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Effect of elevated CO_2 and temperature on growth and yield of winter rice under Jorhat condition

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ABSTRACT

A pot experiment was conducted during *kharif*, 2018 inside CO_2 Temperature Gradient Tunnels (CTGT) to assess the effect of elevated CO_2 and temperature [T_0: ambient temperature & ambient CO_2, T_1: elevated temperature (ambient +1°C) & elevated CO_2 (ambient+25% of ambient) and T_2: elevated temperature (ambient +2°C) & elevated CO_2 (ambient + 50% of ambient)] under three different transplanting dates (D_1: 25th June, D_2: 10th July and D_3: 25th July) on growth and yield of rice in Jorhat district of Assam. The result showed that occurrence of different phenological stages was earlier under elevated CO_2-Temperature conditions resulting in reduction of crop duration by about 8-15 days. On the other hand, days to tiller initiation increased whereas days to panicle initiation, flowering and physiological maturity reduced with delay in transplanting. Yield attributing parameters were improved under elevated CO_2-Temperature condition. With respect to dates of transplanting, D_2 recorded higher number of panicles hill^{-1} (17.9) and higher filled grains panicle^{-1} (156.6). Higher grain yield (55.9g hill^{-1}) was found under T_2 which was at par with T_1 and it was significant higher over the ambient. Grain yield was significantly reduced when transplanting was delayed after 10th July. The results revealed that the growth and yield of rice was found to be better under elevated CO_2-temperature levels when transplanted on 10th July.

Keywords : CO_2-Temperature Gradient Tunnels, climate change, dates of transplanting, phenology.

With each decadal warming of the earth's surface, rise in atmospheric CO_2 and temperature to unprecedented levels has become a major global concern. Anthropogenic activities induced global warming has been estimated to increase global mean surface temperature (GMST) by approximately 1.0°C above pre-industrial levels with a likely range of 0.8°C to 1.2°C and is predicted to reach 1.5°C between 2030 and 2052 if it continues to increase at the current rate (IPCC, 2018) due to emission and accumulation of the greenhouse gases. Carbon dioxide (CO_2), though present in relatively small concentration in the atmosphere, can persist for a very long time. Atmospheric CO_2 concentration has increased from 280 µmol mol^{-1} in 1750 to 412 µmol mol^{-1} in 2019 (NOAA, 2019) and is likely to increase up to 540-970 µmol mol^{-1} by the end of the 21st century (IPCC, 2014).

Temperature and CO_2 concentration are two of the key factors affecting growth, development and yield of crops. Increases in atmospheric CO_2 concentration and associated further warming are likely to severely affect the food grain production of tropical and subtropical countries including India (Satapathy *et al.*, 2015). FAO and IPCC have estimated that cereals production in India would go down up to 125 million tonnes (mt) with an overall increase of 2.0°C in temperature. Typically, doubling the atmospheric CO_2 concentration above the present day concentration raises the productivity of most of the C_3, C_4 and CAM plants (Gebregergis, 2016) with greatest impact on C_3 plants such as rice (Ward, 2007). An increase in ambient CO_2 raises the internal leaf CO_2 concentration and the CO_2/O_2 ratio at the rubisco site, thus favoring carboxylation over oxygenation. With respect to temperature, although rice has a wide physiological adaptability, it has variable temperature preferences over different phenophases. Duration of each phenological stage of rice is influenced by temperature and has direct impact on yield (Rani and Maragatham, 2013). High temperature stimulates grain filling rate but shortens the grain filling duration. Besides, high temperature not only decreases grain weight, but also causes spikelet sterility due to reduced pollen germination, thereby reducing grain yield (Kim and You, 2010). Moreover, impact of climate change on rice production is location-specific, due to the varying temperature sensitivity of the crop in different agroclimatic regions (Cho and Oki, 2012). In general, with the increase in temperature, rice yields in eastern and western

India were less affected, moderately affected in north whereas severely affected in southern India (Aggarwal and Mall, 2002). Within eastern India, considerable differences in yield predictions among different locations were reflected from the findings of Krishnan *et al.* (2007) who found an increasing trend for rice yield in Jorhat but declining trend in Cuttack and Bhubaneshwar with an increase in temperature at the current CO_2 level.

