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Studies on different Agrometeorological indices and thermal use Efficiencies of rice in New Alluvial Zone of West Bengal

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ABSTRACT
A field experiment was conducted during kharif season of 2016 in the experimental farm of Bidhan Chandra Krishi Viswavidyalaya to study the growing degree days (GDD), heliothermal unit (HTU), photothermal unit (PTU) and phenothermal index (PTI) and also to assess the effect of inorganic fertilizer as well as bio-fertilizers on thermal use efficiencies of rice in terms of dry matter accumulation and grain yield. The results revealed that the accumulated GDD, HTU, PTU and PTI for the entire growth period were 2505.30 day °C, 11515.03 day °C hour, 31013.33 day °C hour and 169.83 day °C day^{-1} respectively. T_2 treatment (100% RDF) recorded the maximum dry matter accumulation (622.52 g m^{-2}) and grain yield (5.66 t ha^{-1}). The highest heat use efficiency (0.25 g m^{-2} day $^0C^{-1}$) in terms of dry matter accumulation was observed in T_2 and T_4, heliothermal use efficiency (0.05 g m^{-2} day $^0C^{-1}$ hour^{-1}) in T_2, T_4 and T_5, photothermal use efficiency (0.02 g m^{-2} day $^0C^{-1}$ hour^{-1}) in all treatments except control. On the other hand, T_2 treatment recorded the maximum HUE (2.26 kg ha^{-1} day $^0C^{-1}$), HTUE (0.49 kg ha^{-1}day $^0C^{-1}$hour^{-1}) and PTUE (0.18 kg ha^{-1}day $^0C^{-1}$hour^{-1}) in terms of grain yield.
Key words: GDD, HTU, PTU, PTI, Thermal use efficiencies, Rice

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INTRODUCTION

Rice (*Oryza sativa* L.) is a staple food for about 50 per cent of the world's population that resides in Asia, where 90 per cent of the world's rice is grown and consumed. It constitutes 23% of the global cereal acreage (680 million ha) and 29% to the global cereal production (2064 million tons). Rice plays a vital role in our food as well as nutritional security for millions of livelihood. But the important yield limiting factors of rice cultivation are the water and mineral stress, diseases, insect pests, and weeds. To improve and/or stabilize yield, these yield limiting factors should be managed sustainably. Research data related to yield limiting factors indicates that much work is needed to improve rice yield under different agro-ecosystems. The increase in rice production could be achieved through adoption of suitable and newer technologies. Among the limited options, hybrid technology and utilization of bio-fertilizers are the proven technologies currently available for stepping up rice production significantly. Bio-fertilizer, an alternate low cost resource have gained prime importance in recent decades and play a vital role in maintaining long term soil fertility and sustainability. They are cost effective, eco-friendly and renewable sources of plant nutrients to supplement chemical fertilizers. The ground realities are that farmers are still adopting undesired practices because of various reasons like use of old varieties, imbalance use of fertilizers, minimum uses of bio-fertilizer etc. Therefore, a technological breakthrough in agro-techniques especially in nutrient management by utilizing bio-fertilizers should be adopted in improving production potential of rice in terms of yield performance in new alluvial zone of West Bengal. Rice is very much sensitive to photo thermal regimes and the crop growth is influenced largely by the growing environmental conditions. Among them temperature plays a significant role in physiological, chemical and biological processes of plants. It is an important environmental factor influencing the growth and development of crops. During growth and development of a cereal, several growth stages are distinguishable in which important physiological processes occur. Influence of temperature on phenology and yield of crop plants can be studied under field condition through accumulated heat units [2, 5, 13]. Plants have a definite temperature requirement for attainment of certain phenological stages. The duration of each phenophase determines the accumulation and partitioning of dry matter in different parts as well as crop responses to environmental and external factors [6]. The occurrence of different phenological events during crop growth period in relation to temperature can be estimated by using accumulated heat units or growing degree-days (GDD) [7]. Growing degree days are based on the concept that the real time to attain a phenological stage is linearly related to temperature in the range between mean temperature and base temperature [12]. A degree day or heat unit is the departure from the mean daily temperature above the minimum threshold temperature [1]. The heat unit concept assumes that a direct and linear relationship between growth and temperature is advantageous for the assessment of yield potential of a crop in different weather conditions. Reaumur was the first to suggest that duration of particular stages of growth is directly related to temperature summation. Knowledge of accumulated GDD can provide an estimate of harvest date as well as crop development stage [3, 10, 15, 19]. Dynamic crop growth simulation models are being used extensively for predicting growth and yield of crops, but these being very detailed models require large input data besides being very complex to use [18]. Therefore, simplified models, with less input data requirement, would be quite useful. Agroclimatic models based on thermal indices can possibly meet these objectives. Heat use efficiency (HUE) *i.e.* efficiency of utilization of heat in terms of dry matter accumulation or grain yield depends on crop type, genetic factors and sowing time as well as has great practical application [14]. Initiation as well as duration of crop phenophases is an essential component of weather based dynamic crop growth and yield simulation models. Crop phenology can be used to specify the most appropriate date and time of specific development process. The growing degree day (GDD), heliothermal unit (HTU), photothermal unit (PTU) and phenothermal index (PTI) are some simple tools to find out the relationship between plant growth, temperature, bright sunshine hours and day length. However, the impact of temperature, bright sunshine hour as well as day length on the growth habits of this crop are not well documented. The present experiment has been undertaken to address this lacunae.

