INFLUENCE OF NEW PLANTING GEOMETRY- PAIRED ROW PLANTING ON INCIDENCE OF DISEASES IN RICE

By

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THESIS

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DECLARATION

I, **Geethika T. V. (2020-11-100)** hereby declare that the thesis entitled **"Influence of new planting geometry - paired row planting on incidence of diseases in rice"** is a bonafide record of research done by me during the course of research and that this thesis has not been previously formed the basis for the award of any degree, diploma, fellowship or any other similar title, of any other University or Society.

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LIST OF ABBREVIATIONS

%	Per cent
ºC	Degree Celsius
AT	Active Tillering
B	Booting
CD	Critical Difference
CT	Canopy Temperature
cfu	Colony forming units
cm	Centimeter
DAS	Days after sowing
et al.	And other co workers
g	Gram
H	Heading
ha	Hectare
i.e.	that is
kg	kilogram
mL	Millilitre
No.	Number
PI	Panicle Initiation
PM	Physiological Maturity
RARS	Regional Agricultural Research Station
RH I	Forenoon relative humidity
RH II	Afternoon relative humidity
RH	Average relative humidity

Introduction

1. INTRODUCTION

Rice is the most important food crop in the world and the staple food of more than half of the world's population including India. Being the staple food for more than 65 per cent of the population in the country, rice is critical to the food and livelihood security of people. The total area under rice cultivation in the country is 450.67 lakh hectares with an annual production of 122.27 million tonnes (GOI, 2022). In Kerala, 1.98 lakh hectare is under rice cultivation with a production of 5.87 lakh tonnes (GOK, 2022). The growing demand for rice due to the increasing population and urbanization enhances the importance of increasing its production in the future. As the area under rice is stabilized, the only option left for achieving target production is yield improvement.

Diseases and insect pest infestations are the major biotic constraints of rice production. The incidence of major diseases such as bacterial blight and sheath blight has increased tremendously in recent years in Kerala. Other diseases such as blast, brown spot, false smut and grain discolouration are also prevalent in various intensities. Similarly, among the insect pests, yellow stem borer and brown plant hopper are considered as the major pests of paddy. Recently, gall midge, leaf folder, caseworm and rice bug have also emerged as major problems in rice cultivation. The increasing scarcity of land and water resources, environmental degradation and loss of biodiversity also have started to constrain the expansion of food grain production. So, there is a dire need to develop technologies that can increase the yield from limited resources.

Rice crop establishment methods in Asia are very diverse and include direct sowing and transplanting of seedlings at different spacing. These different crop establishment methods lead to differences in the structure of the rice plant canopy, *i.e.*, in plant geometry. The plant geometry and spatial configuration influence the factors contributing to the better establishment of the crop.

Variation in planting geometry can be achieved through different row spacing and their arrangements. This, in turn, leads to variations in crop density, spatial arrangement of canopy and associated microclimate that will eventually influence the intensity and spread of diseases and pests as well as the growth and yield.

Many studies have reported that an improvement in growth and yield attributes of rice could be achieved by manipulating spacing and thereby optimizing plant density.

The reduced intra-plant competition for resources like solar radiation, space and nutrients was considered as the possible factor contributing to this improvement. In these studies, even though higher plant density in closer spacing tended to increase plant height and dry matter production, an appreciable improvement in other growth and yield attributes *viz*. number of tillers, number of panicles, panicle length, panicle weight, number of filled grains and thousand seed weight was attained in wider spacing due to the better utilization of space, solar radiation and other inputs (Naklang *et al*., 1996; Gautam *et al*., 2008, Sihag *et al*., 2015; Iwuagwu *et al*., 2017).

The epidemiology of various crop diseases can also be altered with suitable crop density. Changes in crop density influence disease incidence through direct geometrical effects on the frequency of infection and indirectly through interactions with the environment (Burdon and Chilvers, 1982). Contact between infected and healthy tissues accelerates the spread of diseases like sheath blight. Thus, closer spacing of hills favours sheath blight epidemics in the case of transplanted rice (Willocquet *et al*., 2000). It is also reported that wider row spacing reduced severity of bacterial leaf blight (Rashid *et al*., 2019) and grain discolouration (Misra and Vir, 1992). Similarly, skip row planting reduced incidence and severity of sheath rot (Rautaray, 2007). Changes in host density alter the physiological characteristics of target plants by influencing the competitive interactions among them for natural resources thereby affecting the predisposition factors of host plants to disease infection. The change in planting geometry can also have an impact in the behaviour of vectors, and thereby in disease incidence. Planting density also influences the micrometeorological parameters of the crop stand including light levels, temperature differentials between day and night, wind velocities, and relative humidity within the stands. These environmental variables particularly influence inoculum release, flight, collection, and the prepenetration phase of the infection process (Burdon and Chilvers, 1982). It is reported that incidence of sheath blight and brown spot in closely spaced crop stands with increased relative humidity was higher than widely spaced stands (Yang *et al*., 2008; Biswas *et al*., 2012; Dhaliwal *et al*., 2018).

Planting geometry also influences the abundance and diversity of pest population. Closely spaced plants shade each other and alter the microclimate within the crop canopy, making rice plants more vulnerable to pests. There are reports that the population of plant hoppers increases with narrow seedling spacing (Satpathi *et al*., 2012; Asghar *et al*., 2020). It is also reported that the close canopy formation resulted in the maintenance of higher relative humidity in the basal portion of rice plants, enhancing the activity of nymphs of plant hoppers and gall midge (Jena *et al*., 2018). The changes in plant density alter the flight behaviour, landing response and feeding activity of insects by creating a change in their perceived environment (Burdon and Chilvers, 1982). This in turn influences the insect pest population within the crop canopy.

Various studies have been conducted to compare and optimize a suitable crop establishment method by modifying existing planting geometry to enhance yield and reduce pest and disease incidence. Paired row planting is a modified planting geometry developed at the Regional Agricultural Research Station, Pattambi which utilizes the border effect to enhance the yield of rice. By adopting this method, a yield increase of 23 per cent without any additional inputs was obtained (Moossa *et al.*, 2017). This method is getting wide acceptance among farmers. Understanding crop establishment methods in relation to disease incidence helps to evolve IDM strategies. In this context, the present study was undertaken to assess the incidence of diseases in new planting geometry, paired row planting.

Review of literature

2. REVIEW OF LITERATURE

The crop establishment methods in rice are diverse and include direct sowing and transplanting of seedlings at different spacing and row arrangements. The variations in planting geometry and spatial configuration in these crop establishment methods lead to changes in crop density and associated microclimate, which in turn influence the intensity and spread of diseases and pests as well as the growth and yield components. The studies that have been conducted on this aspect so far are reviewed here.

2.1 DIFFERENT CROP ESTABLISHMENT METHODS IN RICE

2.1.1 Conventional crop establishment methods

Direct sowing and normal transplanting are the crop establishment methods conventionally followed in rice. Various studies have been conducted to compare these methods with respect to growth and yield performance and pest and disease management.

Naklang *et al*. (1996), conducted a study to analyze the growth of rice cultivars in direct seeding and transplanting under upland and lowland conditions and found that the direct seeding by broadcasting produced more dry matter than transplanting. The reduced transplanting shock, better root establishment during initial growth period and higher plant density were considered as the contributing factors.

Iwuagwu *et al*. (2017) reported that different planting methods of rice influenced yield, some yield components, disease incidence and severity significantly. According to them, transplanting in rice produced higher number of tillers, panicles and yield than direct seeding due to optimum spacing and growth conditions. On the other hand, poor spacing and high population density of direct seeding favoured fungal pathogens by forming a dense and humid canopy.

2.1.2 Paired row planting

Paired row planting is a modified planting geometry developed at the Regional Agricultural Research Station, Pattambi which utilizes the border effect to enhance the yield of rice. In a study conducted by Moossa *et al*. (2017), four types of planting geometry - paired row planting (35 -15 cm ×10 cm and 30 - 15 cm × 10 cm), equal row spacing planting (20 cm × 15 cm) and circular planting (with each plant getting 50 cm spacing towards one side) - were compared to assess the border effect and its effect on yield and yield attributes and found that paired row planting with 35 - 15 cm × 10 cm spacing produced 23 per cent higher yield over others by utilizing the border effect.

Mahmud *et al*. (2014) conducted an experiment to study the effect of planting density on the performance of *boro* rice and came up with a similar conclusion that paired row planting at a spacing of 35 - 15 cm × 10 cm acquired highest grain yield when compared to other single row and paired row configurations considered in the study. Mahajan et al. (2014) also observed that grain yield of some rice cultivars could be improved by exploiting their competitiveness through paired-row planting patterns with less use of herbicides.

Mandal *et al.* (2019) compared three planting methods - paired row, ridge and furrow and traditional flat bed - in groundnut and showed that the root dry weight, intercepted photosynthetically active radiation, chlorophyll fluorescence and rate of leaf photosynthesis registered higher in paired row planting when compared to other two systems that eventually contributed to higher yield and nutrient uptake.

2.2 INFLUENCE OF PLANTING GEOMETRY ON INCIDENCE OF DISEASE

Burden and Chilvers (1982) assessed the role of host density as a factor in plant disease ecology and reported that it could influence disease incidence directly through geometrical effects on inoculation frequency and indirectly through interactions with the environment. Changes in host density were also reported to alter the physiological characteristics of target plants by influencing the competitive interactions among them for natural resources thereby affecting the predisposition factors of host plants to disease infection. They also added that host density would change micrometeorological parameters which would in turn influence inoculum release, flight, and collection, and the prepenetration phase of the infection process.

Pangga *et al*. (2013) suggested that the relationships between canopy architecture and microclimate of host plant, pest and pathogen populations were multi-dimensional. They interacted with each other in such a manner that a change that occurred in one relationship induced changes in one or more relationships. However, Giesler *et al.* (1996), observed that extreme weather conditions like precipitation could mask the effect of crop geometry and the associated microclimate.

It was reported that dense canopies were more efficient in the retention of precipitation resulting in extended periods of surface wetness and relative humidity that acted as congenial factors for the development of various diseases (Pangga *et al*., 2013). Ando *et al*. (2007) suggested that manipulating plant architecture could be considered as a productive alternative for managing disease severity by reducing contact with pathogen, creating barriers to the growth and dispersal of pathogen and inducing unfavourable microclimate for disease development.

2.2.1 Influence of planting geometry on incidence of diseases in cereal crops

Agrios (1997) reported that close spacing would produce etiolated plants, increasing susceptibility to pathogens. Humid microclimate created by close spacing has been reported to increase the incidence and severity of various plant diseases. Adipala *et al*. (1994) observed that severity of northern leaf blight in maize increased with higher plant density due to the favourable microclimate created within the crop canopy. Similarly, the number of maize plants infected with sorghum downy mildew decreased with increased distance from the primary inoculum sources, *i.e*. the infected plant tissues (Hau *et al*., 1995).

Cook *et al*. (2000) found that the more open canopy provided by paired row spacing in wheat limited pressure from root diseases, namely take all disease, *Rhizoctonia* root rot and *Pythium* root rot because of a microenvironment effect that disturbed the cool and moist soil conditions favouring root diseases. Similarly, higher incidence of *Erysiphe graminis* on wheat and *Rhizoctonia solani* in rice were reported in closely spaced plots than in widely spaced plots (Agrios, 1997; Willocquet *et al*. 2000).

2.2.2 Influence of planting geometry on incidence of diseases in rice

Castilla *et a*l. (1996) reported that the inoculation efficiency was higher in closer planting in rice. They found that the effect of plant spacing on the number of leaf-to-sheath contacts was marginal, suggesting that leaf-to-leaf contacts played a more crucial role than leaf-to-sheath contacts in the horizontal spread of sheath blight. They reported that the increased contact between healthy and diseased tissues in closer planting acted as a bridge for the spread of mycelial hyphae.

Rice sheath blight epidemics were compared during two seasons in two different crop establishment methods: direct broadcasting of pre-germinated seeds and transplanting of seedlings at spacing of 20 cm × 20 cm, 13 cm × 25 cm and 25 cm × 25 cm between hills. In both years, the apparent infection rate and the terminal severity of sheath blight was lower in the direct-seeded crops than the transplanted ones. The role of foliar contact in the spread of sheath blight was also revealed in this study (Willocquet *et al*., 2000). Approving this observation, Rautaray (2007) also suggested that the discontinuity of canopy in skipped rows might help in restricting the disease spread, particularly, at early vegetative stage when the canopy coverage is low.

In a study conducted by Yang *et al*. (2008), the square method of transplanting resulted in decrease of the relative humidity and temperature below the crop canopy as well as increase in evapotranspiration and sunlight penetration, resulting in unfavourable environment for sheath blight disease development.

Meteorological parameters like mean air temperature, mean relative humidity within crop canopy can be modified by closer and wider plant spacing which ultimately affect disease development. In a study conducted by Biswas *et al.* (2012) under closer spacing (20 cm × 15 cm), median temperature was around 30.5ºC and relative humidity remained between 96 to 100 per cent which proved to be driving factor in severe development of sheath blight. On the other hand, median temperature was around 32ºC and relative humidity was between 85 and 92 per cent under wider spacing (20 cm × 20 cm) and thus less conducive for disease development. Kaur *et al*. (2015) reported that sheath blight was more in conventional transplanted crop as compared to bed transplanted crop. High relative humidity (more than 90 per cent) favoured the spread of the disease.

Koshkdaman *et al*. (2020) analyzed sheath blight development and yield loss on rice in different epidemiological conditions and reported that higher dose of nitrogen application increased number of tillers and reduced plant height resulting in dense canopy with altered microclimate favouring sheath blight development. They also observed that the closer spacing increased relative humidity and decreased canopy temperature when compared to sparse planting which resulted in increased sheath blight severity. According to them, close space planting increased contact of infected tissues with healthy ones on adjacent plants which acted as a physical bridge for the running hyphal strands. This observation was consistent with the finding made by Wu *et al.* (2015) who categorized nitrogen application and dense planting as factors favouring sheath blight development.

Rashid *et al.* (2019) conducted an experiment to study row spacing as a strategy to control bacterial leaf blight in direct seeded rice. Among the three different row spacing (15, 22.5 and 30 cm) tested, wider row spacing significantly reduced bacterial blight severity. This was in corroboration with the findings made by Meah (1987) during his assessment of effect of nitrogen and plant spacing on bacterial leaf blight of rice. He found that plants in narrower spacing were severely affected by bacterial blight. Amin *et al*. (2022) reported that higher relative humidity and cloudy weather favoured bacterial blight incidence and severity.

The field experiments conducted to study the effect of meteorological factors on incidence of brown spot of rice, under different planting methods revealed that brown spot was high in conventional planting followed by SRI. The disease incidence was five per cent higher in high plant population as compared to lower population mainly because of high relative humidity within the crop canopy (Dhaliwal *et al*., 2018).

During a study conducted by Rautaray (2007) to assess the effect of planting geometry on grain yield and disease incidence in rice, it was found that the incidence and severity of sheath rot were less under the planting geometry of skipping one row after every three rows with 15 cm × 15 cm spacing. The restricted movement of leaf hoppers, the insect vectors of the tungro virus, across the skipped rows was attributed as the possible contributing factor for this reduction in incidence and severity considering the association of sheath rot disease with virus infected plants.

Misra and Vir (1992) studied the extent of seed discolouration in paddy under different spacing *i.e.,* 15 cm × 15 cm, 20 cm × I5 cm, 20 cm × 20 cm and 25 cm × 20 cm and found that discolouration was less when larger spacing *i.e.* 25 cm × 20 cm was provided in the field. They also studied the effect of crop establishment method on disease incidence and found that discolouration was more in transplanted crop when compared to direct sown crop.

Shafaullah *et al*. (2011), when studying the effect of epidemiological factors on the incidence and severity of paddy blast, found that relative humidity and temperature exhibited a negative and positive correlation respectively with blast incidence.

Jiehui *et al.* (2022) observed that higher relative humidity and more moderate temperatures increased the severity of rice false smut disease in the rice–crayfish coculture when compared to rice monoculture. The germination rate of conidia of

Ustilaginoidea virens was found to be higher under rice-crayfish coculture than that under rice monoculture.

2.3 INFLUENCE OF PLANTING GEOMETRY ON PEST INCIDENCE

Studies that have been conducted to elucidate the influence of planting geometry on pest population showed that the closely spaced plants shaded each other and altered the microclimate within the crop canopy, making rice plants more vulnerable to insect pests. The changes in planting density were also reported to alter the flight behaviour, landing response and feeding activity of insects by creating a change in their perceived environment (Burdon and Chilvers, 1982). This in turn influenced the insect pest population within the crop canopy.

Asghar *et al*. (2020) reported that the number of rice plant hoppers remained higher in wider spacing than in closer spacing. Dhillon *et al.* (2020) also came up with a similar observation stating that an increased seedling density resulted in a higher plant hopper population in rice.

Similarly, narrow and compact planting of rice seedlings resulting in the development of bushy and dense canopy often resulted in the creation of microclimate congenial for the brown plant hopper (BPH) population. To reinforce the inference regarding the influence of a closed canopy on increased BPH population, it was stated that skipping rows in the rice field to control BPH population would not result in a reduced yield (Satpathi *et al*., 2012).

Pangga *et al.* (2013) observed that the size of crop canopy determined the abundance and diversity of pests. Large canopies by providing more resources nurtured diverse insect fauna. It was reported that the variation in relative humidity at different heights produced variation in insect distribution in the canopy (Haile, 2000). Supporting this finding, Jena *et al*. (2018) reported that the close canopy formation resulted in the maintenance of higher relative humidity in the basal portion of rice plants, enhancing the activity of nymphs of plant hoppers and gall midge.

Oyediran *et al.* (1999) reported that the population of diopsid flies and the per cent dead hearts and white ear heads formed by stem borer feeding were generally higher in transplanted rice with closer spacing of 10 cm × 10 cm than in wider spacing of 30 cm × 30 cm. They also reported similar results when they compared the arthropod populations in direct seeded and transplanted lowland rice. The diopsid population remained higher at closer spacing irrespective of the method of planting. However, during this study, it was reported that planting method and spacing showed little effect on stem borer damage.

Ukwungwu (1987) made an attempt to study the effect of spacing on rice gall midge and showed that an increase in per cent silver shoots was recorded at increased plant populations. Similar results were obtained by Saroja and Raju (1982). The humid and cooler microenvironment favouring the insect populations created at the base of the plants due to the less received radiation was considered as the possible reason for the observation.

Justin and Preetha (2013) observed that the yellow stem borer population in rice exhibited a significant positive correlation with relative humidity and a significant negative correlation with minimum temperature and rainfall. A similar observation was made by Yang *et al*. (2009).

Priyadharsan and Muthukumaran (2020) reported that the leaf folder population was positively correlated with relative humidity and negatively correlated with maximum and minimum temperature, sunshine and rainfall. These findings were consistent with that reported by Rasul *et al*. (2019).

Nirala and Chandrakar (2018) analyzed the seasonal incidence of rice caseworm in different rice ecosystems and found that the insect population recorded maximum in lowland conventional ecosystem when compared to midland and upland transplanted ecosystems. In that study, the caseworm damage recorded a maximum value during vegetative stages and then disappeared thereafter. Singh and Singh (2010) also reported similar results stating that caseworm damage was observed at seedling and tillering stages and disappeared after the maximum tillering stage. Rao and Padhi (1984) suggested that the seedling density and plant spacing did not influence caseworm incidence significantly. On the other hand, it got increased significantly with increased depth of standing water.

The correlation studies conducted between the rice bug and various weather parameters revealed a significant negative correlation with minimum temperature, average temperature, morning relative humidity, evening relative humidity, average relative humidity, rainfall and significant positive correlation with sunshine hours (Paikra *et al*., 2021). Mohanta *et al*. (2020) also came up with similar correlation results.

However, contrary to this, Kumar *et al*. (2017) reported that the population of rice bug showed non significant association with biotic and abiotic factors including relative humidity and temperature.

Pathak (1968) studied the ecology of rice bugs and reported that all life stages were vulnerable to changes in temperature and humidity. They appeared to be abundant at a temperature of 27° to 28° C and 80 to 82 per cent relative humidity. He reported warm weather, overcast skies, and frequent drizzle during flowering stage as favouring factors and heavy rainfall as detrimental factor of rice bug population. The population was found to be decreased after the onset of cool and dry period favouring some of the late planted varieties.

Recent research conducted by Wang *et al*. (2022) reported that rice grown at lower density exhibited greater antioxidant enzyme activity, which was associated with defense responses of plants against insects. Also, the closer spacing and associated shading effect were reported to create a humid microclimate favouring insect pest population.

Therefore, maintaining a wide spacing with low plant density may reduce insect pest population to an extent. Supporting this observation, Rautaray (2007) reported that skip row plantings might be beneficial in restricting the spread of hoppers due to their low mobility, especially at nymph stage. He also mentioned the additional advantage of skip row planting in facilitating efficient chemical control by directing the nozzle of the insecticide spray towards the base of the plant, just above the water level, where brown and white backed plant hoppers usually congregate in addition to its role in managing pests naturally.

2.4 INFLUENCE OF PLANTING GEOMETRY ON RHIZOSPHERE MICROFLORA

As per the study conducted by Hortal *et al*. (2017), the plants and associated rhizosphere microflora interacted closely with each other and responded jointly to the changing environmental conditions and got subjected to environmental selection as a single entity. They assumed that plants played a pivotal role in shaping rhizosphere microbial communities by inducing changes in soil temperature, moisture, structure, litter quality and root exudates. Soil microbial communities, in turn, affected plants by influencing plant health, performance and other functional traits.

The direct studies designed to assess the influence of planting geometry on associated rhizosphere microflora happened to be fewer. However, several related studies could be found in the literature. Pattanayak *et al.* (2022) reported that significant variation in enzymatic activity and microbial count was observed among treatments involving crop establishment methods. It was reported that planting geometry with wider spacing and lower planting density with good soil aeration and reduced competition for resources, promoted better root development. It was also reported that plants that developed larger root systems and bigger canopies contributed more root exudates to the rhizosphere, where they acted as substrates for soil organisms promoting their abundance and biodiversity. This in turn promoted plant health and performance (Jones *et al*., 2009; Anas *et al*., 2011).

Cavalieri *et al*. (2020) while analyzing the effects of intra and interspecific plant density on rhizosphere bacterial communities, observed that an increase in the plant density changed the rhizosphere bacterial communities. This became evident when it was observed that the population of methylotrophic bacteria decreased with increased plant density. They stated that reduced plant cell growth due to high planting density resulted in decreased release of methanol as exudate declining methylotrophic bacteria in the rhizosphere. They also found that the relative abundance of a specialized community increased whereas, the richness and diversity of the rhizosphere communities decreased with density and intraspecific competition. The intraspecific competition resulted due to high plant density also reported to influence the competition between rhizosphere microbial communities.

In a study conducted by Lay *et al.* (2018) to assess the canola root associated microbiomes, it was reported that the relative abundance of *Olpidium brassicae*, a known pathogen of *Brassicaceae* family, was significantly reduced in the roots of canola planted at higher seeding density. Their results also suggested the possible role of seeding density in modifying the abundance of bacterial and fungal taxa that form the core microbiomes of canola by involving in the interactions between them and thereby influencing crop growth.

Aslam *et al*. (2013), during their attempt to elucidate the diversity of the bacterial community in the rice rhizosphere under conventional and no-tillage practices, found that crop growth stages exhibited a strong influence on bacterial diversity in addition to tillage practices and thus both seemed important in characterizing bacterial communities. During this study, it was observed that the population of a group of *Actinobacteria* declined from vegetative to ripening stages. Even though the trend of change in bacterial communities during different crop growth phases appeared to be similar irrespective of field conditions, the diversity varied.

Ghoshal and Singh (1995) also reported that the microbial biomass decreased sharply from seedling to flowering stage and then increased slightly. The less competition for nutrients by the plants, resulting in the availability of nutrients for rhizosphere microorganisms was considered as the factor responsible for the increase in microbial biomass during the initial growth phases. According to them, the accelerated nutrient uptake by the plants followed in the successive stages resulted in the decline in microbial biomass.

However, Wieland *et al*. (2001) reported that the plant development stages played a less significant role in the shifts of microorganism communities when compared to the soil type and plant species. Between the latter two, the effect of the soil type was higher than that of the plant species. Latour *et al.* (1996) also concluded that the diversity of the fluorescent Pseudomonas population in the rhizosphere was influenced mainly by the soil type.