Though, a series of experiments had been conducted under both field and controlled environments to assess the impacts of climate change on rice, using OTCs, TGTs, FACE facilities, etc. in India and abroad, information on interactive effect of elevated CO_2 and temperature in rice crop are rather limited in Assam. Keeping this in view, the present experiment was conducted to assess the impact of elevated CO_2 and temperature on growth and yield of winter rice and concurrently evaluate its response under different transplanting windows to elevated CO_2 and temperature.

MATERIALS AND METHODS

The study was carried out with the help of a pot experiment in rice in the Carbon dioxide Temperature Gradient Tunnels (CTGTs) at Assam Agricultural University, Jorhat, Assam during *Kharif*, 2018. The CTGT of the dimensions 10 m length, 2.5 m breadth and 2 m height, is a sophisticated structure constructed with a series of semi-circular bows anchored to the soil, fitted with MS pipes and covered with polycarbonate sheet or UV stabilized polythene sheet of more than 85% transparency which facilitates the controlled environment required for the experiment. Air inside the CTGT was heated naturally by incident solar radiation together with infrared heating facilities. Thermal gradient was created by sucking in ambient air from one end (inlet) and releasing it from the other end (outlet) of the tunnel with the help of exhaust fans.CO_2 monitors and temperature and humidity sensors were used to record CO_2 concentration, temperature and relative humidity (RH) inside the CTGTs periodically. The system for monitoring and controlling the CO_2 inside the CTGT was fully automatic. The CTGT was connected to a computer monitoring system running Winlog software wherein desired CO_2 concentrations were set in different tunnels at the same time. Temperature and RH data were monitored at one minute interval throughout the cropping season with the help of data loggers. CO_2 gas cylinders were used for the supply of CO_2 gas. The CO_2 supply was switched on and temperature was maintained only during the daylight hours (i.e. from 10.00 am to 01.00 pm).

The experiment was laid out in Completely Randomized Design (CRD) having two factors each with three levels with a total of 9 treatment combinations, each combination replicated four times. The details of the treatments are given below:

Factor A: CO_2-Temperature levels (T)

T_0: CTGT-1; Ambient temperature + Ambient CO_2

T_1: CTGT-2; Elevated temperature (ambient+ 1°C) + Elevated CO_2 (ambient + 25% of ambient)

T_2: CTGT-3; Elevated temperature (ambient+ 2°C) + Elevated CO_2 (ambient + 50% of ambient)

Factor B: Dates of transplanting (D)

D_1: June 25, 2018

D_2: July 10, 2018

D_3: July 25, 2018

The bulk soil was collected from the rice growing plot of Instructional Cum Research (ICR) Farm of AAU, Jorhat. The soil was alluvial, sandy loam in texture (sand, silt and clay content was 61.9%, 26.1% and 12% respectively) with a pH and organic carbon content of 5.1 and 0.82% respectively. Fertilizers at recommended dose (N: P_2O_5: K_2O @ 60:20:40 kg ha^{-1}) were thoroughly mixed with the soil and each pot was filled with 5 kg of soil. Nitrogen was applied through Urea in three splits, half as basal and remaining half top dressed in two equal splits at tillering (37 DAT) and panicle initiation (61DAT) stages respectively. Basal doses of P_2O_5 and K_2O were applied in the form of SSP and MOP respectively. Seeds of rice variety 'Ranjit' were sown in seedling trays in three different dates (May 26, June 10 and June 25) so that the age of the seedlings became 30 days at the time of transplanting in each date of transplanting (D_1, D_2 and D_3). Each batch of transplanted pots (2 seedlings per pot) was shifted to the respective CTGTs after 10 days of transplanting. On an average, 5±2cm of irrigation water was maintained in all the pots from transplanting to flowering and thereafter alternate wetting and drying procedure was followed till the crop reached physiological maturity stage.

