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Assessment of PAR Interception and Radiation Use Efficiency on Tomato Growth and Yield in the Upper Brahmaputra Valley Zone of Assam, India

A. Kalita [a++], P. Neog [b#], R. L. Deka [c#], D. B. Phookan [d†], K. Kurmi [e‡], N. S. Paschapur [f^*] and K. Medhi [c##]

[a] APART AAU-ZRS, Gossaigaon, India.
[b] Department of Agricultural Meteorology, Biswanath college of Agriculture, AAU, Jorhat, India.
[c] Department of Agricultural Meteorology, College of Agriculture, AAU, Jorhat, India.
[d] Department of Horticulture, College of Agriculture, AAU, Jorhat, India.
[e] Department of Agronomy, College of Agriculture, AAU, Jorhat, India.
[f] Department of Climate Change and Agricultural Meteorology, Punjab Agricultural University, Ludhiana, India.

Authors' contributions

This work was carried out in collaboration among all authors. Authors AK and PN collaboratively drafted the research manuscript by performing the experiment in field as well as done the analysis. Authors RLD, DBP and KK statistically validated the results of the field trial. Authors NSP and KM in involved in framing the final manuscript and also scrutinized the scientific justification of different findings in the said manuscript. All authors read and approved the final manuscript.

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[++] Project Associate;
[#] HOD and Professor;
[†] Professor;
[‡] Principal Scientist;
[^] PhD Scholar;
[##] Junior Scientist;
**Corresponding author: E-mail: nikhilsp7039@gmail.com;*

ABSTRACT

A field experiment was conducted in Jorhat, Assam during the *rabi* season of 2019-20 to examine the effects of PAR interception, radiation use efficiency, and modified microclimates on tomato growth and yield. The variety *Arka Rakshak* was grown in split plot design with 4 dates of planting (P1: 25th October, P2: 14th November, P3: 3rd December, and P4: 8th January) in main plots and three types of mulching (M0: no mulch, M1: rice straw mulch, and M2: black polythene mulch) in sub-plots. Measurements of incident PAR (IPAR), reflected PAR (RPAR), transmitted PAR (TPAR) were taken at 10 days regular intervals. The results showed that IPAR ranged from 531 to 1431 μ mol s^{-1} m^{-2}, with an average of 1140.4 μ mol s^{-1} m^{-2}. RPAR varied between 41 and 285 μ mol m^{-2} s^{-1} under different microclimates. The tomato yield ranged from 76.6 to 392.6 q ha^{-1}, with an average of 234.9 q ha^{-1}. Planting on November 14th (P2) provided the most favorable microclimate conditions, while black polythene mulch (M2) was found to be the most suitable for crop growth, yield, and radiation use efficiency due to increased soil temperature. The study indicated that selecting the right planting date and implementing black polythene mulch can enhance tomato growth, yield, and radiation use efficiency in Upper Brahmaputra Valley Zone of Assam (Jorhat) agro-climatic condition.

Keywords: Tomato; microclimate; mulching; PAR interception; radiation use efficiency.

1. INTRODUCTION

Tomato is one of the most important vegetable crops in Assam with total production and productivity of 396.24 thousand MT and 21.67 MT ha^{-1}, respectively [1]. The growth, development and yield of the crop are greatly influenced by environmental factors mainly-temperature, soil moisture and solar radiation. Generally, in Assam, the daily minimum temperature goes below 10ºC from mid of December to mid of February, which coincided with reproductive growth stages of tomato, while in case of late planted crop, fruit development stage of the crop is coincided with increasing temperature from the beginning of March. Thus, both these situations are detrimental and cause significant reduction of fruit yield of the crop; however, the problem of such low or high temperature can be successfully addressed by modifying microclimate in the crop fields, as the soil hydrothermal environment can be altered considerably by modifying microclimate in the crop field.

