LSD (p=0.05) | NS | NS | 29.4 | 20.8 | NS | NS | NS | NS |

NS refers to Non-significant

**Table 5.** Effect of age of seedlings at the time of transplanting on yield of rice cultivar PR 126

| Age of seedling | Grain yield (q ha$^{-1}$) | | Straw yield (q ha$^{-1}$) | | Harvest index | |
|---|---|---|---|---|---|---|
| | 2017 | 2018 | 2017 | 2018 | 2017 | 2018 |
| 3 weeks | 80.7 | 79.2 | 138.8 | 137.0 | 36.7 | 36.7 |
| 4 weeks | 79.0 | 78.4 | 136.7 | 134.7 | 36.7 | 36.5 |
| 5 weeks | 77.1 | 76.8 | 135.6 | 132.7 | 36.2 | 36.3 |
| 6 weeks | 76.6 | 73.6 | 134.2 | 130.0 | 36.4 | 36.5 |
| 7 weeks | 72.3 | 70.2 | 130.7 | 124.0 | 35.6 | 36.4 |
| LSD (p=0.05) | 3.8 | 5.1 | NS | NS | NS | NS |

NS refers to Non-significant

when 3 weeks old nursery was transplanted which was statistically at par with that produced by 4 and 5 weeks old nursery and significantly higher than 6 and 7 weeks old nurseries. The average increase in yield of 3 weeks old nursery was 1.6, 3.9, 6.5 and 12.2 over 4,5,6 and 7 weeks old nursery. This might be because of $T_{max}$ temperature which remained above 33°C at time of heading in case of 6-7 week old nursery as compared to 3, 4 or 5 week old nursery where it remained optimal i.e. below 33°C. Also, our study showed that the number of days taken to attain 50% flowering after transplanting were more in 3 weeks old nursery as compared to 4, 5, 6 and 7 weeks old nursery, indicating more vegetative growth in younger seedlings as compared to older ones and grain filling duration was also more in younger seedlings as compared to older ones (Table 1). Younger seedlings in comparison to older seedlings are capable of establishing early and have faster growth rate and due to higher root development which leads to more nutrient uptake (Gurjar *et al.,* 2018) and more number of ripened grains (Sahoo and Rout, 2004). Degeneration of primary tiller buds on lower nodes of main culm results in reduced tillering when nursery is retained for longer period of time. Reduction in the number of tillers, shortened vegetative duration and dry matter accumulation resulted in reduction in the grain yield of older seedlings due to delayed transplanting was also reported by Liu *et al*. (2015). The straw yield as well as harvest index was not affected significantly by age of seedlings.

### *Relationship between seed yield and agroclimatic indices*

The regression equations obtained between grain yield as dependent variable and AGDD/ AHTU/APTU as independent variables based on mean data of two crop seasons are shown below. Linear and polynomial relationship between grain yield and AGDD /AHTU/ APTU were observed. The relationship was found highly significant as $R^2$ values ranged between 0.851 to 0.870 for linear equations and 0.963 to 0.987 for quadratic equations. Such relations also indicate great application of such equations in predicting behavior of the crop from these agroclimatic indices. Similar results were reported by Sharma *et al.* (2013).

1. AGDD and Grain yield

   $Y = -7E\text{-}05x^2 + 0.344x - 328.4 \quad R^2 = 0.985$

   $Y = -0.021x + 130.1 \quad R^2 = 0.863$

2. AHTU and Grain yield

   $Y = -9E\text{-}07x^2 + 0.030x - 175.1 \quad R^2 = 0.963$

   $Y = -0.002x + 116.1 \quad R^2 = 0.851$

3. APTU and Grain yield

   $Y = -3E\text{-}07x^2 + 0.020x - 243.1 \quad R^2 = 0.987$

   $Y = -0.001x + 125.6 \quad R^2 = 0.870$

### *Energetics*

The data depicted in Table 6 showed that highest energy input was observed in 3 and 4 week old nurseries and least was obtained in 7

**Table 6.** Effect of age of seedlings at the time of transplanting on Energetics of rice cultivar PR 126

| Age of seedling | Energy input ($\times10^3$ MJ/ha) | | Energy output ($\times10^3$ MJ/ha) | | Net energy gain ($\times10^3$ MJ/ha) | | Energy use efficiency | |
|---|---|---|---|---|---|---|---|---|
| | 2017 | 2018 | 2017 | 2018 | 2017 | 2018 | 2017 | 2018 |
| 3 weeks | 24.6 | 23.0 | 313.9 | 309.0 | 289.3 | 286.0 | 12.7 | 12.4 |
| 4 weeks | 24.6 | 23.0 | 308.4 | 303.0 | 283.7 | 280.0 | 12.5 | 12.2 |
| 5 weeks | 24.3 | 22.7 | 303.6 | 297.2 | 279.3 | 274.4 | 12.5 | 12.1 |
| 6 weeks | 24.0 | 22.4 | 301.1 | 292.3 | 277.1 | 269.9 | 12.5 | 12.0 |
| 7 weeks | 23.7 | 22.1 | 289.1 | 278.3 | 265.4 | 256.2 | 12.2 | 11.6 |
| LSD (p=0.05) | - | - | 14.9 | 13.1 | NS | 13.1 | NS | NS |

NS refers to Non-significant

week old nursery, mainly due to more irrigation water consumption in the former. During first year, the energy output was maximum in 3 week old nursery, statistically at par with 4, 5 and 6 week old nursey but significantly higher than 7 week nursery only but during second year it was significantly better than both 6 and 7 week old nurseries. Net energy gain was not affected significantly by age of nursery during first year but during second year, it was highest in 3 week old nursery, statistically at par with 4 and 5 week old nursery and significantly superior than 6 and 7 week old nursery. Although energy use efficiency was not affected by nursery age but it was highest when 3 week old nursery was transplanted and least was in 7 week old nursery.

## Conclusion

The study reveals that the yield of transplanted rice is largely determined by seedling age, younger seedlings of 3,4 or 5 weeks age can be transplanted for higher yields of short duration rice cultivar. Both thermal energy utilization as well as energy use efficiencies of rice crop have been improved by transplanting younger seedlings as compared to the older ones. Thus, it can be concluded that agronomic measures such as optimum age of seedling at the time of transplanting can be effectively used for harnessing the freely available solar energy.

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