Original Research Article

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

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 experiment included different planting dates (P1: 25th October, P2: 14th November, P3: 3rd December, and P4: 8th January) and three types of mulching (M0: no mulch, M1: rice straw mulch, and M2: black polythene mulch). Measurements of incident PAR (IPAR), reflected PAR (RPAR), transmitted PAR (TPAR) were taken at 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]. 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 [4]. Plastic mulches, specifically polythene mulches, tend to increase both the maximum and minimum soil temperatures [5]. On the other hand, organic mulches decrease the maximum temperature but increase the minimum temperature compared to un-mulched soil [6]. Consequently, microclimate modifications through the application of organic mulches offer a solution to counteract rising temperatures and diminishing soil moisture [7].

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 [7-8, 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 [9]. 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 [10-12]. 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. MATERIAL 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). 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).

The interception of photosynthetically active radiation (iPAR) by tomato grown under various planting dates and mulching treatments were worked out from the incident PAR, reflected PAR and transmitted PAR data with help of the formula given below following Kumar *et al*., [13] and Dhaliwal *et al*., [2].

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

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

Plant samples for leaf area were taken periodically at 15 days interval starting from 30 days after planting (DAP) and leaf area were measured using leaf area meter (Biovis PSM -leaf Version: 4.56). The plant samples were obtained randomly from one square meter area from each plot at two places at the time of harvest for working out tuber yield and total biomass production. The fruit yield was recorded following standard procedures.

The conversion efficiency or quantity of dry matter produced per unit PAR intercepted is known as radiation use efficiency (RUE), which was calculated for total biomass and fruit yield using following formula given by Gallo and Daughtry, [14].

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

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 bellow.

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

Simple regression analysis worked out between intercepted PAR and RUE with biomass and fruit yield were calculated and developed best fitted model equations.