MATERIALS AND METHODS

A field experiment was conducted during the *kharif* season of 2016 at 'C' block farm of Bidhan Chandra Krishi Viswavidyalaya, Kalyani, Nadia, West Bengal. The experimental farm was situated at 22.5°N latitude and 89.0°E longitude and at an elevation of 9.75 m above mean sea level. The soil of the experimental field was new alluvial (type – Entisol) and sandy loam in texture with pH 6.81 and had good water holding capacity and moderate fertility. The sand, silt and clay content of the soil were 54.8%, 21.8% and 23.1% respectively and the bulk density was 1.31 g cc^{-1}. On the other hand, the organic carbon, available nitrogen, phosphorus and potassium content were 0.30%, 320.52 kg ha^{-1}, 35.6 kg ha^{-1} and 106.2 kg ha^{-1} respectively. The climate of the region was warm and humid. The average annual rainfall was 1450 mm, 75% of which was received during June to September. Temperature during summer period was high but during winter was mild. The temperature began to rise from the end of February reaching towards April-May. The relative humidity remained high during June to October. During the experimental year (2016), the average rainfall received was in the range 0.3 mm to 20.4 mm. The average maximum temperature varied from 25.2^{0}C to 34.2^{0}C and the mean minimum temperature varied from 10.9^{0}C to 28.6^{0}C. The average maximum and minimum relative humidity ranged from 87.9% to 98.4% and 48.1% to 87.1% respectively and the average daily sunshine hour varied from 3 to 9 hours per day. The climatic parameters during the experimental year are shown in Fig. 1.

