Effects of Light Intensity and Quality on Physiological Changes in Winter Rice (*Oryza Sativa* L.)

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Abstract— *An investigation into the effects of low light (≈meanPPFD169-493µMs^{-1}m^{-1}), red light (≈meanPPFD657-843µMs^{-1}m^{-1}) and normal light (≈meanPPFD1061-1260µMs^{-1}m^{-1}) on physiological changes including yield attributes, nutritional status at Panicle initiation (PI), flowering and harvest stages in winter rice (genotype: Monoharsali) was carried out from 40 days after transplanting (DAT) to crop maturity under both pot and field conditions. There was reduction in available PPFD at flowering as compared to PI stage of the crop. The genotype exhibited significantly higher total dry matter (TDM) and lower leaf area index (LAI) values at normal light or red light than at reduced light situation. The bio-economical yield and harvest index (HI) under normal light exceeded those at low light regime. The yield attributes viz., number of panicles, number of field grains per panicle, 1000 grain weight (test weight), high density (HD) grains, potential 1000 grain weight and sink capacity were superior at normal or red light to low light condition. Higher the total carbohydrate contents in grains, higher were the sink capacity with the normal /red light illuminations at harvest stage. At PI stage, leaf nitrogen content was reduced by low light, but it increased at flowering stage significantly. Grain protein contents, under normal/red light exceeded its value at low light treatment. A positive correlation of most of the yield attributes with grain yield at normal/red light, and a negative correlation of these parameters were found at low light conditions.*

Keywords— low light, red light, white light, PPFD, HI, test weight, HD grains, Sink capacity.

I. INTRODUCTION

Rice (*Oryza sativa* L.) grown in winter season in tropical and subtropical regions are influenced adversely by the climatic conditions, which is characterized by overcast sky posing low sunshine hours during the vegetative to reproductive growth stages of the crop. Rice plant requires about 1500 bright sunshine (BSS) hours for the period from transplanting to maturity. Instead, prevalence of only about 800-900 BSS hours during August to December in places like Northeastern region of India hampers the physiological efficiencies, and ultimately the productivity of winter rice crop (Bharali et al., 1994). It's because, solar radiation in tropics is one of the major climatic factors limiting grain yield in rice (Vergara et al., 1976).

Apart from light intensity, an illumination condition is determinant for proper growth and development of plant, which ensures interactions of all photoreactions (Voskresenenskya, 1979). Many vital biosynthetic processes of plant can be regulated by simple alteration of light quality. Accumulation of carbohydrate, particularly starch is a notable metabolic feature of plants photosynthesizing under red light during a long period. In plants under the influence of blue light, the carbon is preferentially utilized for biosynthesis of proteins (Pierson and Lowallik, 1964). The peculiarities in metabolism due to effects of light quality are accompanied by changes in chloroplast organization. The plants under red light form lesser active chloroplast than plants under blue light. Moreover, the plants photosynthesizing under red light have limited CO_2 exchange, week photophosphorylation and low activity of electron transport from water (Voskresenskaya, 1972). Low light at PI and flowering stages of crop causes physiological aberrations in rice including nutritional imbalance (Bharali et al., 1993). The present study attempted to compare the physiological performance of winter rice crop modulated by low light and red light in comparison to normal light in field and pot culture conditions.

II. MATERIALS AND METHODS

A field experiment laid in RBD and another pot culture experiment framed in CRD, were conducted on winter rice (Variety Manoharsali), to study the impacts of low light cum red light and normal sunlight light on physiological changes of the crop.

In field, 30 days old seedlings (n=2) were transplanted at 10cm (Plant x Plant) and 20cm (Row x Row) apart onto the well puddle and leveled plots. Fertilizers @40:20:20 NPK per hectare were applied as Urea, Single super phosphate (SSP) and Muriate of potash (MoP). In case of pot culture, rice seedlings (n=1) of 30 days old, was transplanted to the earthen pots (diameter: 32cm). A mixture of sandy loamy soil with FYM @4:1 was used to fill in one pot (capacity: 6.5 Kg soil). The pot mixture also contained the NPK fertilizers @40:20:20. In both the experiments, half of N and entire doses of P and K were applied as basal, and the remaining half of the N was top-dressed at 30 days after transplanting (DAT). In the field plots and laboratory pots, constant water supply (2-3cm) was ensured from transplanting till seven days before harvesting.

Normal sunlight was reduced to 50% (Low light) using standard hessian cloth fitted in a bamboo frame at one meter above the ground, at 40 DAT till maturity of the crop. Each plant was wrapped with two layers of red cellophane papers loosely allowing the gaseous exchange, which permitted only the red spectrum of visible light with emission maximum 650nm (Sharma et.al., 1976). Light intensity below and above the crop canopy was measured using a Lux Meter (York Scientific Industries, YORCO) at PI and flowering stages of the crop. The light intensity readings (Lux) were converted into $\mu ES^{-1}m^{-2}$ (Dhopte et al., 1989; Clayton, R. K. (1970)). The total rainfall and BSS during the crop season (July to December) were 927.4mm and 1060.7 hours respectively (Meteorological Observatory, AAU, Jorhat).