Microclimate modifications can create a favorable microenvironment for tomatoes, leading to higher interception of photosynthetically active radiation (PAR) and improved growth, development, and yield. Additionally, adjusting the planting date can be an effective strategy to combat the negative effects of heat and moisture stress, as well as to optimize radiation interception for increased tomato production. Mulching plays a vital role in enhancing crop growth and yield by facilitating soil moisture retention, temperature control, and improving soil properties. By adding nutrients to the soil, mulching contributes to the overall health of the crop [2].

The use of mulches also brings about changes in the microclimate of the crop, affecting both the soil hydrothermal regime and radiation distribution within the canopy [3,4]. Typically, organic materials such as water hyacinth, rice straw, ash, sawdust, and crop residues are utilized as mulches to modify the soil microclimate. However, plastic mulches have gained popularity due to their advantages over organic mulches and their ability to influence soil temperature in different ways, making them suitable for various climates, soils, and seasons [5]. Plastic mulches, specifically polythene mulches, tend to increase both the maximum and minimum soil temperatures [6]. On the other hand, organic mulches decrease the maximum temperature but increase the minimum temperature compared to un-mulched soil [7]. Consequently, microclimate modifications through the application of organic mulches offer a solution to counteract rising temperatures and diminishing soil moisture [8].

Mulching plays a crucial role in enhancing crop growth and yield by increasing leaf area index and maximizing the interception of photosynthetically active radiation (PAR). This leads to higher biomass production and improved yields [8-9,2]. For example, in potato cultivation in Assam, the use of organic mulches like water hyacinth creates a favorable growth environment by improving soil moisture retention and reducing soil temperature, resulting in higher leaf area index, increased biomass, and improved crop yield [3]. In tomato cultivation, mulching helps increase fruit yield by reducing weed infestation, soil moisture depletion, evaporation rates, and by improving hydrothermal and radiation conditions [10]. Straw mulch and black polythene have also shown positive effects in terms of increased branches, fruit weight, harvest duration, and yield through improved hydrothermal and radiation regimes within the tomato canopy [11-13]. The planned experiment aims to address these agricultural challenges effectively while building on previous research findings. Keeping the above points in view, the present investigation was proposed to study the impact of thermal and radiation regimes on growth and yield of Tomato under varying microenvironments.

2. MATERIALS AND METHODS

2.1 Study Area

The study was carried out at the Experimental Farm of Dept. of Horticulture, Assam Agricultural University, Jorhat, Assam (26°42' N and 93°15' E) during *rabi* season in 2019-20. Tomato cultivar *Arka Rakshak* was grown under rainfed condition in split-plot design with four dates of planting *i.e.,* P1: 25th October, P2: 14th November, P3: 3rd December and P4: 8th January; and three mulching treatments (M0: Non mulch, M1: Rice straw mulch and M2: Black polythene) were replicated thrice. They comprised of twelve main plots (planting dates) and thirty-six sub-plots (mulching) treatments with the size of each plot of 6.75 m^2. A distance of 50 cm and 30 cm were maintained between two main and subplots, respectively. The recommended fertilizer doses of 120:75:75 kg ha-1 of N: P2O5: K2O were applied. The dates of planting and mulching treatments represented different micro-climatic regimes influencing growth, development as well as yield of the tomato crop. Along with the daily maximum and minimum air temperatures and bright sun-shine hours recorded in the observatory adjacent to the experimental field, the different components of photo-synthetically active radiation (PAR), *viz*., incident (IPAR), reflected (RPAR) and transmitted (TPAR) were recorded at 10 days interval starting from 30 days after planting (DAP) using line quantum sensor (Model LQM-70-10) at local noon time (11:30 AM).