Data on plant height and number of tillers were noted down at 5 days interval during the entire crop season whereas yield attributing parameters (number of panicles, total number of grains $panicle^{-1}$, number of filled and unfilled grains $panicle^{-1}$, 1000-grain weight) and yield of grain and straw were recorded after harvest. Besides, timely observations of the dates of occurrence of tillers, panicle

Table 1: Occurrence of phenological stages (DAT) in rice crop as affected by elevated CO_2-Temperature and dates of transplanting during khar*if*, 2018

Phenological stages	T_0			T_1			T_2		
	D_1	D_2	D_3	D_1	D_2	D_3	D_1	D_2	D_3
Tiller initiation	13	17	18	12	16	17	11	15	16
Panicle initiation	71(58)	68(51)	65(47)	65(53)	63(47)	61(44)	61(50)	59(44)	57(41)
Flowering	101(30)	96(28)	93(28)	94(29)	90(27)	87(26)	88(27)	85(26)	82(25)
Soft dough	110(9)	105(9)	102(9)	102(8)	98(8)	94(7)	95(7)	92(7)	89(7)
Physiological maturity	130(20)	124(19)	120(18)	122(20)	117(19)	112(18)	114(19)	109(17)	105(16)

Figures in parenthesis indicate duration between two successive stages

initiation, flowering, dough and physiological maturity were recorded from each replication of each treatment in all the three CTGTs. The data were analyzed using SPSS software and significance of treatment means was tested by F-test.

RESULTS AND DISCUSSION

Effect on phenology of rice

As the CO_2 concentration increased from 400 ppm to 600 ppm and temperature increased by 1°C and 2°C above the ambient levels, number of days to tiller initiation and panicle initiation reduced significantly which led to a shorter vegetative phase across the three dates of transplanting. Duration of vegetative phase in D_1 was observed to decrease by 6 and 10 days in T_1 and T_2 compared to T_0 (Table 1). Similarly, it decreased by 5 and 9 days in D_2 and 4 and 8 days in D_3 under T_1 and T_2 treatments respectively over ambient condition. Unlike the vegetative phase, very little variation was observed in the duration of the reproductive phase and ripening phase due to simultaneous CO_2-Temperature elevation across the three dates of transplanting. The lowest number of days to physiological maturity (PM) (109) was recorded under T_2 while maximum number of days (125) was recorded under ambient condition (Table 2). Increasing CO_2 concentration by 25% and temperature by 1°C than the ambient (T_1) brought the rice crop to PM stage in about 117 days. On an average, total crop duration was reduced by 8 days and 15 days in T_1 and T_2 respectively compared to T_0 (Table 1) irrespective of dates of transplanting which may be due to the fact that high levels of CO_2 and increase in temperature accelerates the growth processes of the crop. Similar results were reported by Satapathy *et al.* (2014) who found that the total crop duration of rice to be shortened by 3-5 days under elevated CO_2-Temperature condition in sub-tropical region of Kharagpur, India. Liu *et al.* (2017) and Baker and Allen (1993) also reported similar findings. With respect to dates of transplanting, number of days required to attain PM significantly reduced by 5 days and 10 days in 10th July (D_2) and 25th July (D_3) respectively compared to 25th June (D_1) transplanted crop. It is to be noted that mean temperature was found to be higher initially in D_1 but gradually similar mean temperature regime was observed during the vegetative stage across all the three dates of transplanting (~28.1-30°C). Whereas during reproductive and ripening phases, the mean temperature was relatively higher for D_1 (27.2-29.8°C and 23.5-27.3°C) compared to D_2 (26-28.6°C and 22.1-25.7°C) and D_3 (23.9-27.4°C and 20.5-24.8°C) transplanted crop, ultimately resulting in accumulation of required thermal units in a comparatively shorter period in D_1. Results also showed that days to tiller initiation was increased but days to panicle initiation, flowering and physiological maturity were reduced with delay in transplanting time. These results were in accordance with the findings of Geethalakshmi *et al.* (2017) under Tamilnadu condition.

Effect on growth parameters

Plant height : Elevated CO_2 and temperature levels brought about significant difference in the height of rice plants across different dates of transplanting. Taller plants were observed under T_2 followed by T_1 and T_0 at 30, 60 and 90 DAT (Table 3). Maximum plant height was observed at 90 DAT under elevated CO_2-Temperature levels, after which no increase was observed. The plant height at harvest was 8.2% and 4.6% more in T_2 and T_1 respectively compared to that observed under ambient condition (T_0) and the variations were statistically significant at 5% level. This might be due to effect of elevated CO_2-temperature levels which favoured cell elongation resulting in taller plants. Similar results on increase in plant height under elevated CO_2-Temperature environment were reported by Kaur *et al.* (2019) and Dwivedi *et al.* (2015). With respect to dates of transplanting, taller plants were seen in D_2 (142 cm) followed by D_1 (138 cm) and D_3 (131 cm) irrespective of CO_2-temperature