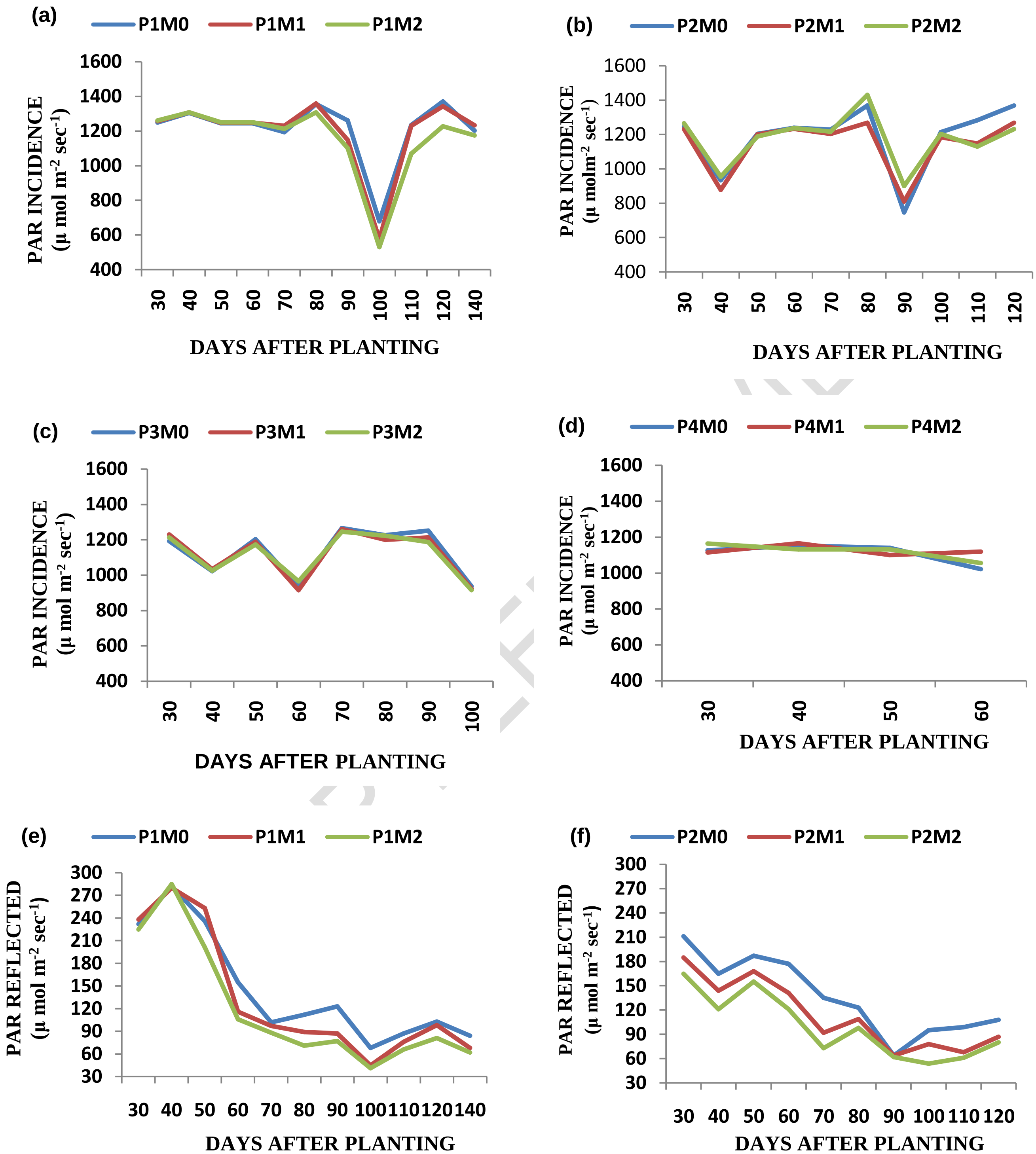
3. RESULTS AND DISCUSSION

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^{o}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)).



(a)
P1M0
P1M1
P1M2
PAR INCIDENCE
(µ mol m-2 sec-1)
DAYS AFTER PLANTING
(b)
P2M0
P2M1
P2M2
PAR INCIDENCE
(µ molm-2 sec-1)
DAYS AFTER PLANTING
(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

