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Mitigation of Abiotic and Biotic Stress Using Plant Growth Regulators in Rice

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Abstract: Split plot design experiments were conducted to assess the performance of growth regulating compounds for mitigating moisture stress and the incidence of Brown Plant Hopper (BPH) in rice. The main plot treatments (4) comprised moisture stress free control (M_1), moisture stress during panicle initiation stage alone (M_2), moisture stress during flowering stage alone (M_3), and moisture stress during both panicle initiation and flowering stages (M_4). The sub-plot treatments (5) were foliar application of growth regulating compounds including chlormequat chloride at 200 ppm (S_1), mepiquat chloride at 200 ppm (S_2), brassinolide at 0.1 ppm (S_3), pink pigmented facultative methylotrophs (PPFM) at 1% (S_4), and no spray control (S_5). The reduced plant growth attributes were registered under moisture stress at both panicle initiation and flowering stages. The spraying of 1% PPFM during the flowering or both at panicle initiation and flowering stages led to better performance than the other treatments. Also, spraying 1% PPFM brought down the population of BPH to a considerable level during both years of experiments. This suggests that spraying 1% PPFM in the post-flowering stage helps to mitigate the ill effect the moisture stress and BPH incidence.

Keywords: moisture stress; brown plant hopper; brassinolide and pink pigmented facultative methylotrophs (PPFM)

1. Introduction

Rice (*Oryza sativa* L.) is a wonder grain that can be grown in wide ecological zones and has an extensive range of production. Rice is the only crop that can grow in heavy rainfall areas and deltaic river belts around the world. Rice production must urgently be improved due to stagnant yield levels and rising food demand in India. Rice is the main diet for millions of people and is one of Asia's most water-intensive cereal crops, consuming

more than 80% of the continent's irrigated freshwater resources. Due to increased water stress, rice yield in Asia, where growing circumstances were previously more favorable, has declined [1].

Water stress is a critical limiting factor for rice production and yield stability in poorly watered locations [2,3]. The plant's ability to respond and live in the face of a water shortage is dependent on whole-plant processes that can combine cellular responses. In India, water scarcity (also known as drought) affects 23 million hectares of rice on a regular basis, resulting from insufficient soil moisture to maintain average crop yields [4]. Plant responses are influenced by the duration and severity of water stress [5,6], as well as the stage of development of the plant [7]. Drought stress is highly damaging to rice during the flowering stage, resulting in significant output reductions [8]. Spikelet fertility is significantly impacted by physiological mechanisms during the sensitive flowering stage when water stress is present. According to the United Nations, the greatest threat to humanity in the twenty-first century is a water shortage [9]. Due to the vagaries of monsoon, water stress at any given development stage, resulting in considerable yield reduction, is inescapable in these situations. In this perspective, it is vital to understand the many strategies for reducing water consumption in rice production without sacrificing yield. It is necessary to determine appropriate stress management measures in order to offset increasing water scarcity.

Plant growth regulators (PGRs) played a key role in integrating plant stress responses [10]. Plant growth regulators are chemical compounds that, when used at low concentrations, alter plant growth by activating or inhibiting a portion of the plant's natural growth regulation system [11]. There are about sixty plant growth regulators on the market presently, and several of them have become very important in agricultural production. Growth promoters and retardants are both growth regulators that alter the canopy structure and their expression in the form of yield. PGRs have been found to efficiently regulate water absorption during stressful situations by increasing membrane permeability or increasing the internal concentration of osmotically active solutes [10,12]. By sealing the loop, growth regulators could enhance water use efficiency by closing the stomata. They also boosted the above-ground biomass of the roots and may have an impact on the buildup of antioxidants that protect plants from stress [13]. One of the biotic stresses influencing rice yield is insect infestations. The brown plant hopper, *Nilaparvata lugens* (Hemiptera: Delphacidae) is a phloem sap sucking insect pest and is one of the notorious insect pests in major rice growing region. The physiological changes induced by the growth regulating compounds may also affect the plant insect interactions. The apple trees sprayed with growth regulator, i.e., prohexadoine calcium were also less colonized by sucking insects including aphids, psyllids, and leaf hoppers [14]. This may be due to changes in the physiology in the plant systems, i.e., the production of flavonoids.

Hence, the present study tested two hypotheses: (1) effect of moisture stress on the growth, development of rice and the incidence of BPH on the stressed rice plants, and (2) whether the foliar application of plant growth regulators can provide protection to the rice plants against the moisture stress and brown plant hopper.

2. Materials and Methods

2.1. Experimental Design and Weather Conditions

Field experiments were conducted during the rabi season of 2017–18 and 2018–19. The experimental fields are situated in the Northwestern agro-climatic zone of Tamil Nadu, at 11° N latitude and 77° E longitude at an altitude of 426.7 m above MSL. Split-plot designs with three replications were used in the field trials. The treatments consisted of induced moisture stress in the main plots and spraying growth regulating compounds in the sub-plots. In all the two seasons, the gross plot size of 5.0 × 4.0 m and the net plot size of 4.25 × 3.0 m were uniformly maintained. Each plot consisted of 420 rice plants. The medium duration rice variety CO (R) 50 was used as a test variety during *rabi* 2017–18 and 2018–19.

The annual mean maximum and minimum temperatures were 31.5 °C and 21 °C, respectively. The mean relative humidity (RH) ranged from 49.1% to 84.9%. Mean bright sunshine hours was 7.3 h day^{-1}.

The weather parameters were recorded for the standard weeks of both the years. In *rabi* 2017–18, there was a total rainfall of 144.9 mm received in 10 rainy days, whereas in *rabi* 2018–19, a total rainfall of 497.3 mm was received in 26 rainy days. The average maximum and minimum temperatures were 31.4, 21.5 °C, and 30.8, 22.7 °C, respectively, for *rabi* 2017–18 and *rabi* 2018–19. With regard to the relative humidity, the mean RH of 86.2% was recorded at 07.22 h and 52.8% was recorded at 14.22 h in *rabi* 2017–18. In *rabi* 2018–19, an average of 87.2 percent was recorded at 0722 h and 51.2% was recorded at 1422 h. The evaporation and bright sunshine hours day^{-1} ranged from 3.4 to 7.4 mm and 3.3 to 9.9 h, respectively, for *rabi* 2017–18, whereas in *rabi* 2018–19, evaporation ranged from 3.8 to 7.5 mm and sunshine hours day^{-1} ranged from 2.3 to 9.5 h.

2.2. Soil Characteristics

The soil of the experimental site was clay loam in texture. The composite soil samples collected from the layers of 20–40 cm from each field prior to conducting the experiment were analyzed for various physico-chemical characteristics during two seasons. The initial analyses of the experimental sites revealed that the soil was alkaline in pH (8.12–8.26), medium in organic carbon content (0.62–0.68%), low in available nitrogen (210.6 kg ha^{-1} to 224.2 kg ha^{-1}), medium in available phosphorus (15.8 kg ha^{-1} to 18.8 kg ha^{-1}), and high in available potassium (ranged from 416.1 to 428.5 kg ha^{-1}) (Table 1).

Table 1. Soil characteristics of experimental field.

Particulars	2017–18 *Rabi*	2018–19 *Rabi*
A. Mechanical analyses		
Clay (%)	45.8	46.2
Silt (%)	11.7	12.1
Sand (%)	42.4	41.4
Textural class	Clay loam	Clay loam
Bulk density (Mg m^{-3})	1.34	1.34
B. Chemical analyses		
Available nitrogen (kg ha^{-1})	215.7	224.2
Available phosphorus (kg ha^{-1})	15.8	18.8
Available potassium (kg ha^{-1})	420.8	416.1
pH (1:2 of soil:water)	8.10	8.26
Electrical conductivity (dS m^{-1})	0.60	0.64
Organic carbon (%)	0.62	0.63

2.3. Sowing and Transplanting

The paddy seeds were obtained from the Department of Rice, Tamil Nadu Agricultural University. The seeds were soaked in water for 24 h and incubated overnight. The sprouted seeds with a seed rate of 40 kg ha^{-1} sown in the wet nursery area at 20 cents ha^{-1}. The seedlings for rabi crops were transplanted 25 days after sowing and 21 days after sowing for summer crops. The seedlings were pulled out and transplanted with two seedlings hill $^{-1}$ at the spacing of 20 cm × 15 cm.

2.4. Fertilizer Application

Nitrogen, phosphorus, and potassium were applied at 150:50:50 kg ha^{-1} as urea, single super phosphate, and muriate of potash, respectively. Twenty-five% of nitrogen, a full dose of phosphorus, and 25% of potassium were applied as a basal at the time of planting. The balance of 75% of nitrogen and potassium was top dressed thrice at active tillering, panicle initiation, and heading stages.

2.5. Irrigation

The conventional method of irrigation practice was followed up to panicle initiation stage. The irrigation water was measured using a water meter installed in the field. After inducing stress, the irrigation schedules were adopted as per the treatment requirements.

2.6. Harvesting and Threshing

The border rows all around the plots were harvested first and then the net plots of each treatment were harvested and threshed separately, cleaned, and the grain weights were recorded in a treatment-wise manner. Grain yields were adjusted to 14% moisture and expressed in kg ha^{-1}. The straw yields were recorded based on the dry weight of the straw sun dried for three days and expressed in kg ha $^{-1}$.