Table 2: Number of days taken to attain different phenological stages of rice as affected by elevated CO_2-Temperature and dates of transplanting during *kharif*, 2018

Treatments	Days to tiller initiation	Days to panicle initiation	Days to flowering	Days to physiological maturity
(A) CO_2-Temperature treatment				
T_0	16.0	68.0	96.7	124.7
T_1	15.0	63.0	90.3	117.0
T_2	14.0	59.0	85.0	109.3
SEd	0.46	0.67	0.59	0.69
CD (0.05)	0.95	1.38	1.21	1.43
(B) Date of Transplanting (DOT)				
D_1	12.0	65.7	94.3	122.0
D_2	16.0	63.3	90.3	116.7
D_3	17.0	61.0	87.3	112.3
SEd	0.46	0.67	0.59	0.69
CD (0.05)	0.95	1.38	1.21	1.43
Interaction (A×B)	NS	NS	NS	NS

treatments due to better environmental conditions experienced by 10th July transplanted crop during vegetative phase resulting in good growth and produced taller plants with higher number of tillers.

Tiller number : Number of tillers hill^{-1} gradually increased with the advancement of crop growth and reached maximum at about 60 DAT after which it declined due to tiller degeneration during reproductive stage, irrespective of CO_2-Temperature treatment and dates of transplanting. Elevated CO_2 and temperature significantly produced more number of tillers hill^{-1}. Highest tiller number was recorded under T_2 (17.8) followed by T_1 (16.8) over ambient (15.1) at all the dates of observation (Table 3). This increment was mainly attributed to the production of additional carbohydrates due to enhanced photosynthesis which resulted in higher accumulation of biomass under elevated CO_2 condition. Similar results on increase in tiller number under elevated CO_2-Temperature conditions were reported by Jitla *et al.* (1997) and Kim *et al.* (2003). No significant difference was found between dates of transplanting in terms of tiller number hill^{-1} at 30 and 60 DAT (Table 3). However, at 90 DAT, D_2 significantly recorded the highest number of tillers (17.9) followed by D_1 (16.8) and D_3 (15.0). Tiller number was increased by up to 42% at 30 DAT, 16% at 60 DAT and 18% at 90 DAT when CO_2 concentration was elevated up to 600 ppm and temperature increased by 2°C above the ambient level. Geethalakshmi *et al.* (2017) also reported that earlier transplanted crop (1st July) produced more tillers m^{-2} (1126) compared to those transplanted on 15th July under Tamilnadu condition of India.

Effect on yield and yield attributing parameters

Number of panicles hill^{-1} : Number of panicles hill^{-1} was the highest in T_2 (17.8) which differed significantly from T_0 (15.1) and at par with T_1 (16.8).Among the dates of transplanting, significantly higher number of panicles hill^{-1} was recorded in D_2 (17.9) followed by D_1 (16.8) and D_3 (15.0). Number of panicles hill^{-1} affected by CO_2-Temperature treatment and dates of transplanting is depicted in Table 4.

Length of panicle : Elevated CO_2 and temperature brought about statistically significant difference in the length of the panicle irrespective of dates of transplanting. Length of panicle was the highest in T_2 (24.9 cm) and was found to be significantly higher over T_0 (23.7 cm). Length of panicle under T_1 (24.1 cm) was statistically at par with T_0 (Table 3). Similarly, a significant difference in length of panicle was observed in different dates of transplanting. Longest panicle (25.2 cm) was produced in 2nd transplanted crop (D_2) whereas D_3 recorded the shortest (22.6 cm) panicle (Table 4).

Filled grains panicle^{-1} : Table 4 indicated that number of filled grains panicle^{-1} in T_1 was 156.8, which was at par with T_2 (153.3) and significantly more compared to T_0 (135.8). On the other hand, highest number of filled grains panicle^{-1} was produced under D_2 (156.6) followed by D_1 (150.6) and D_3 (138.7) with respect to dates of transplanting.