The experiment consisted of seven treatments *viz*. T_1: control, T_2: chemical fertilizer at 100% recommended dose of NPK, T_3: 50 % recommended dose of NP + 100% RDK + *Bacillus polymyxa* @ 5 kg ha^{-1}, T_4: 75% recommended dose of NP + 100% RDK + *Azotobacter chroococcum* @ 5 kg ha^{-1}, T_5: 75 % recommended dose of NP + 100% RDK + *Bacillus polymyxa* @ 5 kg ha^{-1}, T_6: 50 % recommended dose of NP + 100% RDK + *Pseudomonas fluorescence* @ 5 kg ha^{-1} and T_7: 50 % recommended dose of NPK + *Bacillus polymyxa* @ 5 kg ha^{-1}. The experiment was conducted in randomized block design with 3 replications. The size of each plot was 5 m x 3 m. Rice cultivar 'IET-4786 (Shatabdi)' was sown. The recommended dose of N: P_2O_5: K_2O for rice was 60:30:30 kg ha^{-1} and the chemical fertilizer in the form of urea, single super phosphate (SSP) and muriate of potash (MOP) were broadcasted and incorporated into 15 cm depth of soil. Half dose of nitrogen and full dose of P_2O_5 and K_2O were applied as basal and remaining half nitrogen was top dressed at 30 days after transplanting (DAT). All the bio-fertilizers were applied @ 5 kg ha^{-1} as seed treatment 24 hours before sowing. For raising of seedlings about 50 kg seeds of rice were broadcasted in the 4th week of June in nursery bed and transplanting was done in 3rd week of July at a spacing of 20 cm × 15 cm. 2-3 seedlings per hill were transplanted. Weeding was done manually at 30 and 50 DAT to keep the plot weed free. The seedbed was prepared with irrigation and the water soaked seeds were sown in seedbed provided continuous submergence with water. About 2 cm water depth was maintained through the nursery period. After transplanting in the main field 2-3 cm water depth and at tillering and panicle initiation stage, alternate wet and dry soil condition was maintained as far as possible. The irrigation was stopped at 15 days before harvesting of the crop. After harvesting of the crop, dry matter accumulation (g m^{-2}) and grain yield (t ha^{-1}) were recorded separately. The entire crop growing season was divided into nine distinct stages *viz*. germination, active tillering, panicle initiation, booting, heading, anthesis, milking, dough and maturity. Agro-meteorological indices *i.e*. GDD, HTU, PTU and PTI were computed during different growing phases [11].

Computation of agro-meteorological indices:

Growing degree day (GDD) = ($T_m - T_b$)

Heliothermal unit (HTU) = GDD x BSSH

Photothermal unit (PTU) = GDD x DL

Phenothermal unit (PTI) =GDD/ growth days

Where, DL = Day length (Possible sunshine hours: from dawn to twilight), BSSH = Bright sunshine hours (Hour) T_m= Daily mean temperature in ^{0}C. T_b = Base temperature of rice (10^{0}C).

Thermal use efficiencies were evaluated in terms of both grain yield and dry matter accumulation by using the following formula [17].

Thermal use efficiencies = (Grain yield or dry matter accumulation/ Accumulated thermal indices)

RESULTS AND DISCUSSION

Phenology

Rice crop was sown on 25th June, 2016 and the crop duration was 133 days. Flowering occurred mostly in the first week of October. The results showed that days for attainment of different phenological stages differed significantly (Table 1). In this growing condition, Shatabdi required 7 days for germination, 45 days for active tillering, 66 days for panicle initiation, 74 days for booting, 80 days for heading, 99 days for anthesis, 106 days for milking, 112 days for dough and the crop took 133 days for attaining the maturity stage.

Growing degree days (GDD)

During *kharif* season of 2016 the crop took 2505.30 units accumulated GDD with total 133 days till harvesting. Every crop needs a certain amount of GDD to enter its next crop stage (Table 1) and this explains the direct impact of temperature on crop growth. Heat unit concept was applied to correlate phenological development in crops to predict maturity dates [14]. It was observed that the combined effect of growing conditions and cultivars on heat unit (GDD) was significant at all the phenological stages. The lowest heat unit (GDD) requirement was observed in case of attaining dough stage but the other stages like active tillering, panicle initiation, booting, heading, anthesis, milking and maturity showed increasing trend of heat unit (GDD) requirement with the maximum value recorded for the attainment of active tillering stage. Under normal growing condition, the accumulated GDD values in Shatabdi were 122.55 day °C for germination, 705.75 day °C for active tillering, 415.15 day °C for panicle initiation, 149.55 day °C for booting, 119.15 day °C for heading, 421.75 day °C for anthesis, 134.10 day °C for milking, 105.55 day °C for dough and 331.75 day °C for maturity. Flowering is related to mean air temperature and it acts as an important factor limiting the initiation of flower [8]. The GDD requirement for different phenophases varied depending upon the duration of a particular phenophase [4].