2.7. Treatment Details

2.7.1. Main Plot (Moisture Stress (Induced))

M_1: moisture stress free control; M_2: moisture stress at panicle initiation stage; M_3: moisture stress at flowering stage; M_4: moisture stress at both panicle initiation and flowering stages (Note: stresses were enforced during panicle initiation, flowering stages, and both the stages by withholding irrigation for 10 days).

2.7.2. Sub Plot (Growth Regulating Compounds)

S_1: chlormequat chloride @ 200 ppm; S_2: mepiquat chloride @ 200 ppm; S_3: brassinolide @ 0.1 ppm; S_4: pink pigmented facultative methylotrophs (PPFM) @ 1%; S_5: no spray (control).

2.8. Stress Imposition

The conventional method of irrigation practice (irrigating the field with 5 cm depth of irrigation one day after disappearance of previously ponded water) was followed. In order to maintain a 5 cm level, a wooden peg was fixed in each plot to show the depth of standing water.

The amount of water used in each irrigation was measured by regulation through a 'water meter' fixed at the head of the experimental field. The time required for the flow of the calculated volume of water was worked out and the water was allowed to each plot only for a specified time to get a desired depth (5 cm) of irrigation.

Moisture stress was imposed in two phases including the first during panicle initiation (45 to 55 days after transplanting (DAT) for CO (R) 50 during *rabi* season, and the second during flowering stage (65 to 75 DAT for *rabi*) by withholding irrigation in the specified stages in both the seasons. The stress was imposed one day after the disappearance of ponded water of 5 cm depth during panicle initiation and flowering stages.

After the termination of the stress period, the stressed plots were irrigated to the required depth. In both non-stressed and stressed plots, irrigation was suspended ten days before the expected time of harvest.

2.9. Stages of Spray

The growth regulating compounds were dissolved in water as per their concentration requirements and sprayed at 500 litres ha^{-1} in both the panicle initiation and flowering stages one day after the imposition of the stress in the respective stages in both the seasons.

2.10. Biometric Observations

The biometric observations were taken in compliance with the standards of the All India Co-ordinated Rice Improvement Project [15]. The five plants were selected at random and labelled for recording observations in each replication.

2.11. Growth Attributes

Growth attributes including plant height, number of tillers per hill, dry matter production, specific leaf weight, leaf area index, and crop growth rate were recorded at

active tillering, panicle initiation, flowering, and harvest stages during rabi 2017–18 and rabi 2018–19.

2.11.1. Plant Height

The plant height was measured from ground level to the tip of the longest leaf extended in active tillering, panicle initiation, flowering, and harvest stages of rice and expressed in cm. The plant height was measured from five plants from each plot.

2.11.2. Number of Tillers Hill^{-1}

At active tillering, panicle initiation, flowering, and harvest stages, the tillers of labelled plants in each plot were counted and expressed as tillers hill^{-1}.

2.11.3. Dry Matter Production

The five plants were removed randomly from each main and sub plots at active tillering, panicle initiation, flowering, and harvest stages. These samples were first air dried in shade and then oven dried at 70 ± 5 °C for 48 h to constant weight and dry weights were recorded and reported in kg ha^{-1}.

2.11.4. Specific Leaf Weight

The formula of Garnier et al. [16] was used to compute the specific leaf weight (SLW), which was represented in mg cm^{-2}.

$$\text{SLW} = \frac{\text{Leaf dry weight}}{\text{Leaf area}}$$

2.11.5. Leaf Area Index

The leaf area was calculated using Palanisamy and Gomez's method [17], which used 0.75 as a rabi adjustment factor. The leaf area index was calculated by dividing the total leaf area by the ground area.

$$\text{LAI} = \frac{\text{L} \times \text{W} \times \text{K} \times \text{Number of leaves per plant}}{\text{Land area occupied by plant}}$$

where,

L—Length of leaf (cm),
W—Width of leaf (cm),
K—Correction factor (0.75 for wet season).

2.11.6. Crop Growth Rate

The rate of increase in dry weight per unit land area per unit time is known as the crop growth rate (CGR). Watson's [18] formula was used to calculate the CGR. The CGR was expressed in g m^{-2} day^{-1}.

$$\text{CGR} = \frac{\text{W}_2 \times \text{W}_1}{P\,(t_2 - t_1)}$$

where,

W_1 and W_2 are whole plant dry weight (g) at time t_1 and t_2, respectively,
t_1 and t_2 are the initial and final day of period of observation, respectively,
P is the plant spacing (20 × 15 cm) adopted (m^2).

2.12. Incidence of Brown Plant Hopper

The experiment was conducted to find out the effect of PGR on the incidence of BPH. The motile stages of BPH were randomly counted on five selected hills and expressed as number of BPH per hill.

2.13. Statistical Analysis

According to Gomez and Gomez's procedures [19], the data on numerous characters evaluated during the study was analyzed in a two-way analysis of variance (ANOVA). The Least Significant Difference (LSD) was used to calculate the critical difference between the pair-wise comparison means. This method provides for a single LSD value (Critical Difference (CD)), at a prescribed level of significance, which was used as the boundary between significant and nonsignificant differences between any pair of treatment means. The two treatments are declared significantly different at the prescribed level of significance if their difference exceeds the computed CD value at the 0.05 level of probability, otherwise, they are not significantly different.

3. Results

3.1. Plant Height

Plant height is a measure of crop development as influenced by the environment and management. At the active tillering and panicle initiation stages of rice growth, moisture stress and growth regulators had no effect on plant height (Table 2).

However, the plant height of rice was significantly influenced by moisture stress and growth regulating compounds at the flowering and harvest stages. Regarding moisture stress treatments, stress free control (M_1) recorded taller plant height (109.6 cm) at the flowering and (112.3 cm) at harvest stage compared to rest of the treatments. However, moisture stress at the flowering stage (M_3) was on par with moisture stress free control (M_1). Plant height was stunted when stress was induced at both panicle initiation and flowering stages (M_4). Similar results were also noted during *rabi* 2018–19.

In terms of growth-regulating compounds applied to the leaves, spraying one percent PPFM (S_4) was better for all other treatments in a considerable way. PPFM at 1% (S_4) registered increased plant height of 113.2 cm and 113.4 cm at harvest stage in *rabi* 2017–18 and *rabi* 2018–19, respectively. At the harvest stage, the plants were shorter in control plots (S_5) recorded the plant height of 100.9 cm and 103.7 cm during *rabi* 2017–18 and *rabi* 2018–19, respectively.

At all stages of rice growth during *rabi* in both years, there was no significant interaction between moisture stress and growth regulating compounds on plant height.

Table 2. Effect of moisture stress and growth regulating compounds on plant height (cm) at different growth stages of *rabi* rice.

Treatment	*Rabi* 2017–18				*Rabi* 2018–19			
	Active Tillering	Panicle Initiation	Flowering	Harvest	Active Tillering	Panicle Initiationn	Flowering	Harvest
M_1	58.3	80.2	109.6	112.3	58.5	80.7	111.8	114.7
M_2	58.3	80.2	101.7	105.4	58.6	80.7	104.1	108.7
M_3	58.3	80.3	107.1	108.1	58.7	80.8	108.6	109.0
M_4	58.4	80.2	99.8	102.5	58.6	80.7	101.2	100.1
SEd	0.7	1.7	1.5	0.8	1.3	2.2	1.9	2.4
CD at 5%	NS	NS	3.8	1.9	NS	NS	4.7	5.9
S_1	58.5	80.0	102.5	105.5	58.6	80.9	104.2	105.8
S_2	58.2	80.2	103.7	106.5	58.5	80.7	105.4	107.7
S_3	58.3	80.3	106.8	109.4	58.3	80.6	108.1	110.1
S_4	58.2	80.1	109.9	113.2	58.8	80.7	112.1	113.4
S_5	58.4	80.5	100.3	100.9	58.6	80.8	102.4	103.7

Table 2. *Cont.*

Treatment		*Rabi* 2017–18				*Rabi* 2018–19			
		Active Tillering	Panicle Initiation	Flowering	Harvest	Active Tillering	Panicle Initiationn	Flowering	Harvest
SEd		1.1	2.0	3.0	0.7	1.9	2.2	1.9	1.6
CD at 5%		NS	NS	6.2	1.5	NS	NS	4.0	3.2
M at S	Sed	2.1	3.9	5.6	1.5	3.7	4.6	4.0	3.7
	CD at 5%	NS	NS	NS	NS	NS	NS	NS	NS
S at M	Sed	2.2	3.9	6.1	1.4	3.8	4.4	3.9	3.2
	CD at 5%	NS	NS	NS	NS	NS	NS	NS	NS

Main plot	:	Moisture stress (Induced)	Sub plot	:	Growth regulating compounds
M_1	:	Moisture stress free control	S_1	:	Chlormequat chloride (200 ppm)
M_2	:	Moisture stress at PI stage	S_2	:	Mepiquat chloride (200 ppm)
M_3	:	Moisture stress at flowering stage	S_3	:	Brassinolide (0.1 ppm)
M_4	:	Moisture stress at both PI and flowering stage	S4	:	PPFM (1%)
			S_5	:	Control

3.2. Total Number of Tillers Hill^{-1}

The total number of tillers hill^{-1} at active tillering, panicle initiation, flowering, and harvesting stages of rabi 2017–18, rabi 2018–19. (Table 3).