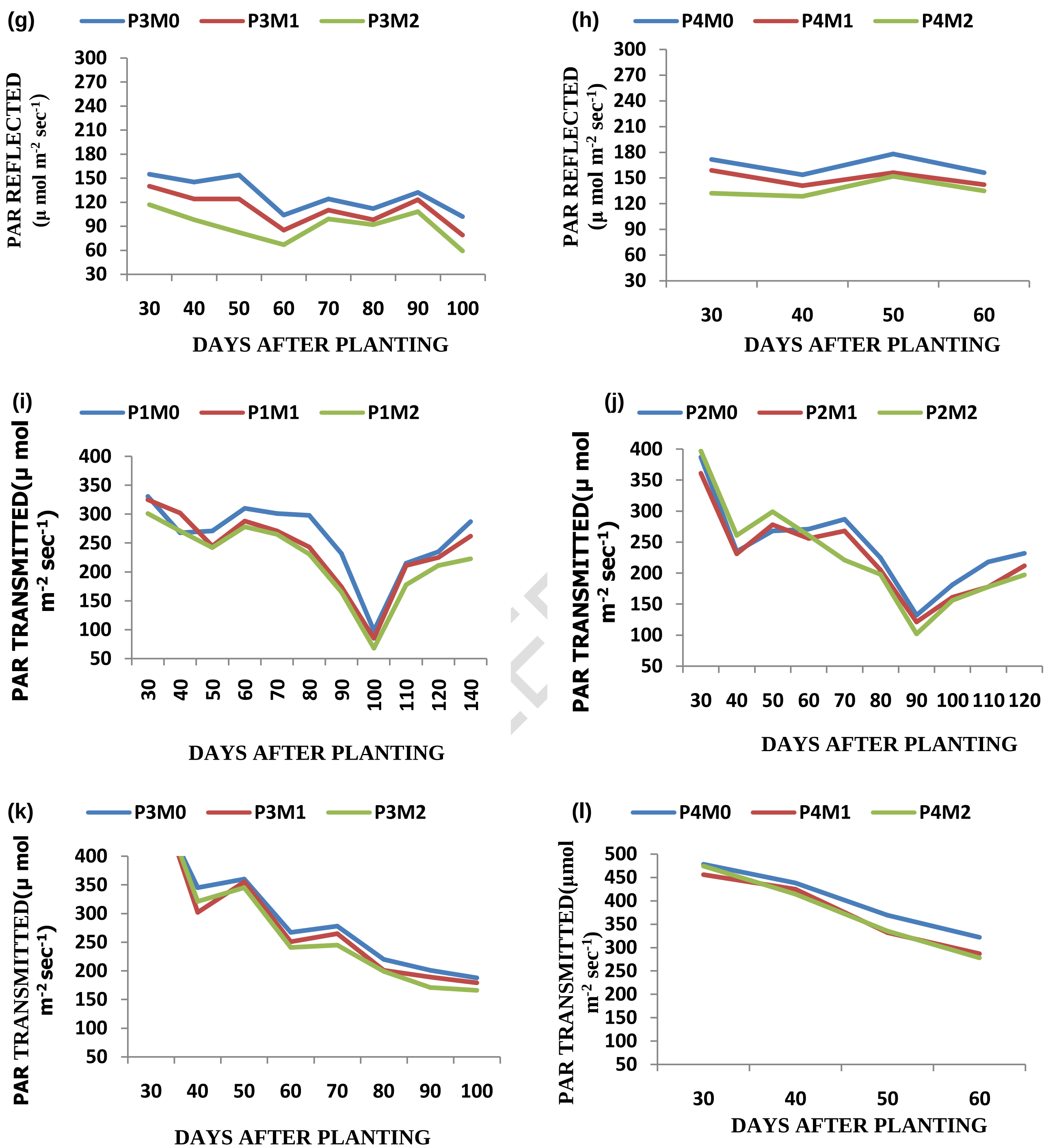


Fig. 1. (a-l) Variation of Incidence PAR (a-d), Reflected PAR (e-h) and Transmitted PAR (i-l) under different dates of planting and mulching treatments in tomato variety *Arka Rakshak* during *rabi* 2019-20

3.3 Interception PAR (iPAR) under different microclimates

The data pertaining to the interception of photosynthetically active radiation (iPAR) of tomato as influenced by different planting dates and mulching treatments at different days after planting during 2019-20 are presented in Table 1. Irrespective of mulching treatments, the maximum PAR interception under different dates of planting was recorded in the crop planted on 14th November (69.99 %), and it decreased gradually with successive delay in planting. The maximum PAR interceptions recorded were 69.29, 64.67 and 51.75 per cent in case of crop planted on 25thOctober (P1), 3rd December (P3) and 8th January (P_4), respectively. Similar to dates of planting, maximum PAR interception of tomato recorded was considerably influenced by different mulching treatments. Above results are supported by the findings of Wilson et al., [15], who reported that mature crop canopy of tomato intercepted on an average 76 per cent of incident light as it was close to the observed maximum iPAR ranged between 71 and 81 per cent under different planting dates and mulching treatments in the study.