III. PHYSIOLOGICAL PARAMETERS

Leaf area (L x B x constant factor) was measured at PI and flowering stages (Yoshida et al., 1976) of crop growth, where L: maximum length, B: Average breath of leaf. Constant factor for PI: 0.69 & Flowering stage: 0.75. LAI was calculated as the ratio of total leaf area to the ground area covered by the plant canopy. The second leaf from the top was sampled, oven dried at 60^{o}C to a constant weight and recorded as specific leaf weight (SLW). Panicle length measured from the nodal base to the tip of the panicle.

The above ground parts of five observational plants in each plot or the whole plant in each pot, were oven dried at 60^{o}C to a constant weight. Dry matter /m^2 (average dry weight x total no. of plants/m^2) was converted into kg/ha at PI and flowering stages. At harvest, plants/m^2 area from each plot were threshed to separate grains from straw and after proper drying in sunshine, biological (straw + grains) and economic yield were expressed as q/ha. In case of pot experiment, these parameters were recorded as g/pot. Harvest index (HI) were calculated by proportioning biological yield to grain yield. 1000 seeds were randomly collected from each seed lot of individually harvested plot and pot, weighed in electrical balance after proper drying (14% moisture) and recorded as test weight. The per cent well filled grains, high density (HD) grains were determined using 1.20 specific gravity salt solution and 50g seed from each treatment in the experiments (Nichiporovich, 1967). Sink capacity (number of panicles/m^2 x spikelet/panicle x individual grain weight) was calculated as suggested by Venkateswrulu and Visperas (1987).

IV. CHEMICAL ANALYSIS

In field and pot experiments, five randomly selected leaves were ground in electrical grinder after drying in oven at 60^{o}C into a constant weight. Powdered materials were sieved and stored in desiccators. Nitrogen estimation in leaf samples was done by Micro-Kjeldhal method (A.O.A.C. 1965) at PI and flowering stages. Nitrogen estimated in grains on dry weight basis following the same procedure was converted into crude protein multiplying it by a factor of 5.95 (Juliano, 1972). Total carbohydrate content was determined in leaf and dehusked grain (Daniel, 1982; Yoshida et. al. 1976) too.

V. STATISTICAL ANALYSIS

Data for each character was analyzed by Fisher's method of analysis of variance. Least significance difference (LSD) between a pair of treatment means at $P<0.05$ was used for determination of the significance difference between two treatment means. The relationship of economic yield with yield attributing parameters under different light regimes was determined from simple correlation studies.

VI. RESULTS

Data on light intensity under different light regimes at PI and flowering stages of rice crop are portrayed in Table 1 (a & b). In the field experiment, light intensity was lesser than at flowering stage. There was always higher interception of light above the canopy than below the canopy level of the crop irrespective of growth stages. In field, the highest mean PPFDs was found in normal light and the lowest was in low light treatment at both PI and flowering stages respectively. The similar trend of available PPFD was also observed in the pot experiment.

TABLE1(A)

VARIATION OF LIGHT INTENSITY (μE $s^{-1}m^{-1}$) AT PI AND FLOWERING STAGES OF RICE CROP

Field experiment						
	PI stage			Flowering stage		
Light regimes	Below canopy	Above canopy	Mean	Below canopy	Above canopy	Mean
Normal sunlight (400-700nm):NL	657.271	1725.472	1224.768	609.178	1513.326	1061.252
Red light (600-700nm):RL	378.330	1272.861	823.990	339.857	971.479	657.271
Low light (50% of NL): LL	227.640	955.448	583.528	169.929	766.282	468.105

TABLE1(B)

VARIATION OF LIGHT INTENSITY (μE $s^{-1}m^{-1}$) AT PI AND FLOWERING STAGES OF RICE CROP

	Pot culture experiment					
	PI stage			Flowering stage		
Light regimes	Below canopy	Above canopy	Mean	Below canopy	Above canopy	Mean
Normal sunlight (400-700nm):NL	663.683	1859.596	1260.037	631.621	1538.976	1083.696
Red light (600-700nm):RL	407.187	1282.48	843.231	365.507	981.097	673.302
Low light (50% of NL):LL	230.846	971.479	602.766	198.784	785.519	493.755

In the field trial, total dry matter production (TDMP) varied significantly in different light regimes (Table 2). At PI stage the highest TDMP (9244kgha^{-1}) was found under normal light, whereas, it was the lowest (8274kgha^{-1}) under low light condition. At flowering stage, the similar trend was found in respect of TDMP under different light regimes. In pot culture experiment, too, the TDMP at harvest stage was alike (NL:52.58>RL50.62>LL46.72) with the field observation.