Table 3: Plant height and tiller number in rice crop as affected by elevated CO_2-Temperature and dates of transplanting during *kharif*, 2018

Treatment	Plant height (cm)			Tiller number ($hill^{-1}$)		
	30 DAT	60 DAT	90 DAT	30 DAT	60 DAT	90 DAT
(A)CO_2-Temperature treatment						
T0	53.3	91.2	131.4	11.8	20.7	15.1
T1	60.4	108.8	137.4	13.8	22.7	16.8
T2	67.8	118.6	142.2	16.8	24.0	17.8
SEd	1.82	3.57	0.53	1.21	1.60	0.81
CD (0.05)	3.76	7.36	1.09	2.49	NS	1.67
(B)Date of Transplanting						
D1	60.5	106.0	138.0	14.5	22.3	16.8
D2	61.9	110.3	142.0	15.1	24.0	17.9
D3	59.1	102.4	131.0	12.7	21.0	15.0
SEd	1.82	3.57	0.53	1.21	1.60	0.81
CD (0.05)	NS	NS	1.09	NS	NS	1.67
Interaction (A×B)	**NS**	**NS**	**1.89**	**NS**	**NS**	**NS**

***Unfilled grains panicle^{-1}* :** Elevated CO_2-Temperature levels recorded significantly higher number of unfilled grains panicle^{-1} over the ambient condition. Number of unfilled grains panicle^{-1} was the lowest (58.3) under T_0 and highest (102.1) under T_2 (Table 4). No significant effect of dates of transplanting was observed on unfilled grain number panicle^{-1}. An average maximum temperature of 28.1 to 29.3°C in T_1 and 29.7 to 30.6°C in T_2 in contrast to the corresponding ambient temperature of 25.7 to 28.1°C was observed during the grain filling period which might be the main cause behind poor grain filling rate under elevated CO_2-Temperature condition. Similar to our findings, Satapathy *et al.* (2015) reported that average day time temperature of 28.1 to 30.4°C during the grain filling period, against the ambient temperature of 27.3 to 29.6°C decreased the grain filling rate in rice under West Bengal situation.

***1000-grain weight* :** The 1000-grain weight was significantly higher under T_2 (20.5g) compared to T_0 (19.2 g) and was at par with T_1 (Table 4). Similarly, averaging over all the CO_2-temperature levels, 1000-grain weight was highest (20.3 g) in D_1 which was at par with D_2 (20.1 g) but was found to differ significantly from D_3 (19.4 g). Similar to the present study, Rosalin *et al.* (2018) and Dwivedi *et al.* (2015) reported about 11% and 3% increase in 1000 grain weight when rice plants were exposed to 25% higher CO_2 and 2°C higher temperature than ambient.

***Grain yield hill^{-1}* :** A perusal of the data presented in Table 4 indicated a significant difference in grain yield hill^{-1} due to different CO_2-Temperature levels and dates of transplanting. On an average, T_2 produced the highest grain yield (55.9 g hill^{-1}) due to more number of panicles hill^{-1} followed by T_1 (53.1 g hill^{-1}) and T_0 (39.2 g hill^{-1}). The per cent increment of grain yield over ambient condition (T_0) was 42.6% and 35.5% in T_2 and T_1 respectively due to more tillering, grain-bearing panicles, filled grains panicle^{-1} and individual grain weight. These results are in accordance with the findings of Krishnan *et al.* (2007), Satapathy *et al.* (2015) and Madan *et al.* (2012). Among the dates of transplanting, the lowest grain yield (40.6 g hill^{-1}) was recorded in 3rd transplanted crop (D_3) and the highest (56.2 g hill^{-1}) being recorded in 2nd transplanted crop (D_2). The per cent increase in grain yield in D_2 and D_1 over D_3 were 38.4% and 26.6% respectively. Rice plants under D_2 were exposed to a relatively higher temperature regime during the vegetative stage followed by D_1 and D_3. The favourable thermal regime combined with CO_2 fertilization effect were congenial for good growth and resulted in better accumulation of biomass and increased tiller number, which consequently increased grain and straw yield of rice in 10th July (D_2) transplanted crop. Assessing the impacts of climate change on rice under different dates of transplanting, Geethalakshmi *et al.* (2017) reported marked increase in grain yield of rice planted on 10th July than the 15th July planted crop and referred this increasing yield to the prevalence of favourable weather conditions during different phenophases of crop growth.