An increasing trend was observed from the flowering to harvest stages regarding number of tillers hill^{-1} at all the growing seasons of rice (Tables 4 and 5). At the flowering stage, maximum number of tillers hill^{-1} were noticed with moisture stress free control (M_1) with 13.6, 13.8 tillers hill^{-1}, as was observed during *rabi* 2017–18 and *rabi* 2018–19, respectively, which was comparable with moisture stress at panicle initiation stage (M_2) and moisture stress at flowering stage (M_3), whereas stress at both panicle initiation and flowering stages (M_4) produced lower number of tillers hill^{-1}.

Table 3. Effect of moisture stress and growth regulating compounds on tillers (number hill^{-1}) at active tillering and panicle initiation stages of rice.

Treatment		*Rabi* 2017–18		*Rabi* 2018–19	
		Active Tillering	Panicle Initiation	Active Tillering	Panicle Initiation
M_1		7.7	11.5	7.9	11.7
M_2		7.7	11.5	7.9	11.9
M_3		7.7	11.5	7.9	11.8
M_4		7.7	11.5	7.9	11.8
Sed		0.2	0.3	0.2	0.2
CD at 5%		NS	NS	NS	NS
S_1		7.8	11.4	7.9	11.6
S_2		7.6	11.7	7.9	11.8
S_3		7.7	11.6	7.9	11.9
S_4		7.7	11.7	7.9	11.7
S_5		7.7	11.5	7.8	11.9
Sed		0.2	0.4	0.2	0.2
CD at 5%		NS	NS	NS	NS
M at S	SEd	0.4	0.7	0.5	0.5
	CD at 5%	NS	NS	NS	NS
S at M	SEd	0.4	0.7	0.5	0.5
	CD at 5%	NS	NS	NS	NS

Main plot	:	Moisture stress (Induced)	Sub plot	:	Growth regulating compounds
M_1	:	Moisture stress free control	S_1	:	Chlormequat chloride (200 ppm)
M_2	:	Moisture stress at PI stage	S_2	:	Mepiquat chloride (200 ppm)
M_3	:	Moisture stress at flowering stage	S_3	:	Brassinolide (0.1 ppm)
M_4	:	Moisture stress at both PI and flowering stage	S4	:	PPFM (1%)
			S_5	:	Control

Table 4. Effect of moisture stress and growth regulating compounds on tillers (number hill^{-1}) at flowering stage of rice.

Treatment	*Rabi* 2017–18						*Rabi* 2018–19				
	M_1	**M_2**	**M_3**	**M4**	**Mean**		**M_1**	**M_2**	**M_3**	**M4**	**Mean**
S_1	13.2	12.4	12.9	13.5	13.0	S_1	13.1	12.8	12.4	13.5	12.9
S_2	14.8	12.8	13.0	12.8	13.4	S_2	14.7	12.9	12.8	12.8	13.3
S_3	13.6	14.4	14.8	13.6	14.0	S_3	14.4	14.5	14.8	12.5	14.0
S_4	14.4	14.8	14.6	12.6	14.1	S_4	14.6	14.7	14.4	13.6	14.3
S_5	12.1	12.8	12.1	11.8	12.2	S_5	12.1	11.9	13.5	11.8	12.3
Mean	13.6	13.4	13.5	12.9			13.8	13.3	13.6	12.8	
	M	S	M at S	S at M			M	S	M at S	S at M	
SEd	0.2	0.2	0.4	0.4			0.2	0.2	0.5	0.4	
CD at 5%	0.4	0.4	NS	NS			0.6	0.5	NS	NS	

Main plot	:	Moisture stress (Induced)	Sub plot	:	Growth regulating compounds
M_1	:	Moisture stress free control	S_1	:	Chlormequat chloride (200 ppm)
M_2	:	Moisture stress at PI stage	S_2	:	Mepiquat chloride (200 ppm)
M_3	:	Moisture stress at flowering stage	S_3	:	Brassinolide (0.1 ppm)
M_4	:	Moisture stress at both PI and flowering stage	S4	:	PPFM (1%)
			S_5	:	Control

Table 5. Effect of moisture stress and growth regulating compounds on tillers (number hill^{-1}) at harvest stage of rice.

Treatment	*Rabi* 2017–18						*Rabi* 2018–19				
	M_1	**M_2**	**M_3**	**M4**	**Mean**		**M_1**	**M_2**	**M_3**	**M4**	**Mean**
S_1	13.0	12.4	12.9	13.6	13.0	S_1	13.1	12.8	12.5	13.6	13.0
S_2	14.5	12.7	13.0	12.9	13.5	S_2	14.6	12.9	12.8	12.9	13.3
S_3	14.5	14.4	14.6	12.7	14.1	S_3	14.6	14.4	14.5	12.6	14.1
S_4	14.3	14.2	14.7	13.7	14.2	S_4	14.5	14.6	14.3	13.7	14.4
S_5	12.3	14.0	12.3	11.4	12.2	S_5	12.4	12.3	14.1	11.4	12.4
Mean	13.7	13.5	13.5	12.9			13.9	13.4	13.6	12.8	
	M	S	M at S	S at M			M	S	M at S	S at M	
SEd	0.2	0.4	0.7	0.8			0.2	0.4	0.7	0.8	
CD at 5%	0.5	0.8	NS	NS			0.5	0.8	NS	NS	

Main plot	:	Moisture stress (Induced)	Sub plot	:	Growth regulating compounds
M_1	:	Moisture stress free control	S_1	:	Chlormequat chloride (200 ppm)
M_2	:	Moisture stress at PI stage	S_2	:	Mepiquat chloride (200 ppm)
M_3	:	Moisture stress at flowering stage	S_3	:	Brassinolide (0.1 ppm)
M_4	:	Moisture stress at both PI and flowering stage	S4	:	PPFM (1%)
			S_5	:	Control

A similar trend in results was obtained at the harvesting stage during all the growing seasons. PPFM at one percent (S_4) produced a considerably greater number of tillers hill^{-1} at harvest stage in *rabi* 2017–18 and *rabi* 2018–19 recording 14.2 and 14.4; and 14.6 and 14.8 tillers hill^{-1}, respectively. However, it was comparable with application of 0.1 ppm brassinolide (S_3) in all the four seasons. This was followed by foliar spraying of 200 ppm mepiquat chloride (S_2) and chlormequat chloride (S_1). In the control (S_5) plots, however, there were less tillers recorded hill^{-1}.

In *rabi* season, the interaction was not significant during both the years of experimentation. The spraying of 1% PPFM foliar spray (S_4) detailed an increased number of tillers hill^{-1}. Moisture stress at both stages of panicle development and blossoming produced a lower number of tillers hill^{-1} in control (S_5) plots during all the growing seasons.

3.3. Dry Matter Production in Plant

The Dry Matter Production (DMP) assessed at various crop growth stages was not significantly influenced by moisture stress and growth regulating compounds at active tillering and panicle initiation stages (Table 6).

Table 6. Effect of moisture stress and growth regulating compounds on dry matter production (kg ha^{-1}) at different growth stages of rice.

		Rabi 2017–18			*Rabi* 2018–19		
Treatment		**Active Tillering**	**Panicle Initiation**	**Flowering**	**Active Tillering**	**Panicle Initiation**	**Flowering**
M_1		2635	5564	9105	2883	5913	9124
M_2		2667	5587	8390	2814	5937	8461
M_3		2651	5523	8827	2869	5944	8860
M_4		2656	5567	8212	2849	5932	8154
SEd		29	86	119	81	203	166
CD at 5%		NS	NS	NS	NS	NS	407
S_1		2678	5483	8423	2896	5938	8477
S_2		2638	5640	8571	2808	5959	8595
S_3		2678	5581	8897	2825	5905	8831
S_4		2599	5496	9179	2835	5959	9105
S_5		2668	5477	8098	2905	5898	8240
SEd		36	105	141	75	176	134
CD at 5%		NS	NS	NS	NS	NS	272
M at S	SEd	70	207	279	156	374	291
	CD at 5%	NS	NS	NS	NS	NS	NS
S at M	SEd	71	211	282	149	352	267
	CD at 5%	NS	NS	NS	NS	NS	NS

Main plot	:	Moisture stress (Induced)	Sub plot	:	Growth regulating compounds
M_1	:	Moisture stress free control	S_1	:	Chlormequat chloride (200 ppm)
M_2	:	Moisture stress at PI stage	S_2	:	Mepiquat chloride (200 ppm)
M_3	:	Moisture stress at flowering stage	S_3	:	Brassinolide (0.1 ppm)
M_4	:	Moisture stress at both PI and flowering stage	S_4	:	PPFM (1%)

Treatments for moisture stress and foliar spraying of growth regulators showed positive influence on DMP at flowering stage and attained maximum at harvest stage (Table 7).

Table 7. Effect of moisture stress and growth regulating compounds on dry matter production (kg ha^{-1}) at harvest stage of rice.