2.2 Intercepted Photosynthetically Active Radiation (iPAR)

The calculation of photosynthetically active radiation (iPAR) interception for tomatoes, cultivated under different planting dates and mulching treatments, was determined using incident PAR, reflected PAR, and transmitted PAR data. The formula employed for this calculation is as follows, based on the methodology described by Kumar et al. [14] and Dhaliwal et al. [2].

$$\text{iPAR}\,\% = \frac{\text{IPAR} - \text{TPAR} + \text{RPAR}}{\text{RPAR}} \text{ x } 100$$

Where, IPAR = Incident photosynthetically active radiation,
RPAR = Reflected photosynthetically active radiation and
TPAR = Transmitted photosynthetically active radiation

2.3 Crop Growth Parameters

Plant samples for leaf area were collected regularly at 15-day intervals, starting from 30 days after planting (DAP). The leaf area was then measured using a leaf area meter (Biovis PSM - leaf Version: 4.56). During the time of harvest, plant samples were randomly obtained from a one square meter area in each plot at two different locations to calculate tuber yield and total biomass production. Fruit yield was recorded following standard procedures.

2.4 Radiation Use Efficiency (RUE)

Radiation use efficiency (RUE), defined as the conversion efficiency or amount of dry matter produced per unit PAR intercepted, was calculated for total biomass and fruit yield. The calculation followed the formula provided by Gallo and Daughtry [15].

$$\text{RUE} = \frac{\text{Amount of dry matter produced (g/m}^2\text{)}}{\text{Amount of cumulative IPAR } (Mj/m^2)} \text{ x } 100$$

The average PAR (μ mol s^{-1} m^{-2}) values were converted to the (MJ m^{-2} day^{-1}) using the following formula as suggested by Kumar *et al.* (2008), which is given below.

1 MJ m^{-2} day^{-1} = 0.0007826 × PAR (μ mol $s^{-1}m^{-2}$) × BSSH (Bright sunshine hours).

2.5 Statistical Analysis

A simple regression analysis was carried out to determine the relationship between intercepted PAR and RUE (Radiation Use Efficiency) for biomass and fruit yield. The best-fitted model equations were calculated and developed based on the results of the analysis.

3. RESULTS AND DISCUSSION

3.1 Weather Condition during the Crop Growth Period

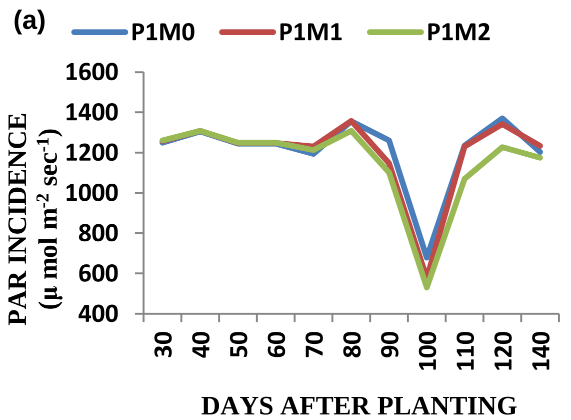
The range for weekly mean maximum and minimum temperature throughout the crop growing period was found within 21.7 to 31.7°C and 8.4°C to 20.8°C with their respective averages of 26.7°C and 14.5°C. Thus, the daily maximum temperature never exceeded 34.6°C, but increasing daily maximum temperature above 30°C after mid-March (11 SMW) was detrimental to the crop as the optimum temp for the crop is 18 to 24°C. Similarly, the lower average daily minimum temperature (<10°C) during 49th to 5th SMW affected growth of the crop. Rainfall recorded was 319.8 mm received during 25 rainy days in entire crop growth period. The daily bright sunshine hour during the crop season varied from 0.5 to 8.2 hours with the mean values of 5.0 hours.