TABLE 2
VARIATION OF TOTAL DRY MATTER PRODUCTION (TDMP) AT PI, FLOWERING AND HARVEST STAGES OF RICE CROP

	Field experiment		Pot experiment
	PI stage	Flowering stage	Harvest stage
Light regimes	Kgha^{-1} x 10^{2}	Kgha^{-1} x 10^{2}	g pot^{-1}
Normal white light (400-700nm)	92.44^{a}	140.56^{a}	52.58^{a}
Red light (600-700nm)	87.30^{a}	135.64^{a}	50.62^{a}
Low light (50% of NL)	82.74^{b}	110.58^{b}	46.72^{b}
SEDiff. (±)	3.091	2.751	1.429
LSD (0.05)	6.894	5.727	3.029
Values with similar superscript letters within a column are not significantly different at P(0.05)			

Data on field experiment (Table 3) indicates that leaf area index (LAI) differed significantly amongst the three light treatments at PI stage, but the difference was not significant at flowering stage of the crop. At PI stage, LAI was the highest (7.16) under low light and the lowest (5.13) was recorded in plants exposed to normal light condition. At flowering stage, the highest (6.10) and the lowest (5.85) LAI were found under low and normal light regimes respectively. The results of the pot experiment (PI: LL 7.12>RL5.85>NL5.11 & FS:LL6.0>RL5.95>NL5.25) similar to the field experiment also.

TABLE 3
VARIATION OF LEAF AREA INDEX (LAI) AT PI AND FLOWERING STAGES OF RICE CROP

	Field experiment		Pot experiment	
	PI stage	Flowering stage	PI stage	Flowering
Light regimes				
Normal white light (400-700nm)	5.13^{a}	5.85^{a}	5.11^{a}	5.25^{a}
Red light (600-700nm)	5.90^{b}	6.08^{a}	5.85^{b}	5.95^{a}
Low light (50% of NL)	7.16^{b}	6.10^{a}	7.12^{c}	6.00^{a}
SEDiff. (±)	0.078	0.226	0.0532	0.556
LSD (0.05)	0.174	n.s.	0.167	n.s.
n.s.: non significant				

Total carbohydrate contents (TCC) in leaf and grain are displayed in Table 4. In field, TCC in leaf varied significantly both at PI and flowering stages of growth due to the treatments of different lights. At PI stage, plants under normal light produced the highest (5%), and the low light treated plants had the lowest (3.87%) TCC in leaf. At flowering stage, the highest (8.10%) and the lowest (5.75%) values of TCC in leaf were recorded in plants under normal and low light conditions respectively. Moreover, the TCC in leaf under normal light and red light conditions were equal at both PI and flowering stages statistically.

TABLE 4
VARIATION IN TOTAL CARBOHYDRATE CONTENT (TCC) AT PI AND FLOWERING STAGES OF RICE CROP

	Field experiment			Pot experiment		
	TCC in leaf (% d.w.)		TCC in grains (% d.w.)	TCC in leaf (% d.w.)		TCC in grains (% d.w.)
Light regimes	PI stage	Flowering stage	Harvest stage	PI stage	Flowering stage	Harvest stage
Normal white light (400-700nm)	5.00^{a}	8.10^{a}	64.14^{a}	5.01^{a}	8.00^{a}	64.12^{a}
Red light (600-700nm)	4.94^{a}	7.84^{a}	63.26^{a}	4.96^{a}	7.86^{a}	63.27^{a}
Low light (50% of NL)	3.87^{b}	5.75^{b}	60.07^{b}	3.90^{b}	5.54^{b}	59.12^{b}
SEDiff. (±)	0.1759	0.1759	0.4605	0.1827	0.0783	0.391
LSD (0.05)	0.392	0.392	1.050	0.387	0.166	1.553
n.s.: non significant, d.w.: dry weight.Values with similar superscript letters within a column are not significantly different at P(0.05)						

In field, TCC in grain at harvest differed significantly between red light and low light as well as normal light and low light conditions. Of course, under low light, plants produced the highest (64.14%) TCC in grain. The lowest (60.07%) TCC in grain was found under low light condition. A similar trend was also found in respect of TCC in leaf (NL:5.01%>RL:4.96>LL3.90) and grain (NL:64.12>RL:63.27>LL:59.12) in case of pot experiment.

Nitrogen contents in leaf at PI and flowering stages differed significantly amongst low light and red light or normal light both in filed and pot culture conditions (Table 5). In field, at PI stage, the leaf N content was maximum under normal light (1.89%) and the same was minimum with low light. In contrast, leaf N content increased under low light (1.87%) as compared to normal or red light conditions at flowering stage. There was no significant difference in grain protein content among the light regimes. The similar trend in case of leaf nitrogen at PI (NL:1.88% R>RL:1.87>LL1.41%), at flowering (LL:1.86>RL:1.42:>NL:1.35) and grain protein contents were recorded in pot culture .