Treatment	*Rabi* 2017–18						*Rabi* 2018–19				
	M_1	**M_2**	**M_3**	**M4**	**Mean**		**M_1**	**M_2**	**M_3**	**M4**	**Mean**
S_1	13,706	12,475	11,317	10,225	11,931	S_1	14,071	12,991	11,785	10,648	12,374
S_2	13,847	12,612	11,669	9855	11,996	S_2	14,273	13,134	12,151	10,263	12,455
S_3	14,236	13,825	12,432	10,428	12,730	S_3	14,420	13,998	12,595	10,756	12,942
S_4	14,281	12,977	13,326	10,812	12,849	S_4	14,490	13,166	13,461	11,260	13,094
S_5	13,462	11,910	10,512	9270	11,289	S_5	14,018	12,403	10,947	9726	11,773
Mean	13,906	12,760	11,851	10,118			14,254	13,138	12,188	10,531	
	M	S	M at S	S at M			M	S	M at S	S at M	
SEd	192	166	353	332			180	180	368	359	
CD at 5%	469	338	762	675			439	366	785	731	

Main plot	:	Moisture stress (Induced)	Sub plot	:	Growth regulating compounds
M_1	:	Moisture stress free control	S_1	:	Chlormequat chloride (200 ppm)
M_2	:	Moisture stress at PI stage	S_2	:	Mepiquat chloride (200 ppm)
M_3	:	Moisture stress at flowering stage	S_3	:	Brassinolide (0.1 ppm)
M_4	:	Moisture stress at both PI and flowering stage	S_4	:	PPFM (1%)

The DMP was significantly increased under moisture stress free control (M_1) at harvest during all the growing seasons recording 13,906 and 14,254 kg ha^{-1} during *rabi* 2017–18 and *rabi* 2018–19. Moisture stress in different growth stage studies indicated that stress at panicle initiation stage (M_2) was better than all other therapies in a considerable way with particular attention to dry matter production. Reduced dry matter production was noticed when moisture stress at both panicle initiation and flowering stages (M_4).

Foliar spraying of growth regulating compounds revealed that spraying 1% PPFM (S_4) recorded more DMP during *rabi* 2017–18 and *rabi* 2018–19 with 12,849 and 13,094 kg ha^{-1} at harvest stage. However, it was comparable to brassinolide concentrations of 0.1 ppm (S_3). This was followed by 200 ppm of mepiquat chloride (S_2) and 200 ppm of chlormequat chloride (S_1) which were on par with each other. The lower DMP was noticed in control plot for foliar application of growth regulating compounds (S_5) during all the growing seasons.

An increased amount of DMP was recorded in combination of moisture stress free control in conjunction with one percent of PPFM (M_1S_4). Among other treatments, Moisture stress during the panicle initiation stage combined with foliar spraying of 0.1 ppm brassinolide (M_2S_3) resulted in more DMP. This was followed by moisture stress at flowering stage with one percent of PPFM (M_3S_4). Moisture stress at both panicle initiation and flowering stages in combination with control for foliar application of growth regulating compounds (M_4S_5) produced significantly lower amount of DMP in all the growing seasons.

3.4. Specific Leaf Weight

Moisture stress and foliar application of growth regulating compounds had little effect on specific leaf weight during active tillering and panicle initiation (Table 8).

Table 8. Effect of moisture stress and growth regulating compounds on specific leaf weight (g cm^{-2}) at active tillering and panicle initiation stages of rice.

Treatment		*Rabi* 2017–18		*Rabi* 2018–19	
		Active Tillering	Panicle Initiation	Active Tillering	Panicle Initiation
M_1		4.47	7.84	4.53	7.93
M_2		4.48	7.85	4.52	7.92
M_3		4.47	7.85	4.52	7.93
M_4		4.47	7.86	4.52	7.92
SEd		0.12	0.23	0.1	0.24
CD at 5%		NS	NS	NS	NS
S_1		4.49	7.83	4.52	7.91
S_2		4.45	7.86	4.54	7.92
S_3		4.46	7.84	4.50	7.94
S_4		4.49	7.87	4.51	7.95
S_5		4.48	7.85	4.53	7.92
SEd		0.13	0.26	0.12	0.27
CD at 5%		NS	NS	NS	NS
M at S	SEd	0.25	0.52	0.23	0.55
	CD at 5%	NS	NS	NS	NS
S at M	SEd	0.25	0.53	0.24	0.55
	CD at 5%	NS	NS	NS	NS

Main plot	:	Moisture stress (Induced)	Sub plot	:	Growth regulating compounds
M_1	:	Moisture stress free control	S_1	:	Chlormequat chloride (200 ppm)
M_2	:	Moisture stress at PI stage	S_2	:	Mepiquat chloride (200 ppm)
M_3	:	Moisture stress at flowering stage	S_3	:	Brassinolide (0.1 ppm)
M_4	:	Moisture stress at both PI and flowering stage	S_4	:	PPFM (1%)
			S_5	:	Control

At flowering stage, moisture stress free control (M_1) showed increased specific leaf weight recording 11.78 and 12.13 g cm^{-2} during *rabi* 2017–18 and *rabi* 2018–19 which was on par with the plots in which stress was induced at flowering stage (M_3). Invariably, in all the four seasons, moisture stress free control (M_1) was superior to all other therapies by a substantial margin and the SLW recorded was lower in stress at both panicle initiation and flowering stages (M_4) (Tables 9 and 10).

Table 9. Effect of moisture stress and growth regulating compounds on specific leaf weight (g cm^{-2}) at flowering stage of rice.

Treatment	*Rabi* 2017–18						*Rabi* 2018–19				
	M_1	**M_2**	**M_3**	**M_4**	**Mean**		**M_1**	**M_2**	**M_3**	**M_4**	**Mean**
S_1	11.63	8.70	11.39	9.11	10.21	S_1	11.71	10.22	11.09	10.08	10.78
S_2	11.84	10.13	11.49	9.47	10.73	S_2	12.39	9.24	11.8	9.45	10.72
S_3	11.94	10.38	12.53	9.55	10.92	S_3	12.36	10.94	12.97	10.17	11.61
S_4	12.17	9.67	12.54	9.93	11.25	S_4	12.6	10.68	13.64	10.55	11.87
S_5	11.30	7.66	10.88	8.38	9.55	S_5	11.58	8.17	11.12	8.97	9.96
Mean	11.78	9.31	11.76	9.29			12.13	9.85	12.12	9.85	
	M	S	M at S	S at M			M	S	M at S	S at M	
SEd	0.19	0.24	0.47	0.48			0.18	0.20	0.38	0.39	
CD at 5%	0.46	0.49	NS	NS			0.45	0.40	0.80	0.79	

Main plot	:	Moisture stress (Induced)	Sub plot	:	Growth regulating compounds
M_1	:	Moisture stress free control	S_1	:	Chlormequat chloride (200 ppm)
M_2	:	Moisture stress at PI stage	S_2	:	Mepiquat chloride (200 ppm)
M_3	:	Moisture stress at flowering stage	S_3	:	Brassinolide (0.1 ppm)
M_4	:	Moisture stress at both PI and flowering stage	S_4	:	PPFM (1%)
			S_5	:	Control

Table 10. Effect of moisture stress and growth regulating compounds on specific leaf weight (g cm^{-2}) at grain filling stage of rice.

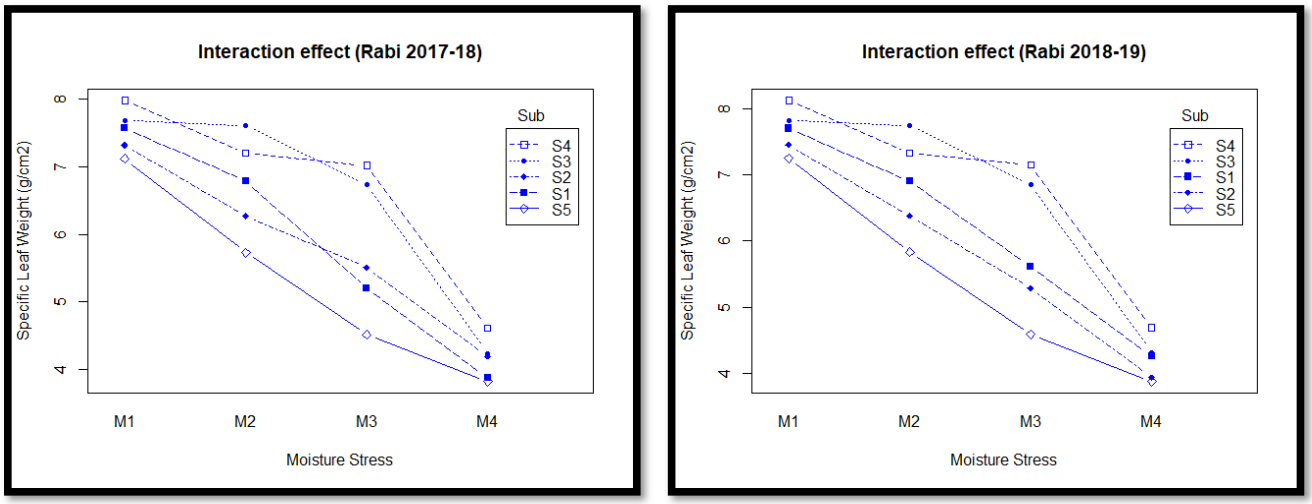
Treatment	*Rabi* 2017–18						*Rabi* 2018–19				
	M_1	**M_2**	**M_3**	**M_4**	**Mean**		**M_1**	**M_2**	**M_3**	**M_4**	**Mean**
S_1	7.57	6.79	5.2	3.87	5.86	S_1	7.70	6.90	5.61	4.26	6.12
S_2	7.32	6.27	5.51	4.19	5.82	S_2	7.45	6.38	5.29	3.94	5.77
S_3	7.69	7.61	6.73	4.23	6.57	S_3	7.82	7.74	6.85	4.31	6.68
S_4	7.98	7.2	7.02	4.61	6.70	S_4	8.12	7.33	7.15	4.69	6.82
S_5	7.12	5.73	4.51	3.82	5.30	S_5	7.25	5.83	4.59	3.88	5.39
Mean	7.54	6.72	5.80	4.14			7.67	6.84	5.90	4.22	
	M	S	M at S	S at M			M	S	M at S	S at M	
SEd	0.05	0.11	0.20	0.21			0.12	0.10	0.21	0.20	
CD at 5%	0.13	0.22	0.41	0.43			0.28	0.20	0.46	0.41	

