Vol. 23, No. 2, pp. 206-215 (2023)
Journal of Agricultural Physics
ISSN 0973-032X
http://www.agrophysics.in

Research Article

Impact of Conservation Agriculture on Growth and Photosynthetically Active Radiation (PAR) Use Efficiency of Cowpea Grown in Summer Season of West Bengal

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ABSTRACT

The roles of conservation agriculture (CA) in conserving natural resources, biodiversity and labour had been studied exhaustively but little research work was conducted to study its effect on micrometeorology. The present research work aimed to explore the impact of different tillage practices, crop residue mulching, and fertilizer management on the regulation of radiation components, specifically photosynthetically active radiation (PAR) interception and absorption pattern, as well as PAR use efficiency (PARUE). The experiment was conducted during the *pre-Kharif* season of 2019-2020 at Bidhan Chandra Krishi Viswavidyalaya, taking cowpea as the test crop. The experimental design followed a split plot design with three levels of tillage [conventional tillage (CT), zero tillage (ZT), and reduced tillage (RT)]as the main plot factor, and two levels of nutrient management. The results indicated that conservation agricultural practices (i.e., ZT and RT) can modify microclimate in the crop field and influence soil water hydraulic properties, nutrient uptake, which was responsible for enhanced intercepted PAR, absorbed PAR, PARUE and ultimately grain yield. The highest PARUE (2.45 g MJ^{-1}) was obtained in case of ZT with 0% residue and 100% RDF treatment followed by RT with 0% residue and 100% RDF treatment (2.28 g MJ^{-1}).Therefore, conservation agricultural practice has certain impact on microclimatic modification towards better crop growth and yield. The findings of this experiment could provide valuable insights into optimizing agricultural practices to enhance PAR interception, absorption, and utilization efficiency, ultimately improving crop yields during *pre-kharif* season of West Bengal.

Key words: Conservation tillage, Conventional tillage, Cowpea, Crop residue mulching, Intercepted PAR, PAR use efficiency

Introduction

West Bengal (WB) is predominantly an agrarian state. The state has occupied only 2.7% of India's geographical area but contributes 6.51% food grain production in India (Agricultural Statistics at a Glance, 2021). There are 71.23 lakh farm families of whom 96% are small and marginal farmers. The average size of land holding is only 0.77 ha (West Bengal State Portal, 2023).The state ranks 13th in terms of area among India's 28 states and 8 union territories, with one of the highest population densities (1028 people per sq. km.) and the smallest land area per capita. The agriculture driven economy is greatly depending on monsoon rain. The rainfed rice is the major crop grown solely depending on erratic distribution of south west monsoon rainfall.

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After the harvesting of *Kharif* rice, most of the farmer go for the cultivation of *Boro* rice, potato, mustard and vegetables as a *Rabi* season crop. But after the *Rabi* season, overall water scarcity is observed as most of the surface and ground water are utilized for irrigating *Rabi* crops. Moreover, low amount of rainfall is observed in post monsoon and winter seasons. So, a dry condition and water scarcity can be observed during end of *Boro* season to start of *kharif* season. During this dry period, arable land is kept fallow by most of the farmers. In recent years, there has been increasing interest in promoting the use of fallows for various purposes, including for tree planting, soil conservation, and climate change mitigation. Various government and non-governmental organizations are also working to promote sustainable and productive land use practices among farmers in India.

Conservation agriculture is a resource saving crop production approach that strives to earn acceptable profits while conserving and strengthening natural resources in the long run. CA basically relies on three linked principles: minimum mechanical soil disturbance (reduced or no tillage), cover crop maintenance and diversified crop rotation (Pathak *et al.,* 2021). By maintaining a permanent soil cover and minimizing soil disturbance, CA practices improve soil structure and protect the soil against erosion and nutrient losses. This in turn, enhances soil organic matter levels and nutrient availability, leading to longer periods of arable land productivity. Additionally, CA requires less water use due to increased infiltration and water holding capacity from crop residues left on soil surface, and mulches also protect the soil surface from extreme temperatures and surface evaporation. The economic benefits of CA, particularly no-till farming, have led to widespread adoption among both large- and small-scale farmers worldwide. The reduced use of fossil fuels and agrochemicals also has significant environmental benefits, including reduced greenhouse gas emissions and improve air, soil and water quality (Francaviglia *et al.*, 2023). Overall, CA is a sustainable and promising approach for achieving global food security and sustainability goals. By promoting soil health, water use efficiency, and nutrient cycling, CA can improve both the environment and society.