TABLE 5
VARIATION IN LEAF N AND GRAIN PROTEIN CONTENTS AT DIFFERENT GROWTH STAGES OF RICE CROP

	Field experiment			Pot experiment		
	Leaf N (% d.w.)		Grain protein (% d.w.)	Leaf N (% d.w.)		Grain protein (% d.w.)
Light regimes	PI stage	Flowering stage	Harvest stage	PI stage	Flowering stage	Harvest stage
Normal white light (400-700nm)	1.89[a]	1.36[a]	9.35[a]	1.88[a]	1.35[a]	9.30[a]
Red light (600-700nm)	1.88[a]	1.43[a]	9.30[a]	1.87[a]	1.42[a]	9.25[a]
Low light (50% of NL)	1.42[b]	1.87[b]	9.10[a]	1.41[b]	1.86[b]	9.12[a]
SEDiff. (±)	0.0513	0.0056	0.0056	0.0361	0.0445	0.024
LSD (0.05)	0.114	n.s.	0.077	0.077	0.094	n.s.

n.s.: non significant, d.w.: dry weight Values with similar superscript letters within a column are not significantly different at P(0.05)

Data displayed in Table 6 showed significant differences among the treatment means in respect of number of spikelets /panicle and well filled grains/panicle and sink capacity. Normal light produced the highest spikelet numbers (159.27&18.66) and well filled grains (123.08 & 123.58) under field and pot culture conditions respectively. The lower of these two parameters viz., (119.69 & 106.69) and (139.12& 108.19) were recorded in case of low light conditions of field and pot experiments respectively. The highest sink capacity was found with normal light (1045 & 1722.01gm^{-2}), and the lowest of it was in low light (643.06& 1085gm^{-2}) in field and pot experiments respectively.

TABLE 6
VARIATION IN NUMBER OF SPIKELETS, WELL FILLED GRAINS AND SINK CAPACITY OF RICE CROP

	Field experiment			Pot experiment		
Light regimes	No. of spikelets /panicle	No. of well filled grains/panicle	Sink capacity (gm^{-2})	No. of spikelets /panicle	No. of well filled grains/panicle	Sink capacity (gm^{-2})
Normal white light (400-700nm)	159.27[a]	123.08[a]	1045.36[a]	159.42[a]	123.58[a]	1722.01[a]
Red light (600-700nm)	156.07[a]	120.16[a]	1011.12[a]	156.38[a]	119.75[a]	1656.80[a]
Low light (50% of NL)	119.69[b]	106.69[b]	643.06[b]	139.12[b]	108.19[b]	1085.42[b]
SEDiff. (±)	1.610	1.603	138.033	7.352	3.641	82.562
LSD (0.05)	3.581	3.570	307.53	15.586	7.718	175.03

n.s.: non significant, d.w.: dry weight Values with similar superscript letter within a column are not significantly different at P(0.05)

Data executed in Table 7 showed that there were significant differences among the treatment means of 1000 grain weight (test weight), proportion of HD grains and potential 1000 grain weight. Low light produced the lowest test weight (20.81g); HD grains (50.49%) and potential 1000 grain weight (25.44%). However, the highest 1000 grain weight (24.92g), HD grains (61.33%) and potential 1000grain weight (28.54g) were recorded under normal light condition. All the three parameters possessed the parallel values under normal light and red light conditions. The results obtained in the pot experiment confirmed the validity of these data also.

TABLE 7
VARIATION IN 1000 GRAIN WEIGHT, HD GRAINS AND POTENTIAL 1000 GRAIN OF RICE CROP

Light regimes	Field experiment			Pot experiment		
	1000 grain weight (g)	HD grains (%)	Potential 1000 grain weight (g)	1000 grain weight (g)	HD grains (%)	Potential 1000 grain weight (g)
Normal white light (400-700nm)	24.92[a]	61.33[a]	28.54[a]	24.52[a]	60.47[a]	28.21a
Red light (600-700nm)	24.31[a]	60.21[a]	28.05[a]	24.50[a]	58.98[a]	27.13a
Low light (50% of NL)	20.81[b]	50.49[b]	25.44[b]	20.25[b]	49.33[b]	26.25b
SEDiff. (±)	1.325	1.934	0.7683	1.243	1.982	0.648
LSD (0.05)	3.070	4.301	1.711	2.982	4.201	1.373

n.s.: non significant, d.w.: dry weight, Values with similar superscript letters within a column are not significantly different at P(0.05)

There was compelling evidence on the significant impacts of light treatments on economic yield, biological yield and harvest index (Table 8). Under normal light, they were recorded as the highest with the values 36.77qha^{-1}, 88.74qha^{-1} and 41.03% respectively. The values of these parameters under normal light and red light were similar. However, plants under low light produced the lowest economic yield (23.50qha^{-1}), biological yield (63.0qha^{-1}) and HI (36.96%). The findings of the pot culture stood parallels with the trend in data from the field experiment.