Main plot	:	Moisture stress (Induced)	Sub plot	:	Growth regulating compounds
M_1	:	Moisture stress free control	S_1	:	Chlormequat chloride (200 ppm)
M_2	:	Moisture stress at PI stage	S_2	:	Mepiquat chloride (200 ppm)
M_3	:	Moisture stress at flowering stage	S_3	:	Brassinolide (0.1 ppm)
M_4	:	Moisture stress at both PI and flowering stage	S_4	:	PPFM (1%)
			S_5	:	Control

In different growth regulating compounds, PPFM at 1% (S_4) resulted in increased specific leaf weight (6.70 and 6.82 g cm^{-2}, during *rabi* 2017–18 and *rabi* 2018–19) in comparison to other forms of treatment. After that, 0.1 ppm brassinolide was sprayed on the leaves (S_3) at grain filling stage. However, a lower SLW was noticed in the control (S_5) during all two growing seasons.

The interaction effect was significant only at grain filling stage of *rabi* season crop (Figure 1). During all growing seasons, the treatment included moisture stress free control and a 1% PPFM spray (M_1S_4) recorded increased specific leaf weight. Among the different

growth stages, the treatment combination of moisture stress at panicle initiation stage along with 0.1 ppm brassinolide (M_2S_3) registered a more specific leaf weight. Moisture stress resulted in reduced specific leaf weight at both the panicle initiation and flowering stages when compared to foliar administration of growth regulating compounds (M_4S_5).



(**a**) (**b**)

Figure 1. Interaction effect of moisture stress and growth regulating compounds on specific leaf weight (g cm^{-2}) at grain filling stage of rice (**a**) interaction effect during *rabi* 2017–18; (**b**) interaction effect during *rabi* 2018–19.

3.5. Leaf Area Index

The basic instruments for growth analysis are measuring leaf area and determining LAI. Neither the moisture stress treatments nor the foliar spraying of growth regulating compounds had significant influence on LAI at active tillering and panicle initiation stages (Table 11). Regarding moisture stress treatments, increased LAI was observed in the moisture stress free control (M_1) with 5.01 and 5.02 for *rabi* 2017–18 and *rabi* 2018–19 at flowering stage, which was comparable with moisture stress at flowering stage (M_3). At the harvest stage, the moisture stress free control (M_1) was much more effective than the other therapies and decreased LAI was found in stress at both panicle initiation and flowering stages (M_4) during all the two growing seasons.

During all growing seasons, moisture stress treatments and foliar spraying of growth regulating compounds demonstrated different interactions with LAI at the harvest stage. The treatment combination of moisture stress free control and 1% PPFM (M_1S_4) produced higher LAI values. This was followed by moisture stress at panicle initiation stage with 0.1 ppm brassinolide (M_2S_3). Moisture stress during panicle initiation and flowering with foliar administration of growth regulators as a control (M_4S_5) showed the least LAI among all the other treatments studied.

Table 11. Effect of moisture stress and growth regulating compounds on leaf area index at different growth stages of rice.

Treatment		*Rabi* 2017–18			*Rabi* 2018–19		
		Active Tillering	Panicle Initiation	Flowering	Active Tillering	Panicle Initiation	Flowering
M_1		0.90	3.69	5.01	0.91	3.72	5.02
M_2		0.90	3.68	3.71	0.91	3.73	3.72
M_3		0.90	3.69	4.98	0.91	3.73	4.99
M_4		0.90	3.69	3.69	0.92	3.73	3.70
SEd		0.01	0.06	0.09	0.02	0.11	0.10
CD at 5%		NS	NS	0.21	NS	NS	0.26
S_1		0.91	3.70	4.15	0.92	3.73	4.16
S_2		0.90	3.68	4.35	0.91	3.71	4.36
S_3		0.91	3.69	4.58	0.92	3.73	4.59
S_4		0.88	3.67	4.65	0.89	3.74	4.66
S_5		0.92	3.71	4.01	0.93	3.72	4.02
SEd		0.03	0.14	0.10	0.03	0.12	0.09
CD at 5%		NS	NS	0.21	NS	NS	0.18
M at S	SEd	0.06	0.26	0.20	0.06	0.24	0.19
	CD at 5%	NS	NS	NS	NS	NS	NS
S at M	SEd	0.05	0.28	0.20	0.07	0.24	0.17
	CD at 5%	NS	NS	NS	NS	NS	NS

Main plot	:	Moisture stress (Induced)	Sub plot	:	Growth regulating compounds
M_1	:	Moisture stress free control	S_1	:	Chlormequat chloride (200 ppm)
M_2	:	Moisture stress at PI stage	S_2	:	Mepiquat chloride (200 ppm)
M_3	:	Moisture stress at flowering stage	S_3	:	Brassinolide (0.1 ppm)
M_4	:	Moisture stress at both PI and flowering stage	S_4	:	PPFM (1%)
			S_5	:	Control

In terms of the treatment of subplots, 1% PPFM (S_4) showed increased LAI during *rabi* 2017–18 and *rabi* 2018–19 with 4.65 and 4.66 at flowering stage, and it was comparable with application of 0.1 ppm brassinolide (S_3), whereas LAI had the least control for foliar application of growth regulating compounds (S_5). Similar results were also noticed at harvest stage during all the two growing seasons of rice (Table 12).

Table 12. Effect of moisture stress and growth regulating compounds on leaf area index at harvest stage of rice.

Treatment	*Rabi* 2016–17						*Rabi* 2017–18				
	M_1	M_2	M_3	M4	Mean		M_1	M_2	M_3	M4	Mean
S_1	4.18	3.68	3.21	2.68	3.44	S_1	4.43	3.93	3.46	2.93	3.69
S_2	4.25	3.75	3.37	2.59	3.49	S_2	4.50	4.00	3.62	2.84	3.74
S_3	4.35	4.35	3.85	2.84	3.85	S_3	4.60	4.60	4.10	3.09	4.10
S_4	4.46	4.22	3.91	3.12	3.93	S_4	4.71	4.47	4.16	3.37	4.18
S_5	4.17	3.33	2.75	2.48	3.18	S_5	4.42	3.58	3.00	2.73	3.43
Mean	4.28	3.87	3.42	2.74			4.53	4.12	3.67	2.99	
	M	S	M at S	S at M			M	S	M at S	S at M	
SEd	0.06	0.05	0.11	0.11			0.08	0.06	0.14	0.13	
CD at 5%	0.14	0.11	0.23	0.21			0.19	0.13	0.3	0.26	

Main plot	:	Moisture stress (Induced)	Sub plot	:	Growth regulating compounds
M_1	:	Moisture stress free control	S_1	:	Chlormequat chloride (200 ppm)
M_2	:	Moisture stress at PI stage	S_2	:	Mepiquat chloride (200 ppm)
M_3	:	Moisture stress at flowering stage	S_3	:	Brassinolide (0.1 ppm)
M_4	:	Moisture stress at both PI and flowering stage	S_4	:	PPFM (1%)
			S_5	:	Control

3.6. Crop Growth Rate

Moisture stress treatments and growth-regulators had little effect on the crop growth rate from active tillering to panicle initiation (Tables 13 and 14). During *rabi* 2017–18 and *rabi* 2018–19, the moisture stress free control (M_1) had a higher crop growth rate from panicle initiation to flowering, with 17.15 and 18.18 g m^{-2} day^{-1}, respectively. At both the panicle initiation and flowering stages, crop growth rate was reduced when moisture stress was present (M_4). Similar results were also observed from the flowering to harvest stages at the two growing seasons of rice.

Table 13. Effect of moisture stress and growth regulating compounds on crop growth rate (g m^{-2} day^{-1}) at different growth stages of *rabi* rice 2017–18.