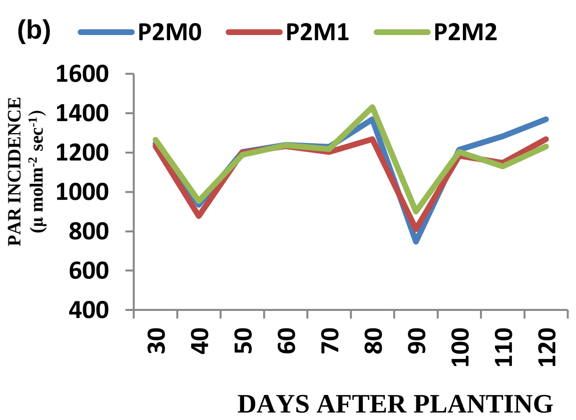
3.2 Variation of Components of PAR under Different Microclimates

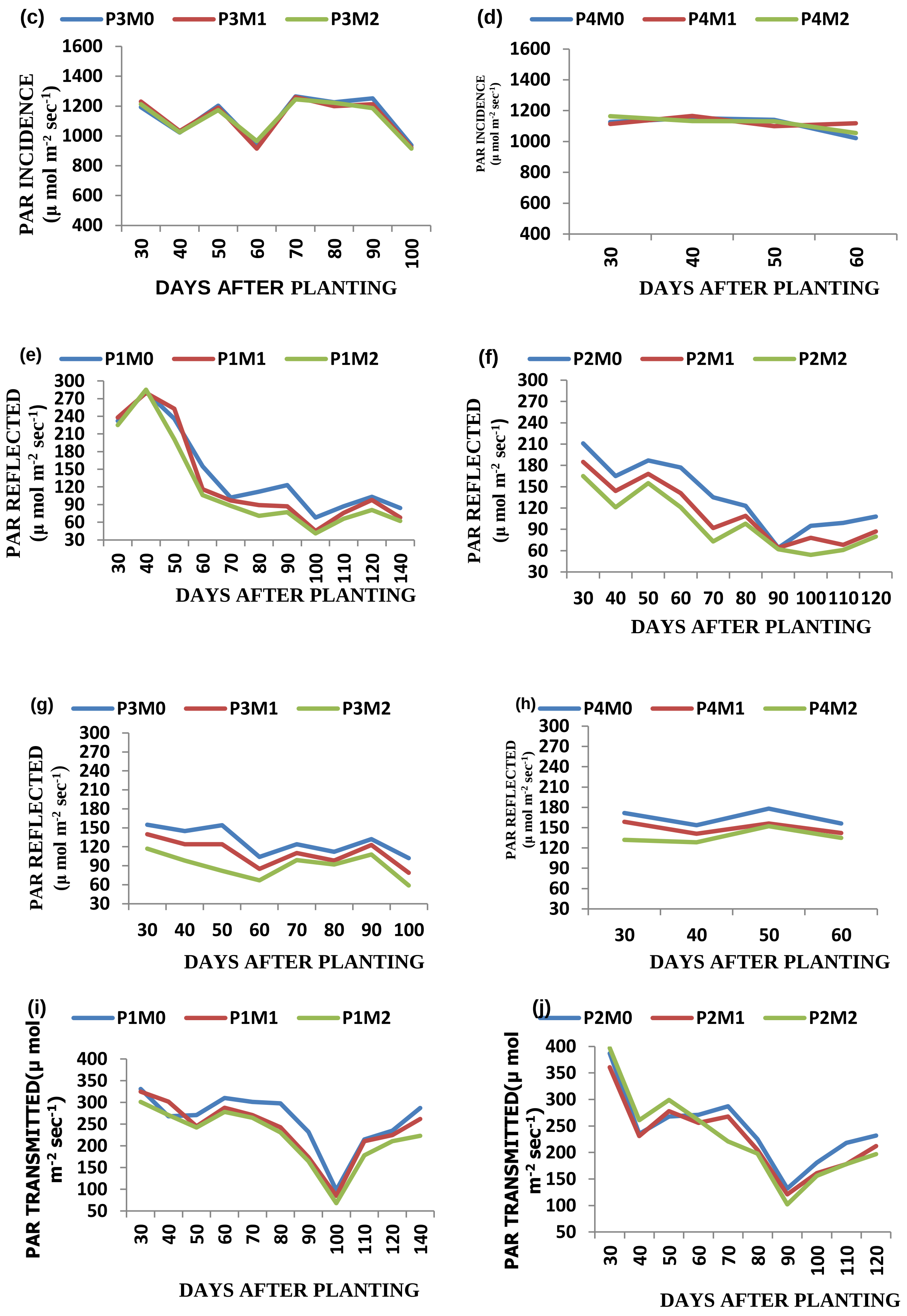
The data pertaining to the interception (iPAR), reflection (RPAR) and transmission (TPAR) of photosynthetically active radiation in tomato as influenced by different planting dates and mulching treatments at different days after planting during 2019-20 are presented in Fig. 1. (a-l). Irrespective of planting dates and mulching treatments, incident PAR (IPAR) during the crop growth season varied from 531 to 1431 μ mol s^{-1} m^{-2} with the mean value of 1140.4 μ $mols^{-1}$ m^{-2} (Fig. 1. (a-d)). The reflected PAR varied from 41 (P1M2) to 285 (P1M2) μ $mols^{-1}m^{-2}$ in different planting dates and mulching treatments (Fig. 1. (e-h)). As a whole, the highest RPAR was recorded at 30 DAP and decreased gradually as age of the crop increased, however it increased again in later growth period with the onset of leaf senescence. Irrespective of planting dates, the lowest (111 μ mol s^{-1} m^{-2}) RPAR value recorded under black polythene might be due to greater radiation absorption by black surface during early crop growth stages, but due to more canopy coverage during later growth stages. In all dates of planting and mulching treatments, the lowest transmitted PAR was recorded at 90 to 100 DAP (in case of P1 to P3) when the crop was with full canopy coverage, thereafter it increased with the advancement of the age of the crop (Fig. 1. (i-l)).