2.5 INFLUENCE OF PLANTING GEOMETRY ON GROWTH AND YIELD ATTRIBUTES

Various studies have been conducted to optimize planting geometry to enhance growth and yield attributes. Crop yield can be altered by adopting different row spacing and arrangements and thereby altering the plant density.

Rautaray (2007) reported that variation in planting geometry could be achieved by altering row spacing and skip row arrangements. In a study, when skip row planting by skipping one row after every three rows (3:1) at spacing 15 cm × 15 cm and skipping two rows after every two rows (2:2) at spacing 15 cm × 15 cm and normal row planting with spacing 30 cm × 15 cm , 25 cm × 15 cm , 20 cm × 15 cm and 15 cm × 15 cm were compared, it was found that the planting geometry of skipping one row after every three rows with 15 cm × 15 cm spacing resulted in highest grain yield compared to other arrangements. The reduced number of grains per panicle nullified the effect of increased number of panicles and hills per unit area under close spacing. However, panicles per hill were observed to be higher under wide row spacing and skip row plantings which resulted in low plant density. A similar observation was reported by Kumar (2001) who stated that wide spacing tended to increase the number of tillers.

Gautam *et al.* (2008) compared growth, productivity and quality of rice at three spacing - 20 cm × 20 cm, 20cm × 15 cm, 20 cm × 10 cm - and showed that narrow spacing of 20 cm × 10 cm produced comparatively taller plants, higher leaf area index and more dry matter production over the wide spacing. However, number of tillers per hill, grain yield and quality were recorded highest at wide spacing of 20 cm × 20cm. Yield parameters *viz*. filled grains per panicle, panicle length, panicle weight and test weight and quality parameters *viz*., hulling, milling and head rice recovery were recorded highest in wide spacing.

Verma *et al*. (2012) during analyzing the response of crop geometry and nitrogen management on growth and yield of hybrid rice reported a similar observation. According to them, all the growth and yield attributes were maximum under wider crop geometry of 20 cm × 15 cm and minimum under closer crop geometry of 15 cm × 15 cm. However, grain yield obtained from closer crop geometry of 20 cm × 10 cm was found to be higher than that obtained from wider crop geometry of 20 cm × 15 cm, due to the higher plant population under former treatment in spite of better growth and yield attributing characters under the later treatment.

Sihag *et al*. (2015) conducted a study to assess the influence of spacing on growth and yield potential of dry direct seeded rice and found that the number of tillers per metre square recorded significantly higher in wide spacing of 25 cm × 25 cm compared to plant spacing of 20 cm × 10 cm and 20 cm × 20 cm. However, grain yield obtained from spacing of 25 cm × 25 cm was found to be at par with that obtained from the spacing of 20 cm × 10 cm. They also observed that the increase in number of plants and tillers per unit area at closer spacing tended to increase dry matter production than the wider spacing.

In a study conducted by Zhimomi *et al*. (2021) to analyze the effect of spacing and age of seedling on yield of rice under system of rice intensification, it was found that yield and yield attributes like panicle length, total number of grains per panicle, number of filled grains per panicle and test weight were recorded higher in wide spacing of 40 cm × 40 cm when compared to other two spacing - 30 cm × 30 cm, 20 cm × 20 cm analyzed in the study. The increase in the number of filled grains per panicle might be due to lower spikelet sterility. They also observed that difference in spacing did not influence plant height significantly. However, it influenced total dry weight, which recorded highest in closer spacing of 20 cm × 20 cm, and dry matter per plant, which recorded highest in wider spacing of 40 cm × 40 cm.

Some similar observations were made in the studies discussed above. Planting geometry influenced growth and yield attributes in rice. The growth parameters, yield and yield attributes were observed to be highest in the widest spacing considered in the respective studies. This appreciable improvement was attributed to the better utilization of space, solar radiation, light interception, soil aeration, root development and reduced competition among plants for resources in planting geometry with wide spacing and low planting density. According to the studies, the reduced competition and decreased population pressure on the individual plant for the resources and better partitioning of photosynthates from source to sink eventually resulted in improved yield and quality of grains. The ease in performing interculture operations in wider spacing was also considered as one of the contributing factors for the improved yield.

On the other hand, the growth parameters like number of hills per metre square and number tillers per metre square, which recorded highest in closer spacing, were considered as the factors responsible for the increased dry matter production and leaf area index. However, other growth and yield parameters were recorded as lowest in close spacing. It was reported that the increased dry matter production might have restricted the diversion of photosynthates toward reproductive organs, *i.e.* grains. It was also reported that the increased competition for resources among plants under high plant density made the plants fragile, susceptible to diseases and pests which resulted in deterioration of yield and quality parameters of rice. (Rautaray, 2007; Gautam *et al*., 2008; Bezbaruha *et al*., 2011; Sihag *et al*., 2015; Iwuagwu *et al*., 2017).

Materials & Methods

3. MATERIALS AND METHODS

The present study entitled "Influence of new planting geometry - paired row planting on incidence of diseases in rice" was conducted at the Regional Agricultural Research Station, Pattambi over two seasons (*rabi* 2021 and *kharif* 2022). In addition to diseases, pest incidence was also recorded in this study. The materials used and methods followed in this study are detailed below.

3.1 ASSESSMENT OF INFLUENCE OF PAIRED ROW PLANTING ON DISEASE AND PEST INCIDENCE IN RICE

A field experiment was laid out in randomized block design with three treatments and seven replications at Regional Agricultural Research Station, Pattambi over two seasons (*rabi* 2021 and *kharif* 2022) to assess the incidence of diseases and pests in paired row planting, a new planting geometry. The details of the experiment are as follows.

Design	: Randomized Block Design (RBD)
Variety	: Jyothi
Replications	: 7
Plot size	: 40 m^2
Treatments	: 3

T1 - Paired row planting (30 - 15 cm × 10 cm) - 40 hills m^{-2}

T2 - Normal transplanting (15 cm × 10 cm) - 66 hills m^{-2}

T3 - Direct sowing (Wet seeding by broadcasting)

Seeds were sown in the main field in direct sown treatment (T3) and in nursery for treatments T1 and T2 on the same day. The seed rate adopted in the direct sown plot was 100 kg per ha. The seedlings were transplanted 25 days after sowing in normal transplanting (T2) and paired row planting (T1) systems according to the spacing mentioned above. All crop management practices were followed as per the KAU Package of Practices Recommendations (Plates 1. and 2.). However, no crop protection measures were adopted.

3.1.1 Assessment of incidence and severity of diseases

3.1.1.1 Assessment of incidence of diseases

The disease incidence was calculated at ten days interval by counting the total number of plants and the number of infected plants from an area of one square metre selected randomly from each plot. The disease incidence (DI) was then calculated using the following formula.

$$\text{Disease incidence} = \frac{\text{Total number of infected plants}}{\text{Total number of plants observed}} \times 100$$

3.1.1.2 ***Assessment of severity of diseases***

From each plot, ten plants were selected randomly and disease reactions were scored at every ten days interval after the first notice of symptoms in the field based on the Standard Evaluation System (SES) for rice given by IRRI. The respective SES scale used for assessing the severity of each observed disease is depicted below. Using the recorded observations, per cent disease index (PDI) was calculated using the following formula (Wheeler, 1969).

$$\text{PDI} = \frac{\text{Sum of numerical ratings}}{\text{Total number of observations} \times \text{Maximum Disease grade}} \times 100$$

Table 1 a. SES scale for bacterial blight of rice (IRRI, 2014)

Sl.No.	Per cent leaf area diseased	Score
1.	1-5%	1
2.	6-12%	3
3.	13-25%	5
4.	26-50%	7
5.	51-100%	9

Table 1 b. SES scale for brown spot of rice (IRRI, 2014)

Sl.No.	Per cent leaf area diseased	Score
1.	No disease observed	0
2.	Less than 1%	1
3.	1-3%	2
4.	4-5%	3
5.	6-10%	4
6.	11-15%	5
7.	16-25%	6
8.	26-50%	7
9.	51-75%	8
10.	76-100%	9

Plate 1. Overview of the field - *Rabi* 2021

Plate 2. Overview of the field - *Kharif* 2022

Table 1 c. SES scale for sheath blight of rice (IRRI, 2014)

Sl.No.	Relative lesion height	Score
1.	No infection observed	0
2.	Lesions limited to lower 20% of the plant height	1
3.	20-30%	3
4.	31-45%	5
5.	46-65%	7
6.	More than 65%	9

Table 1 d. SES scale for sheath rot of rice (IRRI, 2014)

Sl.No.	Per cent diseased tillers	Scale
1.	No disease observed	0
2.	Less than 1%	1
3.	1-5%	3
4.	6-25%	5
5.	26-50%	7
6.	51-100%	9

Table 1 e. SES scale for false smut of rice (IRRI, 2014)

Sl.No.	Percentage of infected florets	Score
1.	No disease observed	0
2.	Less than 1%	1
3.	1-5%	3
4.	6-25%	5
5.	26-50%	7
6.	51-100%	9

3.1.2 Assessment of pest incidence

The observations of major insect pest infestations in rice were recorded at ten days interval selecting ten hills randomly from each plot.

3.1.2.1 Assessment of yellow stem borer incidence

The infestation of yellow stem borer was expressed in terms of per cent dead heart at vegetative stage and per cent white ear head at reproductive stage. During the vegetative stage, the total number of tillers and the number of dead hearts (DH) were counted from ten hills selected randomly from each plot and the per cent dead heart was calculated by using the following formula.

$$\text{Per cent dead heart (DH \%)} = \frac{\text{Number of dead hearts}}{\text{Total number of tillers per hill}} \times 100$$

At reproductive stage, total number of panicles and the number of white ear heads were counted from ten hills selected randomly from each plot. The per cent white ear head was then calculated using the following formula.

$$\text{Per cent white ear head (WEH \%)} = \frac{\text{Number of white ear heads}}{\text{Total number of panicles per hill}} \times 100$$

3.1.2.2 Assessment of caseworm incidence

The damage caused due to caseworm was computed by counting the total number of leaves and the number of damaged leaves from ten hills selected randomly from each plot at an interval of ten days. The per cent damage due to caseworm was then calculated by using the following formula.

$$\text{Per cent damage due to caseworm} = \frac{\text{Number of damaged leaves}}{\text{Total number of leaves per hill}} \times 100$$

3.1.2.3 Assessment of leaf folder incidence

The leaf folder damage was assessed by counting the total number of leaves and the number of leaves infested by leaf folder of ten hills randomly selected from each plot at an interval of ten days. The per cent damage due to leaf folder was then calculated by using the following formula.

$$\text{Per cent damage due to leaf folder} = \frac{\text{Number of damaged leaves}}{\text{Total number of leaves per hill}} \times 100$$

3.1.2.4 Assessment of rice bug incidence

The damage caused due to rice bug was estimated by counting the number of infected grains of ten panicles randomly selected from each plot during the harvesting stage. The per cent damage due to rice bug was estimated by using the following formula.

$$\text{Per cent damage due to rice bug} = \frac{\text{Number of infected grains}}{\text{Total number of grains per panicle}} \times 100$$

3.2 ENUMERATION OF RHIZOSPHERE MICROFLORA

Enumeration of rhizosphere microflora was carried out using serial dilution and plate count technique (Johnson and Curl, 1972) at 20, 50 and 75 days after sowing. The media and dilutions used for enumerating different groups of microorganisms are presented in Table 2.

Table 2. Media and dilutions used for isolation of microorganisms

Sl. No.	Target microorganisms	Media	Dilutions
1	Fungi	Martin's rose Bengal agar	10^{-3}
2	Actinomycetes	Kenknight agar	10^{-5}
3	Bacteria	Nutrient agar	10^{-7}

Ten gram of soil sample diluted aseptically in 100 ml of sterilized distilled water was vortexed to obtain a uniform suspension of 10^{-1} dilution. 1 ml of this suspension was added to 9 ml of sterilized distilled water to give 10^{-2} concentration. Similarly, serial dilutions were made to give concentrations upto 10^{-7}. Triplicates of each dilution of 10^{-3}, 10^{-5}, and 10^{-7} were used to isolate fungi, actinomycetes and bacteria respectively. One ml aliquot from each dilution was poured aseptically in to the Petri plate. 20 ml of molten and cooled agar media was then poured in the Petri plate. The plates were then rotated clockwise and anticlockwise manually for uniform distribution of the suspension in medium. After solidification, the plates were incubated in an inverted position at room temperature for 3-5 days. After the incubation period, the number of colony forming units (CFU) per plate was counted and the average of the triplicate microbial counts was taken and expressed as colony forming units per gram of soil in the respective dilutions.

3.3 MICROMETEOROLOGICAL OBSERVATIONS

The relative humidity within the crop canopy was recorded at every ten days interval at 7.00 a.m. and 2.00 p.m. by using a whirling psychrometer. The whirling psychrometer which gives dry bulb and wet bulb temperature was used to measure the relative humidity using the psychrometric chart. Canopy temperature was also recorded at ten days interval using infrared thermometer at 2.00 p.m. The recorded micrometeorological observations were correlated with corresponding disease and pest variables using Statistical Package for Social Sciences (SPSS) and MS Excel software.

3.4 BIOMETRIC OBSERVATIONS

Biometric observations *viz*. plant height, number of tillers, number of leaves and leaf area were recorded at an interval of ten days.

3.4.1 Plant height

Ten plants were selected randomly from each plot and height was measured from the base of each plant to the tip of the topmost leaf. The mean height was computed and expressed in centimetre (cm).

3.4.2 Number of tillers

The number of tillers was counted from ten hills selected randomly from each plot at an interval of ten days and the mean was computed and expressed as the number of tillers per hill.

3.4.3 Number of leaves

The number of leaves was counted from ten randomly selected hills of each plot at an interval of ten days and the mean was computed and expressed as the number of leaves per hill.

3.4.4 Leaf area

Ten hills were selected randomly from each plot at an interval of ten days and the area of the topmost leaf of each hill was measured. The mean leaf area was computed and expressed in centimetre square (cm^2).

3.5 YIELD AND YIELD ATTRIBUTES

3.5.1 Number of hills per metre square

The number of hills were counted from an area of one metre square selected randomly from each plot during the harvesting stage and the mean was computed and expressed as number of hills per metre square.

3.5.2 Number of panicles per hill

The number of panicles was counted from ten hills selected randomly from each plot during the harvesting stage and the mean was computed and expressed as number of panicles per hill.

3.5.3 Number of grains per panicle

The number of grains of ten randomly selected panicles from each plot was counted and the mean was computed and expressed as number of grains per panicle.

3.5.4 1000 grain weight

Thousand grains were taken randomly from the produce of each plot and weighed. The mean thousand grain weight was expressed in gram (g).

3.5.5 Grain yield

The harvested grains from each plot were weighed after winnowing, cleaning and drying. The mean was calculated and expressed in kilogram per hectare (kg ha^{-1}).

3.6 STATISTICAL ANALYSIS

Analysis of variance was performed on the observed and computed values from the experiment using the Web Agri Stat Package (WASP 2.0) and MS Excel software.

Results

4. RESULTS

The results of the study entitled "Influence of new planting geometry - paired row planting on incidence of diseases in rice" conducted at the Regional Agricultural Research Station, Pattambi during the year 2020-2022 are detailed below. In addition to diseases, pest incidence was also recorded in this study (Plates 3 - 5).

4.1 ASSESSMENT OF INFLUENCE OF PLANTING GEOMETRY ON INCIDENCE OF DISEASES IN RICE

A field experiment was conducted over two seasons (*rabi* 2021 and *kharif* 2022) to study the influence of paired row planting on disease incidence in rice. Disease incidence and severity were recorded at ten days intervals from the first notice of the symptom in the field. During the *rabi* season the diseases observed were bacterial blight, sheath blight, brown spot and false smut. In the *kharif* season, in addition to these diseases, sheath rot was also observed. The incidence of blast and grain discolouration was not observed in both seasons.

4.1.1 Incidence of bacterial blight in different planting systems of rice

The incidence and severity of bacterial blight, caused by *Xanthomonas oryzae* pv. *oryzae*, were recorded based on the typical symptoms caused by the pathogen. The symptom appeared as yellowish or straw coloured lesions starting from the tips of leaves and extending downwards through the margins (Plate 6.).

4.1.1.1 Disease incidence and severity of bacterial blight during rabi season

The incidence and severity of bacterial blight in different planting systems of rice during the *rabi* season is depicted in Table 3 a. and Table 3 b. respectively. The results showed that when the disease progressed from the initial growth stages to the physiological maturity stage, significant differences in disease incidence and severity were observed between the different systems.

During the first observed interval of this study (30 DAS), no disease symptoms were observed in paired row planting and normal transplanting, whereas in the direct sowing, incidence of disease was recorded (Table 3 a). The disease gradually advanced and in the next interval, the disease was noticed in all three systems. However, the disease incidence (DI) in paired row planting (20.67%) was statistically on par with that of normal transplanting (21.31%) and significantly lower than in direct sowing (36.19%). During the active tillering stage (50 DAS), a significant difference in DI was

Table 3 a. Incidence of bacterial blight in different planting systems of rice (*Rabi* season)

Sl. No.	Treatments	DI (%)							
		30 DAS	40 DAS	50 DAS	60 DAS	70 DAS	80 DAS	90 DAS	100 DAS
				AT	PI	B	H	F	PM
1.	T1-Paired row planting	0.00 (0.29)[b]	12.50 (20.67)[b]	22.38 (28.21)[c]	26.00 (30.65)[c]	29.88 (33.13)[c]	27.25 (31.46)[c]	15.13 (22.83)[c]	19.13 (25.91)[c]
2.	T2-Normal transplanting	0.00 (0.29)[b]	13.25 (21.31)[b]	28.88 (32.50)[b]	30.75 (33.68)[b]	42.50 (40.69)[b]	34.88 (36.19)[b]	18.88 (25.74)[b]	24.50 (29.66)[b]
3.	T3-Direct sowing	8.25 (16.55)[a]	34.88 (36.19)[a]	43.88 (41.48)[a]	47.25 (43.42)[a]	57.00 (49.03)[a]	51.63 (45.93)[a]	47.38 (43.50)[a]	39.88 (39.16)[a]
CD (0.05)		1.55	1.08	1.29	0.82	0.62	0.98	1.48	1.18

Table 3 b. Severity of bacterial blight in different planting systems of rice (*Rabi* season)

Sl. No.	Treatments	PDI							
		30 DAS	40 DAS	50 DAS	60 DAS	70 DAS	80 DAS	90 DAS	100 DAS
				AT	PI	B	H	F	PM
1.	T1-Paired row planting	0.00 (0.29)[b]	10.25 (18.65)[c]	19.63 (26.29)[c]	22.75 (28.48)[c]	29.13 (32.64)[c]	24.00 (29.32)[c]	22.75 (28.48)[c]	17.63 (24.82)[c]
2.	T2-Normal transplanting	0.00 (0.29)[b]	18.25 (25.28)[b]	27.38 (31.54)[b]	31.75 (34.29)[b]	41.00 (39.81)[b]	36.88 (37.38)[b]	26.25 (30.86)[b]	23.63 (29.08)[b]
3.	T3-Direct sowing	3.75 (9.18)[a]	34.5 (35.97)[a]	47.25 (43.42)[a]	50.38 (45.22)[a]	58.88 (50.12)[a]	53.25 (46.87)[a]	52.00 (46.15)[a]	41.50 (40.10)[a]
CD (0.05)		4.31	1.22	1.03	1.51	1.01	1.68	1.53	0.71

DAS: Days after sowing; DI: Disease incidence; PDI: Per cent disease index; AT: Active tillering; PI: Panicle initiation; B: Booting; H: Heading; F: Flowering; PM: Physiological maturity

Values in parenthesis are arcsine transformed

Plate 3 a. Layout

Plate 3 b. Sowing

Plate 3 c. Transplanting

Plate 3 d. Overview of the field

Plate 3 e. Harvesting

Plate 3 f. Threshing

Plate 3. Various operations performed in the field (*Rabi* 2021)

Plate 4 a. Layout

Plate 4 b. Sowing

Plate 4 c. Transplanting

Plate 4 d. Overview of the field

Plate 4 e. Harvesting

Plate 4 f. Threshing

Plate 4. Various operations performed in the field (*Kharif* 2022)

Plate 5 a. Paired row planting

Plate 5 b. Normal transplanting

Plate 5 c. Direct Sowing

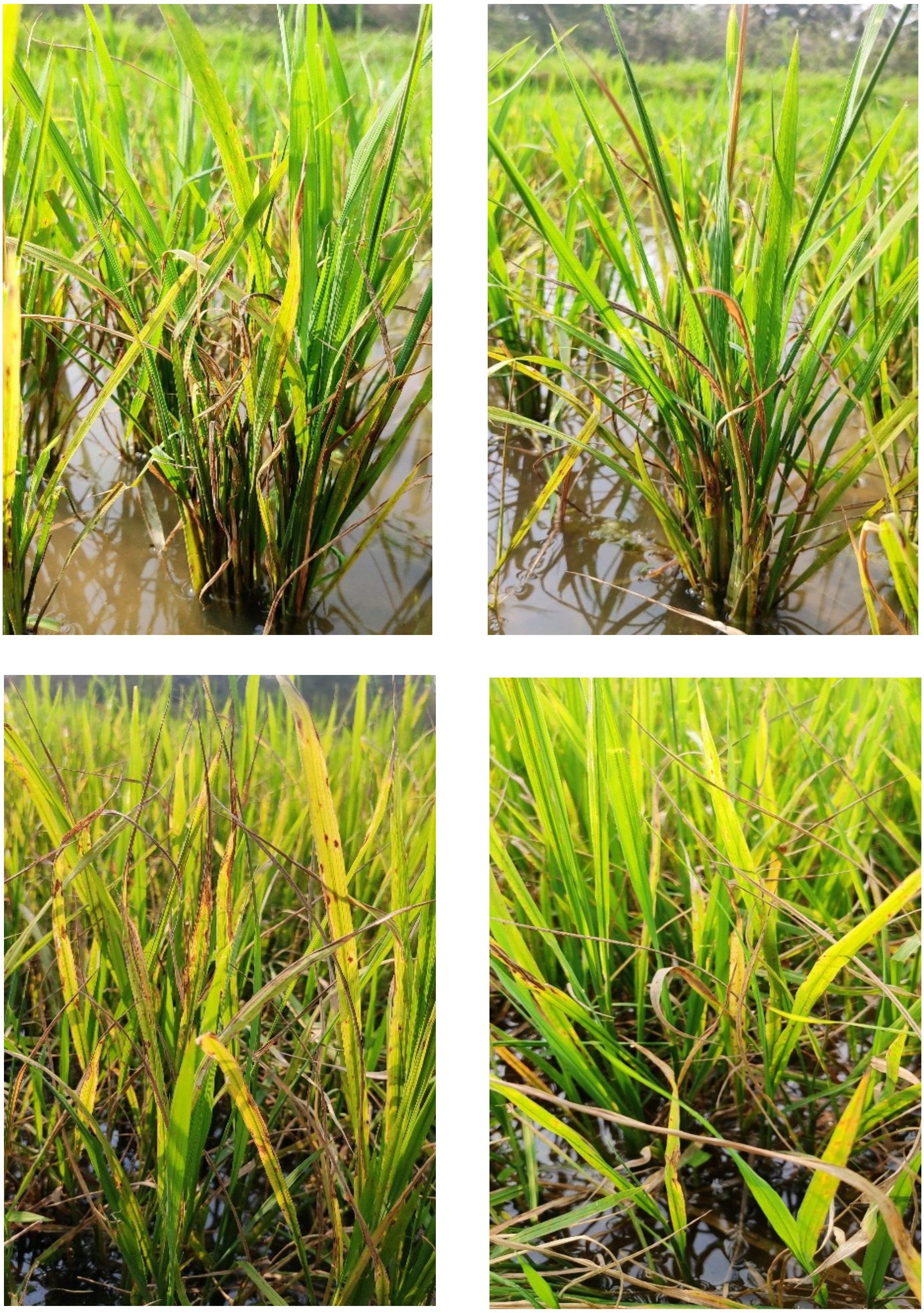


Plate 6. Symptoms of bacterial blight

noticed again. In this stage, the lowest DI was recorded in paired row planting (28.21%) and the highest in direct sowing (41.48%). Similar observations were obtained in the succeeding stages. In paired row planting, the DI (30.65%) recorded in panicle initiation stage (60 DAS) was significantly lower than that recorded in normal transplanting (33.68%) and direct sowing (43.42%). The highest DI was observed in booting stage (70 DAS) in all the three systems, the lowest being in paired row planting (33.13%) and the highest being in direct sowing (49.03%). During the heading stage (80 DAS) also, the DI recorded in paired row planting (31.46%) was significantly lower compared to that in normal transplanting (36.19%) and direct sowing (45.93%). The same trend repeated in flowering and physiological maturity stages wherein the DI recorded in paired row planting was significantly lower than in the other two systems (Table 3 a.) In all the observed intervals, DI recorded in paired row planting was significantly lower than the other systems, except in the initial stages, where the DI recorded in paired row planting was on par with that observed in normal transplanting.