Table 4: Yield and yield attributing parameters in rice crop as affected by elevated CO_2-Temperature and dates of transplanting during *kharif*, 2018

Treatment	Number of panicles hill^{-1}	Panicle length (cm)	Filled grains panicle^{-1}	Unfilled grains panicle^{-1}	1000 grain weight(g)	Grain yield hill^{-1} (g)	Straw yield hill^{-1} (g)	Biological yield hill^{-1} (g)	Harvest Index
(A) CO_2-Temperature treatment									
T_0	15.1	23.7	135.8	58.3	19.2	39.2	94.2	133.4	0.29
T_1	16.8	24.1	156.8	87.2	20.2	53.1	101.1	154.1	0.34
T_2	17.8	24.9	153.3	102.1	20.5	55.9	102.9	158.8	0.35
SEd	0.81	0.24	2.75	4.57	0.24	1.83	3.35	3.18	0.013
CD (0.05)	1.67	0.50	5.67	9.43	0.50	3.77	6.92	6.56	0.027
(B) Date of Transplanting									
D_1	16.8	24.9	150.6	86.6	20.3	51.4	104.2	155.6	0.33
D_2	17.9	25.2	156.6	83.4	20.1	56.2	106.7	162.9	0.34
D_3	15.0	22.6	138.7	77.5	19.4	40.6	87.2	127.8	0.32
SEd	0.81	0.24	2.75	4.57	0.24	1.83	3.35	3.18	0.013
CD (0.05)	1.67	0.50	5.67	NS	0.50	3.77	6.92	6.56	NS
Interaction (A×B)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

***Straw yield hill^{-1}* :** Elevated CO_2 and temperature brought about significant increase in straw yield in rice. Straw yield was significantly higher in T_2 (102.9 g hill^{-1}) over T_0 (94.2 g hill^{-1}) and at par with T_1 (101.1 g hill^{-1}) (Table 4). The increase in straw yield hill^{-1} over the ambient (T_0) was 9.2% and 7.3% in T_2 and T_1 respectively. With respect to dates of transplanting, straw yield was significantly higher in D_2 (106.7 g hill^{-1}) and D_1 (104.2 g hill^{-1}) compared to D_3 (87.2 g hill^{-1}).

***Biological yield* :** Data pertaining to the biological yield (Table 4) indicated that it was highest (158.8 g hill^{-1}) in T_2 which was statistically at par with T_1 (154.1 g hill^{-1}) and lowest (133.4 g hill^{-1}) under ambient condition. A significant variation among dates of transplanting was observed in terms of biological yield, irrespective of CO_2-Temperature treatment. It was highest in D_2 (162.9 g hill^{-1}) followed by D_1 (155.6 g hill^{-1}) and D_3 (127.8 g hill^{-1}).

***Harvest Index (HI)* :** A significant difference in HI was observed due to the different CO_2-Temperature levels. T_2 recorded the highest HI (0.35) and it was statistically at par with T_1 (0.34), while T_0showed the lowest HI (Table 4.10). The per cent increase in HI in T_2 and T_1 over T_0 was about 20.7% and 17.2% respectively. No significant difference in HI was observed with respect to dates of transplanting (Table 4).

CONCLUSION

The study revealed that occurrence of different phenological stages in rice, duration of vegetative, reproductive and ripening phases as well as plant morphological, yield attributes and yield were markedly influenced by varying levels of CO_2-Temperature enrichment and dates of transplanting. Total duration of the rice crop was reduced with elevation in CO_2-Temperature levels which was mostly due to distinct reduction in the duration of vegetative phase over the ambient. Similarly, delay in transplanting dates of rice from 25th June led to reduction of vegetative phase by 2.4-4.7 days irrespective of CO_2-Temperature levels, consequently advancing the subsequent dates of occurrence of different phenological stages. Rice plants performed better under elevated CO_2-temperature conditions, however, number of filled grains panicle^{-1} was slightly reduced under T_2 due to exposure of the reproductive and maturity phase to a comparatively higher temperature regime resulting in spikelet sterility. Hence, elevation of CO_2 concentration up to 600 ppm and temperature up to 2°C will have no negative influence on growth and yield of rice crop under the agroclimatic condition of Jorhat.

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