3.3 Interception PAR (iPAR) under Different Microclimates

The interception of photosynthetically active radiation (PAR) in tomatoes was studied about different planting dates and mulching treatments during 2019-20 are presented in Table 1. The crop planted on 14th November exhibited the highest PAR interception (69.99%), gradually decreasing with delayed planting. PAR interceptions for P1, P3, and P4 were 69.29%, 64.67%, and 51.75%, respectively. The study also found significant influence of mulching treatments on tomato's maximum PAR interception. These findings align with Wilson et al.'s [16] results, where mature tomato canopy intercepted 76% of incident light, similar to the observed maximum iPAR values (ranging from 71% to 81%) under different planting dates and mulching treatments.






(c)
P3M0
P3M1
P3M2
PAR INCIDENCE (µ mol m-2 sec-1)
DAYS AFTER PLANTING
(d)
P4M0
P4M1
P4M2
PAR INCIDENCE (µ mol m-2 sec-1)
DAYS AFTER PLANTING
(e)
P1M0
P1M1
P1M2
PAR REFLECTED (µ mol m-2 sec-1)
DAYS AFTER PLANTING
(f)
P2M0
P2M1
P2M2
PAR REFLECTED (µ mol m-2 sec-1)
DAYS AFTER PLANTING
(g)
P3M0
P3M1
P3M2
PAR REFLECTED (µ mol m-2 sec-1)
DAYS AFTER PLANTING
(h)
P4M0
P4M1
P4M2
PAR REFLECTED (µ mol m-2 sec-1)
DAYS AFTER PLANTING
(i)
P1M0
P1M1
P1M2
PAR TRANSMITTED(µ mol m-2 sec-1)
DAYS AFTER PLANTING
(j)
P2M0
P2M1
P2M2
PAR TRANSMITTED(µ mol m-2 sec-1)
DAYS AFTER PLANTING