In addition to disease incidence, disease severity was also recorded at ten days intervals and per cent disease index (PDI) was calculated. The PDI also showed the same trend as DI (Table 3 b.). The severity of bacterial blight developed progressively from the initial tillering stage till the booting stage and a further increase was not noticed thereafter. During the first observed interval (30 DAS), the disease was observed only in the direct sown plot (9.18). However, in the next stage (40 DAS), the disease was recorded in all three systems with significant differences between them. During the active tillering stage (50 DAS), a similar observation was made. In this stage, the PDI observed in paired row planting, normal transplanting and direct sowing respectively were 26.29, 31.54 and 43.42. In the panicle initiation stage, PDI recorded in paired row planting (28.48) was significantly lower than normal transplanting (34.29) and direct sowing (45.22). The highest PDI was recorded in the booting stage in all the systems with the direct sowing showing the highest PDI (50.12), followed by the normal transplanting (39.81) which was significantly low. In this stage, PDI recorded in paired row planting (32.64) was significantly less compared to the other two systems. In the heading stage, the PDI observed in paired row planting was 29.32, which was significantly lower than normal transplanting (37.38) and direct sowing (46.87). A similar trend was observed in flowering and physiological maturity stages also (Table 3 b.)

4.1.1.2 Disease incidence and severity of bacterial blight during kharif season

The incidence and severity of bacterial blight in different planting systems of rice during *kharif* season is depicted in Table 4 a. and Table 4 b. respectively. The disease incidence and severity increased gradually as the crop developed, with the highest levels observed during the flowering stage. After the flowering stage, the disease incidence and severity showed no further increase.

The paired row and normal transplanted plots were observed to be free from bacterial blight when it was first noticed in the direct sown plot (30 DAS) (Table 4 a.). In the next observed interval (40 DAS), DI was significantly higher in direct sowing (26.91%) than that observed in the other two systems. During this interval, there was no significant difference between the DI observed in paired row planting (20.44%) and normal transplanting (21.61%). However, a significant difference with respect to DI was observed between the systems in the succeeding intervals. In the active tillering stage, the DI recorded in paired row planting (23.53%) was significantly lower than the DI observed in normal transplanting (26.28%) and direct sowing (36.42%). Similarly in the panicle initiation, booting and heading stages, the DI remained significantly lower in paired row planting. In these three stages, DI recorded in normal transplanting was significantly less compared to direct sowing (Table 4 a). The highest DI was recorded at the flowering stage in all three systems. In this stage, the lowest incidence was recorded in paired row planting (31.46%) and the highest in direct sowing (45.93%). At the physiological maturity stage also, DI recorded in paired row planting (31.28%) was significantly less compared to normal transplanting (35.25%) and direct sowing (45.00%). In all the observed intervals, the lowest DI was observed in paired row planting, followed by normal transplanting and direct sowing.

A similar observation was made when disease severity was recorded (Table 4 b.). The PDI gradually increased till the flowering stage. During the first observed interval, incidence of bacterial blight was not recorded in paired row planting and normal transplanting. The disease was noticed in direct sown plots. However, in the next interval, disease incidence was noticed in all three systems with significant differences between them. In this stage, the lowest PDI was recorded in paired row planting (13.19)

Table 4 a. Incidence of bacterial blight in different planting systems of rice (*Kharif* season)

Sl. No.	Treatments	DI (%)							
		30 DAS	40 DAS	50 DAS	60 DAS	70 DAS	80 DAS	90 DAS	100 DAS
				AT	PI	B	H	F	PM
1.	T1-Paired row planting	0.00 (0.29)[b]	12.25 (20.44)[b]	16.00 (23.53)[c]	19.13 (25.91)[c]	21.38 (27.52)[c]	25.50 (30.33)[c]	27.25 (31.46)[c]	27.00 (31.28)[c]
2.	T2-Normal transplanting	0.00 (0.29)[b]	13.63 (21.61)[b]	19.63 (26.28)[b]	24.50 (29.66)[b]	28.75 (32.42)[b]	31.13 (33.91)[b]	35.38 (36.49)[b]	33.38 (35.25)[b]
3.	T3-Direct sowing	6.75 (15.03)[a]	20.50 (26.91)[a]	35.25 (36.42)[a]	39.88 (39.16)[a]	43.75 (41.41)[a]	47.63 (43.64)[a]	51.63 (45.93)[a]	50.00 (45.00)[a]
CD (0.05)		0.71	1.33	1.22	1.18	1.12	0.83	0.90	2.53

Table 4 b. Severity of bacterial blight in different planting systems of rice (*Kharif* season)

Sl. No.	Treatments	PDI							
		30 DAS	40 DAS	50 DAS	60 DAS	70 DAS	80 DAS	90 DAS	100 DAS
				AT	PI	B	H	F	PM
1.	T1-Paired row planting	0.00 (0.29)[b]	5.25 (13.19)[c]	10.25 (18.65)[c]	17.63 (24.82)[c]	19.63 (26.29)[c]	22.75 (28.48)[c]	24.50 (29.65)[c]	24.00 (29.32)[c]
2.	T2-Normal transplanting	0.00 (0.29)[b]	13.63 (21.61)[b]	18.25 (25.28)[b]	23.63 (29.08)[b]	27.38 (31.54)[b]	31.75 (34.29)[b]	38.88 (38.57)[b]	37.75 (37.91)[b]
3.	T3-Direct sowing	2.13 (6.57)[a]	16.63 (24.05)[a]	28.13 (32.01)[a]	34.50 (35.97)[a]	41.5 (40.10)[a]	47.25 (43.42)[a]	55.88 (48.38)[a]	54.25 (47.44)[a]
CD (0.05)		3.48	1.17	1.22	0.72	1.10	0.69	1.32	0.91

DAS: Days after sowing DI: Disease incidence; PDI: Per cent disease index; AT: Active tillering; PI: Panicle initiation; B: Booting; H: Heading; F: Flowering; PM: Physiological maturity. Values in parenthesis are arcsine transformed followed by normal transplanting (21.61) and direct sowing (24.05). In the active tillering stage also, a significant difference between the systems was observed and, in this stage, a PDI of 32.01 was recorded in direct sowing which was significantly higher than that of normal transplanting (25.28) and paired row planting (18.65). Similar observations were obtained in the panicle initiation, booting and heading stages. Even though PDI increased from a value of 24.82 to 28.48 over these three stages in paired row planting, they remained significantly lower than the PDI recorded in the other two systems (Table 4 b). In the flowering stage, the highest PDI was recorded in all three systems. However, PDI of paired row planting (29.65) was significantly lower than that of normal transplanting (38.57) and direct sowing (48.38). In the physiological maturity stage, the PDI recorded in direct sowing (47.44) was significantly higher compared to that in normal transplanting (37.91) and paired row planting (29.32). As in the case of disease incidence, in all the observed intervals, the PDI recorded in paired row planting remained significantly lower than in the other two systems.

4.1.2 Incidence of sheath blight in different planting systems of rice

The incidence and severity of sheath blight, caused by *Rhizoctonia solani,* were assessed based on the typical symptoms. Small pale, greenish-grey, ellipsoidal water-soaked lesions with dark brown margins appeared initially on the sheath of the plant just above the water level which later enlarged and coalesced to form larger lesions with greyish white centre and brown margins. In later stages, the lesion spread upward and extended to leaves also. Sclerotia of the fungi were also noticed on the infected parts (Plate 7).

4.1.2.1 Disease incidence and severity of sheath blight during rabi season

The incidence and severity of sheath blight in different planting geometry of rice during the *rabi* (2021) season is given in Table 5 a. and 5 b. respectively. The typical sheath blight symptom was first noticed in the field during the panicle initiation stage. Disease incidence and severity were recorded thereafter at ten days intervals in all three systems to evaluate the influence of planting geometry on disease development and spread. The disease developed progressively as the crop matured and entered the physiological maturity stage (Table 5 a.).

Plate 7. Symptoms of sheath blight

Table 5 a. Incidence of sheath blight in different planting systems of rice (*Rabi* season)

Sl. No.	Treatments	DI (%)				
		60 DAS	70 DAS	80 DAS	90 DAS	100 DAS
		PI	B	H	F	PM
1.	T1-Paired row planting	3.38 (10.23)[c]	7.88 (16.13)[c]	10.75 (19.05)[c]	15.75 (23.26)[c]	21.88 (27.85)[c]
2.	T2-Normal transplanting	6.75 (14.88)[b]	10.13 (18.51)[b]	14.63 (22.46)[b]	22.13 (28.03)[b]	29.75 (33.02)[b]
3.	T3-Direct sowing	10.13 (18.36)[a]	12.75 (20.85)[a]	20.00 (26.52)[a]	29.50 (32.85)[a]	39.88 (39.13)[a]
CD (0.05)		3.39	2.33	2.26	2.95	2.94

Table 5 b. Severity of sheath blight in different planting systems of rice (*Rabi* season)

Sl. No.	Treatments	PDI				
			70 DAS	80 DAS	90 DAS	100 DAS
		PI	B	H	F	PM
1	T1-Paired row planting	4.13 (11.50)[c]	7.63 (15.83)[c]	24.00 (29.26)[c]	38.88 (38.55)[c]	45.75 (42.56)[c]
2	T2-Normal transplanting	7.00 (15.14)[b]	15.75 (23.28)[b]	29.75 (33.04)[b]	44.50 (41.84)[b]	53.75 (47.15)[b]
3	T3-Direct sowing	10.63 (18.95)[a]	23.25 (28.73)[a]	36.38 (37.08)[a]	55.75 (48.31)[a]	64.75 (53.60)[a]
CD (0.05)		2.61	2.91	1.73	1.96	1.53

DAS: Days after sowing; DI: Disease incidence; PDI: Per cent disease index; PI: Panicle initiation; B: Booting; H: Heading; F: Flowering; PM: Physiological maturity

Values in parenthesis are arcsine transformed

In the panicle initiation stage, the DI recorded in paired row planting (10.23%) was significantly lower than that recorded in normal transplanting (14.88%) and direct sowing (18.36%). At the booting stage, the DI observed in paired row planting (16.13%) was significantly lower than in the other two systems, whereas the DI recorded in direct sowing (20.85%) was significantly higher than in the other two systems. A similar observation was made in the heading and flowering stages also. In both these stages, DI observed in paired row planting (19.05%, 23.26%) remained significantly lower than normal transplanting (22.46%, 28.03%) and direct sowing (26.52%, 32.85%). The DI recorded the highest in the physiological maturity stage in all three systems. In this stage, the DI observed in direct sowing (39.13%) was significantly higher than normal transplanting (33.02%) and paired row planting (27.85%). The DI observed in paired row planting in all the observed intervals was significantly lower than that observed in other two systems.

The observations of disease severity and disease incidence were found to be similar, with both increasing from the panicle initiation stage to the physiological maturity stage. PDI observed during the panicle initiation stage in paired row planting (11.50) was significantly lower than that observed in normal transplanting (15.14) and direct sowing (18.95). PDI increased from 18.95 to 53.60 in direct sowing, 15.14 to 47.15 in normal transplanting and 11.50 to 42.56 in paired row planting as the crop matured from the panicle initiation stage to physiological maturity. In all the observed intervals, significant differences between systems were observed with respect to PDI. In the booting stage, PDI observed in paired row planting (15.83) was significantly lower than that recorded in normal transplanting (23.28) and direct sowing (28.73). Similarly, in the heading and flowering stages, significantly lower PDI was recorded in paired row planting (29.26, 38.55) when compared to normal transplanting (33.04, 41.84) and direct sowing (37.08, 48.31). In all the observed intervals, the PDI observed in normal transplanting remained significantly higher than paired row planting and lower than direct sowing (Table 5 b.).

4.1.2.2 Disease incidence and severity of sheath blight during kharif season

Disease incidence and severity were computed during *kharif* season in all three systems to study the influence of planting geometry on sheath blight incidence. The corresponding observations are enlisted in Table 6 a and 6 b. Like *rabi* season, DI and

Table 6 a. Incidence of sheath blight in different planting systems of rice (*Kharif* season)

Sl. No.	Treatments	DI (%)				
		60 DAS	70 DAS	80 DAS	90 DAS	100 DAS
		PI	B	H	F	PM
1.	T1-Paired row planting	2.63 (7.29)	5.50 (12.42)^{b}	10.38 (18.66)^{c}	13.25 (21.30)^{c}	21.25 (27.42)^{c}
2.	T2-Normal transplanting	4.88 (11.00)	8.63 (16.82)^{a}	13.63 (21.65)^{b}	20.25 (26.73)^{b}	25.25 (30.15)^{b}
3.	T3-Direct sowing	6.38 (11.70)	10.25 (18.37)^{a}	16.75 (24.10)^{a}	24.88 (29.91)^{a}	32.50 (34.75)^{a}
CD (0.05)		NS	2.71	1.96	1.32	1.36

Table 6 b. Severity of sheath blight in different planting systems of rice (*Kharif* season)

Sl. No.	Treatments	PDI				
		60 DAS	70 DAS	80 DAS	90 DAS	100 DAS
		PI	B	H	F	PM
1.	T1-Paired row planting	1.63 (5.72)	4.88 (11.51)^{c}	12.50 (20.63)^{c}	27.75 (31.76)^{c}	32.13 (34.52)^{c}
2.	T2-Normal transplanting	2.38 (7.43)	7.63 (15.93)^{b}	19.75 (26.36)^{b}	35.00 (36.27)^{b}	47.75 (43.71)^{b}
3.	T3-Direct sowing	3.88 (9.05)	12.00 (20.22)^{a}	27.38 (31.54)^{a}	49.38 (44.64)^{a}	56.75 (48.89)^{a}
CD (0.05)		NS	3.75	1.88	1.51	1.45

DAS: Days after sowing; DI: Disease incidence; PDI: Per cent disease index; AT: Active tillering; PI: Panicle initiation; B: Booting; H: Heading; F: Flowering; PM: Physiological maturity

Values in parenthesis are arcsine transformed

PDI increased progressively from the panicle initiation stage, where the symptoms were first observed, to the physiological maturity stage. In the panicle initiation stage, even though disease appeared in all three systems, there was no significant difference between them with respect to DI (Table 6 a.). However, in the booting stage, DI observed in paired row planting (12.42%) was significantly lower than the other two systems. There was no significant difference between normal transplanting (16.82%) and direct sowing (18.37%) in this stage with respect to DI. In the heading stage, a significant difference was observed between the DI recorded in each system. At this stage, the highest DI was noticed in direct sowing (24.10%) followed by that observed in normal transplanting (21.65%) and paired row planting (18.66%). This trend repeated in the flowering and physiological maturity stages also. In these stages, the DI recorded in paired row planting was significantly less compared to normal transplanting (26.73%, 30.15%) and direct sowing (29.91%, 34.75%).

As in the case of DI, no significant differences were observed between the systems in the first observed interval with respect to the PDI. However, in the next stage, PDI observed in each system was found to be significantly different from one another. At this stage, PDI observed in direct sowing (20.22) was significantly higher than that observed in both the other systems. The disease severity advanced progressively over the stages till the crop entered the maturity stage. During heading and flowering stages, the PDI recorded in paired row planting (20.63, 31.76) were found to be significantly lower than normal transplanting (26.36, 36.27) and direct sowing (31.54, 44.64). Also in these stages, PDI observed in normal transplanting was significantly lower than direct sowing (Table 6 b.). The disease severity escalated to their highest in the physiological maturity stage, regardless of the systems. Even in this stage, a significant difference was noticed between the three systems with respect to disease severity. The PDI recorded in normal transplanting (43.71) in this stage was significantly less than direct sowing (48.89) and significantly higher than paired row planting (34.52). In all the observed intervals except the panicle initiation stage, where disease symptoms were first observed, the PDI recorded in paired row planting remained significantly less than the other two systems.

4.1.3 Incidence of brown spot in different planting systems of rice

The incidence and severity of brown spot disease, caused by *Helminthosporium oryzae*, in rice were assessed based on the symptoms caused by the pathogen. Characteristic oval to round brown spots were observed on leaves during the initial stages. As the disease advanced, these spots enlarged in size to some extent surrounded by yellow halo. Several such spots appeared on leaves (Plate 8).

4.1.3.1 Disease incidence and severity of brown spot during rabi season

The incidence and severity of brown spot recorded during the *rabi* season is presented in Table 7 a. and Table 7 b. respectively. During *rabi* season, the disease symptoms appeared in all three systems during the initial tillering stages itself. The DI recorded in all the three systems during the first observed interval (30 DAS) showed significant differences between them (Table 7 a.). DI was significantly less in paired row planting (15.70%) compared to normal transplanting (18.54%) and direct sowing (21.61%). In the next stage, the DI observed in direct sowing (25.67%) was significantly higher than the other two systems. The same trend followed in the succeeding stages with paired row planting having the lowest DI, followed by normal transplanting and direct sowing. In the active tillering stage, the DI observed in paired row planting (23.30%) was significantly less compared to normal transplanting (25.19%) and direct sowing (29.16%). Similarly in the panicle initiation stage, the DI noticed in direct sowing increased to 34.74 per cent which was significantly higher than the DI observed in the other two systems. In the booting stage, the DI recorded in all systems was more than 30 per cent. However, the DI recorded in paired row planting (30.31%) was still significantly lower than that observed in the other two systems. In the heading and flowering stages, consistent results were obtained with paired row planting (32.64%, 35.89%) having the lowest and direct sowing (41.55%, 44.86%) having the highest DI. The highest incidence of brown spot was observed towards the maturity stage in all the systems. As in the case of the preceding stages, DI was significantly lower in paired row planting (36.92%) compared to normal transplanting (38.94%) and direct sowing (47.08%).

Like disease incidence, disease severity also advanced progressively from the initial stages to the physiological maturity stage. In all the observed intervals, a

Table 7 a. Incidence of brown spot in different planting systems of rice (*Rabi* season)

Sl. No.	Treatments	DI (%)							
		30 DAS	40 DAS	50 DAS	60 DAS	70 DAS	80 DAS	90 DAS	100 DAS
				AT	PI	B	H	F	PM
1.	T1-Paired row planting	7.38 (15.70)[c]	11.13 (19.37)[b]	15.75 (23.30)[c]	21.38 (27.52)[c]	25.50 (30.31)[c]	29.13 (32.64)[c]	34.38 (35.89)[c]	36.13 (36.92)[c]
2.	T2-Normal transplanting	10.25 (18.54)[b]	13.25 (21.23)[b]	18.13 (25.19)[b]	26.50 (30.97)[b]	31.50 (34.13)[b]	35.63 (36.64)[b]	37.63 (37.83)[b]	39.50 (38.94)[b]
3.	T3-Direct sowing	13.63 (21.61)[a]	18.88 (25.67)[a]	23.75 (29.16)[a]	32.50 (34.74)[a]	37.88 (37.98)[a]	44.00 (41.55)[a]	49.75 (44.86)[a]	53.63 (47.08)[a]
CD (0.05)		2.40	2.21	1.48	1.45	0.68	1.30	0.95	1.93

Table 7 b. Severity of brown spot in different planting systems of rice (*Rabi* season)

Sl. No.	Treatments	PDI							
		30 DAS	40 DAS	50 DAS	60 DAS	70 DAS	80 DAS	90 DAS	100 DAS
				AT	PI	B	H	F	PM
1.	T1-Paired row planting	7.00 (15.27)[c]	15.63 (23.27)[c]	18.88 (25.73)[b]	22.63 (28.39)[c]	24.63 (29.74)[c]	29.25 (32.73)[c]	32.13 (34.52)[c]	36.50 (37.16)[c]
2.	T2-Normal transplanting	12.13 (20.32)[b]	17.75 (24.89)[b]	23.50 (28.98)[a]	25.13 (30.07)[b]	29.88 (33.13)[b]	33.13 (35.13)[b]	36.50 (37.16)[b]	43.75 (41.40)[b]
3.	T3-Direct sowing	16.13 (23.66)[a]	20.88 (27.17)[a]	25.25 (30.16)[a]	31.50 (34.14)[a]	35.88 (36.79)[a]	42.50 (40.69)[a]	52.25 (46.29)[a]	59.63 (50.55)[a]
CD (0.05)		1.59	0.96	1.24	1.31	0.66	1.17	1.19	1.54

DAS: Days after sowing; DI: Disease incidence; PDI: Per cent disease index; AT: Active tillering; PI: Panicle initiation; B: Booting; H: Heading; F: Flowering; PM: Physiological maturity; Values in parenthesis are arcsine transformed.

Plate 8. Symptoms of brown spot

significant difference was noticed between the systems with respect to PDI. During the first observed interval (30 DAS), the PDI recorded in paired row planting (15.27) was significantly lower than normal transplanting (20.32) and direct sowing (23.66). In the next observed interval (40 DAS), the PDI recorded in direct sowing (27.17) was significantly higher than that recorded in other two systems. In the active tillering stage, the PDI observed in paired row planting (25.73) was significantly lower than in the other two systems. However, in this stage, no significant difference was noticed in the PDI recorded in normal transplanting (28.98) and direct sowing (30.16). In the panicle initiation stage, the PDI recorded in paired row planting (28.39) was significantly less than the other two systems. In the booting stage also, the three systems differed significantly from each other with respect to the severity of brown spot. In this stage, the PDI recorded in paired row planting (29.74) was significantly lower than that in normal transplanting (33.13) and direct sowing (36.79). A Similar trend was observed in the heading and flowering stages. In these stages, PDI recorded in paired row planting was significantly less compared to other systems (Table 7 b.). The PDI recorded was high in the physiological maturity stage in all the systems. Among them, direct sowing had the highest PDI (50.55), followed by normal transplanting (41.40). The PDI recorded in paired row planting (37.16) was significantly less compared to other systems.

4.1.3.2 Disease incidence and severity of brown spot during kharif season

The incidence and severity of brown spot recorded from the experiment conducted during *kharif* season is given in Table 8 a. and Table 8 b. respectively. During the *kharif* season, the brown spot first appeared in the field at the active tillering stage. Even though disease was observed in all three systems at this stage, the DI recorded in paired row planting (20.38%) was significantly less than direct sowing (26.29%). But it was on par with that recorded in normal transplanting (21.50%). Similarly in the panicle initiation stage also, no significant difference was observed between the DI of paired row planting and normal transplanting. However, the incidence of brown spot in paired row planting (24.05%) was significantly lower than that recorded in direct sowing (29.33%). In the booting stage, a significant difference was noticed between the systems. In this stage, the DI recorded in paired row planting (26.99%) was significantly less than that recorded in direct sowing (34.06%) and normal transplanting (30.41%).