TABLE 8
VARIATION IN ECONOMIC YIELD, BIOLOGICAL YIELD AND HARVEST INDEX OF RICE CROP

Light regimes	Field experiment			Pot experiment		
	Economic yield (qha^{-1})	Biological yield (qha^{-1})	Harvest index (%)	Economic yield (qha^{-1})	Biological yield (qha^{-1})	Harvest index (%)
Normal white light (400-700nm)	36.37[a]	88.74[a]	41.03[a]	34.16[a]	70.16[a]	48.68[a]
Red light (600-700nm)	33.11[a]	80.90[a]	40.31[a]	33.08[a]	69.33[a]	47.76[a]
Low light (50% of NL)	23.50[b]	63.0[b]	36.96[b]	30.18[b]	66.45[b]	45.43[b]
SEDiff. (±)	4.178	8.173	1.536	0.645	1.181	1.037
LSD (0.05)	9.30	18.209	3.420	1.372	2.503	2.199

n.s.: non significant, d.w.: dry weight, Values with similar superscript letters within a column are not significantly different at P(0.05)

In field, the correlations studies expressed in Table 9(a) indicate that panicle length (0.217), panicle number (0.191), spikelet per panicle (0.812), well field grains per panicle (0.189), HD grain weight (0.336), TDMP (0.468) and HI (0.141) were positively correlated with grain yield. All the parameters showed a positive correlation with economic yield under red light condition. Under low light condition, HI (0.991*) had a significant positive correlation with grain yield. Panicle length

(0.466), spikelet per panicle (0.377), well filled grain per panicle (0.478), HD grain weight (0.255) and TDMP (0.412) had positive correlation with grain yield. Low light maintained negative correlation of Panicle/m^2 area (-0.314) with grain yield.

The correlation studies from the pot culture data (Table 9b) exhibited that under normal light condition, number of panicle per pot (0.892*) and number of well filled grains per panicle (0.836*) had significant positive correlations with economic yield. Spikelet number per panicle (0.596), HD grain weight (0.644) and HI (0.778) were also positively correlated with grain yield. Under red light condition, panicle length (0.890*) and HD grain weight (0.816*) only maintained significant positive relationship with economic yield. Panicle number per pot (0.610), number of spikelet per panicle (0.391), number of well filled grains per panicle (0.293), leaf area (0.157), TDMP (0.385) and HI (0.752) were positively correlated with grain yield. Under shade condition, panicle length (0.360), well filled grains per panicle (0.563), HD grain weight (0.393) and HI (0.641) were positively correlated with economic yield. Panicle number per pot, spikelet per panicle, and TDMP, were negatively correlated with grain yield.

TABLE 9
RELATIONSHIP OF GRAIN YIELD WITH YIELD ATTRIBUTING PARAMETERS UNDER DIFFERENT LIGHT REGIMES

(a) In Field	Panicle length	Panicle/m^2	Spikelet/panicle	Well filled grains/Panicle	HD grain weight	TDMP	HI
NL	0.217	0.191	0.182	0.109	0.366	0.468	0.141
RL	0.700	0.122	0.521	0.169	0.086	0.468	0.272
LL	0.466	-0.300	0.377	0.478	0.255	0.412	0.991*
(b) In Pot culture							
NL	0.588	0.892*	0.596	0.863*	0.644	0.760	0.778
RL	0.890*	0.610	0.391	0.293	0.816*	0.385	0.752
LL	0.360	-0.179	-0.363	0.563	0.393	0.248	0.641
NL: Normal white light, RL: Red light, LL: Low light (50% of NL), * Significance at P(0.05).							

VII. DISCUSSION

In the present study, several physiological parameters (e.g. TDMP, TCC, N contents, yield and yield attributes) except LAI were reduced markedly by low light in comparison to red light and normal light both in filed and pot culture conditions. The effects of the light regimes have been studied at the canopy level of the crop. Light intensity declined gradually 'above and below canopy' from panicle to flowering stages under normal white light, red light and low light conditions. Hoover (1934) stated utilization of incident solar radiation by crops of different structures. The rate of photosynthesis and light intensity has a linear relationship, photosynthesis increases with increase in light intensity and declines at light saturation point. In photosynthesis, the only radiation absorbed by chlorophyll is limited to wave band 400-700 nm (PAR). In our field and pot culture studies, light intensity at canopy level was in conformity within the normal ranges (full sunlight: 2500-4500 μEm^{-2} and cloudy: 250-1000μEm^{-2}), which prevail in Northeast India. The percentage utilization of energy in photosynthesis is maximal (2.5-3%) at about 100-200 K Cal m^{-2} hr^{-1}. This relationship suggests that L (Leaf area index) should be sufficiently high to absorb as much as possible of the incoming solar energy. The condition involves some mutual shading of leaves, but still higher L with more severe mutual shading has adverse effects.