Treatment	Active Tillering to Panicle Initiation						Panicle Initiation to Flowering						Flowering to Grain filling				
	M_1	**M_2**	**M_3**	**M_4**	**Mean**		**M_1**	**M_2**	**M_3**	**M_4**	**Mean**		**M_1**	**M_2**	**M_3**	**M_4**	**Mean**
S_1	7.92	8.33	8.18	8.15	8.15	S_1	16.75	13.09	14.85	11.09	13.94	S_1	9.05	8.58	8.03	7.16	8.21
S_2	7.90	8.24	8.22	8.27	8.16	S_2	16.88	13.69	14.99	10.75	14.08	S_2	9.13	8.67	8.30	7.28	8.35
S_3	8.37	7.96	8.37	7.85	8.14	S_3	18.15	15.66	17.73	12.87	16.10	S_3	10.00	9.90	8.45	7.78	9.03
S_4	8.01	8.10	8.16	8.28	8.13	S_4	17.24	15.59	16.76	11.56	15.29	S_4	9.90	9.61	8.90	8.69	9.28
S_5	8.48	8.09	7.77	8.12	8.12	S_5	16.72	11.34	13.52	10.34	12.98	S_5	9.32	7.8	6.96	6.84	7.73
Mean	8.14	8.14	8.14	8.13			17.15	13.87	15.57	11.32			9.48	8.91	8.13	7.55	
	M	S	M at S	S at M			M	S	M at S	Sat M			M	S	M at S	S at M	
SEd	0.23	0.24	0.49	0.48			0.20	0.21	0.42	0.41			0.13	0.14	0.28	0.28	
CD at 5%	NS	NS	NS	NS			0.49	0.42	0.89	0.84			0.31	0.29	0.60	0.58	

Main plot : Moisture stress (Induced)
M_1 : Moisture stress free control
M_2 : Moisture stress at PI stage
M_3 : Moisture stress at flowering stage
M_4 : Moisture stress at both PI and flowering stage

Sub plot : Growth regulating compounds
S_1 : Chlormequat chloride (200 ppm)
S_2 : Mepiquat chloride (200 ppm)
S_3 : Brassinolide (0.1 ppm)
S_4 : PPFM (1%)
S_5 : Control

Table 14. Effect of moisture stress and growth regulating compounds on crop growth rate (g m^{-2} day^{-1}) at different growth stages of *rabi* rice 2018–19.

Treatment	Active Tillering to Panicle Initiation						Panicle Initiation to Flowering						Flowering to Grain filling				
	M_1	**M_2**	**M_3**	**M_4**	**Mean**		**M_1**	**M_2**	**M_3**	**M_4**	**Mean**		**M_1**	**M_2**	**M_3**	**M_4**	**Mean**
S_1	8.30	8.44	8.23	8.53	8.38	S_1	17.78	14.12	15.88	12.12	14.98	S_1	10.33	9.86	9.31	8.44	9.49
S_2	8.21	8.44	8.52	8.41	8.39	S_2	17.91	14.72	16.02	11.78	15.11	S_2	10.41	9.95	9.58	8.56	9.63
S_3	8.53	8.20	8.60	8.08	8.35	S_3	18.27	16.69	17.79	12.59	16.34	S_3	11.28	11.18	9.73	9.06	10.31
S_4	8.44	8.52	8.25	8.37	8.39	S_4	19.18	16.62	18.76	13.90	17.12	S_4	11.18	10.89	10.18	9.97	10.56
S_5	8.38	8.33	8.34	8.43	8.37	S_5	17.75	12.37	14.55	11.37	14.01	S_5	10.6	9.08	8.24	8.12	9.01
Mean	8.37	8.39	8.39	8.36			18.18	14.90	16.60	12.35			10.76	10.19	9.41	8.83	
	M	S	M at S	S at M			M	S	M at S	Sat M			M	S	M at S	S at M	
SEd	0.24	0.38	0.72	0.76			0.24	0.23	0.47	0.45			0.15	0.15	0.31	0.30	
CD at 5%	NS	NS	NS	NS			0.58	0.46	1.01	0.93			0.36	0.31	0.65	0.61	

Main plot : Moisture stress (Induced)
M_1 : Moisture stress free control
M_2 : Moisture stress at PI stage
M_3 : Moisture stress at flowering stage
M_4 : Moisture stress at both PI and flowering stage

Sub plot : Growth regulating compounds
S_1 : Chlormequat chloride (200 ppm)
S_2 : Mepiquat chloride (200 ppm)
S_3 : Brassinolide (0.1 ppm)
S_4 : PPFM (1%)
S_5 : Control

In terms of foliar application of growth regulators, the application of 1% PPFM was better than all other therapies in a considerable way. A higher rate of crop growth was observed when 1% PPFM was sprayed during *rabi* 2017–18 and *rabi* 2018–19 registering 9.28 and 10.56 g m^{-2} day^{-1}, respectively, at flowering to harvest stages. However, this was similar to 0.1 ppm brassinolide foliar application (S_3). The control (S_5) had a lower crop growth rate for both years of the experiment.

The interaction effect between moisture stress treatments and growth regulating compounds was significant only at panicle initiation to flowering and flowering to grain

filling stages of the *rabi* season crop (Figure 2). Throughout all growing seasons, the treatment combination of moisture stress free control and 1% PPFM (M_1S_4) resulted in an improved crop growth rate. Among other treatments, moisture stress at panicle initiation stage along with 0.1 ppm brassinolide (M_2S_3) showed a higher crop growth rate. A reduced crop growth rate was registered with moisture stress at both panicle initiation and flowering stages with control for foliar spraying of growth regulating compounds (M_4S_5).

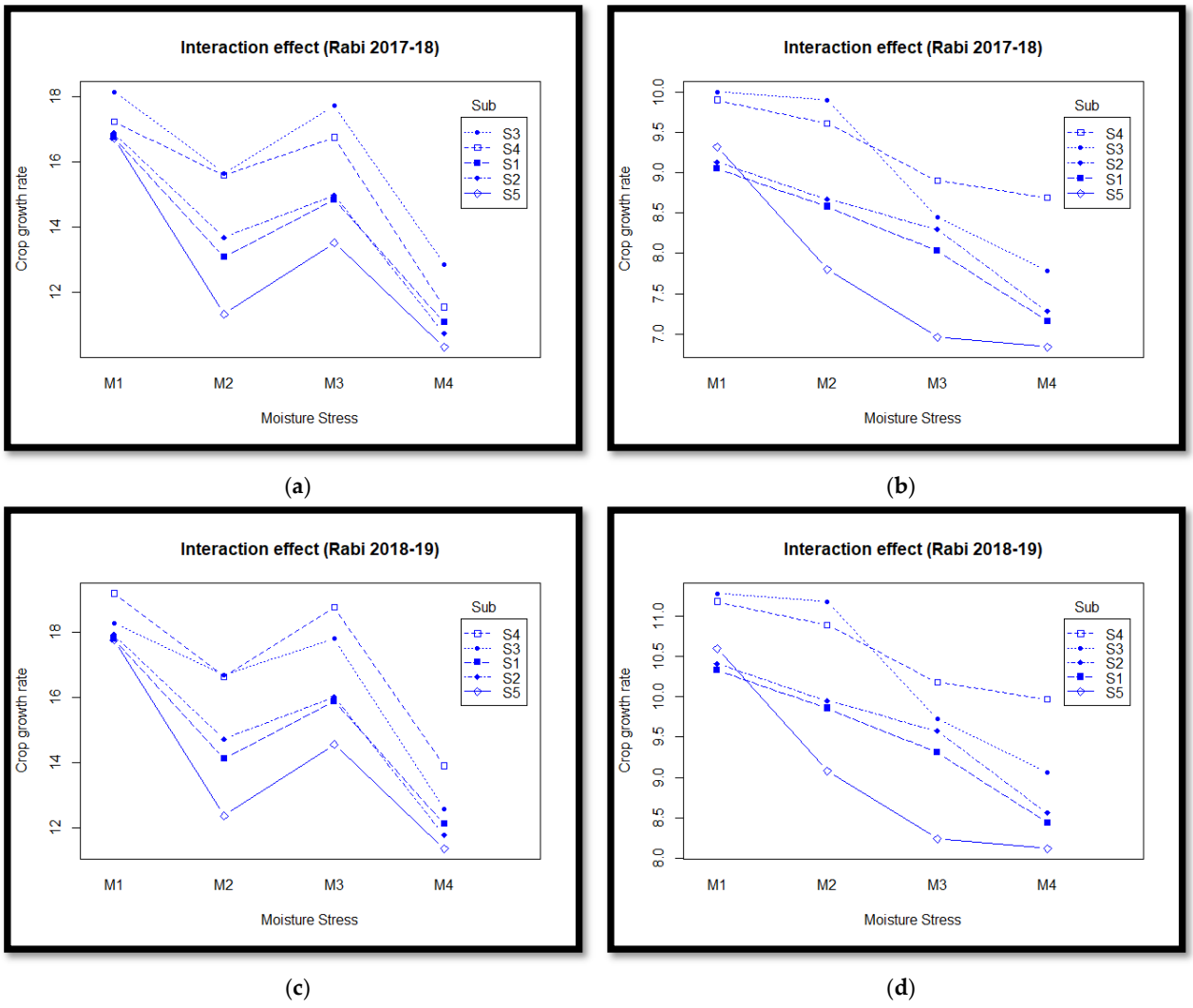


Figure 2. Interaction effect of moisture stress and growth regulating compounds on crop growth rate (g m^{-2} day^{-1}) of rice. (**a**) Interaction effect at panicle initiation to flowering stage during *rabi* 2017–18; (**b**) interaction effect at flowering to grain filling stage during *rabi* 2017–18; (**c**) interaction effect at panicle initiation to flowering stage during *rabi* 2018–19; (**d**) interaction effect at flowering to grain filling stage during *rabi* 2018–19.