Table 8 a. Incidence of brown spot in different planting systems of rice (*Kharif* season)

Sl. No.	Treatments	DI (%)					
		50 DAS	60 DAS	70 DAS	80 DAS	90 DAS	100 DAS
		AT	PI	B	H	F	PM
1	T1-Paired row planting	12.38 (20.38)[b]	16.75 (24.05)[b]	20.63 (26.99)[c]	24.38 (29.57)[c]	27.88 (31.86)[c]	34.38 (35.89)[c]
2	T2-Normal transplanting	13.63 (21.50)[b]	18.50 (25.46)[b]	25.63 (30.41)[b]	28.63 (32.34)[b]	31.50 (34.14)[b]	37.63 (37.83)[b]
3	T3-Direct sowing	19.75 (26.29)[a]	24.00 (29.33)[a]	31.38 (34.06)[a]	35.75 (36.72)[a]	41.13 (39.89)[a]	47.25 (43.42)[a]
CD (0.05)		2.82	1.79	0.97	0.92	0.93	0.78

Table 8 b. Severity of brown spot in different planting systems of rice (*Kharif* season)

Sl. No.	Treatments	PDI					
		50 DAS	60 DAS	70 DAS	80 DAS	90 DAS	100 DAS
		AT	PI	B	H	F	PM
1	T1-Paired row planting	16.13 (23.65)[b]	18.13 (25.17)[b]	20.88 (27.17)[c]	22.75 (28.48)[c]	25.50 (30.33)[c]	31.13 (33.90)[c]
2	T2-Normal transplanting	16.63 (24.02)[b]	19.63 (26.27)[b]	22.75 (28.48)[b]	25.13 (30.08)[b]	31.00 (33.83)[b]	35.50 (36.57)[b]
3	T3-Direct sowing	19.63 (26.27)[a]	23.63 (29.08)[a]	31.50 (34.14)[a]	35.50 (36.57)[a]	43.00 (40.98)[a]	52.88 (46.65)[a]
CD (0.05)		1.74	1.53	1.11	0.65	0.65	1.38

DI: Disease incidence; PDI: Per cent disease index; AT: Active tillering; PI: Panicle initiation; B: Booting; H: Heading; F: Flowering; PM: Physiological maturity

Values in parenthesis are arcsine transformed

A similar trend was observed in the succeeding stages also. The DI of direct sown plots remained significantly higher in the heading (36.72%), flowering (39.89%) and physiological maturity stages (43.42%). In all these stages, DI observed in paired row planting was significantly less than that observed in normal transplanting (Table 8 a.). The disease incidence was higher in the physiological maturity phase, regardless of the systems considered. In all the observed intervals, DI remained lowest in paired row planting and highest in direct sowing. During the *kharif* season, unlike *rabi*, the disease incidence occurred and advanced only in the later stages of the crop.

When the disease severity was observed and PDI was computed and compared statistically, a similar finding was obtained. In the active tillering and panicle initiation stages, the PDI was found to be significantly higher in direct sowing. In these two stages, there were no significant differences observed between the severity of brown spot disease in paired row planting and normal transplanting (Table 8 b.). In the booting stage, however, a significant difference was observed between the systems, with direct sowing having the highest (34.14) and paired row planting having the lowest PDI (27.17). Similarly in the heading and flowering stages, the PDI observed in direct sown plots (36.57, 40.98) remained significantly higher than that observed in paired row planting (28.48, 30.33) and normal transplanting (30.08, 33.83). In these stages, PDI observed in paired row planting was significantly less than that observed in normal transplanting. At the physiological maturity stage, PDI increased to its highest in all three systems. The PDI observed in paired row planting (33.90) was significantly lower than that observed in normal transplanting (36.57) and direct sowing (46.65). The disease severity advanced gradually till the physiological maturity stage and in all the observed intervals, the PDI recorded in direct sowing was significantly higher than in the other two systems. The PDI recorded in paired row planting in all the observed intervals starting from the booting stage was significantly lower than that in normal transplanting and direct sowing.

4.1.4 Incidence of sheath rot in different planting systems of rice

The incidence and severity of sheath rot were recorded by observing the typical symptoms caused by the pathogen, *Sarocladium oryzae*. Symptoms appeared initially as greyish brown lesions on upper leaf sheaths enclosing panicles. At later stages, they enlarged, coalesced and covered the entire sheath with white, powdery masses of

Table 9. Incidence and severity of sheath rot in different planting systems of rice (*Kharif* season)

Sl. No.	Treatments	DI (%)			PDI		
		80 DAS	90 DAS	100 DAS	80 DAS	90 DAS	100 DAS
		H	F	PM	H	F	PM
1	T1-Paired row planting	5.63 (13.53)[b]	9.38 (17.73)[b]	12.00 (20.21)[c]	10.75 (18.85)[c]	15.13 (22.79)[c]	21.38 (27.52)[c]
2	T2-Normal transplanting	6.50 (14.70)[b]	11.75 (20.00)[ab]	17.38 (24.59)[b]	14.00 (21.87)[b]	20.75 (26.97)[b]	28.75 (32.39)[b]
3	T3-Direct sowing	9.88 (18.26)[a]	14.88 (22.48)[a]	23.00 (28.64)[a]	19.88 (26.31)[a]	27.00 (31.29)[a]	38.25 (38.20)[a]
CD (0.05)		2.16	2.86	1.73	2.59	2.94	2.00

Table 10. Incidence and severity of false smut in different planting systems of rice (*Rabi* season)

Sl. No.	Treatments	DI (%)		PDI	
		90 DAS	100 DAS	90 DAS	100 DAS
1	T1-Paired row planting	8.38 (16.73)[b]	10.50 (18.75)[c]	9.88 (18.26)[c]	19.25 (26.01)[c]
2	T2-Normal transplanting	11.13 (19.37)[b]	16.88 (24.17)[b]	14.75 (22.51)[b]	24.50 (29.64)[b]
3	T3-Direct sowing	16.38 (23.79)[a]	24.25 (29.49)[a]	19.00 (25.81)[a]	29.38 (32.81)[a]
CD (0.05)		2.77	1.83	1.72	1.65

DAS: Days after sowing; DI: Disease incidence; PDI: Per cent disease index. Values in parenthesis are arcsine transformed

Plate 9. Symptoms of sheath rot

conidia at the centre of lesions. Panicles from the affected plants did not emerge or partially emerged and were choked inside the sheath. The incidence of sheath rot was observed only during the *kharif* season (Plate 9.).

4.1.4.1 Disease incidence and severity of sheath rot during kharif season

The incidence and severity of sheath rot are given in Table 9. The sheath rot was first observed during the heading stage. Disease incidence and severity were recorded at ten days intervals after the first observation of the disease. In the heading stage, the DI recorded in paired row planting (13.53%) was statistically on par with that of normal transplanting (14.70%). However, the DI observed in direct sowing (18.26%) was significantly higher than in the other two systems. The same trend was observed in flowering stage also. The sheath rot incidence observed in paired row planting (17.73%) was statistically on par with that of normal transplanting (20.00%). The sheath rot incidence recorded in direct sowing (22.48%) was significantly higher than that of paired row planting. When the crop reached to maturity stage, a slight increase in the DI was noticed in all three systems. In this stage, the sheath rot incidence observed in paired row planting (20.21%) was significantly less than that of normal transplanting (24.59%) and direct sowing (28.64%).

The disease severity gradually advanced till the physiological maturity stage. In the heading stage, where the disease was first observed, the PDI recorded in paired row planting (18.85) was significantly less than normal transplanting (21.87) and direct sowing (26.31). The PDI recorded in direct sowing was significantly higher than in the other two systems. At flowering stage also, the same trend was noticed. The sheath rot severity was significantly less in paired row planting (22.79) compared to normal transplanting (26.97) and direct sowing (31.29). Similarly in the physiological maturity stage, disease severity increased gradually, and a significant difference was noticed between the systems during this stage. As in the case of the preceding stages, the PDI in paired row planting (27.52) was significantly less than that observed in normal transplanting (32.39) and direct sowing (38.20). In all the observed intervals, disease severity was significantly lower in paired row planting.

4.1.5 Incidence of false smut in different planting systems of rice

The incidence and severity of false smut, caused by *Ustilaginoidea virens,* were analyzed. The individual spikelets of the panicle were transformed into yellow to orange coloured smut balls, which were found to be covered with whitish to cream coloured membrane initially. In the later stages, the membrane ruptured exposing the yellow dust-like chlamydospores. As the disease advanced, the colour of the smut balls changed to greenish black and finally to black (Plate 10.).

4.1.5.1 Disease incidence and severity of false smut during rabi season

The incidence and severity of false smut recorded during *rabi* season are given in Table 10. During the first observed interval, the disease incidence was observed in all three systems. At this stage, no significant difference was observed in incidence of false smut between paired row planting (16.73%) and normal transplanting (19.37%). DI observed in direct sowing (23.79%) was significantly higher than in the other two systems. However, in the next observed interval, a significant difference was observed between all the systems. The DI recorded in paired row planting (18.75%) was significantly less than that observed in normal transplanting (24.17%) and direct sowing (29.49%). The DI was found to be the highest in the direct sown plot in both observed intervals.

The disease severity was also recorded in addition to disease incidence. A significant difference with respect to PDI was observed between the systems in the first observed interval itself. In this stage, the PDI observed in paired row planting (18.26) was found to be significantly less than that observed in normal transplanting (22.51) and direct sowing (25.81). The PDI recorded in direct sowing was significantly higher than in the other two systems. A similar finding was obtained in the succeeding stages also. The PDI recorded was highest (32.81) in direct sowing and lowest in paired row planting (26.01) which was significantly less than that of normal transplanting (29.64).

4.1.5.2 Disease incidence and severity of false smut during kharif season

Disease incidence and severity of false smut recorded during *kharif* season are given in Table 11. The incidence of false smut recorded during the first stage showed a significant difference between the systems. The incidence of false smut observed in paired row planting (15.12%) was significantly less than normal transplanting (17.91%) and direct sowing (21.51%). Similar observations were made in the next observed interval. The incidence of false smut recorded in paired row planting (19.68%) was significantly less than that of normal transplanting (24.87%). Significantly higher incidence of false smut (28.64%) was reported in direct sowing.

Plate 10. Symptoms of false smut

Table 11. Incidence and severity of false smut in different planting systems of rice (*Kharif* season)

Sl. No.	Treatments	DI (%)		PDI	
		90 DAS	100 DAS	90 DAS	100 DAS
1	T1-Paired row planting	6.88 (15.12)^{c}	11.50 (19.68)^{c}	8.00 (16.35)^{c}	15.25 (22.49)^{b}
2	T2-Normal transplanting	9.50 (17.91)^{b}	17.75 (24.87)^{b}	12.88 (20.82)^{b}	18.75 (25.60)^{ab}
3	T3-Direct sowing	13.50 (21.51)^{a}	23.00 (28.64)^{a}	15.50 (23.17)^{a}	23.00 (28.63)^{a}
CD (0.05)		1.88	1.96	2.34	3.99

Table 12. Incidence of caseworm in different planting systems of rice

Sl. No.	Treatments	Per cent damaged leaves (%)			
		Rabi season		*Kharif* season	
		30 DAS	40 DAS	30 DAS	40 DAS
1	T1-Paired row planting	27.63 (31.65)^{a}	10.13 (17.89)^{a}	32.63 (34.73)^{a}	12.50 (20.11)^{a}
2	T2-Normal transplanting	38.75 (38.48)^{a}	12.00 (19.22)^{a}	35.00 (36.25)^{a}	13.25 (20.54)^{a}
3	T3-Direct sowing	4.50 (10.41)^{b}	2.50 (7.38)^{b}	2.63 (8.24)^{b}	1.63 (5.49)^{b}
CD (0.05)		4.97	5.98	4.27	6.15

DAS: Days after sowing; DI: Disease incidence; PDI: Per cent disease index; PM: Physiological maturity
Values in parenthesis are arcsine transformed

When PDI was taken into consideration, similar observations were obtained in the first observed interval. In this stage, the PDI observed in paired row planting (16.35) was found to be significantly lower than that observed in the other two systems. Also, the PDI observed in direct sown plots (23.17) was significantly higher than the PDI observed in the other two systems. In the next stage, disease severity increased slightly in all three systems. However, in this stage, severity of false smut recorded in paired row planting (22.49) was statistically on par with that of normal transplanting (25.60) and significantly lower than that recorded in direct sowing (28.63).

4.2 ASSESSMENT OF INFLUENCE OF PLANTING GEOMETRY ON INCIDENCE OF PESTS IN RICE

4.2.1 Incidence of caseworm in different planting systems of rice

4.2.1.1 Caseworm incidence during rabi season

The damage caused by caseworm, *Nymphula depunctalis* in the three systems were recorded and is depicted in Table 12. The incidence of caseworm was observed in the field only during the initial tillering stages of rice. Caseworm larvae cut leaf tips from young rice plants and rolled them into tubes called cases, which facilitated their plant-to-plant movement. They were also observed to be fed on leaf tissue, leaving only the papery upper epidermis (Plate 11.). The damage caused by caseworm was recorded in terms of per cent damaged leaves.

During the first observed interval (30 DAS), the caseworm incidence recorded in paired row planting (31.65%) was statistically on par with that in normal transplanting (38.48%) and significantly higher than that in direct sowing (10.41%). The pest infestation was reduced in all three systems by the next observed interval (40 DAS). In this stage also, the caseworm incidence in normal transplanting (19.22%) and paired row planting (17.89%) were statistically on par and remained significantly higher than that in direct sowing (7.38%).

4.2.1.2 Case worm incidence during kharif season

A similar trend was observed during *kharif* season. The incidence of caseworm recorded in the field is given in Table 12. During the first observed interval (30 DAS), caseworm incidence was observed in all three systems. The caseworm damage recorded in paired row planting (34.73%) was statistically on par with that of normal transplanting (36.25%). The caseworm damage in direct sown plot was significantly

Plate 11. Leaf damage due to caseworm

Plate 12. Damage due to leaf folder

low (8.24%). The same trend repeated during the next observed interval (40 DAS). Leaf infestation recorded in direct sowing (5.49%) was significantly lower compared to paired row planting (20.11%) and normal transplanting (20.54%). In the all the observed stages, significant difference was not noticed between the caseworm damage recorded in paired row planting and normal transplanting.

4.2.2 Incidence of leaf folder in different planting systems of rice

4.2.2.1 Leaf folder incidence during rabi season

The incidence of leaf folder*, Cnaphalocrocis medinalis* recorded in three systems during *rabi* season are given in Table 13 a. The leaf folder damage increased progressively from the initial growth stages till the panicle initiation stage and thereafter a significant increase in the damage with respect to leaf infestation was not noticed. The larvae folded the leaves and scraped the green tissues within, causing typical white streaks. In later stages, scorching and leaf drying were also observed (Plate 12.). The leaf folder infestation was recorded with respect to per cent damaged leaves.

During the first observed interval (30 DAS), the leaf folder damage was highest in direct sowing (20.04%). It was lowest in paired row planting (5.61%) and was significantly less than that recorded in normal transplanting (12.01%). A similar trend was obtained in the next observed stage (40 DAS) also. The leaf folder damage was lowest in paired row planting (17.00%) which was significantly less than that recorded in normal transplanting (23.31%) and direct sowing (28.07%). In the active tillering and booting stages, a significant difference with respect to leaf folder damage was not observed between the three systems (Table 13 a.). The highest per cent damage was recorded during the panicle initiation stage in all the systems. In this stage, the leaf folder damage was lowest in paired row planting (30.67%). However, there were no significant differences between other two systems in leaf folder infestation. At the heading stage, no significant difference observed between paired row planting (18.90%) and normal transplanting (20.34%). However, the highest damage was observed in direct sowing (25.33%) at this stage.

4.2.2.2 Leaf folder incidence during kharif season

The leaf folder infestation recorded during *kharif* season is given in Table 13 b. During this season, leaf folder damage increased progressively till the panicle initiation stage and further there was no increase in damage. In all the observed intervals, the leaf

Table 13 a. Incidence of leaf folder in different planting systems of rice (*Rabi* season)

Sl. No.	Treatments	Per cent damaged leaves (%)					
		30 DAS	40 DAS	50 DAS	60 DAS	70 DAS	80 DAS
				AT	PI	B	H
1.	T1-Paired row planting	1.50 (5.61)[c]	8.13 (17.00)[c]	14.12 (21.90)	26.00 (30.67)[b]	21.13 (27.37)	10.25 (18.90)[b]
2.	T2-Normal transplanting	4.00 (12.01)[b]	15.13 (23.31)[b]	19.50 (25.55)	37.75 (38.14)[a]	20.25 (26.35)	11.88 (20.34)[b]
3.	T3-Direct sowing	11.50 (20.04)[a]	22.00 (28.07)[a]	28.75 (31.99)	39.75 (39.12)[a]	24.13 (29.52)	17.75 (25.33)[a]
CD (0.05)		1.55	2.14	NS	0.64	NS	2.40

Table 13 b. Incidence of leaf folder in different planting systems of rice (*Kharif* season)

Sl. No.	Treatments	Per cent damaged leaves (%)					
		30 DAS	40 DAS	50 DAS	60 DAS	70 DAS	80 DAS
				AT	PI	B	H
1.	T1-Paired row planting	6.88 (7.20)[c]	17.75 (18.13)[c]	21.38 (21.56)[c]	24.75 (25.00)[c]	21.63 (21.88)[c]	15.38 (15.63)[c]
2.	T2-Normal transplanting	8.63 (8.71)[b]	21.75 (21.97)[b]	26.25 (26.70)[b]	33.38 (33.90)[b]	26.13 (26.51)[b]	22.13 (22.54)[b]
3.	T3-Direct sowing	14.38 (14.93)[a]	24.88 (25.49)[a]	32.88 (33.28)[a]	38.38 (38.96)[a]	33.88 (34.42)[a]	31.25 (31.82)[a]
CD (0.05)		0.98	2.89	1.91	3.33	3.02	1.93

DAS: Days after sowing; DI: Disease incidence; PDI: Per cent disease index; PM: Physiological maturity
Values in parenthesis are arcsine transformed

infestation noticed in paired row planting was significantly less than that observed in the other two systems. During the first observed interval (30 DAS), the per cent leaf infestation was low in all three systems. The leaf folder damage was significantly low in paired row planting (7.20%) compared to normal transplanting (8.71%) and direct sowing (14.93%). Similarly in the next observed interval, the per cent damage observed in paired row planting (18.13%) was significantly less compared to normal transplanting (21.97%) and direct sowing (25.49%). A similar observation was made in the active tillering stage. In this stage, the leaf folder damage recorded in paired row planting (21.56%) was significantly less than that observed in normal transplanting (26.70%) and direct sowing (33.28%). In the panicle initiation stage, the damage caused due to leaf folder was highest. In this stage, the leaf folder damage recorded in paired row planting (25.00%) was significantly less than that in direct sowing (38.96%) and normal transplanting (33.90%). A similar trend was followed in the booting and heading stages. In both these stages, the leaf folder infestation recorded in paired row planting (21.88%, 15.63%) was significantly less than that of normal transplanting (26.51%, 22.54%) and direct sowing (34.42%, 31.82%).

4.2.3 Incidence of yellow stem borer in different planting systems of rice

4.2.3.1 Yellow stem borer incidence during rabi season

The incidence caused by the lepidopteran pest, yellow stem borer (*Scirpophaga incertulas*), was recorded in the field during the vegetative stage with respect to the per cent dead hearts (DH %) and reproductive stage with respect to the per cent white ear heads (WEH %) produced. Larval feeding and subsequent internodal penetration during the vegetative and reproductive stages caused the destruction of the growing apical plant part and finally resulted in the characteristic symptom of dead heart and white ear head at vegetative and reproductive growth stages of rice plants respectively (Plate 13.). The corresponding observations made during *rabi* season were tabulated and presented in Table 14.

In the active tillering stage, 32.90 per cent dead hearts were observed in direct sowing which was significantly higher than both other systems. However, a significant difference with respect to per cent dead hearts was not observed between normal transplanting (24.57%) and paired row planting (21.87%). During the panicle initiation stage, yellow stem borer damage (white ear heads) was recorded. During this stage, a

Table 14. Incidence of yellow stem borer in different planting systems of rice

Sl. No.	Treatments	*Rabi* season		*Kharif* season	
		DH (%)	WEH (%)	DH (%)	WEH (%)
		AT	PI	AT	PI
1.	T1-Paired row planting	13.75 (21.87)^{b}	10.38 (18.66)^{c}	9.25 (17.43)^{b}	6.38 (14.55)^{c}
2.	T2-Normal transplanting	17.38 (24.57)^{b}	16.63 (24.00)^{b}	12.13 (20.12)^{b}	10.00 (18.35)^{b}
3.	T3-Direct sowing	29.88 (32.90)^{a}	22.38 (28.22)^{a}	26.63 (31.21)^{a}	14.13 (22.10)^{a}
CD (0.05)		5.49	1.90	4.90	1.78

Table 15. Incidence of rice bug in different planting systems of rice

Sl. No.	Treatments	Per cent damaged grains per panicle (%)	
		Rabi season	*Kharif* season
1.	T1-Paired row planting	12.00 (20.26)^{c}	8.50 (16.92)^{c}
2.	T2-Normal transplanting	13.50 (21.54)^{b}	10.88 (19.23)^{b}
3.	T3-Direct sowing	19.38 (26.09)^{a}	16.13 (23.65)^{a}
CD (0.05)		0.99	1.21

DAS: Days after sowing; DH: Dead heart; WEH: White ear head; AT: Active tillering; PI: Panicle initiation; B: Booting; H: Heading; F: Flowering; PM: Physiological maturity

Values in parenthesis are arcsine transformed

Plate 13. Damage due to yellow stem borer

Plate 14. Damage due to Rice bug

significant difference between all the systems was noticed with respect to WEH. The WEH was significantly higher in direct sowing (28.22%) when compared to normal transplanting (24.00%) and paired row planting (18.66%). The WEH damage recorded in paired row planting was significantly less than normal transplanting.

4.2.3.2 Yellow stem borer incidence during kharif season

The observations related to the damage caused by yellow stem borer in all three planting systems during *kharif* season are given in Table 14. The results similar to that of the *rabi* were obtained in this season. During the active tillering stage, the dead heart damage was significantly higher in direct sowing (31.21%) compared to normal transplanting (20.12%) and paired row planting (17.43%). There was no significant difference observed between normal transplanting and paired row planting during this stage with respect to dead heart percentage. However, during the panicle initiation phase, a significant difference was noticed between all three systems with respect to WEH. The damage noticed in paired row planting (14.55%) was significantly lower compared to normal transplanting (18.35%) and direct sowing (22.10%). The pest infestation observed in the direct sowing was significantly higher than that observed in the other two systems.

4.2.4 Incidence of rice bug in different planting systems of rice

4.2.4.1 Rice bug incidence during rabi season

The damage caused by rice bug (*Leptocorisa acuta*), was recorded and expressed in terms of the per cent damaged grains per panicle. They caused damage by feeding on the sap of milky grains and making them chaffy (Plate 14.). The observations of rice bug damage taken during the *rabi* season are presented in Table 15. The per cent damaged grains per panicle recorded the highest value in direct sowing (26.09%) when compared to that recorded in normal transplanting (21.54%) and paired row planting (20.26%). The rice bug damage observed in paired row planting was significantly lower than that observed in the other two systems. Also, the damage recorded in normal transplanting was significantly lower than that observed in direct sowing.

4.2.4.2 Rice bug incidence during kharif season

During *kharif* season, a similar observation was made with respect to rice bug damage and the corresponding observations are enlisted in Table 15. The per cent damaged grains per panicle recorded in paired row planting (16.92%) was significantly

4.3 INFLUENCE OF MICROCLIMATE ASSOCIATED WITH DIFFERENT PLANTING GEOMETRY ON DISEASE AND PEST INCIDENCE IN RICE

Micrometeorological parameters *viz*., canopy temperature and relative humidity were recorded at ten days intervals using infrared thermometer and whirling psychrometer respectively. The observations recorded during *rabi* and *kharif* season are enlisted in Tables 16 a. to 17 d. Correlation analysis of micrometeorological parameters with incidence and severity of diseases and pest incidence was done and the corresponding scatter diagrams were plotted to derive the influence of microclimate on disease and pest incidence in different systems of rice cultivation.

4.3.1 Influence of microclimate on incidence of diseases in rice

4.3.1.1 Influence of microclimate on incidence of bacterial blight of rice

The results of correlation analysis conducted between micrometeorological variables *viz*. forenoon relative humidity (RH I), afternoon relative humidity (RH II), average relative humidity (RH) and canopy temperature (CT) and disease variables *viz*. disease incidence (DI) and disease severity (PDI) are represented in Figures 1-4.

During *rabi* season, the highest incidence (above 40%) and severity (above 40) of bacterial blight was recorded at the forenoon relative humidity range of 87-91 per cent, afternoon relative humidity range of 67-77 per cent, average relative humidity range of 77-84 per cent and canopy temperature range of 30.5-31.5^{0}C. From the scatter plot diagram, it is clear that the maximum number of observations corresponding to this humidity and temperature range were recorded in direct sowing, followed by normal transplanting and paired row planting.