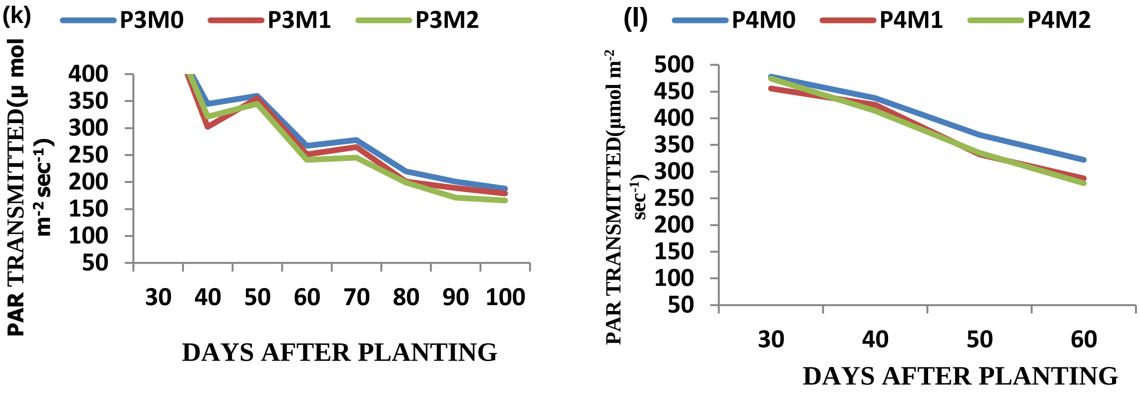


Fig. 1. (a-l) Variation of Incidence PAR (a-d), Reflected PAR (e-h) and Transmitted PAR (i-l) under different dates of planting and mulching treatments in tomato variety *Arka Rakshak* during *rabi* 2019-20

Irrespective of planting dates, black polythene mulch showed the highest PAR interception (66.19%), followed by rice straw (64.11%) and non-mulch (61.48%). The second planting date (14th November) exhibited the highest interception due to better thermal conditions and increased foliar expansion. In contrast, later planting dates (3rd December and 8th January) showed lower PAR interception due to less favorable thermal environments. The better vegetative growth under mulching (M1 and M2) explained the higher PAR interception compared to non-mulched conditions (M0). Mulching positively impacts PAR interception and crop growth [7,16, 2]. Saikia et al. [8] found a 7.2% to 114.1% increase in PAR interception with mulching. Apotikar et al. [17] observed significant PAR absorption improvement in potatoes. Dhaliwal et al. [2] reported higher PAR interception in mulched crops.

3.4 Crop Growth Parameters and Fruit Yield of Tomato under Different Microclimates

The study found that both planting dates and mulching treatments significantly influenced the leaf area index (LAI), ranging from 1.85 to 3.26 (Table 1). Biomass production was highest on the second planting date (284.7 g/plant) and decreased with delayed planting. Black polythene mulch resulted in the highest total biomass (263 g/plant), followed by rice straw mulch (28.1 g/plant), and non-mulched treatment (149.9 g/plant). The crop planted on 14th November yielded the highest fruit production (267.9 q ha^{-1}), while the lowest yield (99.9 q ha^{-1}) was recorded on the last planting date. The findings indicate the beneficial impact of early planting and black polythene mulch on fruit yield. The findings were supported by Mtui [18], who observed that straw mulch resulted in delayed flowering, prolonged fruit production, and extended harvesting compared to non-mulched plots. Similar outcomes were reported by Vos et al. [19], Agele et al. [20], Singh et al. [21] and Moreno-Teruel. [22].

3.5 RUE of Tomato under Different Microclimates

The radiation use efficiency under different dates of planting and mulching treatment varied from 0.48 to 1.64 g MJ^{-1} and 0.30 to 1.10 g MJ^{-1} with the mean value of 1.04 and 0.68 g MJ^{-1} and coefficient of variation 34.5 per cent and 35.8 per cent for total biomass production and fruit yield, respectively (Table 1). Irrespective of mulching treatment, the RUE for both biomass production and fruit yield decreased gradually with successive delay in planting. The findings were consistent with Mahakosee et al. [23], reported that delaying planting can lead to a decrease in RUE, which in turn affects biomass and fruit yield. Irrespective of planting dates, RUE for both biomass production and fruit yield was observed to be highest under black polythene, followed by rice straw mulch and non-mulched condition. The higher value of RUE (biomass production and fruit yield) in early plantings (P1 & P2) and under black polythene (M2) was attributed to higher iPAR, plant height, LAI, biomass production and fruit yield as compared to later dates of planting and other mulching treatments.