In this study, we selected cowpea [*Vigna unguiculata* (L.) Walp] as a test crop to investigate the ability of this species to grow in the new alluvial zone under different CA practices. The cowpea was adequate for such study due to the fact that its beans contain high amount of quality protein (23-32%) and carbohydrate (60.3%) and have a relatively low-fat content (1.8%) and it plays a crucial role in human nutrition. This aspect popular cowpea as a 'Poor man's meat'. Furthermore, cowpea is attracting the attention of researchers and consumers due to its beneficial health properties like anti-cancer, anti-inflammatory, anti-diabetic and anti-hypertensive properties (Jayathilake *et al.*, 2018) and multiple uses like food, feed, forage, fodder, green manuring and vegetable as well. In India, it is a minor pulse, grown in almost 1.3 m ha in arid and semi-arid pockets of Punjab, Haryana, Delhi, and West UP along with considerable area in Rajasthan, Karnataka, Kerala, Tamil Nadu, Maharashtra and Gujarat. However, it also can grow successfully in hill tracts, heavy loam soils, acidic soil but not in saline soil. Cowpea has ability to withstand drought due to its tendency to form deep root system.

Considering this background, the present research work aims at to determine the PAR interception and radiation use efficiency of cowpea grown under different CA practices in new Alluvial Zone of West Bengal. The objectives of the study were: to study the intercepted and absorbed PAR at different growth stages of cowpea and to evaluate the radiation utilization efficiency of cowpea as influenced by different conservation practices.

Materials and Methodology

Field experimentation

The field experiment was conducted during summer season (2nd April to 6th June) of 2019 taking cowpea (cultivar Kashi Kanchan) as test crop. It was conducted at the Balindi Farm (Latitude 22°96′ N and Longitude 88°53′ E), Haringhata, Bidhan Chandra Krishi Viswavidyalaya, Nadia. The experimental area is under the subtropical zone with a mean annual rainfall of 1467.5 mm. The surface soil (0-15cm) being clay loam in structure with a pH of 7.7 (1:2.5 soil water suspension); Total N, available

P_2O_5, available K_2O, available Zn and available Fe content were 222.9 kg ha^{-1}, 30.4 kg ha^{-1}, 194.3 kg ha^{-1}, 1.1 kg ha^{-1} and 32.9 kg ha^{-1}, respectively.

The experimental was laid out in a split plot design with three levels of tillage, namely, conventional tillage (CT), zero tillage (ZT) and reduced tillage (RT) as a main plot factor and two levels of residue mulching with recommended dose of fertilizer (RDF), i.e., NR-1= '0% rice residue + 100% RDF (N:P: K @ 20:40:40 kg/ha)' and NR-2= '100% rice residue (6.3 t/ha) + 50% RDF' as a sub plot factor. The numbers of replication were three and there were 18 numbers of plots. The size of each sub plot was (7.2 m × 6.6 m). The recommended seed rate for cowpea was 25 kg ha^{-1} and spacing was kept at (60 cm × 10 cm).

Biophysical observations

Five phenological stages were considered in the present study, namely, early vegetative stage (P1), late vegetative stage (P2), 20% flowering (P3), 20% pod formation (P4) and 1st picking (P5). Micro-meteorological data were collected covering all the five growth stages. Plant samples were collected from the fields at regular time intervals to determine the temporal variation in plant biomass on dry weight basis (dried in oven for 72 hours at 60°C) and expressed in gram per plant. Leaf area index (LAI) was calculated for different growth stages of all the three replications based on gravimetric method as given by Watson (1947).

A Line Quantum Sensor (Model: APOGEE/MQ-301) was used to measure different components of photosynthetically active radiation (PAR). The incident PAR, transmitted PAR and reflected PAR from crop and soil were recorded keeping the line quantum sensor 50 cm above canopy and 5 cm above soil surface. The photosynthetically active radiation (PAR) intercepted by crop (IPAR) was calculated using the equation (Gallow and Daughtry, 1986).