During *kharif* season, the DI and PDI crossed a value of 35 at forenoon relative humidity range of 88-93 per cent, afternoon relative humidity range of 76-82 per cent, average relative humidity range of 82-87 per cent and canopy temperature range of 29-30^{0}C. From the scatter plot diagram, it is evident that the maximum number of observations corresponding to this micrometeorological range were observed in direct sowing followed by normal transplanting and paired row planting. During both seasons, the incidence and severity of bacterial blight crossed a value of 35 since the active tillering stage. The incidence and severity of bacterial blight recorded in paired row planting during this period was significantly lower than that in normal transplanting and direct sowing (Tables 3 a. to 4 b.). The analysis of scatter diagram also revealed that the

Table 16 a. Relative humidity forenoon (*Rabi* season)

Sl. No.	Treatments	Relative humidity forenoon							
		30 DAS	40 DAS	50 DAS	60 DAS	70 DAS	80 DAS	90 DAS	100 DAS
1	T1-Paired row planting	82.13	82.38	82.88	83.00	83.25	83.88	84.25	87.50
2	T2-Normal transplanting	82.63	83.00	84.63	85.75	86.88	87.38	87.88	89.88
3	T3-Direct sowing	85.88	86.63	87.00	87.63	89.00	89.63	91.00	91.25

Table 16 b. Relative humidity afternoon (*Rabi* season)

Sl. No.	Treatments	Relative humidity afternoon							
		30 DAS	40 DAS	50 DAS	60 DAS	70 DAS	80 DAS	90 DAS	100 DAS
1	T1-Paired row planting	59.25	60.00	60.75	62.75	63.00	66.38	68.38	68.50
2	T2-Normal transplanting	60.13	60.75	63.63	66.38	67.00	71.75	72.13	72.63
3	T3-Direct sowing	64.13	66.75	67.38	68.88	70.50	72.50	75.25	76.63

Table 16 c. Average relative humidity (*Rabi* season)

Sl. No.	Treatments	Average relative humidity							
		30 DAS	40 DAS	50 DAS	60 DAS	70 DAS	80 DAS	90 DAS	100 DAS
1	T1-Paired row planting	70.69	71.19	71.82	72.88	73.13	75.13	76.31	78.00
2	T2-Normal transplanting	71.38	71.88	74.13	76.06	76.94	79.57	80.00	81.25
3	T3-Direct sowing	75.00	76.69	77.19	78.25	79.75	81.07	83.13	83.94

Table 16 d. Canopy temperature (*Rabi* season)

Sl. No.	Treatments	Canopy temperature (^{O}C)							
		30 DAS	40 DAS	50 DAS	60 DAS	70 DAS	80 DAS	90 DAS	100 DAS
1	T1-Paired row planting	32.50	32.13	32.00	32.25	31.75	31.88	32.00	32.50
2	T2-Normal transplanting	32.75	31.63	31.50	31.13	31.38	31.75	31.13	31.88
3	T3-Direct sowing	30.50	31.13	31.25	31.00	31.13	31.13	30.88	31.25

Table 17 a. Relative humidity forenoon (*Kharif* season)

Sl. No.	Treatments	Relative humidity forenoon							
		30 DAS	40 DAS	50 DAS	60 DAS	70 DAS	80 DAS	90 DAS	100 DAS
1	T1-Paired row planting	81.63	83.25	84.38	85.63	86.50	86.75	87.50	88.75
2	T2-Normal transplanting	83.13	84.75	88.38	88.88	89.25	89.50	90.38	90.88
3	T3-Direct sowing	86.25	87.75	88.13	89.00	90.00	90.88	91.75	92.50

Table 17 b. Relative humidity afternoon (*Kharif* season)

Sl. No.	Treatments	Relative humidity afternoon							
		30 DAS	40 DAS	50 DAS	60 DAS	70 DAS	80 DAS	90 DAS	100 DAS
1	T1-Paired row planting	64.13	70.88	71.13	73.75	74.25	75.25	76.75	77.00
2	T2-Normal transplanting	65.50	72.50	74.38	75.88	77.38	77.38	78.00	78.88
3	T3-Direct sowing	68.00	75.25	75.88	76.50	77.75	79.75	80.25	80.63

Table 17 c. Average relative humidity (*Kharif* season)

Sl. No.	Treatments	Average relative humidity							
		30 DAS	40 DAS	50 DAS	60 DAS	70 DAS	80 DAS	90 DAS	100 DAS
1	T1-Paired row planting	72.88	77.06	77.75	79.69	80.38	81.00	82.13	82.88
2	T2-Normal transplanting	74.32	78.63	81.38	82.44	83.31	83.44	84.19	84.88
3	T3-Direct sowing	77.13	81.50	82.00	82.69	83.88	85.32	86.00	86.56

Table 17 d. Canopy temperature (*Kharif* season)

Sl. No.	Treatments	Canopy temperature (^{O}C)							
		30 DAS	40 DAS	50 DAS	60 DAS	70 DAS	80 DAS	90 DAS	100 DAS
1	T1-Paired row planting	32.88	31.88	31.00	31.00	32.75	30.38	30.50	30.13
2	T2-Normal transplanting	31.53	31.13	30.38	30.13	31.38	29.63	29.75	29.88
3	T3-Direct sowing	29.63	29.75	29.50	29.38	29.63	29.75	29.50	28.25

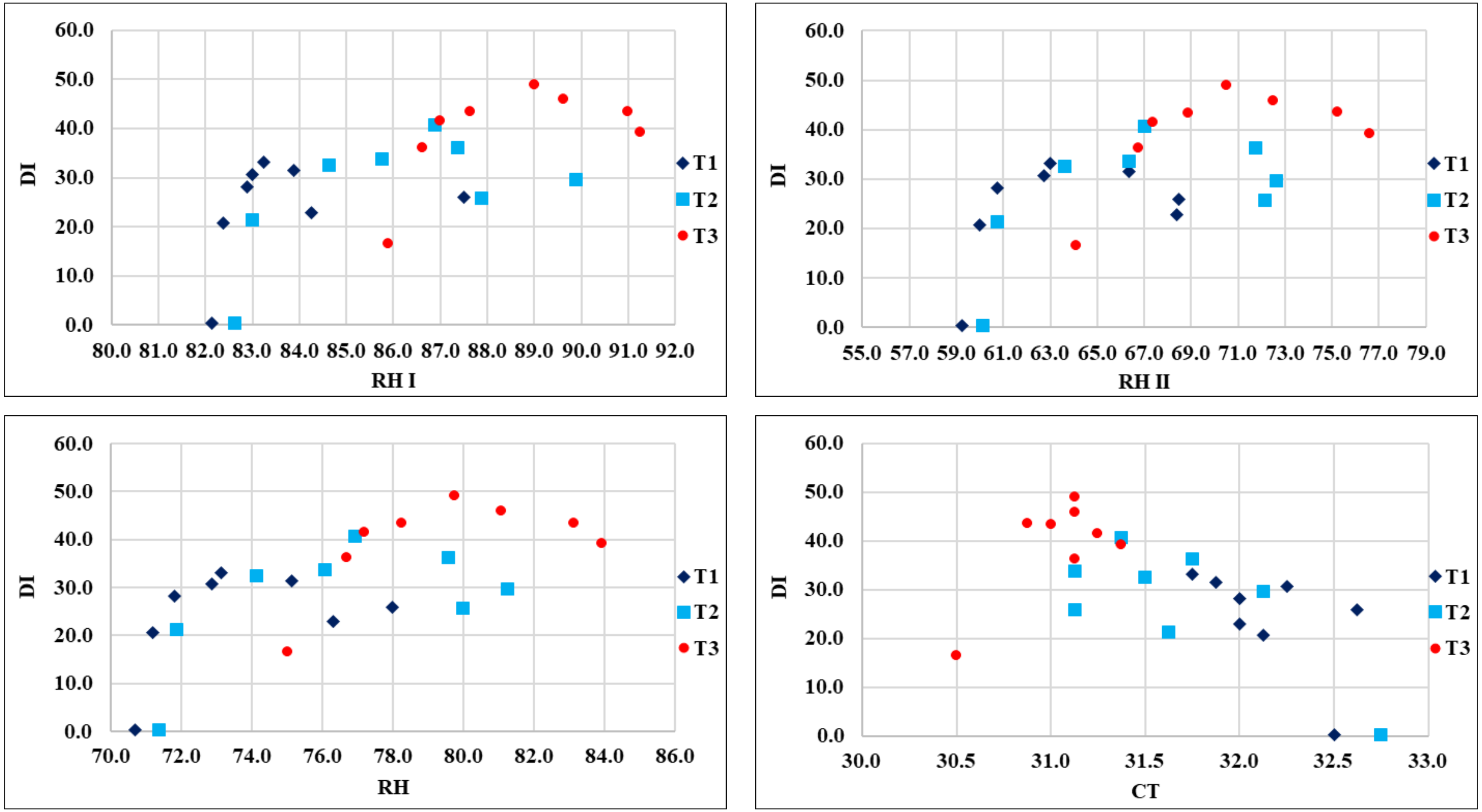
maximum disease incidence and severity was recorded at higher relative humidity and lower canopy temperature. Also, the forenoon, afternoon, average relative humidity recorded in paired row planting since the active tillering stage was lower in paired row planting compared to other two systems, whereas the canopy temperature recorded in paired row planting was higher compared to other two systems (Tables 16 a. to 17 d.). This indicates that the microenvironment with respect to relative humidity and canopy temperature in direct sowing and normal transplanting is more congenial for the incidence and severity of bacterial blight compared to that in paired row planting.

4.3.1.2 Influence of microclimate on incidence of sheath blight in rice

The results corresponding to the correlation analysis conducted between micrometeorological parameters and disease variables related to sheath blight are depicted in Figures 5-8. During *rabi* season, the highest incidence (above 30%) and severity (above 45) were observed at the forenoon relative humidity range of 89-92 per cent, afternoon relative humidity range of 72-78 per cent, average relative humidity range of 81-84 per cent and canopy temperature range of 30.5-32.5^{0}C. When the scatter diagrams depicting the correlation between disease (DI and PDI) and relative humidity variables were analyzed, it was found that, the number of observations recorded in direct sowing within this humidity range, were higher than those recorded in normal transplanting. On the other hand, observations corresponding to this range were not recorded in paired row planting. Also, the relative humidity in paired row planting was lower than that of other two systems. This is an indication of the existence of a more favourable microclimate with increased relative humidity in direct sowing and normal transplanting when compared to paired row planting for the development and spread of sheath blight. However, when canopy temperature was considered, it was observed that irrespective of the systems, all the recorded observations fell under the same canopy temperature range in which the maximum DI and PDI were recorded.

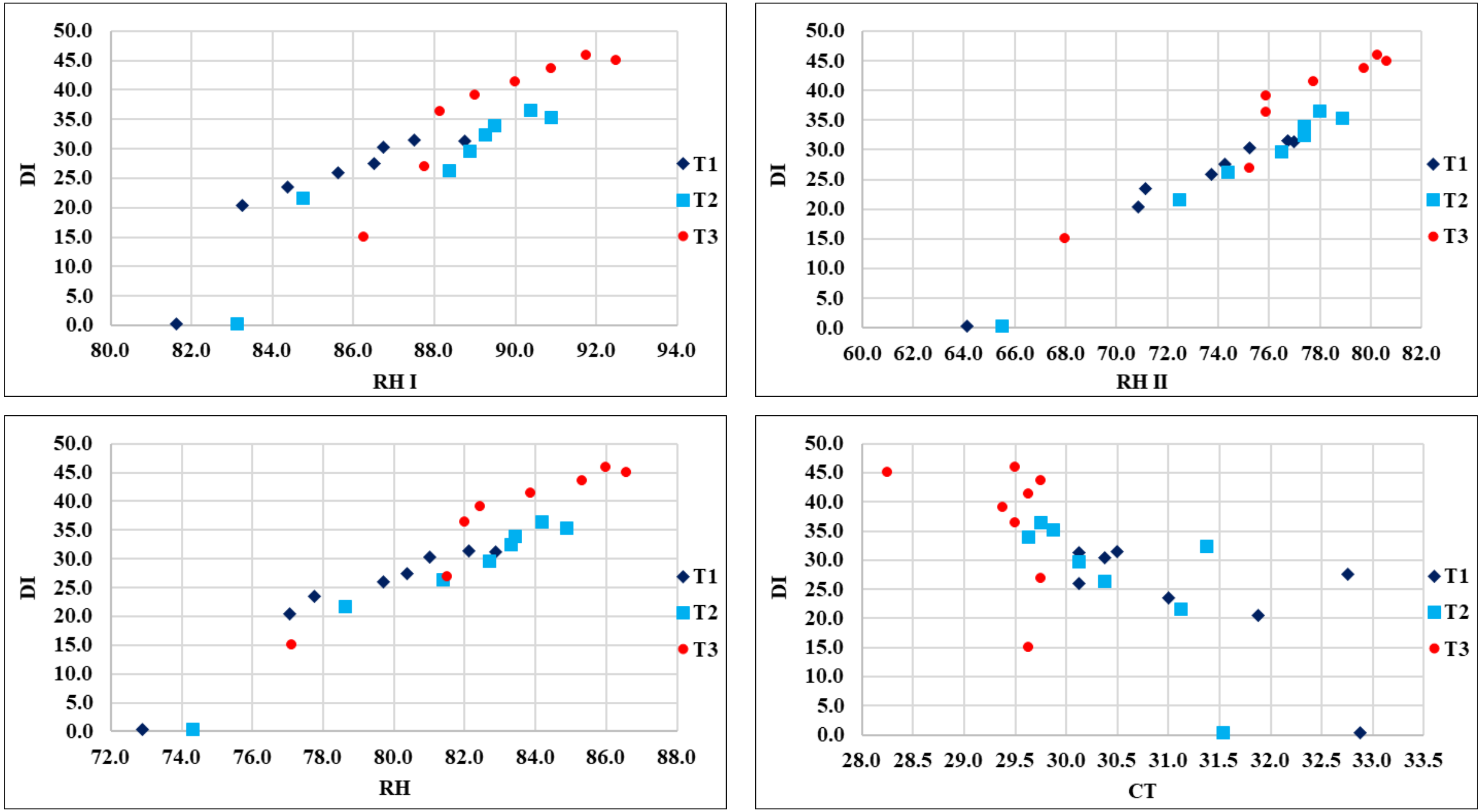
During *kharif* season, the highest DI (above 30%) and PDI (above 40) were recorded at the forenoon relative humidity of 90-93 per cent, afternoon relative humidity of 79-81 per cent, average relative humidity of 84-87 per cent and canopy temperature of 28-30^{0}C. A comprehensive analysis of scatter diagrams correlating disease and relative humidity variables revealed that the observations recorded in direct sowing corresponding to this favourable humidity range were higher than those recorded in

Figure 1. Correlation between incidence of bacterial blight and micrometeorological parameters (*Rabi* season)



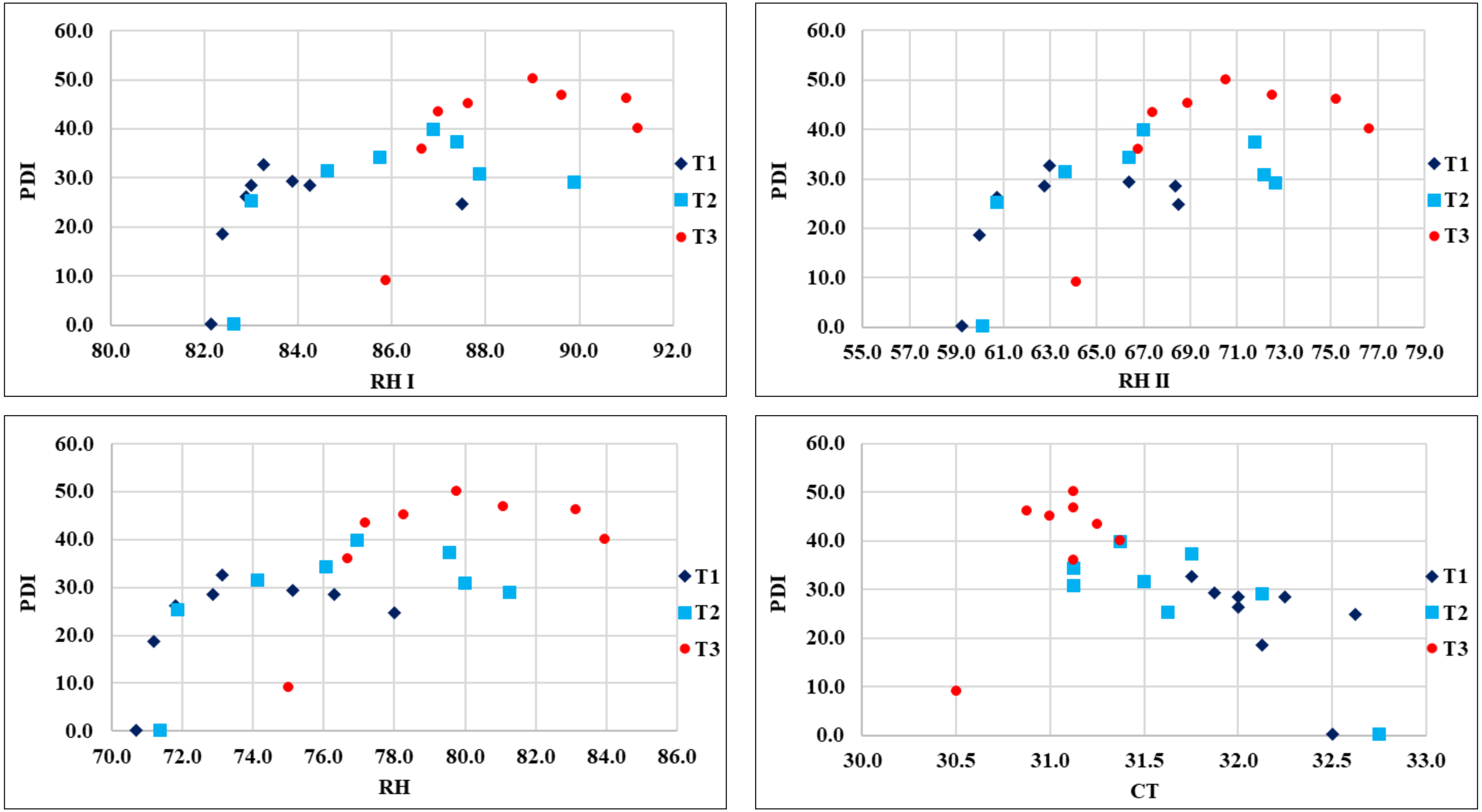
DI: Disease incidence; RH I: Forenoon relative humidity; RH II: Afternoon relative humidity; RH: Average relative humidity; CT: Canopy temperature; T1: Paired row planting; T2: Normal transplanting; T3: Direct sowing

Figure 2. Correlation between incidence of bacterial blight and micrometeorological parameters (*Kharif* season)



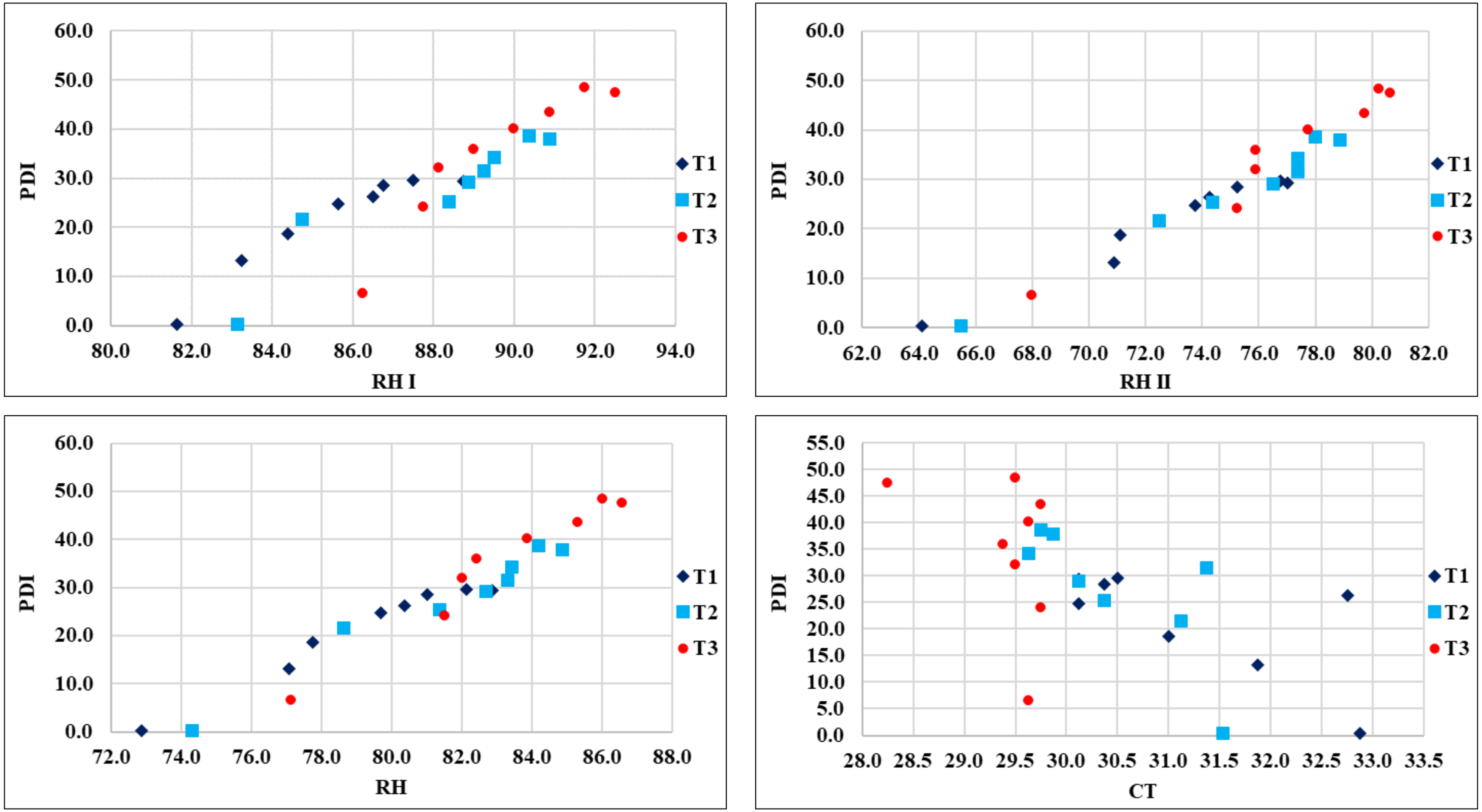
DI: Disease incidence; RH I: Forenoon relative humidity; RH II: Afternoon relative humidity; RH: Average relative humidity; CT: Canopy temperature; T1: Paired row planting; T2: Normal transplanting; T3: Direct sowing

Figure 3. Correlation between severity of bacterial blight and micrometeorological parameters (*Rabi* season)



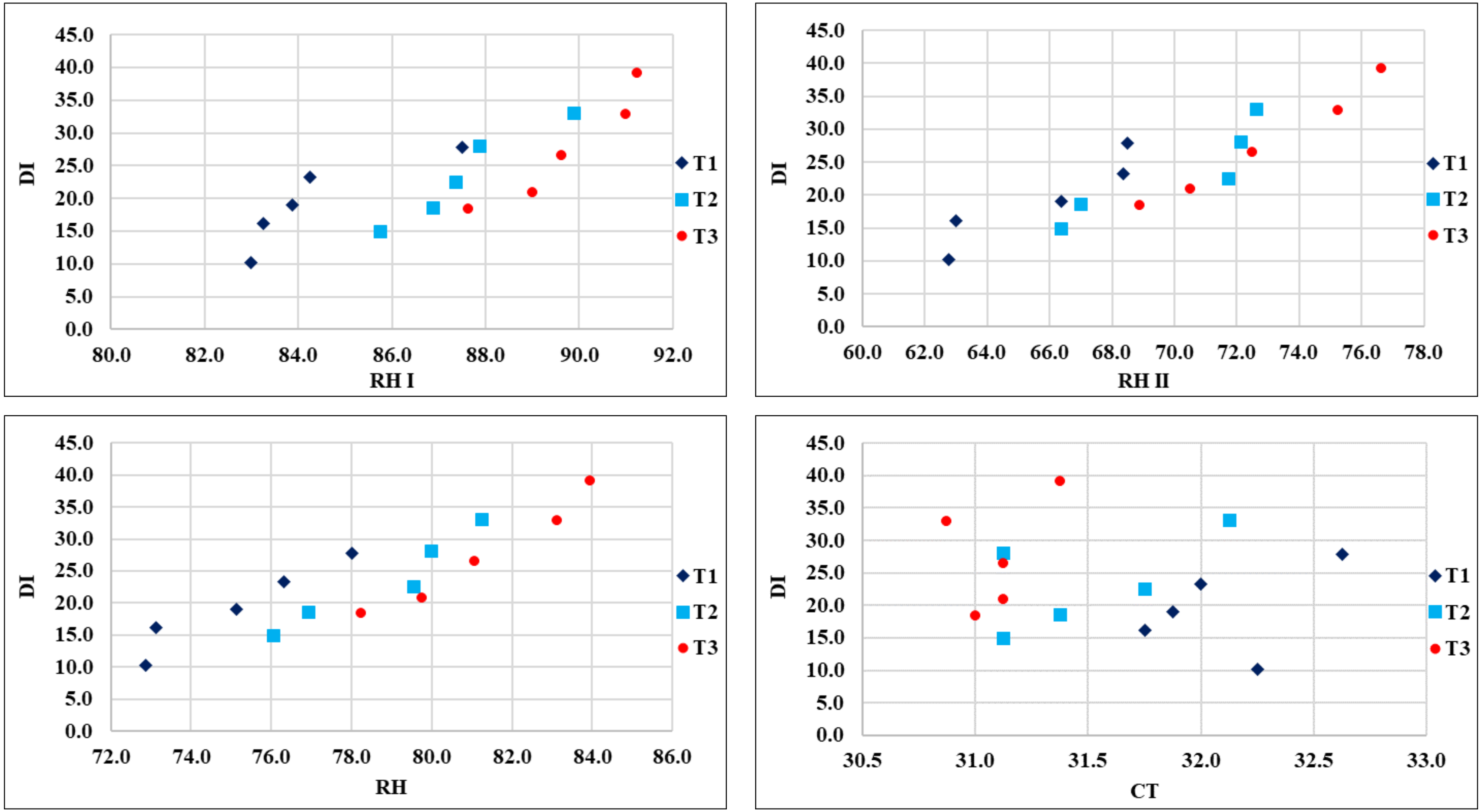
PDI: Per cent disease index; RH I: Forenoon relative humidity; RH II: Afternoon relative humidity; RH: Average relative humidity; CT: Canopy temperature; T1: Paired row planting; T2: Normal transplanting; T3: Direct sowing