Heliothermal Units (HTU)

Heliothermal units (HTU) required for different phenophases of rice for the crop growing season have been depicted in Table 1. The cultivar consumed 11515.03 day °C hour to reach maturity stage by 4th November. Among the different phenophases, the HTU requirement was found to be the highest during dough to maturity phase in the year of experimentation. This was due to the duration, temperature as well as bright sunshine hour available during the period. The booting to heading phase required the lowest heliothermal unit as the duration of this phenophase was minimum. HTU is the product of GDD and actual bright sunshine hours, higher BSSH results in more accumulated HTU. In this growing condition the requirements of HTU were 309.01 day °C hour for germination, 2311.65 day °C hour for active tillering, 2162.16 day °C hour for panicle initiation, 167.67 day °C hour for booting, 130.96 day °C hour for heading, 2167.77 day °C hour for anthesis, 933.15 day °C hour for milking, 830.39 day °C hour for dough and 2502.29 day °C hour for maturity.

Photothermal Units (PTU)

The accumulated values of PTU required to attain different phenological stages in rice cultivar Shatabdi have been shown in Table 1. Photothermal unit is the product of growing degree days and day length indicating that higher day length leads to more accumulated PTU. The cultivars required 1654.43 day °C hour for germination, 9389.40 day °C hour for active tillering, 5326.71 day °C hour for panicle initiation, 1876.61 day °C hour for booting, 1475.51 day °C hour for heading, 5111.23 day °C hour for anthesis, 1143.98 day °C hour for milking, 1236.79 day °C hour for dough and 3798.69 day °C hour for maturity. Among the different phenophases, attainment of active tillering stage required the highest PTU during the crop growing season. The anthesis to milking phase consumed the lowest accumulated photothermal units. During *kharif* season of 2016, the crop took 31013.33 units of accumulated PTU with total 133 days till maturity.

Phenothermal Index (PTI)

The phenothermal index for consecutive phenophases was also computed and is presented in Table 1. The phenothermal index is expressed as growing degree days per growth days [16]. It was observed that the phenothermal index varied significantly from germination to maturity, being highest at anthesis and lowest during dough to maturity indicating a decrease in daily heat consumption towards maturity. The results of the present study suggest that changes in the ambient temperature even for a short period are reflected in the phenothermal index during the individual growth stages. Thus, the index seems to be effective in taking into account and expressing the effect of varying ambient temperature on the duration between the phenological events for comparing the crop response to the ambient temperature between the different phenological stages. The difference in phenothermal indices for different growth stages indicates that the accumulated temperature could be utilized for studying biomass accumulation pattern at different phenological stages which ultimately influences the crop productivity. Phenothermal index (PTI) for rice during the growing period ranged between 15.80 to 22.20 day °C day^{-1} respectively. The values of phenothermal index in Shatabdi were 17.51 day °C day^{-1} at germination, 18.57 day °C day^{-1} at active tillering, 19.77 day °C day^{-1} at panicle initiation, 18.69 day °C day^{-1} at booting, 19.86 day °C day^{-1} at heading, 22.20 day °C day^{-1} at anthesis, 19.16 day °C day^{-1} at milking, 17.59 day °C day^{-1} at dough and 15.80 day °C day^{-1} at maturity.

Dry matter accumulation and grain yield of rice

Application of different sources of fertilizers has shown significant improvement in dry matter accumulation and grain yield than control. Dry matter accumulation gradually increased with the advancement of growth stages and reached their maximum values towards maturity. Full recommended dose of inorganic fertilizer recorded maximum dry matter accumulation at harvest (622.52 g m^{-2}) which were significantly superior to rest of the treatments except treatment T_4. On the other hand, the lowest dry matter accumulation was recorded in T_1 (454.19 g m^{-2}). Both inorganic and bio-fertilizers or their combinations when supplied at recommended dose increased nutrient supply and enhanced absorption of nutrients by the crop. However, the rate of mineralization differed between inorganic and bio-fertilizer sources. In inorganic fertilizer, mineralization process was faster and thereby showed immediate release of nutrient elements like N, P and K with their quick availability.