3.7. Incidence of Brown Plant Hopper

The incidence of BPH on transplanted rice was significantly influenced by moisture stress and plant growth regulating compounds (Tables 15 and 16).

Table 15. Effect of moisture stress and growth regulating compounds on the incidence of brown plant hopper (Number of BPH/5 hill) at different growth stages of *rabi* rice 2017–18.

Treatments	*Rabi* 2017–18															
	Active Tillering to Panicle initiation					Panicle initiation to Flowering					Flowering to Grain filling					
	M_1	M_2	M_3	M_4	Mean		M_1	M_2	M_3	M_4	Mean		M_1	M_2	M_3	M_4	Mean
S_1	29.67	26.33	33.33	24.67	28.50	S_1	32.00	27.33	36.00	22.33	29.42	S_1	27.33	26.67	30.67	22.33	26.75
S_2	27.33	26.67	31.00	24.67	27.42	S_2	30.67	27.33	32.33	22.00	28.08	S_2	25.00	24.67	26.33	21.33	24.33
S_3	27.00	23.33	29.00	21.00	25.08	S_3	27.67	25.00	30.00	20.33	25.75	S_3	25.67	20.33	26.00	18.67	22.67
S_4	22.67	19.67	25.00	16.67	21.00	S_4	23.33	21.00	26.67	15.67	21.67	S_4	19.67	17.00	19.00	13.33	17.25
S_5	36.67	32.33	33.67	29.00	32.92	S_5	38.67	33.33	34.33	25.67	33.00	S_5	29.67	29.00	30.00	25.33	28.50
Mean	28.67	25.67	30.40	23.20		Mean	30.47	26.80	31.87	21.20		Mean	25.47	23.53	26.40	20.20	
	Main	Sub	M at S	S at M			Main	Sub	M at S	S at M			Main	Sub	M at S	S at M	
S.Ed.	1.138	0.720	1.718	1.440			1.230	0.901	2.028	1.802			0.699	0.752	1.516	1.505	
C.D. ($P = 0.05$)	2.784	1.466	3.808	2.932			3.011	1.835	4.437	3.671			1.710	1.532	3.221	3.065	

Main plot : Moisture stress (Induced)
M_1 : Moisture stress free control
M_2 : Moisture stress at PI stage
M_3 : Moisture stress at flowering stage
M_4 : Moisture stress at both PI and flowering stage

Sub plot : Growth regulating compounds
S_1 : Chlormequat chloride (200 ppm)
S_2 : Mepiquat chloride (200 ppm)
S_3 : Brassinolide (0.1 ppm)
S_4 : PPFM (1%)
S_5 : Control

Table 16. Effect of moisture stress and growth regulating compounds on the incidence of brown plant hopper (Number of BPH/5 hill) at different growth stages of *rabi* rice 2018–19.

Treatments	*Rabi* 2018–19															
	Active Tillering to Panicle initiation					Panicle initiation to Flowering					Flowering to Grain filling					
	M_1	M_2	M_3	M_4	Mean		M_1	M_2	M_3	M_4	Mean		M_1	M_2	M_3	M_4	Mean
S_1	30.33	25.67	32.00	25.33	28.33	S_1	32.00	27.00	35.00	24.00	29.50	S_1	29.67	26.00	28.00	21.00	26.17
S_2	27.67	25.33	30.00	24.67	26.92	S_2	31.00	25.33	30.00	23.67	27.50	S_2	27.33	24.00	24.00	20.33	23.92
S_3	26.67	22.00	29.67	21.33	24.92	S_3	26.67	23.33	24.33	20.33	23.67	S_3	25.33	20.67	23.33	18.00	21.83
S_4	24.00	19.00	25.00	14.33	20.58	S_4	23.67	21.33	24.00	16.00	21.25	S_4	21.33	15.33	16.67	14.00	16.83
S_5	32.33	31.00	33.33	27.33	31.00	S_5	37.00	31.00	33.00	25.33	31.58	S_5	29.67	27.00	28.67	24.33	27.42
Mean	28.20	24.60	30.00	22.60		Mean	30.07	25.60	29.27	21.87		Mean	26.67	22.60	24.13	19.53	
	Main	Sub	M at S	S at M			Main	Sub	M at S	S at M			Main	Sub	M at S	S at M	
S.Ed.	1.314	0.767	1.900	1.535			1.124	1.157	2.355	2.313			0.771	1.162	2.217	2.324	
C.D. ($P = 0.05$)	3.215	1.563	4.243	3.126			2.751	2.356	5.016	4.711			1.887	2.367	4.626	4.733	

Main plot : Moisture stress (Induced)
M_1 : Moisture stress free control
M_2 : Moisture stress at PI stage
M_3 : Moisture stress at flowering stage
M_4 : Moisture stress at both PI and flowering stage

Sub plot : Growth regulating compounds
S_1 : Chlormequat chloride (200 ppm)
S_2 : Mepiquat chloride (200 ppm)
S_3 : Brassinolide (0.1 ppm)
S4 : PPFM (1%)
S_5 : Control

In all the moisture stress treatments, moisture stress at panicle initiation and flowering stage plot harbored lower populations of 23.20, 21.20, and 20.20 nymphs and adults/5 hill during *rabi* 2017–18, respectively, and 22.60, 21.86 and 19.53 nymphs and adults/5 hill during *rabi* 2018–19, respectively. The moisture stress at flowering stage alone provided the highest population of BPH. The occurrence of BPH at tillering stage in control plot is depicted in Figure 3.



Figure 3. Occurrence of Brown Plant Hopper at tillering stage in control plot.

With regard to the foliar application of plant growth regulating compounds, the spraying of 1% PPFM was significantly superior to all other treatments. The lowest population of BPH was recorded when 1% of PPFM was sprayed during *rabi* 2017–18 and *rabi* 2018–19 registering 21.00, 21.67, 17.25 and 20.58, 21.25, 16.83, respectively. After PPFM, the 0.1 ppm brassinolide harbored a smaller population of BPH. The highest BPH population was registered in the Chlormequat chloride (200 ppm) treated plot. This was on par with foliar spraying of Mepiquat chloride (200 ppm).

The interaction effect between moisture stress treatments and growth regulating compounds was significant in all the stages of *rabi* season crops (Figure 4). During all the growing seasons, the treatment combination of moisture stress at both PI and flowering stage, along with PPFM at 1% (M_4S_4), showed a lower population of BPH. Among other treatments, moisture stress at panicle initiation stage along with 0.1 ppm brassinolide (M_2S_3) registered a low population of BPH. The highest population of BPH was found in moisture stress free with control for foliar application of growth regulating compounds (M_4S_5).