Figure 4. Correlation between severity of bacterial blight and micrometeorological parameters (*Kharif* season)



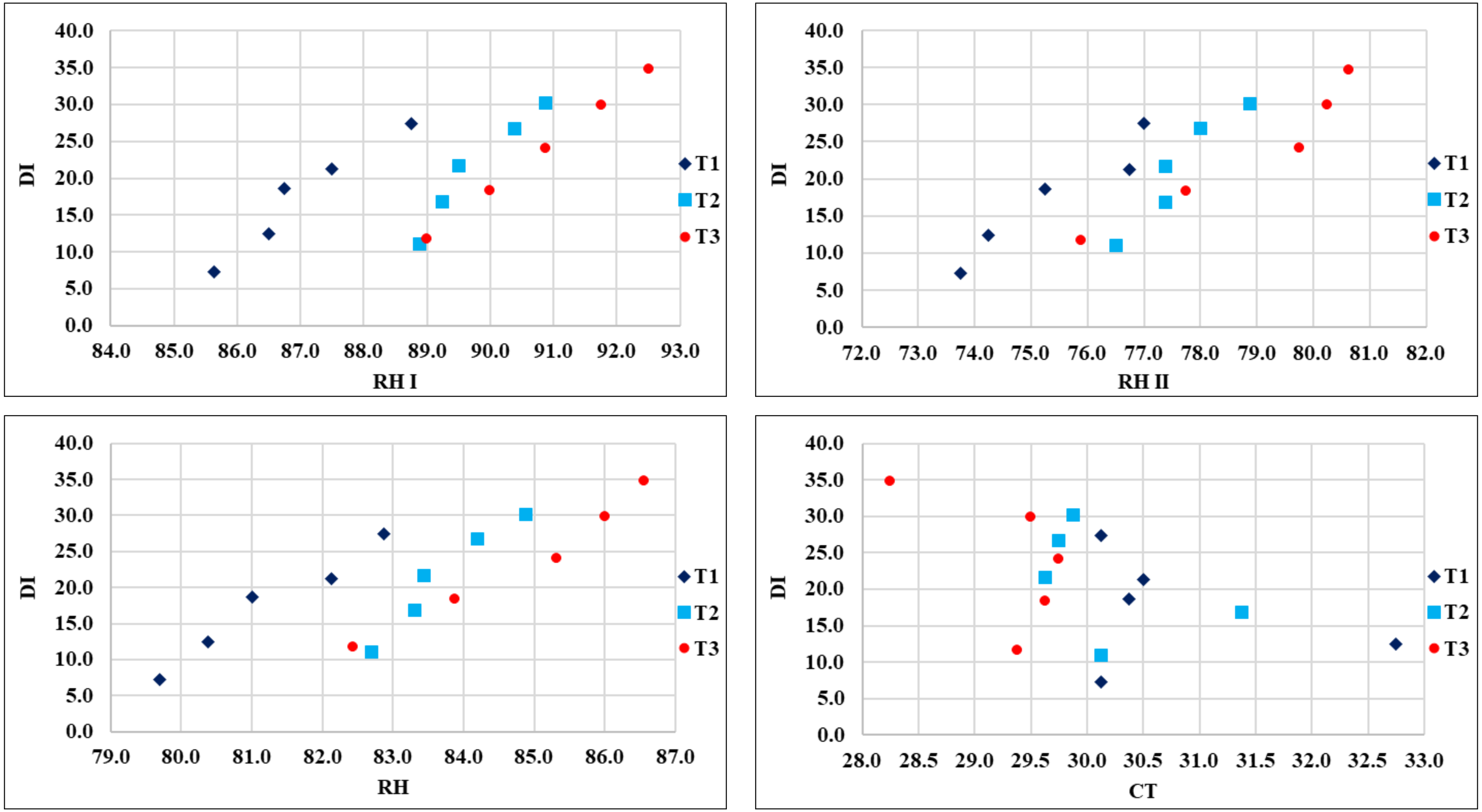
PDI: Per cent disease index; RH I: Forenoon relative humidity; RH II: Afternoon relative humidity; RH: Average relative humidity; CT: Canopy temperature; T1: Paired row planting; T2: Normal transplanting; T3: Direct sowing

Figure 5. Correlation between incidence of sheath blight and micrometeorological parameters (*Rabi* season)



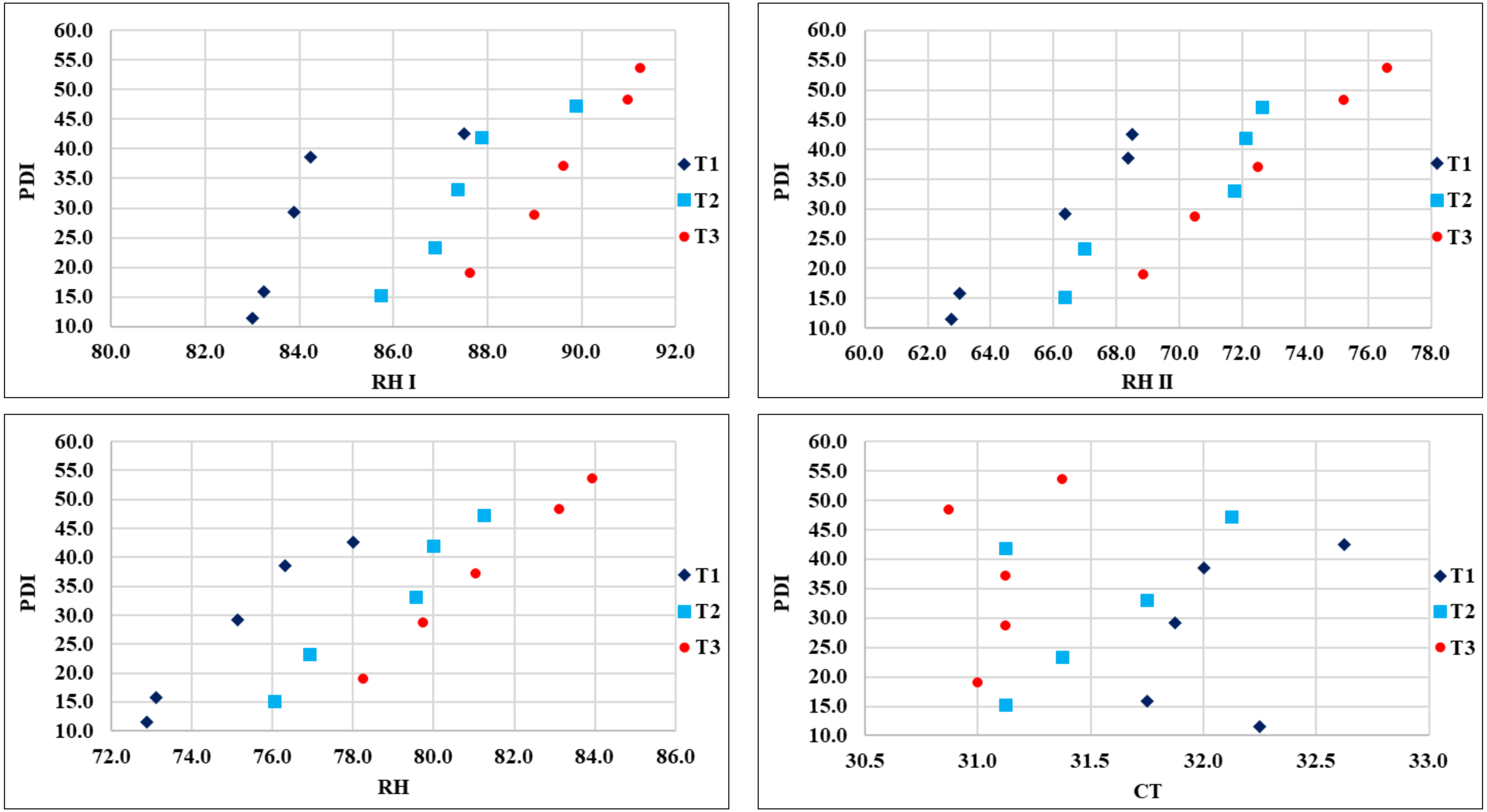
DI: Disease incidence; RH I: Forenoon relative humidity; RH II: Afternoon relative humidity; RH: Average relative humidity; CT: Canopy temperature; T1: Paired row planting; T2: Normal transplanting; T3: Direct sowing

Figure 6. Correlation between incidence of sheath blight and micrometeorological parameters (*Kharif* season)



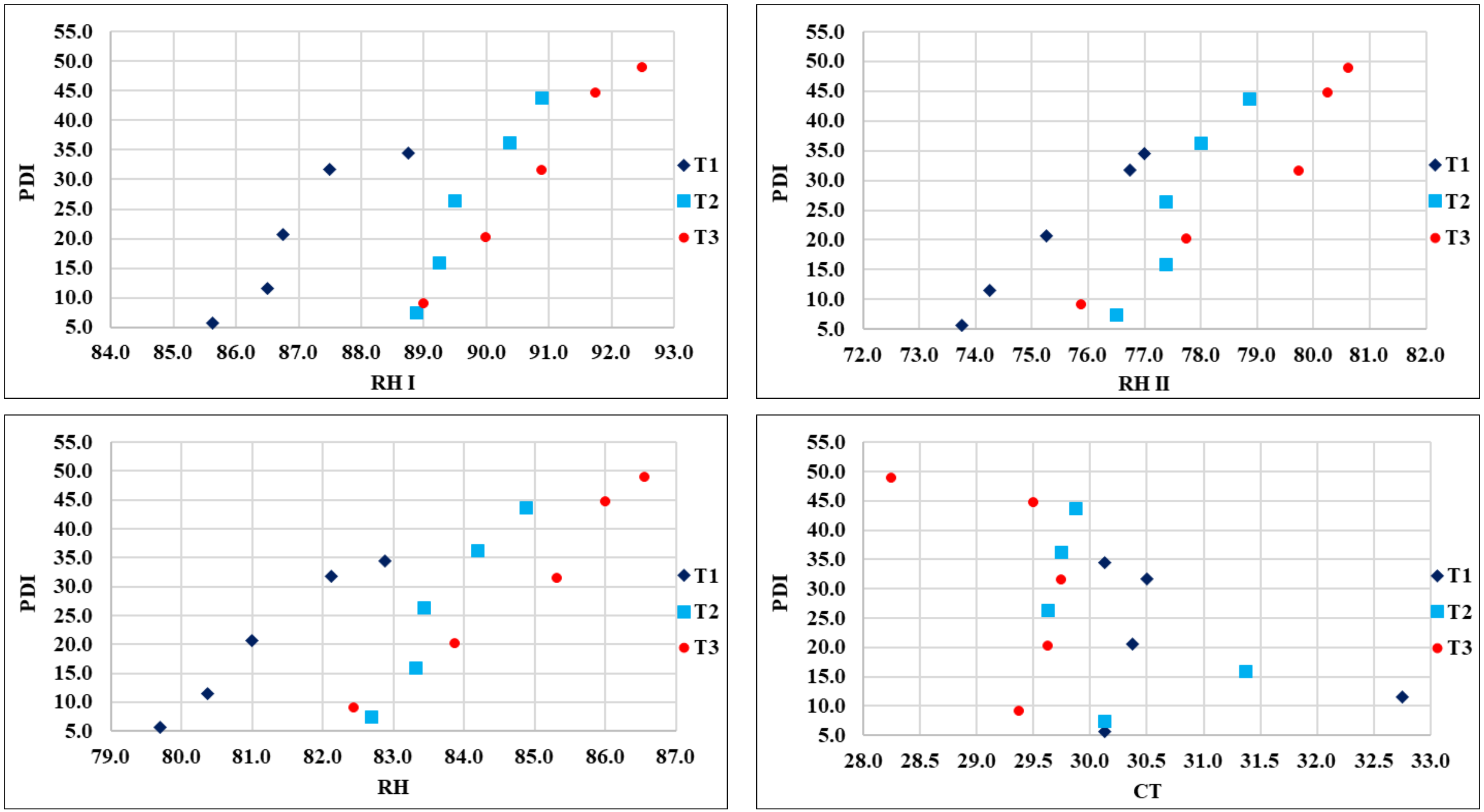
DI: Disease incidence; RH I: Forenoon relative humidity; RH II: Afternoon relative humidity; RH: Average relative humidity; CT: Canopy temperature; T1: Paired row planting; T2: Normal transplanting; T3: Direct sowing

Figure 7. Correlation between severity of sheath blight and micrometeorological parameters (*Rabi* season)



PDI: Per cent disease index; RH I: Forenoon relative humidity; RH II: Afternoon relative humidity; RH: Average relative humidity; CT: Canopy temperature; T1: Paired row planting; T2: Normal transplanting; T3: Direct sowing

Figure 8. Correlation between severity of sheath blight and micrometeorological parameters (*Kharif* season)



PDI: Per cent disease index; RH I: Forenoon relative humidity; RH II: Afternoon relative humidity; RH: Average relative humidity; CT: Canopy temperature; T1: Paired row planting; T2: Normal transplanting; T3: Direct sowing

normal transplanting. As in the case of *rabi* season, observations within this humidity range were not recorded in paired row planting. However, during this season, all the canopy temperature observations recorded from the direct sowing fell within the range in which maximum DI and PDI were recorded. The number of corresponding observations recorded in normal transplanting followed those recorded in direct sowing and paired row planting showed no representation within this canopy temperature range. During both seasons, the highest incidence and severity of sheath blight was recorded in the flowering and physiological maturity stages, wherein the incidence and severity of sheath blight recorded in paired row planting was significantly lower compared to other two systems (Tables 5 a. to 6 b.). Also, in these stages, the relative humidity recorded in paired row planting was significantly higher compared to that recorded in normal transplanting and direct sowing. At the same time canopy temperature recorded in paired row planting was higher than the other two systems (Tables 16 a. to 17 d.). From the scatter diagram it is clear that higher incidence and severity of sheath blight was recorded at high relative humidity and low canopy temperature conditions. This indicated that the more congenial microenvironmental conditions are offered by closely spaced direct sowing followed by normal transplanting compared to widely spaced paired row planting to the progress of sheath blight.

4.3.1.3 Influence of microclimate on incidence of brown spot of rice

The correlation analysis conducted between disease and micrometeorological variables corresponding to brown spot during *rabi* and *kharif* season are presented in Figures 9-12. During *rabi* season, the highest disease incidence (above 40%) and severity (above 40) were recorded at forenoon relative humidity range of 89-92 per cent, afternoon relative humidity range of 72-77 per cent, average relative humidity range of 81-84 per cent and canopy temperature range of 30.5-32.5^{0}C. The correlation analysis between DI and RH variables showed that the maximum number of observations within this humidity range, during the intervals in which disease symptoms were observed, were recorded in direct sowing followed by normal transplanting. In paired row planting, observations falling within this range were not recorded. Similarly, when the correlations between PDI and micrometeorological parameters were analyzed, similar results were repeated with maximum observations recorded in direct sowing followed by normal transplanting and none in paired row planting. However, all the observations pertaining to canopy temperature recorded from the three systems during the observed intervals fell within the range of 30.5-32.5^{0}C.

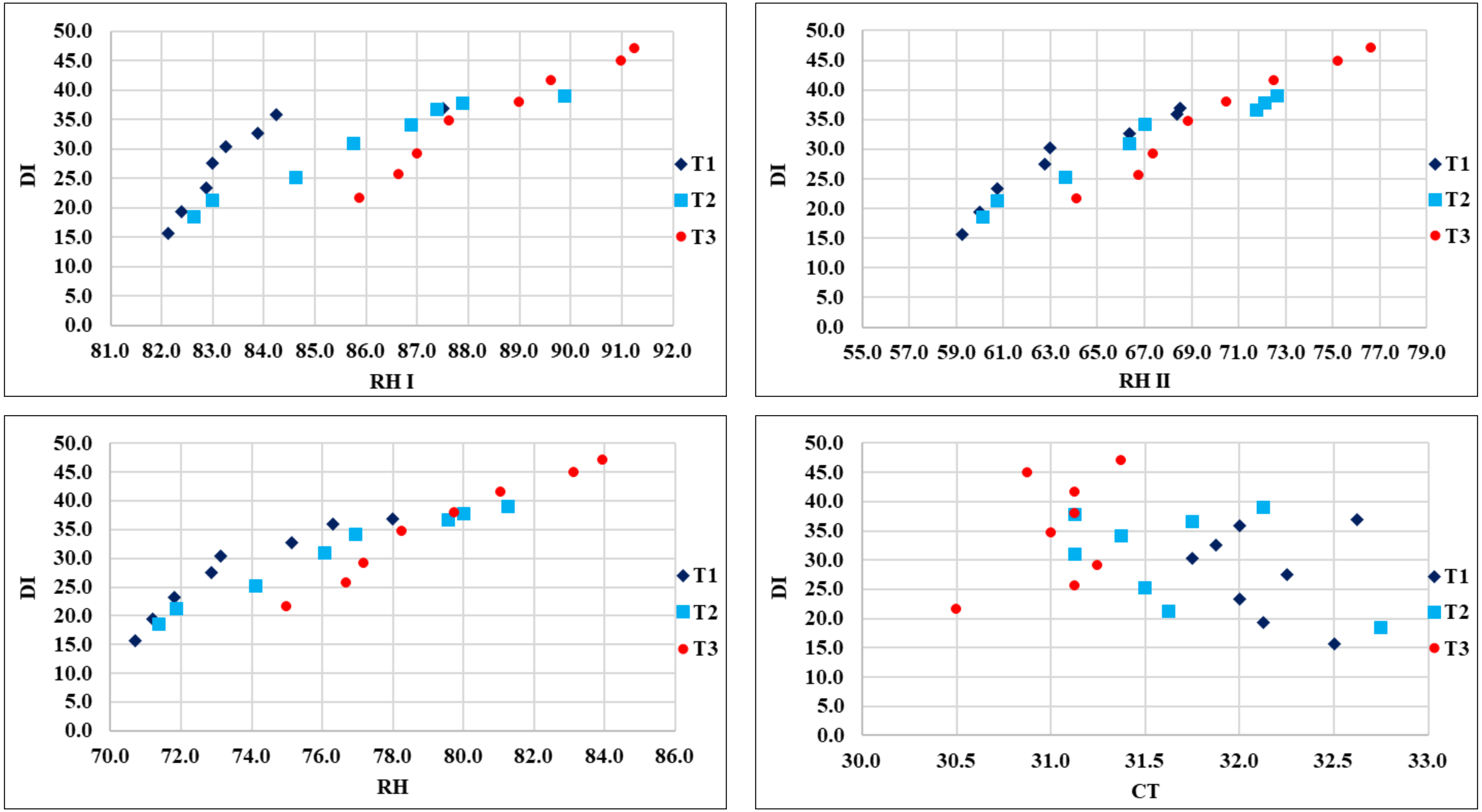
During *kharif* season, the highest disease incidence (above 35%) and severity (above 35) were recorded at forenoon relative humidity range of 89-93 per cent, afternoon relative humidity range of 77-81 per cent, average relative humidity range of 83-87 per cent and canopy temperature range of 28-30^{0}C. The correlation analysis conducted between disease and micrometeorological variables showed that the maximum number of observations within this range, during the intervals in which disease symptoms were observed, were recorded in direct sowing followed by normal transplanting and paired row planting.

During both seasons, the highest incidence and severity of brown spot were recorded in heading, flowering and physiological maturity phases wherein the incidence and severity recorded in paired row planting was significantly lower compared to normal transplanting and direct sowing (Tables 7 a. to 8 b.). Also, in these stages, the forenoon, afternoon and average relative humidity recorded in paired row planting was lower compared to normal transplanting and direct sowing. On the other hand, the canopy temperature recorded in paired row planting was higher compared to other two systems (Tables 16 a to 17 d.). The analysis of scatter diagram showed that the incidence and severity of brown spot was favoured by high relative humidity and low canopy temperature. This can be considered as an indicator of the presence of a more conducive microclimate for the spread and development of brown spot disease within direct sowing and normal transplanting when compared to paired row planting.