Grain yield was also significantly influenced by different fertilizer sources. The grain yield was maximized in T_2 treatment (5.66 t ha^{-1}) which was at par with T_4 (5.48 t ha^{-1}) and significantly superior to rest of the treatments. The lowest grain yield (4.72 t ha^{-1}) was observed in case of control treatment (T_1). The grain yield is the product of yield attributes like panicle length, number of panicles/hill, filled grains/panicle, test weight etc. In our present investigation, application of full recommended dose of inorganic fertilizer produced highest yield attributes. Reduction of the dose of nitrogen and phosphorus fertilizer up to 25% of recommended dose was supplemented by bio-fertilizer. But almost all the yield attributes in this study was drastically reduced when half of the recommended doses of NPK fertilizer were curtailed. A field experiment was conducted with rice variety ADT-31 where foliar spray of *Azotobacter chroococcum* was applied on 15th, 30th and 45th day after transplanting of rice crop. They observed that the foliar spray of *Azotobacter* culture significantly increased the grain and straw yield of rice crop [9]. Satisfying the nutrient requirement of plants through combined application of inorganic fertilizer and bio-fertilizers was also found equally promising in supplying nutrient elements in available form due to rapid release from chemical source as well as slow and steady release from bio-fertilizers in the soil along with essential micronutrients and growth promoting substances which results in higher growth and yield of crops.

Thermal use efficiency (TUE)

Thermal use efficiencies such as heat use efficiency (HUE), heliothermal use efficiency (HTUE) and photothermal use efficiency (PTUE) can be expressed in terms of dry matter accumulation or grain yield. Thermal use efficiencies were influenced due to different weather conditions and nutrient levels (Table 3 and 4). Heat use efficiency (HUE) *i.e.* efficiency of utilization of heat in terms of dry matter accumulation or grain yield depends on crop type, genetic factors and sowing time and has great practical application [14]. The highest HUE (0.25 g m^{-2} day ^{0}C^{-1}) in terms of dry matter accumulation was observed in treatments T_2 and T_4 due to higher dry matter accumulation and the lowest value (0.18 g m^{-2} day ^{0}C^{-1}) was obtained in control *i.e.* T_1. It was also reported that T_2 treatment *i.e.* application of full dose of inorganic fertilizer exhibited the maximum heat use efficiency (2.26 g m^{-2} day ^{0}C^{-1}) in terms of grain yield and T_1 showed the minimum value (1.88 g m^{-2} day $^0C^{-1}$). As the temperature was favourable throughout normal growing condition, it accumulated heat more efficiently and increased physiological activities that confirmed higher grain yield. The highest heliothermal use efficiency (0.05 g m^{-2} day $^0C^{-1}$ $hour^{-1}$) was noted in T_2, T_4 and T_5 treatments but the lowest HTUE (0.04 g m^{-2} day$^0C^{-1}$$hour^{-1}$) was observed in rest of the treatments. On the other hand, the calculated HTUE in terms of grain yield was maximum in treatment T_2 (0.49 g m^{-2} day$^0C^{-1}$ $hour^{-1}$) and minimum in T_1 (0.41 g m^{-2} day $^0C^{-1}$ $hour^{-1}$). In terms of dry matter accumulation, the photothermal use efficiency (PTUE) was recorded highest (0.02 g m^{-2} day $^0C^{-1}$ $hour^{-1}$) in case of all the treatments while control treatment exhibited the lowest PTUE value (0.01 g m^{-2} day $^0C^{-1}$ $hour^{-1}$). With the application of 100% recommended dose of inorganic fertilizer (T_2) and 75% recommended dose of NP + 100% RDK + *Azotobacter chroococcum* @ 5 kg ha^{-1} (T_4), the highest value of PTUE (0.18 g m^{-2} day $^0C^{-1}$ $hour^{-1}$) was obtained but the minimum PTUE (0.15 g m^{-2} day $^0C^{-1}$ $hour^{-1}$) was observed in T_1 treatment in terms of grain yield.