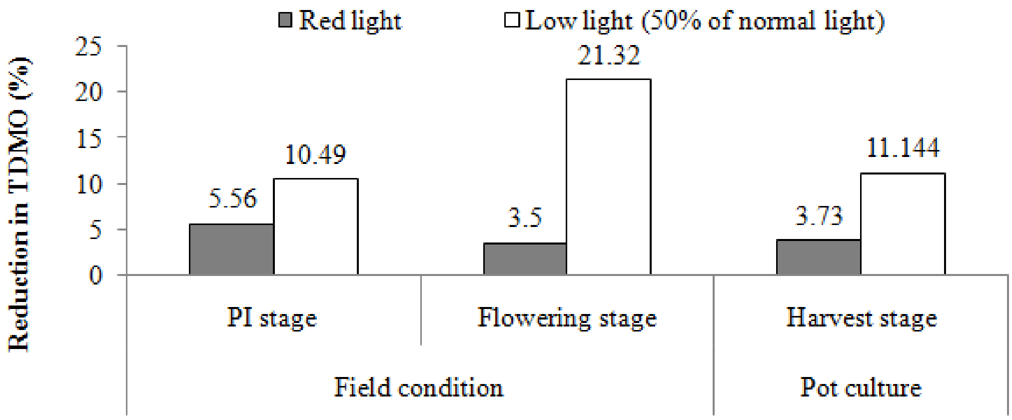

FIG.1 PER CENT REDUCTION IN TOTAL DRY MATTER PRODUCTION (TDMP) IN LIGHT REGIMES IN COMPARISON TO NORMAL WHITE LIGHT

In general there was reduction of total dry matter production of the crop at PI, flowering and harvest stages under red light (≈3-5%) and low light (≈10-21%) as compared to normal white light (Fig.1). However, the reduction is more with low light than red light. This is in agreement with Nayak and Murty, 1980. Dry matter production irrespective of light regimes especially at flowering stage of the crop is of paramount importance for checking spikelet sterility and proper grain filling linked to yield potential (Sahu,1984). However, a wide gap between spikelet number and number of filled grains is apparent during the wet season due to the poor supply of carbohydrates from the source leaf, and it is associated with high spikelet sterility (Venkateswrulu, 1977).

LAI increased with red light (PI:15%; Flowering:≈4%) and low light (PI:39%; Flowering:≈14%) both in field and pot culture conditions in comparison to normal white light. LAI at PI stage under shade condition was more than normal light condition, which was superior significantly to flowering stage. Further, LAI declined with increase in the age of the crop growth, which is clear from the present finding (Fig. 2). Tanaka et al., (1964) also opined that LAI increases according to the compound interest law, reaches its highest value a little before heading and decreases thereafter due to withering of leaves. The influence of solar radiation on LAI may be explained as an adaptation of the plants to develop thin large leaves under weak light. However, increase in LAI is also limited by low a level of solar radiation.

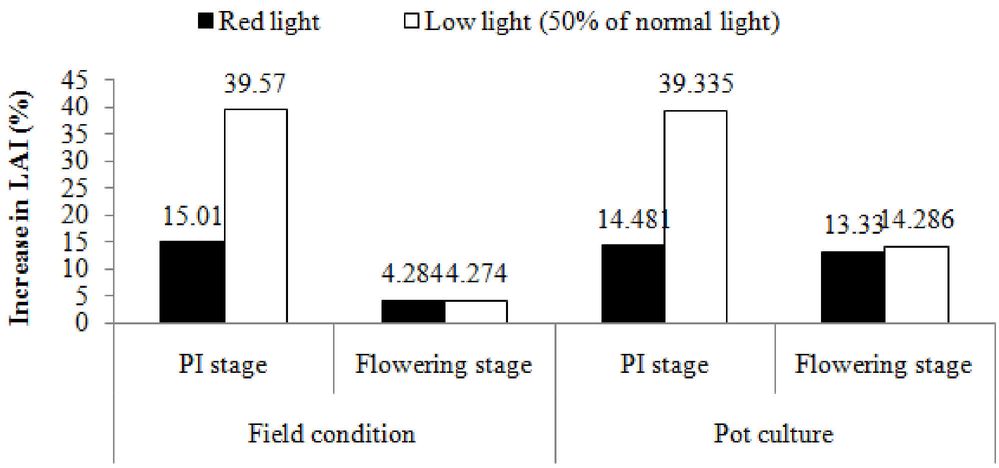

FIG.2 PER CENT INCREASE IN LAI IN RED AND LOWLIGHT IN COMPARISON TO NORMAL WHITE LIGHT

Low light reduced total carbohydrate contents in leaf (22-30%) and grain (6-8%) significantly, and merely by red light invariably at PI and flowering stages of the crop in comparison to normal white light (Fig.3). The reduction in TCC in leaf by reduced light is due to impairment of dry matter production at PI, and even more reduction of it after flowering for partitioning into the developing grains at harvest (Janardhan et al., 1980).