IPAR = Incident PAR – Transmitted PAR …(1)

Reflected PAR percentage from canopy (R_C PAR percentage) was determined by using the following equation:

R_C PAR= (PAR reflected from crop canopy /Incident PAR) ×100% (2)

Reflected PAR percentage from soil (R_S PAR percentage) was determined by using the following equation:

R_S PAR= (PAR reflected from soil /Incident PAR) ×100% …(3)

Similarly, Absorbed PAR (APAR) was worked out by adopting the equation:

APAR percentage = [{(Incident PAR – PAR reflected from crop – Transmitted PAR + PAR reflected from soil)/ Incident PAR}× 100]% …(4)

Photosynthetically active radiation use efficiency (PARUE)

Photosynthetically active radiation use efficiency (PARUE, g MJ^{-1}) is defined as the ratio of accumulated crop mass (i.e., dry matter) to cumulative intercepted PAR. It is a key factor in the determination of the photosynthetic performance of plants growing in any environment (Oluwasemire and Odugbenro, 2014). The PARUE was calculated by regressing dry matter accumulation against intercepted PAR.

Statistical analysis

Significance of treatment differences in yield attributes and yield measurements were tested by analysis of variance and means were separated by least significant difference using R software.

Results and Discussion

Effect of tillage and crop residue management on crop growth

The seasonal variation of LAI of cowpea were found to be gradually increasing up to 45 days after sowing (DAS), irrespective of different tillage and residue with RDF effect. Thereafter, it decreases due to leaf senescence during maturity. Although the variation of LAI follows same pattern for different treatments, tillage significantly influenced the LAI (Table 1) of cowpea during entire crop growth period. Among the tillage practices, highest LAI were recorded under ZT (1.45, 3.29 and 3.05 at 30, 45 and 60 days after sowing) followed by RT (1.31, 2.82 and 2.63 at 30, 45 and 60 days after sowing). On the other hand, CT exhibited lowest values on LAI (1.08,

Table 1. Leaf area index (LAI) and yield of cowpea as influenced by tillage, residue and nutrient management

Treatments		LAI			Yield components	
		30 DAS	45 DAS	60 DAS	Grain yield ($t\ ha^{-1}$)	Biomass yield ($t\ ha^{-1}$)
Tillage	Conventional tillage (C)	1.08^{C}	1.93^{C}	1.81^{C}	1.59^{C}	3.26^{C}
	Zero tillage (Z)	1.45^{A}	3.29^{A}	3.05^{A}	2.76^{A}	5.11^{A}
	Reduce tillage (R)	1.31^{B}	2.82^{B}	2.63^{B}	2.40^{B}	4.55^{B}
	Significance	***	***	***	***	***
Residue and Nutrient (NR)	NR1	1.36^{A}	2.94^{A}	2.76^{A}	2.45^{A}	4.63^{A}
	NR2	1.21^{B}	2.42^{B}	2.23^{B}	2.05^{B}	3.98^{B}
	Significance	***	***	***	***	***
Interactions (Tillage ×NR)	CTNR1	1.11^{E}	2.14^{D}	2.01^{E}	1.70^{E}	3.43^{E}
	CTNR2	1.06^{F}	1.72^{E}	1.61^{F}	1.48^{F}	3.10^{F}
	ZTNR1	1.56^{A}	3.78^{A}	3.50^{A}	2.95^{A}	5.45^{A}
	ZTNR2	1.34^{C}	2.80^{C}	2.60^{C}	2.57^{C}	4.76^{C}
	RTNR1	1.41^{B}	2.90^{B}	2.78^{B}	2.70^{B}	5.02^{B}
	RTNR2	1.22^{D}	2.75^{C}	2.49^{D}	2.10^{D}	4.09^{D}
	Significance	***	***	***	**	***

("***" Significance level: '***' = p<0.001. '**' =p<0.01.The values in the column followed by same letters are not significantly different. CT = Conventional tillage, ZT = Zero tillage, RT = Reduced tillage, NR = Nutrient + Residue)

1.93 and 1.81 at 30, 45 and 60 days after sowing). The similar effect of ZT on rice-wheat cropping system in clay loam type of soil was observed at three sites at farmers' fields in Haryana State(Singh *et al.*, 2014).In general, the application of conservation tillage improves soil physical properties and hydraulic conductivity (Lal, 1997), which might be responsible for better nutrient transmission to leaf, thus better LAI in ZT and RT. Compaction and structural deterioration caused by slaking and dispersion due to mechanical pressure of tillage implement under CT (Busari *et al.,* 2015), might be the cause of reduced cowpea growth. Ewansiha *et al.* (2015) similarly reported that conservation tillage is better in expressing growth of cowpea as compared to CT.