4.3.1.4 Influence of microclimate on incidence of sheath rot in rice

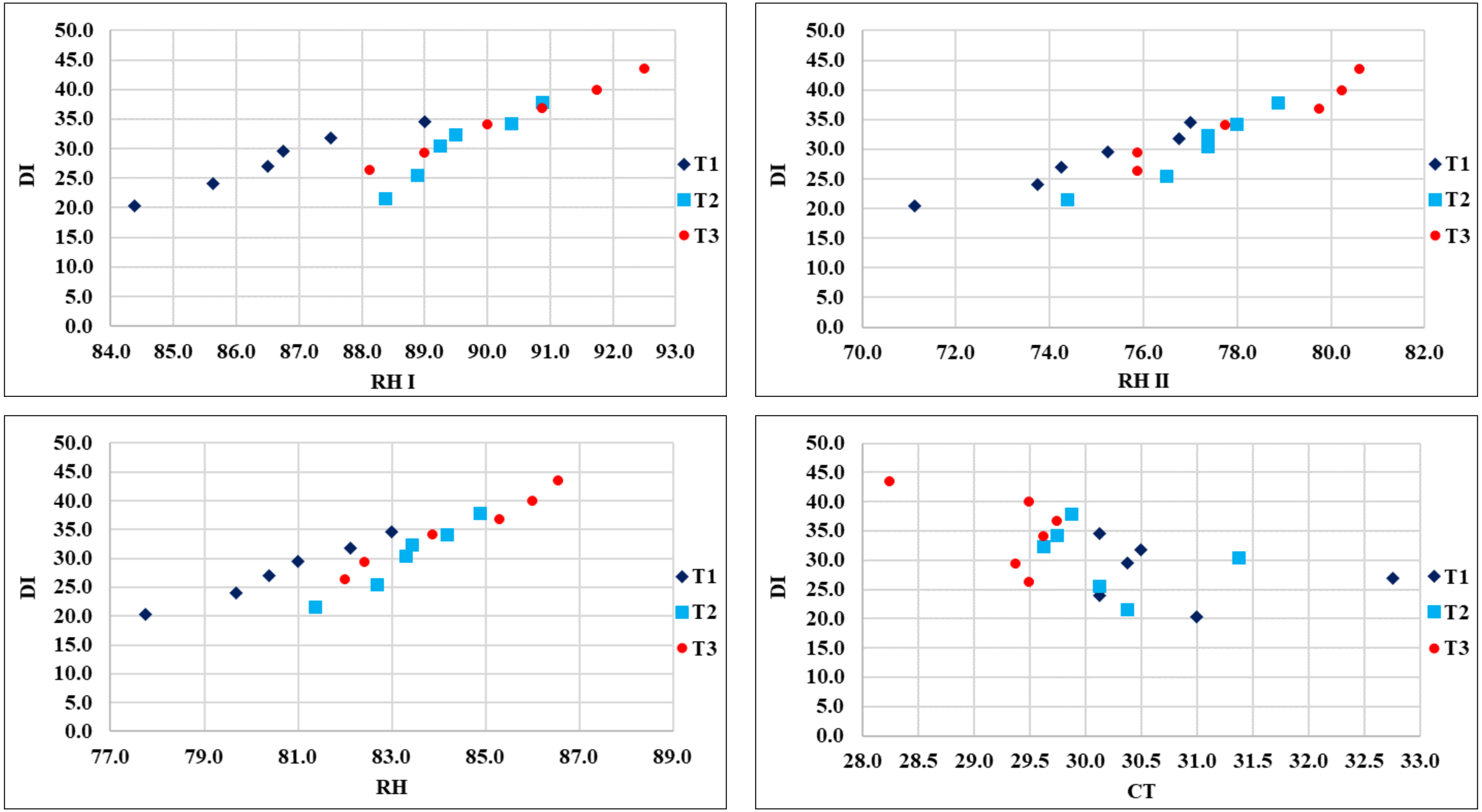
The sheath rot symptoms were noticed in the field during the *kharif* season only. The results of the correlation analysis conducted between micrometeorological and disease variables are depicted in the Figures 13 and 14. The highest DI (above 20%) and PDI (above 30) were recorded at RH I range of 90.5-92.5 per cent, RH II range of 78.5-81 per cent, RH range of 84.5-87 per cent and CT range of 28-30^{0}C. A closer analysis of the scatter diagram indicated that the maximum number of observations falling within this microclimatological data were recorded from direct sowing, followed by normal transplanting. However, the micrometeorological observations recorded in paired row planting did not fall within this range. Unlike other treatments, it experienced

Figure 9. Correlation between incidence of brown spot and micrometeorological parameters (*Rabi* season)



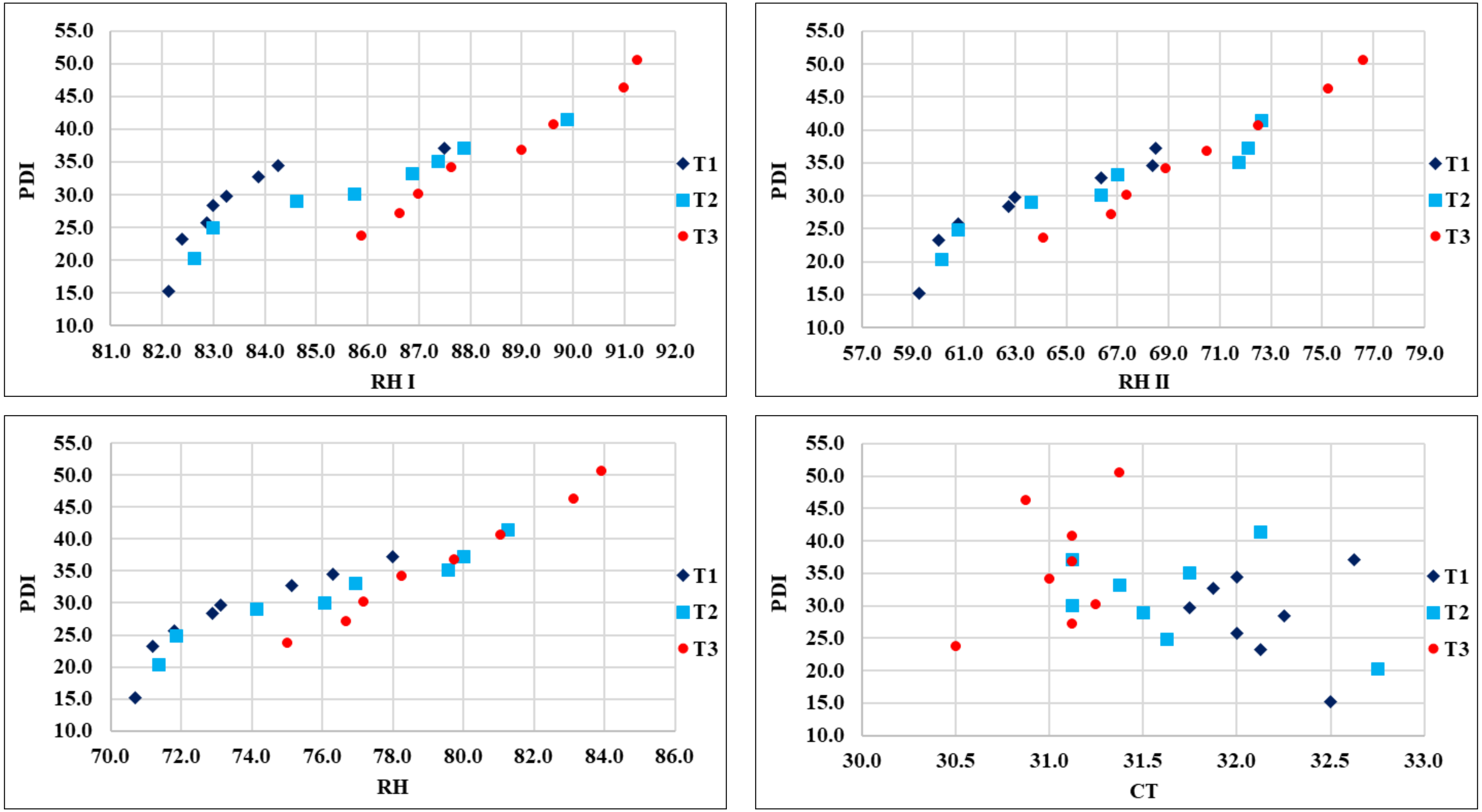
DI: Disease incidence; RH I: Forenoon relative humidity; RH II: Afternoon relative humidity; RH: Average relative humidity; CT: Canopy temperature; T1: Paired row planting; T2: Normal transplanting; T3: Direct sowing

Figure 10. Correlation between incidence of brown spot and micrometeorological parameters (*Kharif* season)



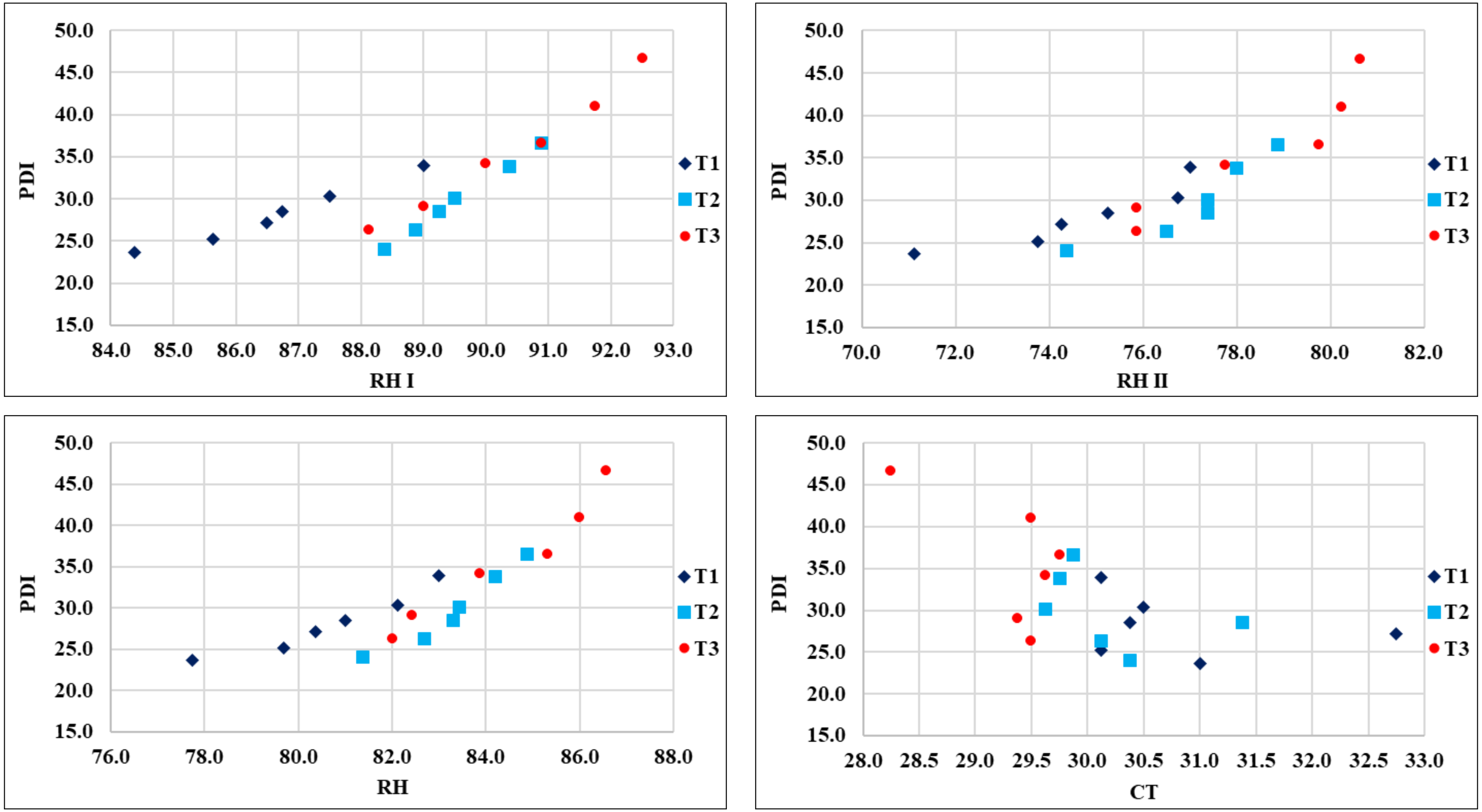
DI: Disease incidence; RH I: Forenoon relative humidity; RH II: Afternoon relative humidity; RH: Average relative humidity; CT: Canopy temperature; T1: Paired row planting; T2: Normal transplanting; T3: Direct sowing

Figure 11. Correlation between severity of brown spot and micrometeorological parameters (*Rabi* season)



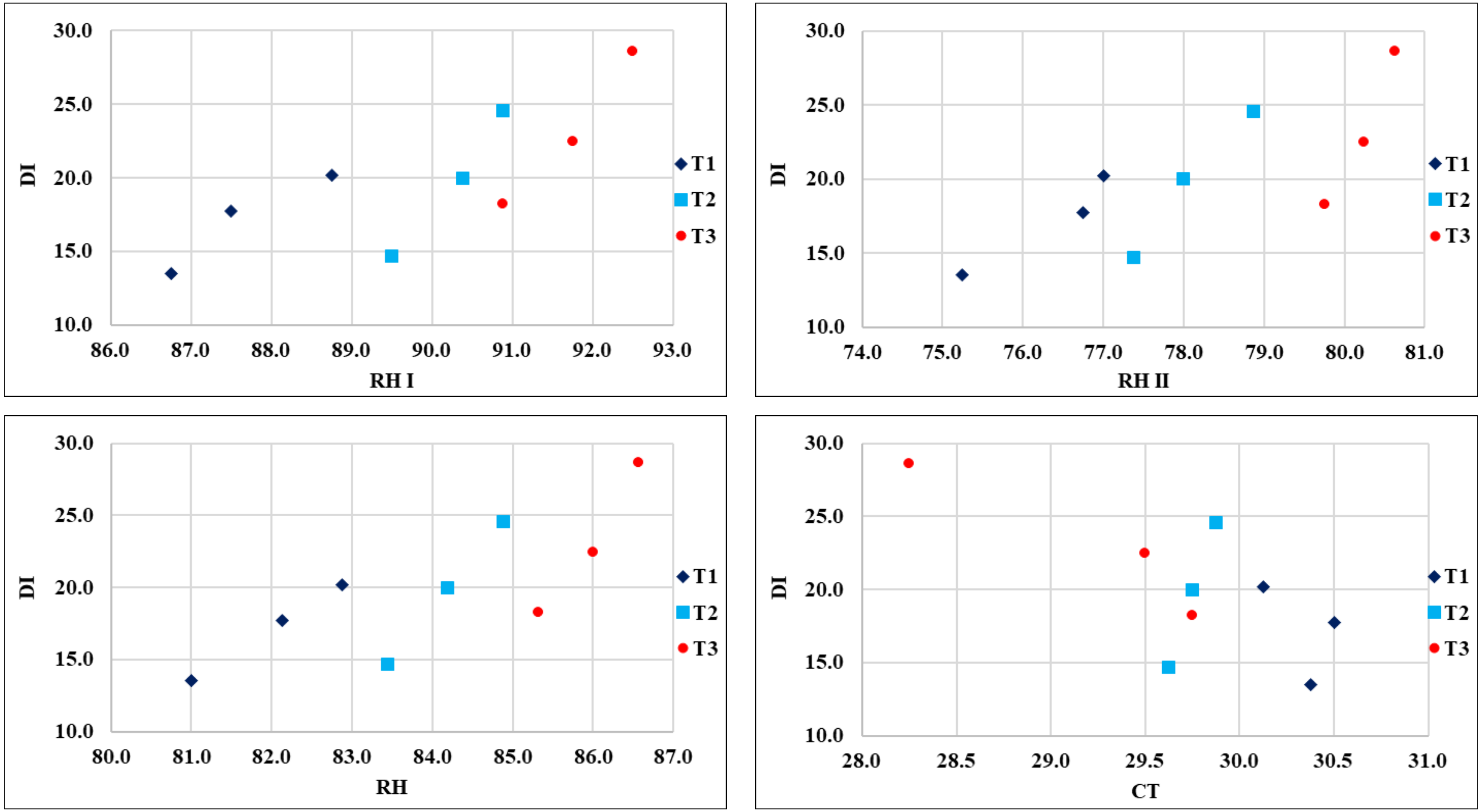
PDI: Per cent disease index; RH I: Forenoon relative humidity; RH II: Afternoon relative humidity; RH: Average relative humidity; CT: Canopy temperature; T1: Paired row planting; T2: Normal transplanting; T3: Direct sowing

Figure 12. Correlation between severity of brown spot and micrometeorological parameters (*Kharif* season)



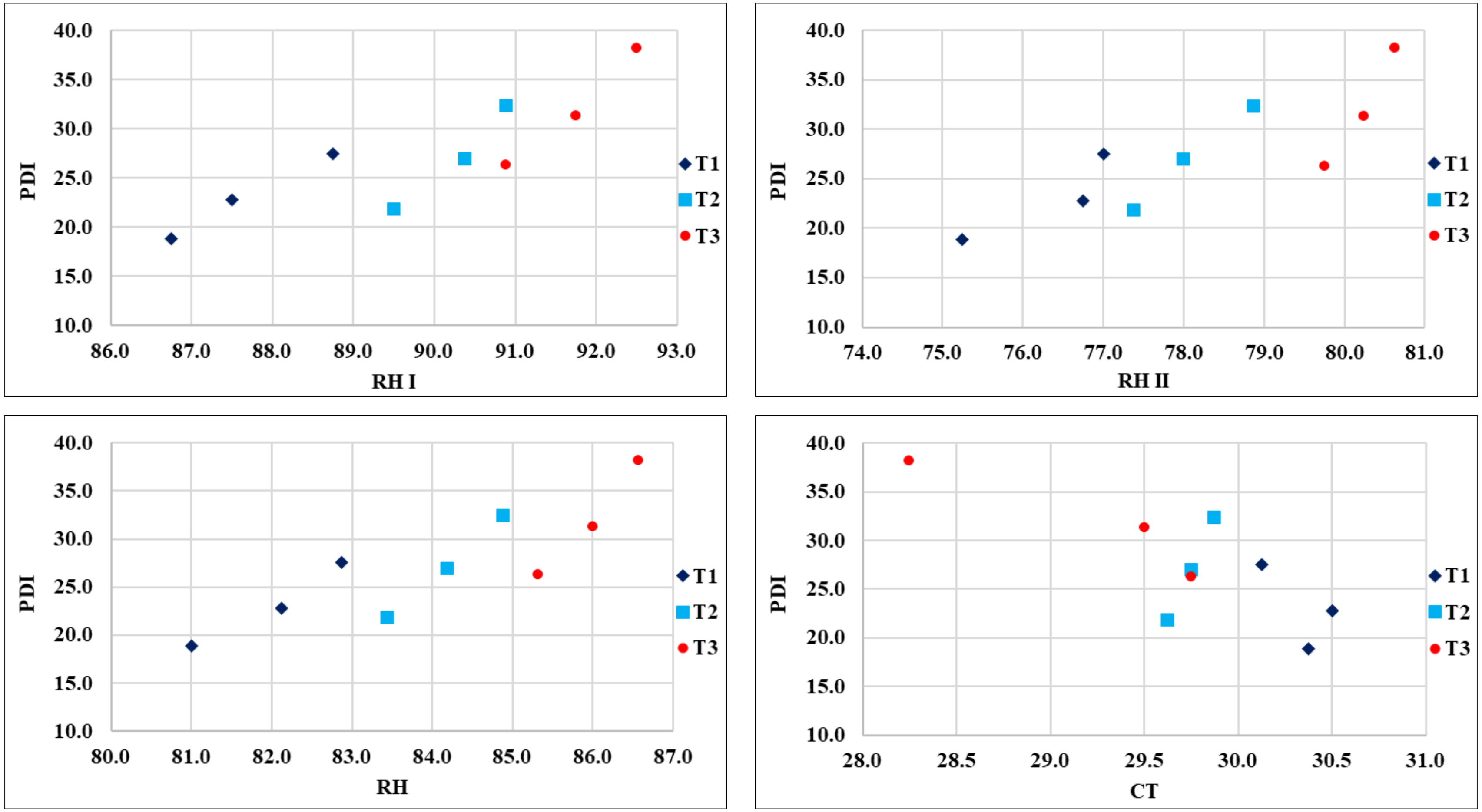
PDI: Per cent disease index; RH I: Forenoon relative humidity; RH II: Afternoon relative humidity; RH: Average relative humidity; CT: Canopy temperature; T1: Paired row planting; T2: Normal transplanting; T3: Direct sowing

Figure 13. Correlation between incidence of sheath rot and micrometeorological parameters (*Kharif* season)



DI: Disease incidence; RH I: Forenoon relative humidity; RH II: Afternoon relative humidity; RH: Average relative humidity; CT: Canopy temperature; T1: Paired row planting; T2: Normal transplanting; T3: Direct sowing

Figure 14. Correlation between severity of sheath rot and micrometeorological parameters (*Kharif* season)



PDI: Per cent disease index; RH I: Forenoon relative humidity; RH II: Afternoon relative humidity; RH: Average relative humidity; CT: Canopy temperature; T1: Paired row planting; T2: Normal transplanting; T3: Direct sowing

an increased canopy temperature and decreased relative humidity. During both seasons, the incidence and severity of sheath rot recorded in paired row planting was significantly lower compared to other two systems (Table 9.). These findings gave implications about the more congenial microclimatic conditions existed in densely planted direct sowing followed by normal transplanting compared to that of paired row planting for the development of sheath rot disease.

4.3.1.5 Influence of microclimate on incidence of false smut in rice

The results of correlation analysis conducted between microclimatological and disease variables corresponding to false smut disease are presented in Figures 15-18. During *rabi* season, the highest DI (above 25%) and PDI (above 30) were recorded at forenoon relative humidity range of 88-95 per cent, afternoon relative humidity range of 71-77 per cent, average relative humidity range of 80-85 per cent and canopy temperature range of 28.5-33^{0}C. A comprehensive analysis of the scatter diagram indicated that the maximum number of observations falling within this humidity range were recorded from direct sowing, followed by normal transplanting. However, in paired row planting, all the observations recorded during the flowering stage were found to be lower than this range. In the case of canopy temperature, some of the observations recorded within paired row planting and all the observations recorded within the other two treatments fell within the range in which the highest DI and PDI were reported. Also, none of the observations recorded in paired row planting were found to be lower than 31^{0}C, whereas more than a quarter of observations recorded in direct sowing and half that in normal transplanting were between 28.5-31^{0}C. This gives an indication about the comparatively higher canopy temperature existed in paired row planting with respect to other treatments.

During *kharif* season, the highest DI (above 25%) and PDI (above 25) were recorded at forenoon relative humidity range of 89-96 per cent, afternoon relative humidity range of 78-82 per cent, average relative humidity range of 83.5-88 per cent and canopy temperature range of 29-30.5^{0}C. A detailed analysis of the scatter diagram indicated that the maximum number of observations falling within this humidity range were recorded from direct sowing and normal transplanting, followed by paired row planting. Most of the observations recorded from paired row planting were lower than this humidity range. On the other hand, all the observations recorded in normal transplanting and direct sowing were found to be within the canopy temperature range in which maximum DI and PDI were reported, with zero representation from paired row planting. Also, during both seasons, the incidence and severity of false smut recorded in paired row planting was significantly lower compared to normal transplanting and direct sowing (Table 10 and Table 11). This clearly indicates that the microclimate created due to the modified planting geometry within paired row planting is characterised with lower relative humidity and higher canopy temperature compared to direct sowing and normal transplanting and thereby leading to less incidence of the disease.

4.3.2 Influence of microclimate on pest incidence in rice

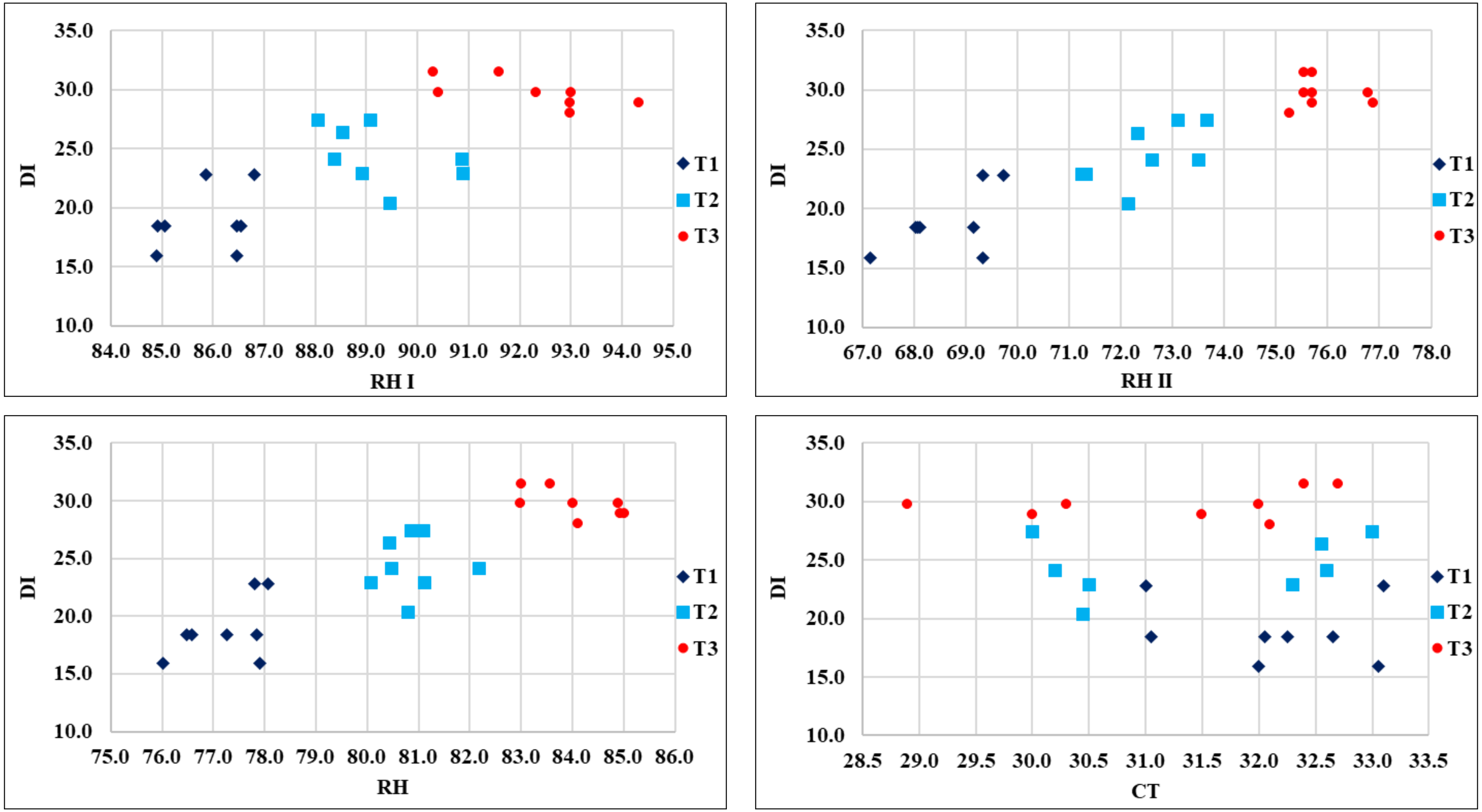
4.3.2.1 Influence of microclimate on incidence of caseworm in rice

The relative humidity and canopy temperature recorded from each planting geometry during the caseworm infestation period were correlated with the respective per cent damage caused by the pest and a scatter diagram was plotted as an attempt to derive a relationship between the microclimate associated with the planting geometry on caseworm incidence (Figures 19 and 20).