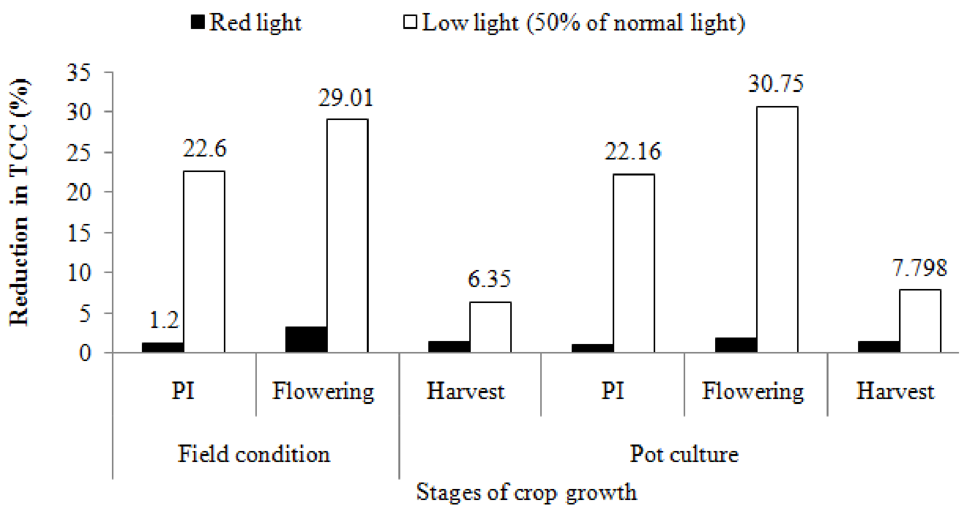

FIG. 3 PER CENT DECREASE IN TCC UNDER RED AND LOW LIGHT IN COMPARISON TO NORMAL WHITE LIGHT

The partitioning of TDMP to panicle is also poor due to weak supply of carbohydrate under low light regimes, which increases spikelet sterility and lower harvest index (Palit et al., 1976; Sahu et al., 1980). Reddy et al (1987) suggested that low light intensity during crop growth helps in accumulation of fructose 2, 6 bisphosphate which modulate the key enzymes of sucrose biosynthesis than regulating carbon flow under conditions of limited photosynthesis. Murty et al. (1976) amply demonstrated that the movement of photosynthates to aerial parts is enhanced under lower light intensity. But, the available photoassimilates are low due to impaired photosynthesis under reduced light intensity, and hence varieties efficient in this trait under low light conditions need to be identified.

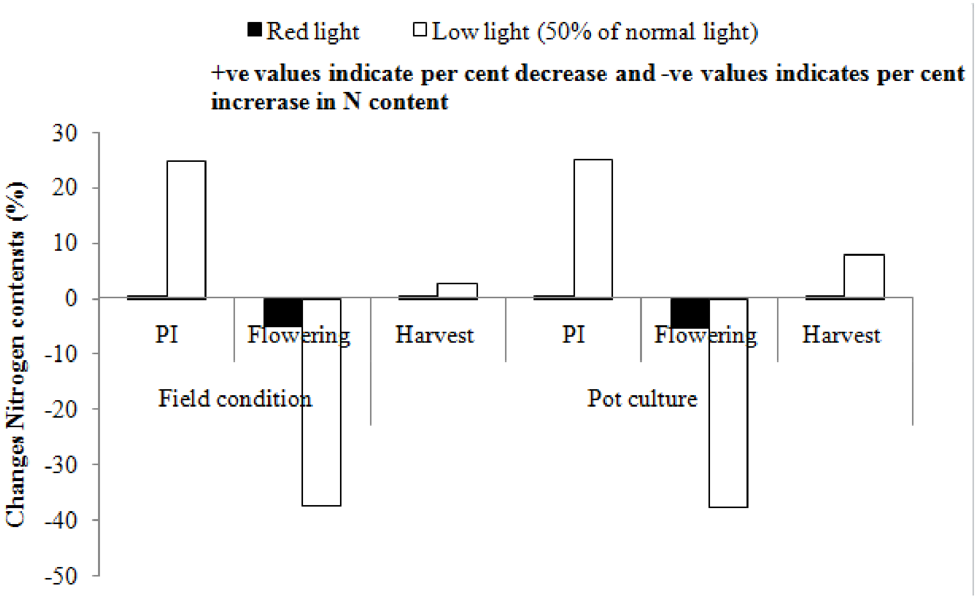

FIG.4 PER CENT CHANGES IN NITROGEN CONTENT IN RED AND LOW LIGHT IN COMPARISON TO NORMAL WHITE LIGHT

At PI stage, N content decreased in low light (≈24-25%) significantly whereas, at flowering stage, N increased in Low light (≈38%) and Red light (≈4-5%) in both the field and pot experiments. Sahu and Murty (1976) also opined that nitrogen uptake at flowering is relatively high in wet season and is reduced only after flowering. So, plants growing under lower light always show higher nitrogen content in shoot and panicle at flowering (Fig. 4). It has consequence on the high sterility of grains in plants under lower light regimes. Greater accumulation of Nitrogen, especially soluble N occurs in panicle during anthesis, and at a juvenile stage of grain development. Low light intensity influences the amount of nitrogen utilized for grain production (Pandaraju et al 1976).

Decreases in number of spikelet/panicle (≈12-24%), well filled grains/panicle (≈12-13%), sink capacity (≈36-38%) were found under low light in comparison to normal white light both in filed and pot culture conditions (Fig. 5). Reduced light during reproductive and ripening stages is much more harmful in economic point of view. As the flowering in the shortest and medium duration rice varieties synchronize with lower light intensity, it has impacts on yield and yield attributes. So, reduction in grains per panicle, increases in spikelet sterility, lower sink capacity and lower grain yield are observed in rice under lower light levels (Murti and Rao, 1982).