Table 1. Average and maximum PAR interception (%), radiation use efficiency for total biomass and fruit yield (g MJ^{-1}), maximum LAI, total biomass and fruit yield of *Arka Rakshak* during *rabi*, 2019-20

Treatments	Total biomass (gm^{-2})	Fruit dry matter (gm^{-2})	LAI	Intercepted PAR (%)		RUE (g MJ^{-1})	
				iPAR 1	iPAR 2	Total biomass	Fruit dry matter
P1M0	488.7	327.6	2.55	67.10	75.55	0.70	0.47
P1M1	839.4	567.0	2.89	69.50	77.43	1.21	0.82
P1M2	939.0	624.0	2.98	71.28	79.47	1.35	0.90
P2M0	621.0	423.0	2.58	67.83	77.27	0.98	0.67
P2M1	909.0	594.0	3.16	69.92	79.81	1.44	0.94
P2M2	1032.0	696.0	3.26	72.23	82.54	1.64	1.10
P3M0	420.0	282.0	1.85	62.15	73.38	0.75	0.50
P3M1	610.5	384.0	2.21	64.74	75.82	1.09	0.68
P3M2	723.0	486.0	2.31	67.13	76.50	1.29	0.87
P4M0	268.5	169.5	1.16	48.84	53.23	0.48	0.30
P4M1	378.6	239.4	1.43	52.26	57.14	0.67	0.43
P4M2	461.4	287.4	1.37	54.14	59.59	0.82	0.51

3.6 Relationship between iPAR and RUE with Crop Growth Parameters and Fruit Yield of Tomato

Regression studies on the tomato cultivar *Arka Rakshak* revealed linear relationships between total biomass, fruit yield, and maximum LAI with iPAR and RUE. The determining factor (R^2) of the best-fitted predictive models, developed using the stepwise regression method, was 0.95 for fruit yield, 0.95 for biomass production, and 0.92 for maximum LAI, respectively. The relationships indicate that RUE explains fruit yield and biomass, while IPAR1 explains maximum LAI. These models effectively explain and predict crop growth such as LAI and biomass production, as well as fruit yield in tomatoes with a high level of accuracy.

Table 2. The best fitted predictive models for predicting crop growth parameters and fruit yield

Dependent variable	Model	R^2
Fruit yield	$Y = 675.55\ RUE_{(Fruit\ yield)} – 37.74$	0.95
Biomass	$Y = 987.94\ RUE_{(Fruit\ yield)} – 33.34$	0.95
Maximum LAI	$Y = .08\ iPAR\ 1 - 3.30$	0.92

4. CONCLUSION

From the field experiment, it can be concluded that the importance of selecting the right planting date and utilizing black polythene mulch for maximizing tomato growth, yield, and radiation use efficiency. Planting on November 14th (P2) proved to be the most suitable date, while black polythene mulch outperformed other mulching treatments in terms of crop performance. The increase in soil temperature, particularly during the coldest period 49th to 5th SMW by up to 1.84°C, under black polythene mulch contributed to improved microclimatic conditions. The developed predictive models ($R^2 \geq 0.92$) demonstrated the strong relationship between radiation use efficiency and key crop parameters. These findings provide valuable insights for optimizing tomato cultivation and enhancing agricultural practices in Upper Brahmaputra Valley Zone of Assam (Jorhat) agro-climatic condition. Further studies could explore additional factors and techniques to refine and enhance the understanding of tomato crop management strategies.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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