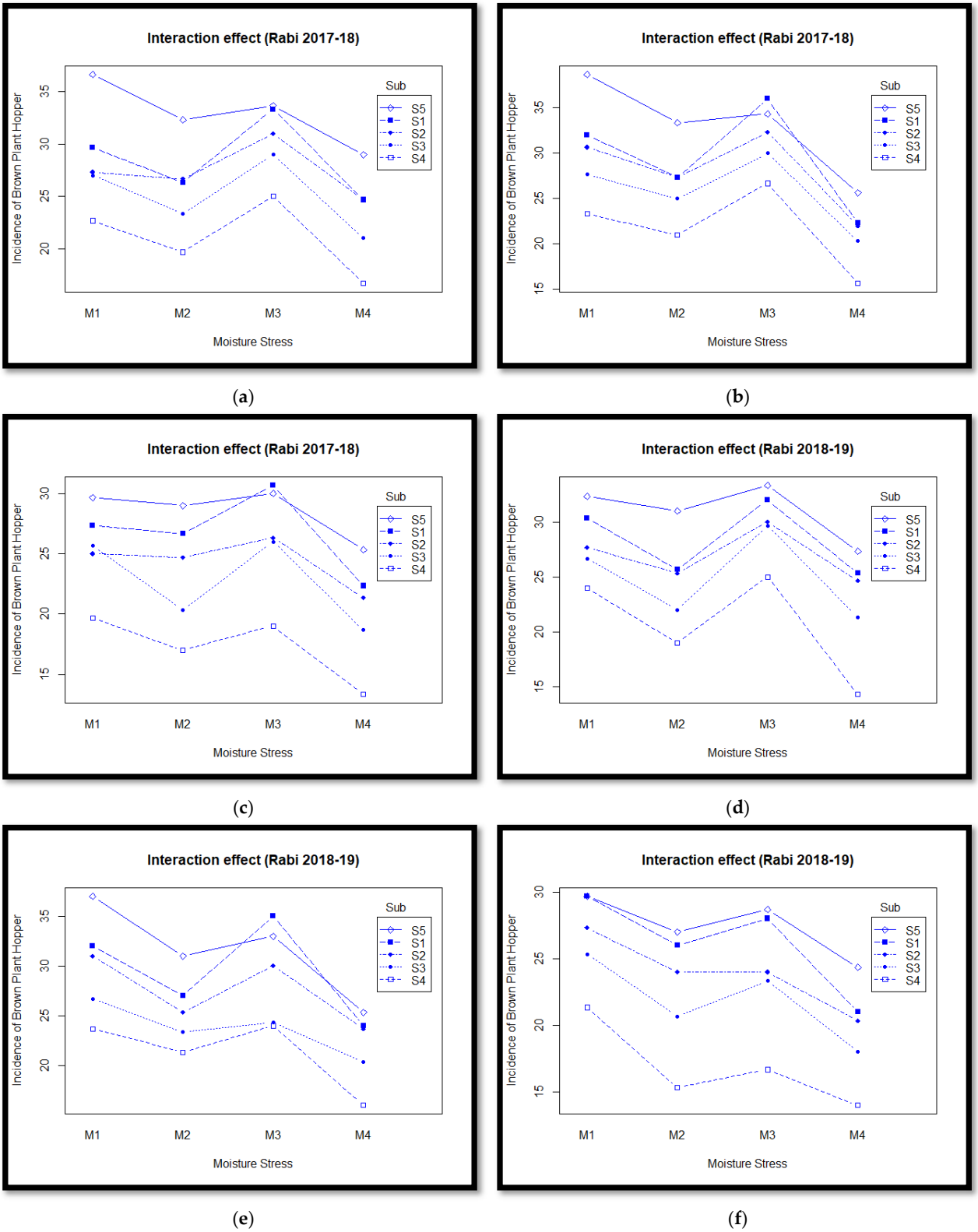


Figure 4. Interaction effect of moisture stress and growth regulating compounds on the incidence of brown plant hopper (Number of BPH/5 hill) at different growth stages of *rabi* rice; (**a**) at active tillering to panicle initiation during *rabi* 2017–18; (**b**) panicle initiation to flowering during *rabi* 2017–18; (**c**) flowering to grain filling during *rabi* 2017–18; (**d**) active tillering to panicle initiation during *rabi* 2018–19; (**e**) panicle initiation to flowering during *rabi* 2018–19; (**f**) flowering to grain filling during *rabi* 2018–19.

4. Discussion

Moisture stress and foliar spraying of growth regulating chemicals had little effect on rice growth characters during the active tillering and panicle initiation phases. This was mostly due to the fact that treatments such as moisture stress and growth-regulating chemicals were only applied after the panicle initiation stage, and that all other agronomic approaches were applied evenly across all treatments prior to this time [20].

Enhanced plant height would help the rice plants produce greater biomass and yield potential, which is an important attribute for growth. Taller plants were observed consistently at flowering and harvesting stages, which was associated with moisture stress free control during all the seasons. Plants were considerably taller when rice was irrigated one day after ponded water dissipated at a 5 cm depth of irrigation. This might have spurred the enhanced meristematic cell activity and cell elongation at internodes, resulting in a faster rate of stem growth and thus an increase in rice plant height [21,22]. At both the panicle initiation and flowering stages, shorter plants were observed in association with moisture stress. The present study's results are in line with the findings of Rahman et al. [23], moisture stress administered at any stage of rice growth before anthesis dramatically reduced plant height. Regarding foliar application of growth regulating compounds, spraying 1% PPFM resulted in the heightening of plants and was comparable with 0.1 ppm application of brassinolide. Spraying of *methylobacterium* might have stimulated the growth and plant height by increasing the amount of auxin and cytokinin in rice. Similar outcomes have been recorded by Mauney and Gerik in soybean [24]. Increasing moisture stress significantly resulted in a decrease in plant height under control for foliar application of growth regulating compounds.

Tillering is the boon of rice heterogeneity. Tiller production often begins following the creation of the node and 5th leaf in the beginning, increases steadily, attains to its peak at the active tillering stage, and then declines as the crop age advances [25]. Among the different moisture stress treatments, the maximum number of tillers hill^{-1} was recorded in the moisture stress free control and this was followed by moisture stress at panicle initiation stage. This could be due to adequate aeration, which favored improved root growth and the absorption of more nutrients, as evidenced by the enhanced nutrient uptake, resulting in increased growth, and tiller production. The outcomes were as expected in comparison to Hameed et al. [26,27].

In terms of foliar application of growth regulators, the application of 1% PPFM produced considerably a greater number of tillers hill^{-1} at harvest stage, whereas it was comparable with 0.1 ppm of brassinolide in all the seasons. This might have helped to increase the cell division activity, cell expansion, and elongation, ultimately leading to a greater number of tillers hill^{-1}. The influence of brassinolide on the endogenous levels of hormones enhanced the photosynthesis and nitrate assimilation, as reported by Sairam [28].

Throughout both years of testing, the only significant interaction was detected during the flowering and harvesting periods. The conjunction of moisture stress-free control and foliar spraying with 1% PPFM resulted in a larger number of tillers hill^{-1}, which was followed by moisture stress at the panicle initiation stage with 0.1 ppm of brassinolide.

This might have facilitated more access to water and nutrients from the roots. This could have resulted in better plant establishment with better tiller production. In the current investigation, regardless of the growth phase at which moisture stress was enforced, the total number of tillers showed a general decrease. It could, however, be avoided by taking stress relievers in the right amounts. This was also in conformity with Vijayalakshmi and Nagarajan's findings [29].

The efficiency with which a crop uses its available resources such as solar radiation, moisture, nutrients, and other niches of the prevailing environmental circumstances is reflected in its dry matter output. It is the result of the interaction of growth characteristics such as the number of tillers, LAI, and crop efficiency in capturing available resources [30].

Dry matter output grew significantly as the growth stages progressed, peaking at harvest. Moisture stress free control resulted in increased DMP. This is because of optimum

plant population and the tillering ability of the variety. This resulted in enhanced tiller production, leaf number, LAI, and improved root properties. Dry matter accumulation may have been accelerated in the presence of an adequate nutrition supply and a bigger photosynthesizing surface, resulting in fast accumulation. This result is consistent with the findings of Hameed et al. [26]. Low moisture availability affecting water and nutrient uptake, photosynthetic rate, and photo assimilate translocation was observed with moisture stress at both panicle initiation and flowering stages, which could be due to low moisture availability affecting water uptake, photosynthesis, and translocation of photo assimilates. Moisture stress lowered plant height, leaf number, leaf size, and tillers, leading in lower dry matter yield [31].

DMP increased more significantly with the foliar application of 1% PPFM and brassinolide (0.1 ppm) under water deficit situation. This might be attributed to increased nitrogen availability due to the presence of nitrogen-fixing facultative methylotrophs [32,33]. Also, the PPFM microbial inoculants' production of plant growth-promoting compounds such as cytokinins, indole acetic acid, gibberellic acid, vitamins, and antibiotic substances may have functioned in concert with it. By enhancing the antioxidant system and boosting dry matter buildup, the foliar application of brassinolides could somewhat mitigate the negative effects of moisture stress on soybean growth [34].

Water stress is known to influence both plants and herbivores which feed on the stressed plants [35]. An insect tends to form a mechanism to cope with the water loss. Some of the authors reported the positive effects of stressed plants on insects, modifying the growth rates, fecundity, and survival [36]. The drought events and reduced precipitation mediate the effects of herbivore infestation on plants in different ways depending upon the plant age and size [37]. In our study, the BPH population was recorded as high during the panicle initiation to flowering stage in both the years of experiment. The highest population of BPH was recorded in the moisture stress during flowering stage. The plant growth regulating compounds also influenced the abundance of BPH in rice. PPFM provided a lower population of BPH. The PPFM could change the physiology of plant systems, i.e., the production of flavonoids, which may, for instance, repel sucking and chewing insects [14]. Similarly, the apple trees sprayed with growth regulator, i.e., prohexadoine calcium were also less colonized by sucking insects including aphids, psyllids, and leaf hoppers [14]. Furthermore, PPFM of the brassinosteroids treated plots showed a smaller population of BPH. In contrast to this, Pan et al. [38] reported that brassinosteroids suppress the SA pathway and harbor a higher BPH on rice plants [31]. This necessitates a molecular basis for the interaction effect of drought and growth regulators.

5. Conclusions

The interaction between moisture stress and foliar application of growth regulating compounds revealed that the treatment combination of moisture stress free control with foliar spraying of 1% PPFM showed an increased number of tillers hill^{-1}, DMP, SLW, LAI, CGR; and decreased the population of BPH. Among the other treatments, moisture stress at panicle initiation stage in combination with spraying 0.1 ppm brassinolide recorded significantly better growth attributes. This clearly indicated that PPFM and brassinolide played a vital role in mitigating the stress and enhancing the growth attributes under moisture stressed environment. A physiological study needs to be conducted in order to find out the impact of growth regulators on rice plants under moisture stress conditions.

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Abbreviations

PPFM	pink pigmented facultative methylotrophs
PGR	Plant Growth Regulator
BPH	Brown Plant Hopper
SLW	Specific Leaf Weight
LAI	Leaf Area Index
CGR	Crop Growth Rate
DMP	Dry Matter Production
CD	Critical Difference
ANOVA	Analysis of Variance
LSD	Least Square Difference

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