Table 1: Accumulated GDD (day °C), HTU (day °C hour), PTU (day °C hour) and PTI (day °C day^{-1}) in rice required for attainment of different phenophases

Growth stage	Accumulated GDD	Accumulated HTU	Accumulated PTU	Accumulated PTI
Germination (01.07.2015)	122.55	309.01	1654.43	17.51
Active tillering (08.08.2015)	705.75	2311.65	9389.40	18.57
Panicle initiation (29.08.2015)	415.15	2162.16	5326.71	19.77
Booting (06.09.2015)	149.55	167.67	1876.61	18.69
Heading (12.09.2015)	119.15	130.96	1475.51	19.86
Anthesis (01.10.2015)	421.75	2167.77	5111.23	22.20
Milking (08.10.2015)	134.10	933.15	1143.98	19.16
Dough (14.10.2015)	105.55	830.39	1236.79	17.59
Maturity (04.11.2015)	331.75	2502.29	3798.69	15.80
Entire growth period (25.06.2015 to 04.11.2015)	2505.30	11515.03	31013.33	169.83

Table 2: Effect of inorganic fertilizer and bio-fertilizers on dry matter accumulation and grain yield of rice

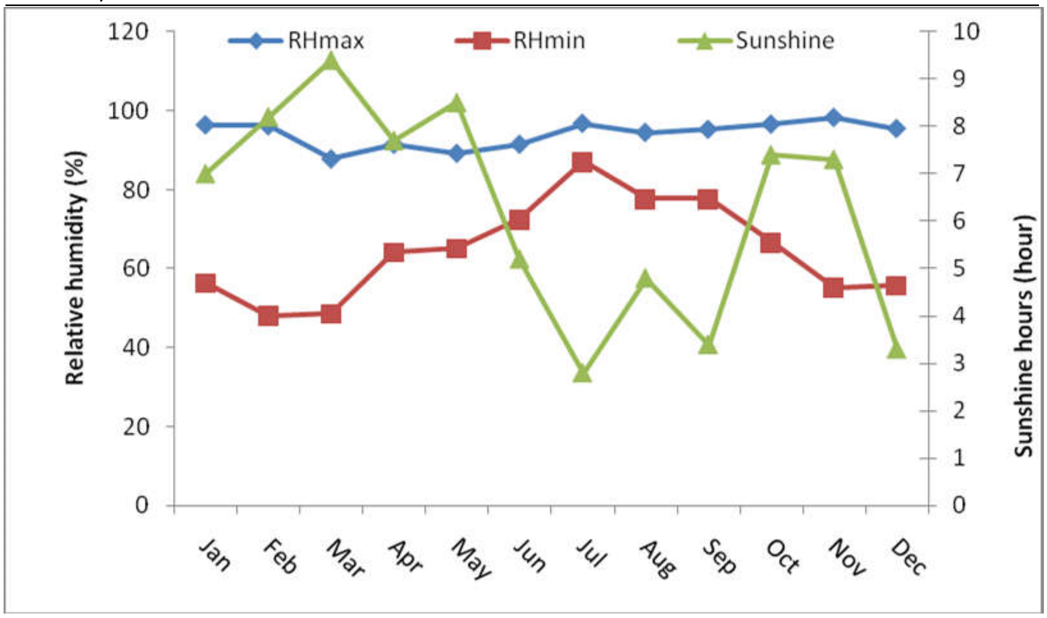
Treatments	Dry matter accumulation ($g\ m^{-2}$)	Grain yield ($t\ ha^{-1}$)
T_1	454.19	4.72
T_2	622.52	5.66
T_3	503.56	5.32
T_4	614.14	5.48
T_5	523.75	5.40
T_6	517.58	5.12
T_7	498.52	4.98
S.Em. (±)	**3.28**	**0.89**
CD (P= 0.05)	**10.77**	**0.20**