Among the residue and RDF treatment, higher LAI was recorded in '0% residue+100% RDF' (1.36, 2.94 and 2.76 at 30, 45 and 60 days after sowing) than '100% residue+50% RDF' treatment (1.21, 2.42 and 2.23 at 30, 45 and 60 days after sowing). It was may be due to application of 100% RDF. Our result is in conformity to the results observed by Nwokwu, (2020). Thus, Combined results of tillage and residue-RDF practices on cowpea revealed that highest LAI was recorded under ZT with '0% residue+100% RDF' followed by RT with '0% residue+100% RDF' and the lowest value of LAI recorded from CT with '0% residue+100% RDF' treatment.

Effect of tillage and crop residue management on canopy reflected PAR (R_C PAR)

In this study, in general, initially the Rc PAR % (Fig.1 and Fig.2) was higher (8.13% to 10.68%) during vegetative stage and later decreases as the season progress. Among different tillage practices, the Rc PAR value was consistently higher (6.32% to 10.68%) in CT and ZT showed the lowest (5.35% to 10.24%). Whereas, in RT the R_C PAR percentage was between 5.84%-10.34%. It shows that crops under conservation tillage (RT and ZT) plots plants reflected less and intercepted more than CT practice, throughout the growing season. The crop stand, plant growth and distribution of LAI were improved in conservation practice (ZT and RT) than CT, which may be the determining factor for R_C PAR variation. Pragya *et al.* (2018) similarly reported that inferiority of conventional tillage in intercepting PAR of mustard as compared to ZT.

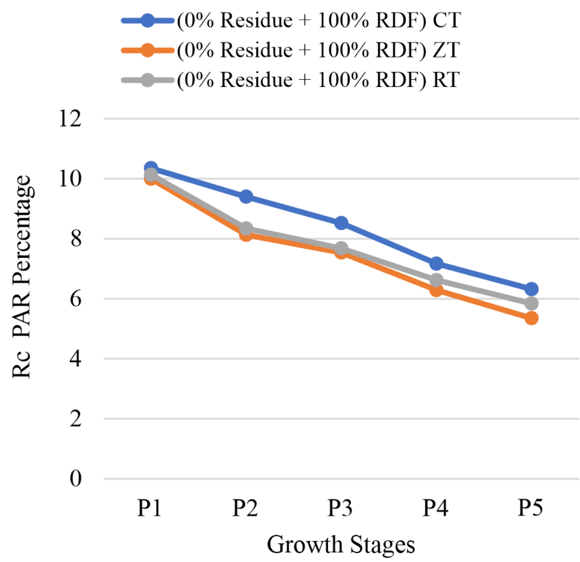


Fig. 1. R_C PAR of cowpea at 0% residue + 100% RDF under different tillage practices

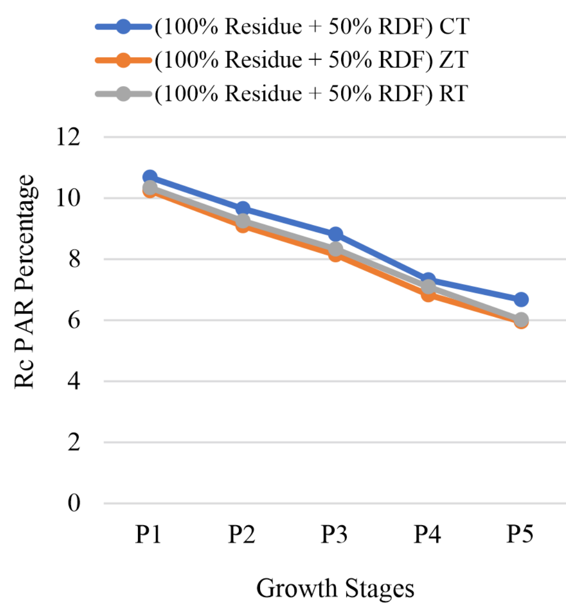


Fig. 2. R_C PAR of maize at 100% residue + 50% RDF under different tillage practices

Variation of % Rc PAR among the different residue and RDF treatment showed that the peak value (5.95%-10.68%) was obtained by 100% residue + 50% RDF treatment and the lowest value (5.35%-10.35%) was seen in 0% residue + 100% RDF treatment. It reflects that application of 100% RDF can reduce Rc PAR value due to better LAI. Hence, conservation tillage with application 100% RDF can diminish Rc PAR probably due to better canopy architecture.