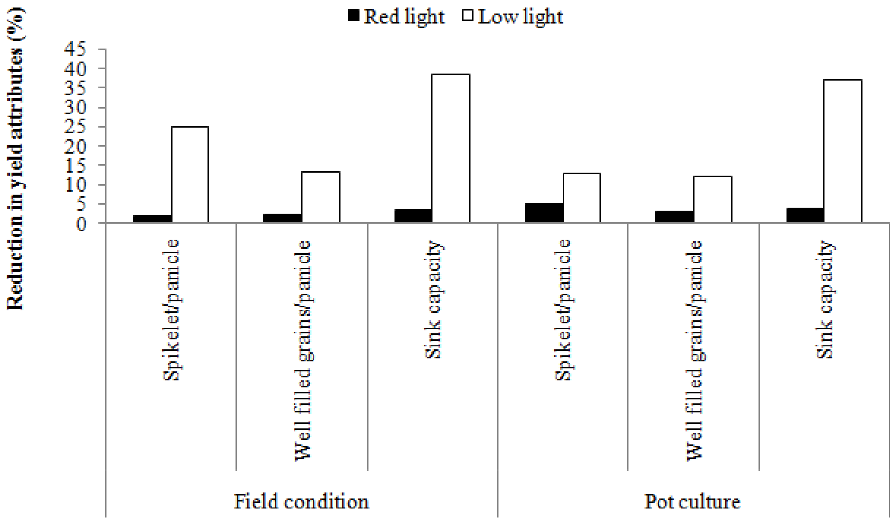

FIG.5 PER CENT REDUCTION IN YIELD ATTRIBUTES IN RED AND LOW LIGHT IN COMPARISON TO NORMAL LIGHT

In the present study there were decreases in 1000grain weight (≈16-17%), HD grains (≈ 17-18%), potential 1000grain weight (≈6-10%) under low light in comparison to normal white light conditions irrespective of field and pot culture. Stansel et al. (1965) stated that low light intensity increases sterility and reduces yield. Spikelet sterility is one of the major constraints in rice productivity as it influences directly the grain yield by limiting the number of filled grains per unit area (Vergara et al., 1966). The lower grain yield during wet season is mostly due to high sterility of spikelets, and consequent reduction in the number of filled grains per panicle per unit ground area (Yoshida and Parao, 1976). High sterility during the cloudy monsoon season is attributed to the prevalent low solar radiation (Venkateswrulu, 1976).

Rao et al. (1986) pointed that the partially filled grains appear in declining order with the initiation of grain-filling, and the number of grain increasers linearly with time. Venkateswarlu et al. (1977) opined that the grain yield can be enhanced by increasing the number of high density grains in rice. The percentage contribution of HD grains to total grain emerges as a major determinant of grain yield. Thus, cultivars possessing a higher production of HD grains would be advantageous even under low PAR.

Economic yield (12-35%), Biological yield (5-29%) and Harvest Index (7-10%) decreased under low light in comparison to normal light from either pot and field experiments. All these yield parameters in red light did not differ significantly from those in normal white light. Janardhan and Murty (1980) reported that grain yield was reduced under low light due to low grain number per panicle and grain size. Better mobilization capacity of the 'Indicas', particularly the late maturity types recorded high yield than the semi dwarf under low light. Low light intensity during the crop growth period, especially at reproductive stage reduces the yield of rice (Yoshida, 1972). However, in late maturing high yielding 'Indica' rice, insufficient solar radiation up to flowering causes reduction in yield due to severe damage of tillers ultimately reducing the number of panicles per unit land area (Murty and Murty, 1982). A sufficient solar radiation is available after flowering in 'kharif' rice crop normally. Low light intensity is likely to reduce the harvest index (HI) because of inadequate grain filling. High photosynthesis rate at low light may be strategized with high light harvesting efficiency, high chlorophyll content, greater dry matter production and HI. (Sahu, et.al.,1980).

This correlation studies among the physiological parameters implies that by putting high selection pressure on these physiological parameters (yield with yield attributes), other genotypes/strains could be identified, and improved through properly oriented breeding programmers in desired direction. Improvement of the traits in the development of genotypes with high physiological efficiency will lead to higher yield in kharif (wet season) rice under agro-ecological conditions of Assam and elsewhere. This was in agreement with the findings of Mishra et al. (1967). Sahu et al (1983) stated that yield is related to LAI and dry matter at flowering (source size) during the wet season. Murty et al (1974) found a high correlation of grain number (sink size) with yield during the dry season. A positive relationship between net carbon assimilation and leaf nitrogen content in rice was also shown by Yoshida and Cornel (1976); Sinclair and Horie (1989).

VIII. CONCLUSION

The foregoing investigation into the effects of different light regimes on the rice crop revealed that low light and even red light reduce most of the physiological parameters in comparison to normal white light. So, it can be inferred that the most favorable illumination condition for proper growth and development of rice crop is the white light with the required bright sunshine hours.

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