Irrespective of dates of planting, maximum PAR interception was recorded in the crop grown under black polythene mulch (66.19%), followed by rice straw (64.11%) and non-mulch (61.48%). Comparatively higher PAR interception recorded on the second date of planting; was probably due to higher rate of foliar expansion with a greater number of leaves per plant and branches as early growth stages of the crop (up to 100 DAP) planted on 14 November was exposed to the better thermal environment with mean air temperature of 20.0°C. Moreover, lesser reflection and transmission of PAR in case of the crop planted on 14 November (P2) attributing higher PAR interception as compared to other dates of plantings. On the other hand, the lowest PAR interception in case of the crop planted on later dates (3rd December and 8 January) might be due to less vegetative growth of the crop which was exposed to comparatively less favorable thermal environment with mean air temperature of 16.9°C and 16.3°C in P3 and P_4, respectively. Likewise, better vegetative growth of the crop grown under black polythene mulch (M2) as well as under rice straw mulch (M1) as compared to non-mulch condition (M0) might be the basis of higher PAR interception under black polythene mulch (M1) and rice straw mulch (M1) as compared to no mulch (M0) treatment. The study's findings align closely with Saikia et al., [7], who observed that better crop growth positively impacts PAR interception, with mulching leading to a 7.2% to 114.1% increase in PAR interception compared to non-mulched plots. Apotikar et al., [16] also supported these results in a study on potato, where organic mulching significantly increased PAR absorption at 56 DAP compared to non-mulched plots. Similarly, Dhaliwal et al., [2] reported increased PAR interception in mulched crops compared to non-mulched ones.

3.4 Crop growth parameters and fruit yield of tomato under different microclimates

The maximum leaf area index recorded were significantly affected by both planting dates and mulching treatments, which ranged from 1.85 to 3.26 irrespective of planting dates and mulching treatments (**Table 1**). The biomass production at maturity was the highest in the second date of planting (284.7 g/plant) and it decreased gradually with delay in planting (**Table 1**). The total biomass production was highest under black polythene mulch (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 was found to be the most suitable planting date because it facilitated optimum weather conditions with improved soil hydrothermal and radiation (PAR) regimes during the crop season. The fruit yield of tomato cultivar *Arka Rakshak* planted under different planting dates and mulching treatments ranged between 76.6 and 392.6 q ha^{-1} with an overall mean of 234.9 q ha^{-1}, irrespective of planting dates and mulching treatments. The fruit yield varied significantly under different dates of planting and mulching treatments. The highest and lowest fruit yield was recorded under the second and last date of planting with average yields of 137.3 and 99.9 q ha^{-1}, respectively. Among the mulching treatments, the highest fruit yield was recorded under black polythene (267.9 q ha^{-1}), followed by rice straw mulch (234.2 q ha^{-1}) and non-mulched treatment (173.7 q ha^{-1}). The higher fruit yield recorded in early dates of plantings (P1& P2) as well as the crop planted under black polythene was attributed to higher iPAR, LAI, biomass production and biomass partitioning towards fruits as compared to later dates of plantings and other mulching treatments. The results presented above were further corroborated by Mtui., [17], who observed that the application of straw mulch led to delayed flowering, prolonged fruit production, and an extended harvesting period compared to non-mulched plots. This outcome was also consistent with the findings of Vos et al., [18] and Agele et al., [19].

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
P_4M0	268.5	169.5	1.16	48.84	53.23	0.48	0.30
P_4M1	378.6	239.4	1.43	52.26	57.14	0.67	0.43
P_4M2	461.4	287.4	1.37	54.14	59.59	0.82	0.51

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. 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.

3.6 Relationship between iPAR and RUE with crop growth parameters and fruit yield of tomato

Regression studies showed that there were linear relationships between total biomass, fruit yield (fruit dry matter) and maximum LAI with iPAR and RUE in tomato variety *Arka Rakshak*. When regression relationships were developed using average iPAR instead of maximum iPAR, relationships turn out to be more efficient with the higher determining factor of 0.95, 0.95 and 0.92 for fruit yield, biomass and maximum LAI respectively. The best fitted predictive models were developed by using stepwise regression method for predicting crop growth parameters and fruit yield from the radiation parameters and model equations are listed on **Table 2.**

The model equations developed can explain the relationships with high determining factor (R^2) of 0.95 and 0.92 for fruit yield, biomass production and maximum LAI, respectively. The relationships indicate that fruit yield and biomass can be suitably explained with the RUE for fruit yield. On the other hand, maximum LAI can be properly explained with the average intercepted PAR (IPAR1). It can be concluded that developed models can be successfully used for predicting crop growth parameters (LAI and biomass production) and fruit yield of tomato with high 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 14^{th} (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 49^{th} to 5^{th} 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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