Effect of tillage and crop residue management on soil reflected PAR (R_S PAR)

The %Rs PAR showed the similar trend (Fig. 3 and Fig. 4) as the % Rc PAR value. But the Rs PAR value was always lower than Rc PAR value. The

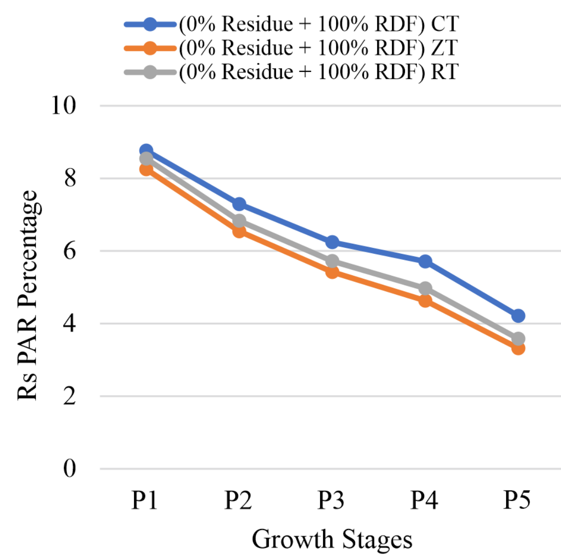


Fig. 3. R_S PAR of maize at 0% residue + 100% RDF under different tillage practices

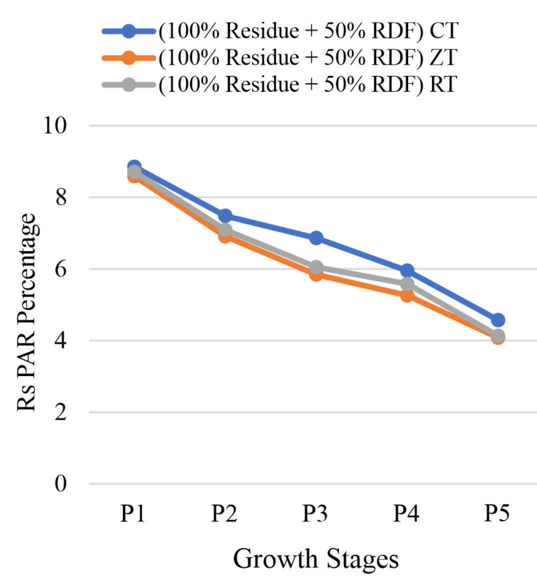


Fig. 4. R_S PAR of maize at 100% residue + 50% RDF under different tillage practices (P1= Early vegetative stage, P2= Late vegetative stage, P3= 20% flowering, P4= 20% pod formation and P5= 1st picking)

variation of Rs PAR % from soil showed that the highest Rs PAR value was obtained by CT (4.21% to 8.85%) followed by RT (3.58% to 8.71%), irrespective of residue and RDF treatment. The lowest value of Rs PAR was seen under ZT (3.32% to 8.59%) treatment. Minimum disturbance of soil through ZT practice effectively conserves soil moisture in the top soil (Bhatt *et al.,* 2017) which might be behind such low Rs PAR value.

Irrespective of tillage practice, 100% residue +50% RDF treatment had the higher Rs PAR value (4.03% to 8.85%) in all the growth stages. Lower R_S PAR value was observed in 0% residue +100% RDF treatment, which ranges between 3.32% to 8.76%. Higher Rs PAR value in 100% residue +50% RDF treatment might be associated with soil surface roughness and soil moisture content due to application of crop residue (Moreno *et al.,* 2008). Therefore, conservation tillage (ZT and RT) with 100% RDF intercepted more PAR than other tillage and RDF treatment.