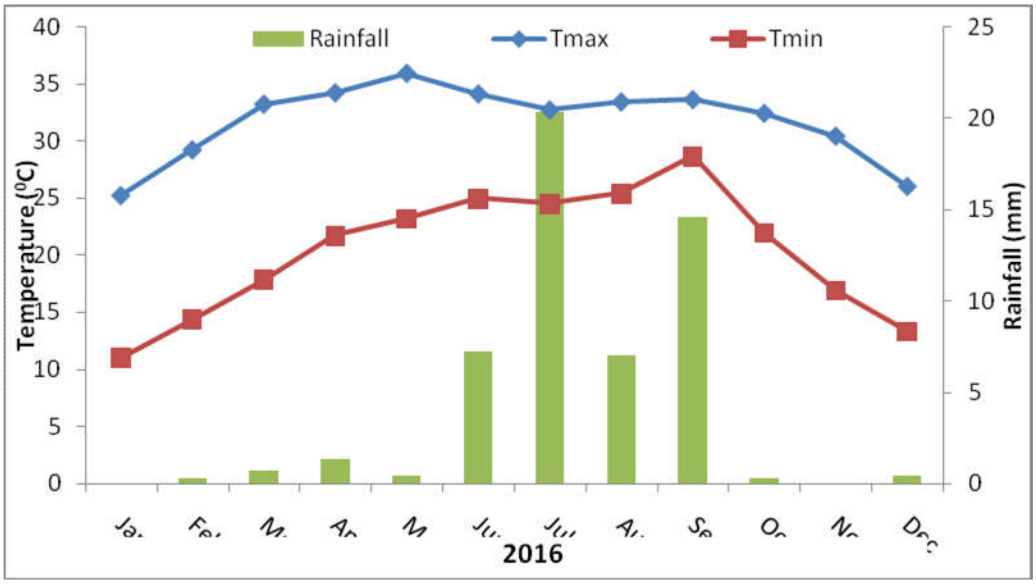
Table 3: Thermal use efficiencies of rice in terms of dry matter accumulation

Treatments	HUE (g m^{-2} day $^0C^{-1}$)	HTUE (g m^{-2} day $^0C^{-1}$ $hour^{-1}$)	PTUE (g m^{-2} day $^0C^{-1}$ $hour^{-1}$)
T_1	0.18	0.04	0.01
T_2	0.25	0.05	0.02
T_3	0.20	0.04	0.02
T_4	0.25	0.05	0.02
T_5	0.21	0.05	0.02
T_6	0.21	0.04	0.02
T_7	0.20	0.04	0.02

Table 4: Thermal use efficiencies of rice in terms of grain yield

Treatments	HUE (kg ha^{-1} day $^0C^{-1}$)	HTUE (kg ha^{-1} day $^0C^{-1}$ hour^{-1})	PTUE (kg ha^{-1} day $^0C^{-1}$ hour^{-1})
T_1	1.88	0.41	0.15
T_2	2.26	0.49	0.18
T_3	2.12	0.46	0.17
T_4	2.19	0.48	0.18
T_5	2.16	0.47	0.17
T_6	2.04	0.44	0.17
T_7	1.99	0.43	0.16





T_{max} – Maximum temperature, T_{min} – Minimum temperature, RH_{max} – Maximum relative humidity, RH_{min} – Minimum relative humidity

Fig.1. Graphical representation of monthly rainfall, maximum and minimum temperature, maximum and minimum relative humidity and sunshine hours

CONCLUSION

In all, rice has taken the advantage of optimum temperature and sunlight during all the stages of plant development and there by avoided adverse situations during its life cycle. The present study indicates that the application of agroclimatic indices provides a scientific basis for determining the effect of temperature, radiation or photoperiod on phenological behaviour of a standing crop. These provide very clear picture of the amount, pattern and efficiency of heat energy consumption at different phenological stages of the crops. These can also be used very effectively for forecasting the occurrence of different phenophases of the crops. From the overall results it might be concluded that the various nutrient sources did not influenced the thermal use efficiencies significantly. The crop in case of all the treatments showed more or less the equal ability to use temperature, bright sunshine hours as well as day length.

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