Variation of absorbed PAR (APAR) governed by different CA practices

The pattern of APAR was followed a trend opposite to that of Rs PAR and Rc PAR (Fig. 5). Among the tillage practices, the value of APAR was consistently higher in ZT (18.12% to 87.36%) followed by RT (17.2% to 84.01%), throughout the growing season. On the other hand, CT exhibited lowest influence on APAR (12.08% to 78.07%). This showed that conservation tillage practice i.e., ZT and RT can enhance radiation absorption due to better leaf area of the plant population. The application of conservation tillage effectively conserved soil moisture and thereby facilitated nutrients uptake and ensured greater photosynthesis (Edwards *et al.,* 1992), which might be some other factors in ensuring higher APAR in ZT and RT. However, irrespective of tillage practices, peak value of APAR was obtained by 0% residue with 100% RDF (15.57% to 87.36%) than 100% residue+ 50% RDF (12.08% to 81.57%) treatment. It was may be due to higher LAI resulted from application of 100% recommended dose of fertilizer. Thus, conservation agriculture practices (i.e., ZT and RT) with application of 100% RDF may increase plants growth rate, expanding its leaf area, and avoiding or delaying the rolling up of leaves, resulting in a higher absorption of solar radiation.

Effect of CA practices on yield component

Data pertaining to the yield viz., grain yield (t ha^{-1}) and biomass yield (t ha^{-1}) of cowpea as influenced by different treatments are presented in

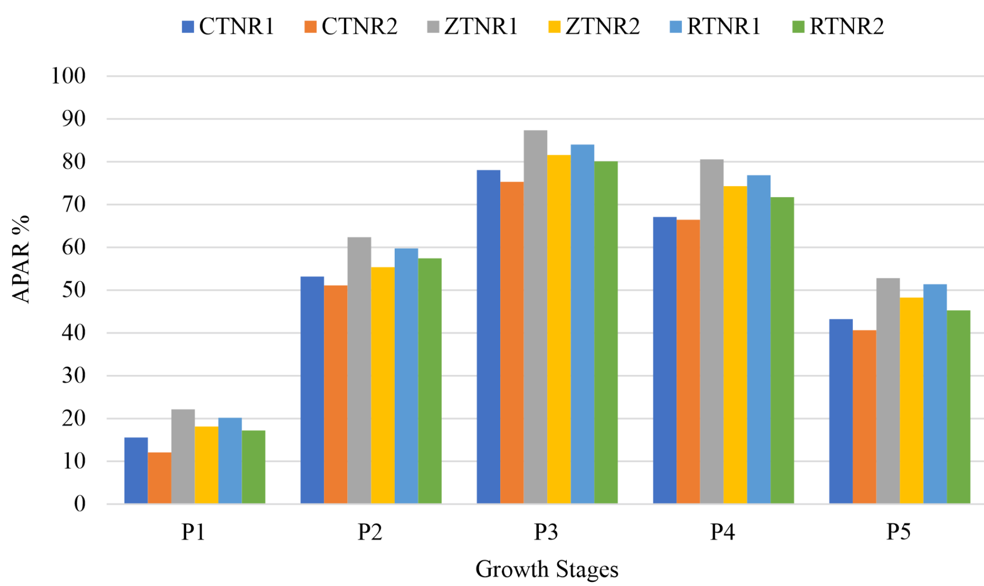
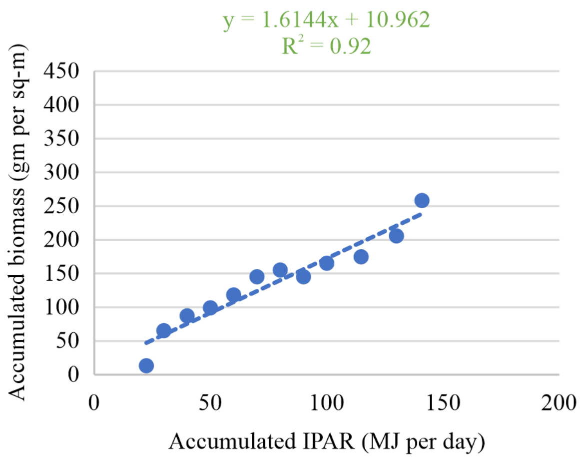
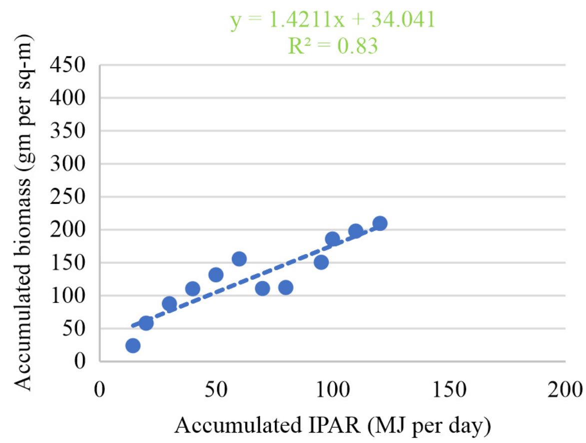


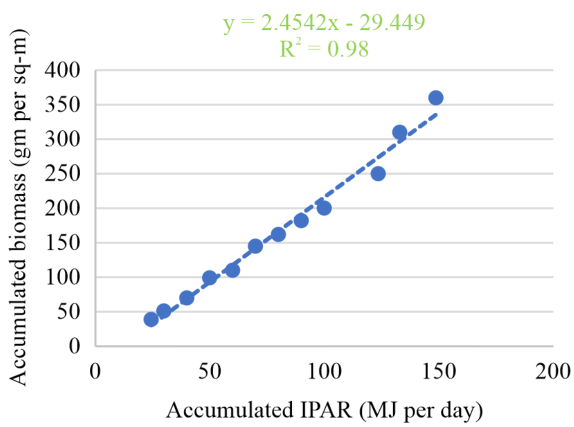
Fig. 5. Absorb PAR (APAR) of cowpea at different conservation agricultural practices
(Here, P1= Early vegetative stage, P2= Late vegetative stage, P3= 20%flowering, P4= 20% pod formation and P5= 1st picking)



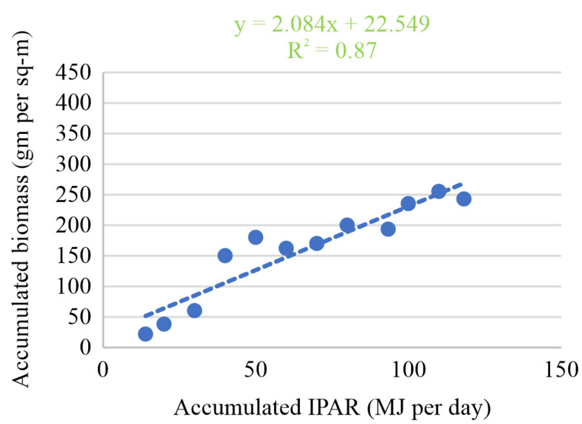
(a) CT with 0% residue+100% RDF



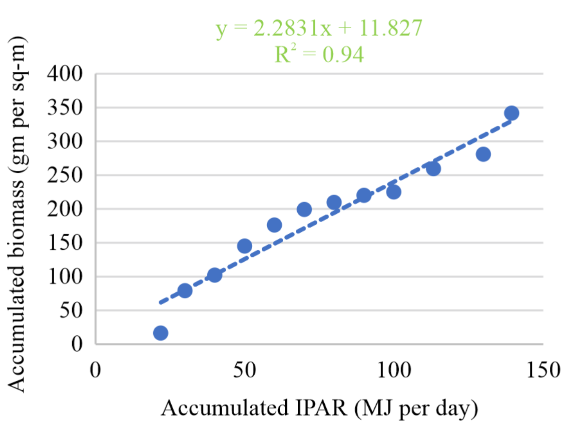
(b)CT with 100% residue+50% RDF



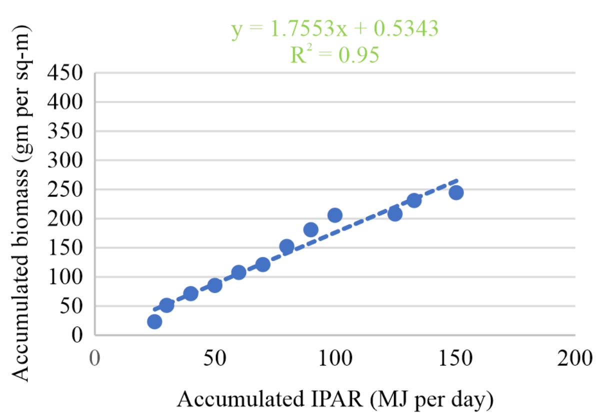
(c) ZT with 0% residue+100% RDF



(d) ZT with 100% residue+50% RDF



(e) RT with 0% residue+100% RDF



(f)RT with 100% residue+50% RDF

Fig. 6. Relationship between biomass and IPAR in CT with 0% residue+100% RDF(a), CT with 100% residue+50% RDF (b), ZT with 0% residue+100% RDF (c), ZT with 100% residue+50% RDF (d), RT with 0% residue+100% RDF (e) and RT with 100% residue+50% RDF(f) treatments

Table 1. The conservation tillage practice and fertilizer application significantly ($p<0.001$) influenced the yield of cowpea. Experimental results showed that ZT produced highest grain and biomass yield (2.76 t ha^{-1} and 5.11 t ha^{-1}) which was significantly higher than CT (1.59 t ha^{-1} and 3.26 t ha^{-1}), irrespective of residue and RDF treatment. Whereas, in RT grain yield and biomass yield was 2.40 t ha^{-1} and 4.55 t ha^{-1}, respectively. The conservation tillage (ZT and RT) practice help to conservation of moisture has been known to help in photosynthesis, fertilization of flowers and nitrogen metabolism (Mukherjee, 2015), thus, improving biomass as well as grain yield. Lower yield in CT was attributed to a poor growth and terminal water stress (Rani *et al.,* 2019). Saha *et al.* (2015) similarly reported that superiority of conservation tillage (ZT and RT) in case of grain and biomass yield of lentil as compared to CT.

Among different residue and fertilizer, the grain yield and biomass yield were found to be highest in crops from 0% residue+100% RDF (2.45 t ha^{-1} and 4.63 t ha^{-1}), whereas in 100% residue+50% RDF grain yield and biomass yield was 2.05 t ha^{-1} and 3.98 t ha^{-1} respectively. It may be due application of 100% recommended dose of fertilizer. Therefore, conservation tillage with improved nutrient management can improve grain yield as well as and biomass yield. Pragya *et al.* (2018) also found that grain and biomass yield of mustard was significantly higher in CA.

Photosynthetically active radiation utilization efficiency (PARUE) of cowpea

In this present experiment, PARUE was calculated for the three different tillage and two residue and RDF practices based on above ground biomass. The PARUE was not affected by residue management practices but increased significantly with increase RDF application. Fig. 6 (a, b, c, d, e, f) clearly showed that the intercepted PAR in 0% residue + 100% RDF was higher than 100% residue+50% RDF treatment. Similarly, irrespective of tillage practices, PARUE in 0% residue + 100% RDF (1.61 g MJ^{-1} to 2.45 g MJ^{-1}) was higher than 100% residue+50% RDF treatment (1.42 g MJ^{-1} to 2.08 g MJ^{-1}). Among different tillage practices, the PARUE was found to be highest in ZT (2.08 g MJ^{-1} to 2.45 g MJ^{-1}), whereas in the RT, PARUE was between 1.75 gMJ^{-1} to 2.28 g MJ^{-1}. The lowest PARUE was recorded with CT, which ranges between 1.42 g MJ^{-1} and 1.61 g MJ^{-1}. CT treatment also had the lowest grain and biomass yield. So, the poor yield might be a cause of poor PARUE value. Thus, conservation tillage (ZT and RT) practice can modify soil moisture characteristics, nutrient availability as well as microclimate which may be responsible for the higher PARUE.

Conclusions

The present research aimed to examine the interception pattern of PAR and its use efficiency(PARUE) in cowpea plants under varying tillage, residue, and nutrient conditions. The findings of the study indicated that CA practices, specifically ZT and RT, brought about changes in soil moisture characteristics, nutrient availability, and microclimate. These changes were responsible for enhancing the IPAR, APAR, and PARUE in cowpea plants. Furthermore, adopting CA practices led to improvements in various biophysical parameters, including LAI, biomass, and grain yield of cowpea. Regardless of the tillage practices, applying the recommended dose of fertilizer (RDF) resulted in increased IPAR, APAR, and PARUE. However, there was no notable difference in the grain and biomass yield of cowpea between plots with 0% residue and 100% residue application. ZT exhibited the highest PARUE, ranging from 2.08 g MJ^{-1} to 2.45 g MJ^{-1}. Consequently, the study suggests that cowpea can be cultivated using the recommended dose of fertilizer (N:P:K @ 20:40:40 kg/ha) alongside CA practices like ZT and RT in the summer season of West Bengal. This approach has the potential to enhance pulse production, improve crop yield, and provide long-term financial benefits to farmers.

Acknowledgement

The fellowship received from Centre for Advanced Agricultural Science and Technology (CAAST) on Conservation Agriculture, BCKV project in the form of P.G. Fellow to undertake this research work as a part of M.Sc. (Ag.) Degree is duly acknowledged.

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Received: 9 October 2023; Accepted: 13 December 2023