Analyzing the data, it was observed that, the highest per cent damage due to caseworm (above 30%) was recorded at forenoon relative humidity of 81.25-83.5 per cent, afternoon relative humidity of 59-62 per cent, average relative humidity of 70.75-72.25 per cent and canopy temperature of 31.75-34.25^{0}C during *rabi* season. Similarly, during the *kharif* season, it was recorded at forenoon, afternoon, and average relative humidity and canopy temperature ranges of 81.75-85 per cent, 62.5-70 per cent, 73-76.5 per cent and 31-33^{0}C respectively. From the scatter plot diagram, it is also evident that the maximum number of observations corresponding to this micrometeorological range were observed in paired row planting and normal transplanting.

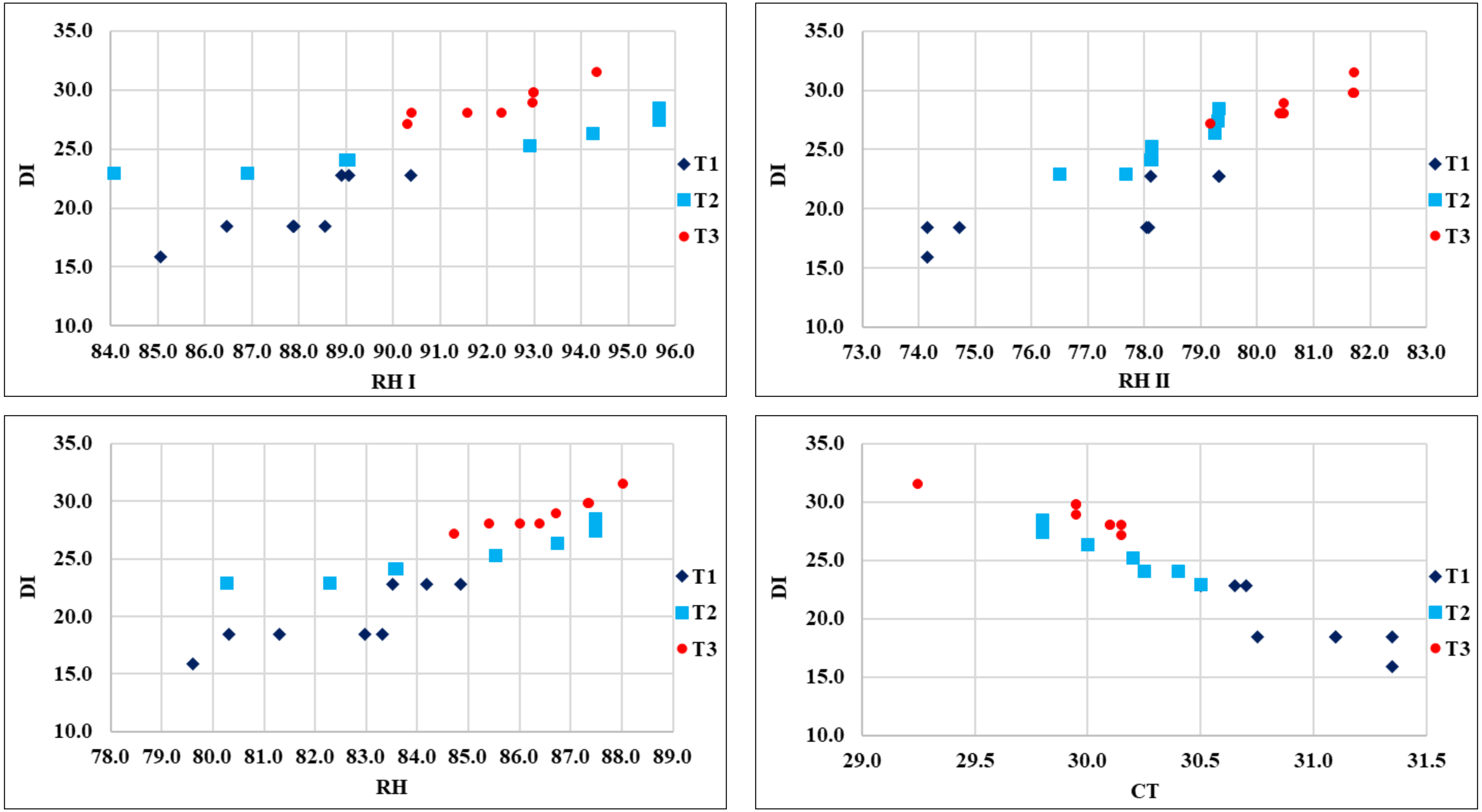
During both seasons, the highest caseworm damage (above 30%) was recorded in the first observed interval (30 DAS), indicating that the plants in the earlier stages of development are susceptible to caseworm damage. In this stage, the caseworm damage recorded in paired row planting (31.65%, 34.73%) was statistically on par with that of normal transplanting (38.48%, 36.25%) and significantly higher than that in direct sowing (10.41%, 8.24%) (Table 12 a. and Table 12 b.). In direct sowing, earlier establishment of plant stands was achieved and this might have helped them to surpass

Figure 15. Correlation between incidence of false smut and micrometeorological parameters (*Rabi* season)



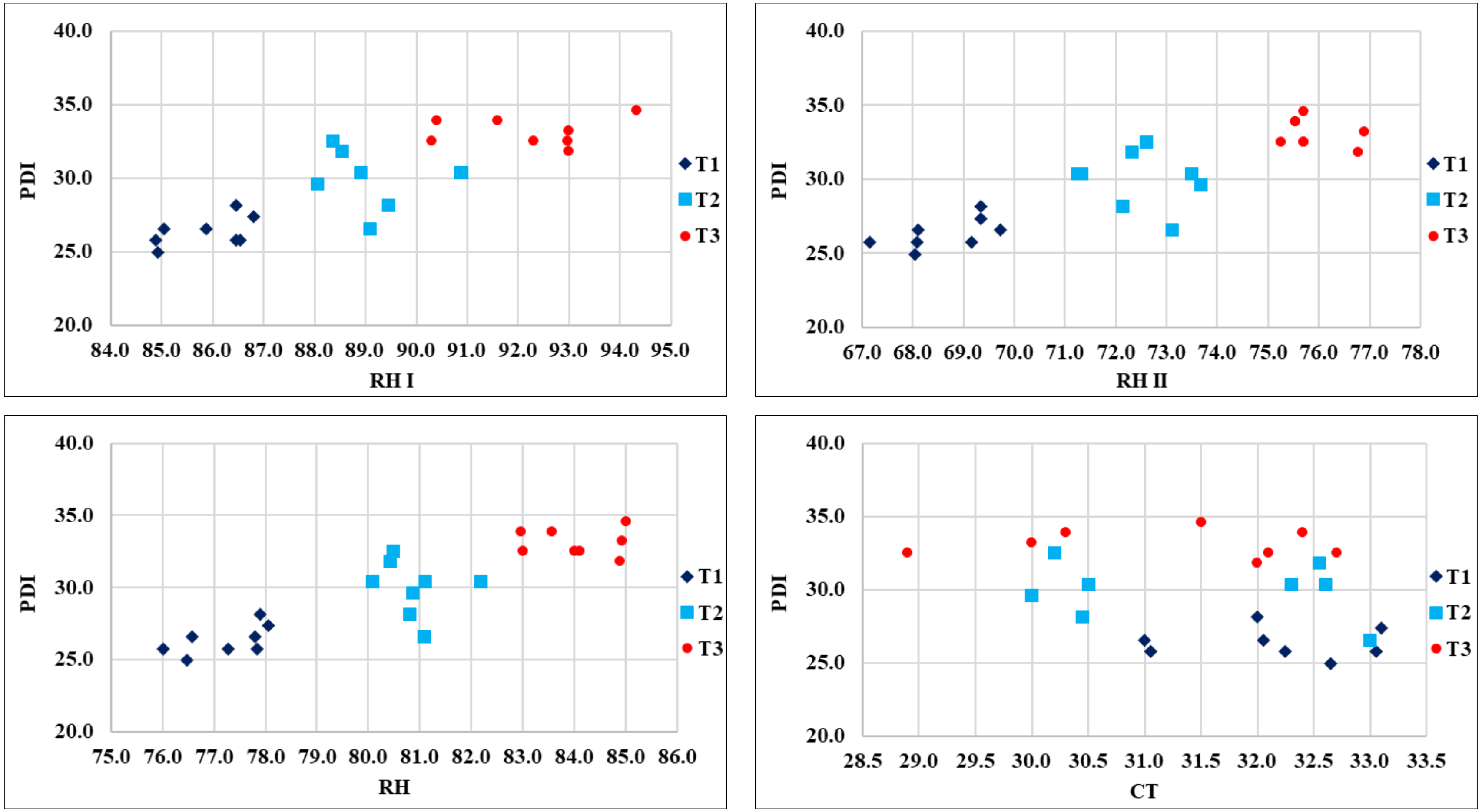
DI: Disease incidence; RH I: Forenoon relative humidity; RH II: Afternoon relative humidity; RH: Average relative humidity; CT: Canopy temperature; T1: Paired row planting; T2: Normal transplanting; T3: Direct sowing

Figure 16. Correlation between incidence of false smut and micrometeorological parameters (*Kharif* season)



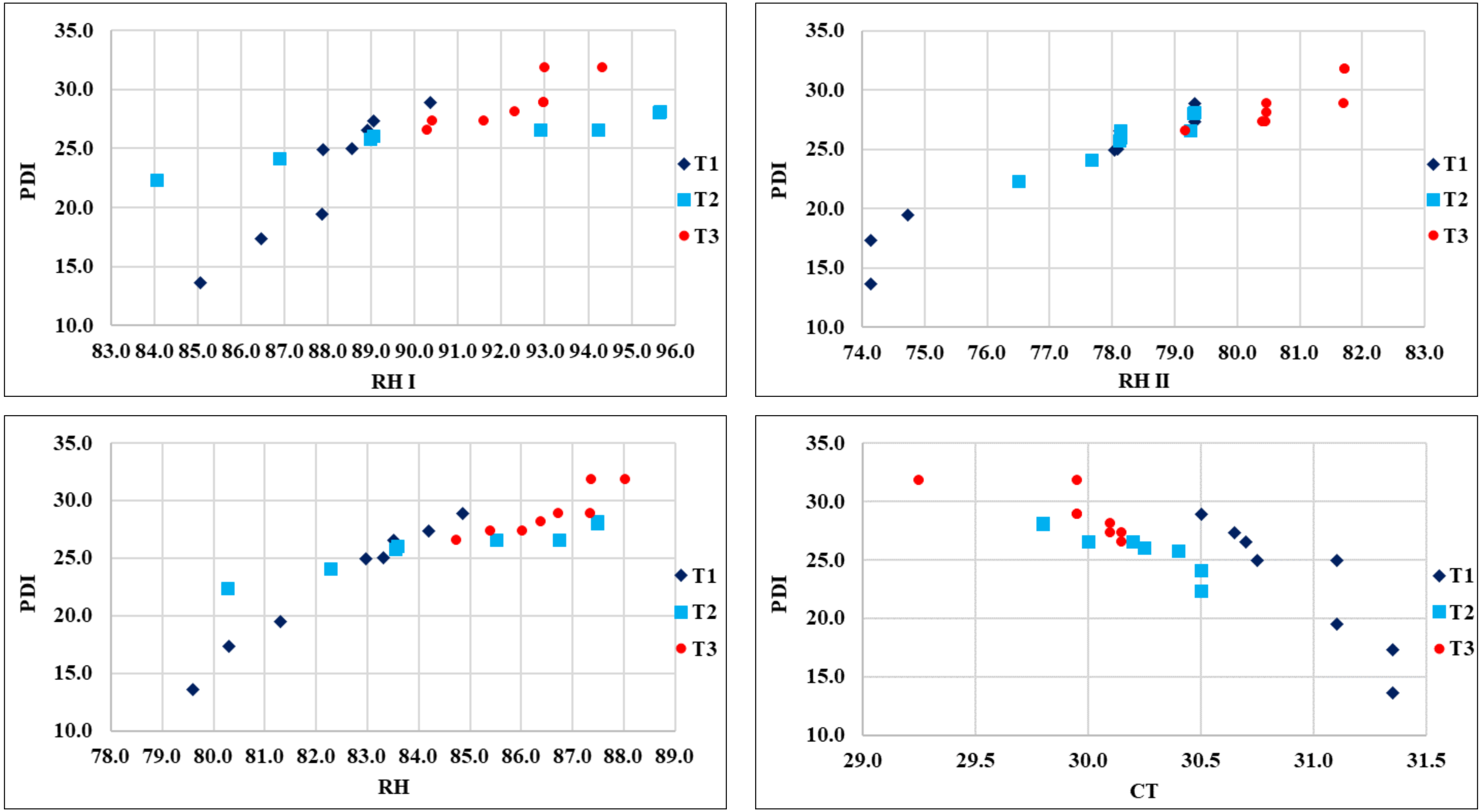
DI: Disease incidence; RH I: Forenoon relative humidity; RH II: Afternoon relative humidity; RH: Average relative humidity; CT: Canopy temperature; T1: Paired row planting; T2: Normal transplanting; T3: Direct sowing

Figure 17. Correlation between severity of false smut and micrometeorological parameters (*Rabi* season)



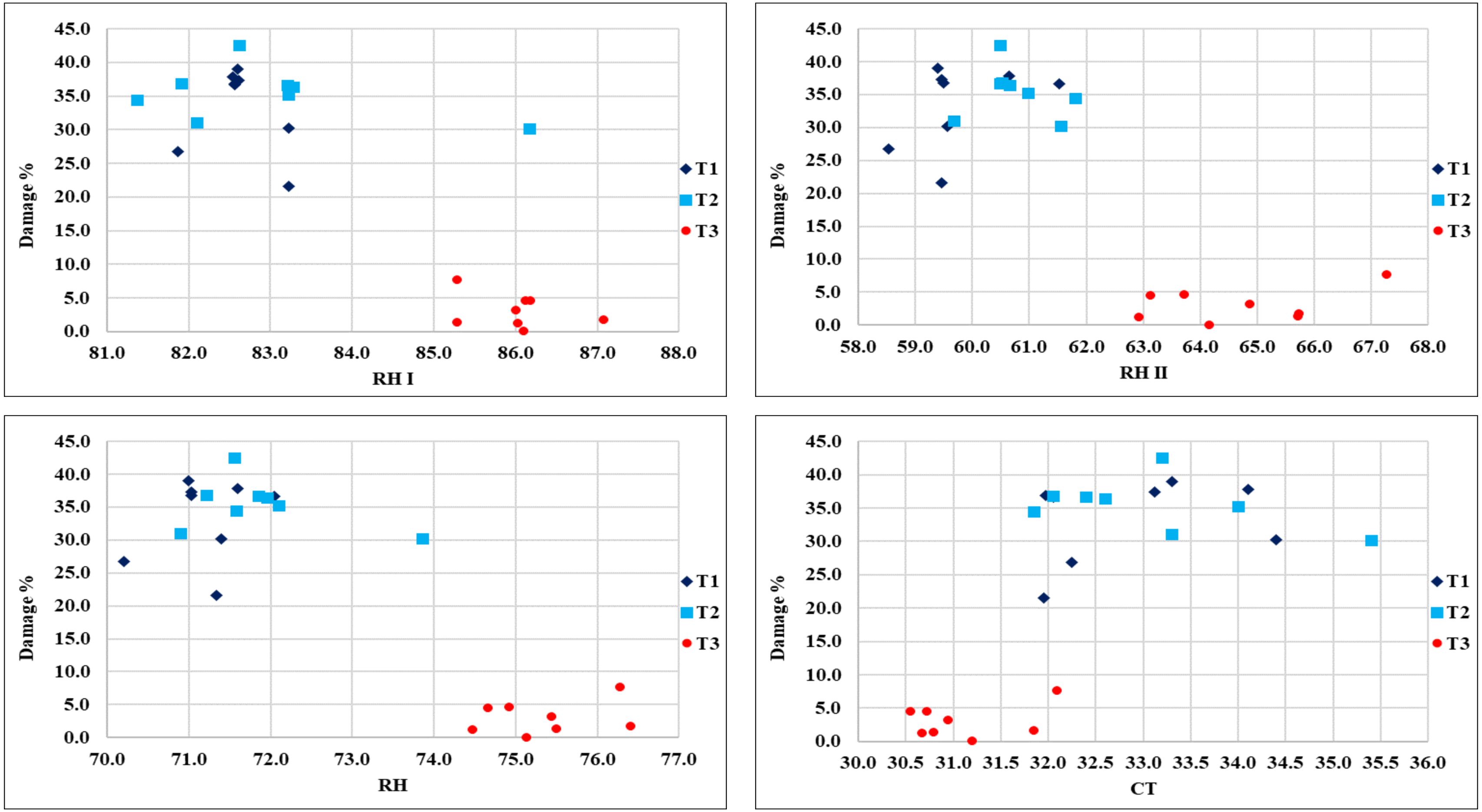
PDI: Per cent disease index; RH I: Forenoon relative humidity; RH II: Afternoon relative humidity; RH: Average relative humidity; CT: Canopy temperature; T1: Paired row planting; T2: Normal transplanting; T3: Direct sowing

Figure 18. Correlation between severity of false smut and micrometeorological parameters (*Kharif* season)



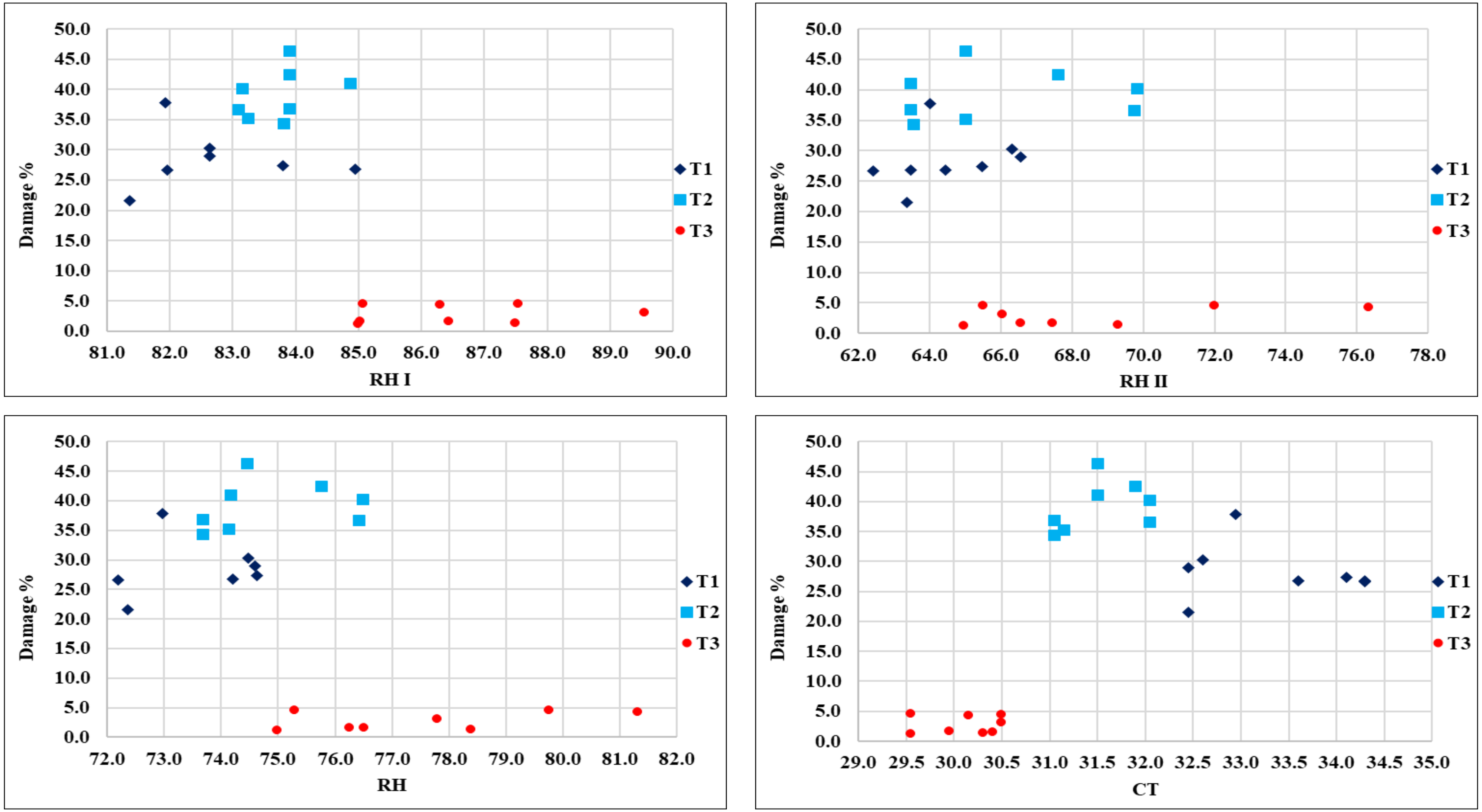
PDI: Per cent disease index; RH I: Forenoon relative humidity; RH II: Afternoon relative humidity; RH: Average relative humidity; CT: Canopy temperature; T1: Paired row planting; T2: Normal transplanting; T3: Direct sowing

Figure 19. Correlation between incidence of caseworm and micrometeorological parameters (*Rabi* season)



RH I: Forenoon relative humidity; RH II: Afternoon relative humidity; RH: Average relative humidity; CT: Canopy temperature; T1: Paired row planting; T2: Normal transplanting; T3: Direct sowing

Figure 20. Correlation between incidence of caseworm and micrometeorological parameters (*Kharif* season)



RH I: Forenoon relative humidity; RH II: Afternoon relative humidity; RH: Average relative humidity; CT: Canopy temperature; T1: Paired row planting; T2: Normal transplanting; T3: Direct sowing

the susceptible stage by the time first observations were taken after transplanting seedlings in paired row and normal transplanted plots. So, it may not be appropriate to idealize a planting geometry with respect to the microclimatic conditions in managing caseworms, considering the susceptibility stage and duration of its attack.

4.3.2.2 Influence of microclimate on incidence of leaf folder in rice

The correlation analysis conducted between micrometeorological parameters and per cent damage caused by leaf folder is portrayed in scatter diagrams for effective analysis (Figures 21 and 22). The data revealed that the highest per cent damage (35%) caused by leaf folders in *rabi* season was at forenoon relative humidity of 85.5-88 per cent, afternoon relative humidity of 66-69 per cent, average relative humidity of 76-78.5 per cent and canopy temperature of 31-31.5^{0}C during *rabi* season. Similarly, during the *kharif* season, it was recorded at forenoon, afternoon, and average relative humidity and canopy temperature ranges of 88-91 per cent, 75-80 per cent, 82-86 per cent and 29-30.5^{0}C respectively. A detailed analysis of the scatter diagram also showed that the highest number of observations recorded within this range were from direct sowing followed by normal transplanting. Most of the observations recorded in paired row planting were lower than the favourable relative humidity range derived. Similarly, the canopy temperature observations recorded in the same were higher than the conducive range. The highest per cent damage due to leaf folder was recorded in panicle initiation phase, wherein the leaf folder damage was significantly less in paired row planting compared to normal transplanting and direct sowing (Table 13 a. and Table 13 b.). Also, during this stage, the forenoon, afternoon, average relative humidity recorded in paired row planting were less compared to that in normal transplanting and direct sowing and the canopy temperature recorded in paired row planting was higher than that recorded in other two systems (Tables 16 a. to 17 d.). This indicated that the microclimate associated with direct sowing and normal transplanting was more conducive for leaf folder damage compared to that associated with paired row planting.

4.3.2.3 Influence of microclimate on incidence of yellow stem borer in rice

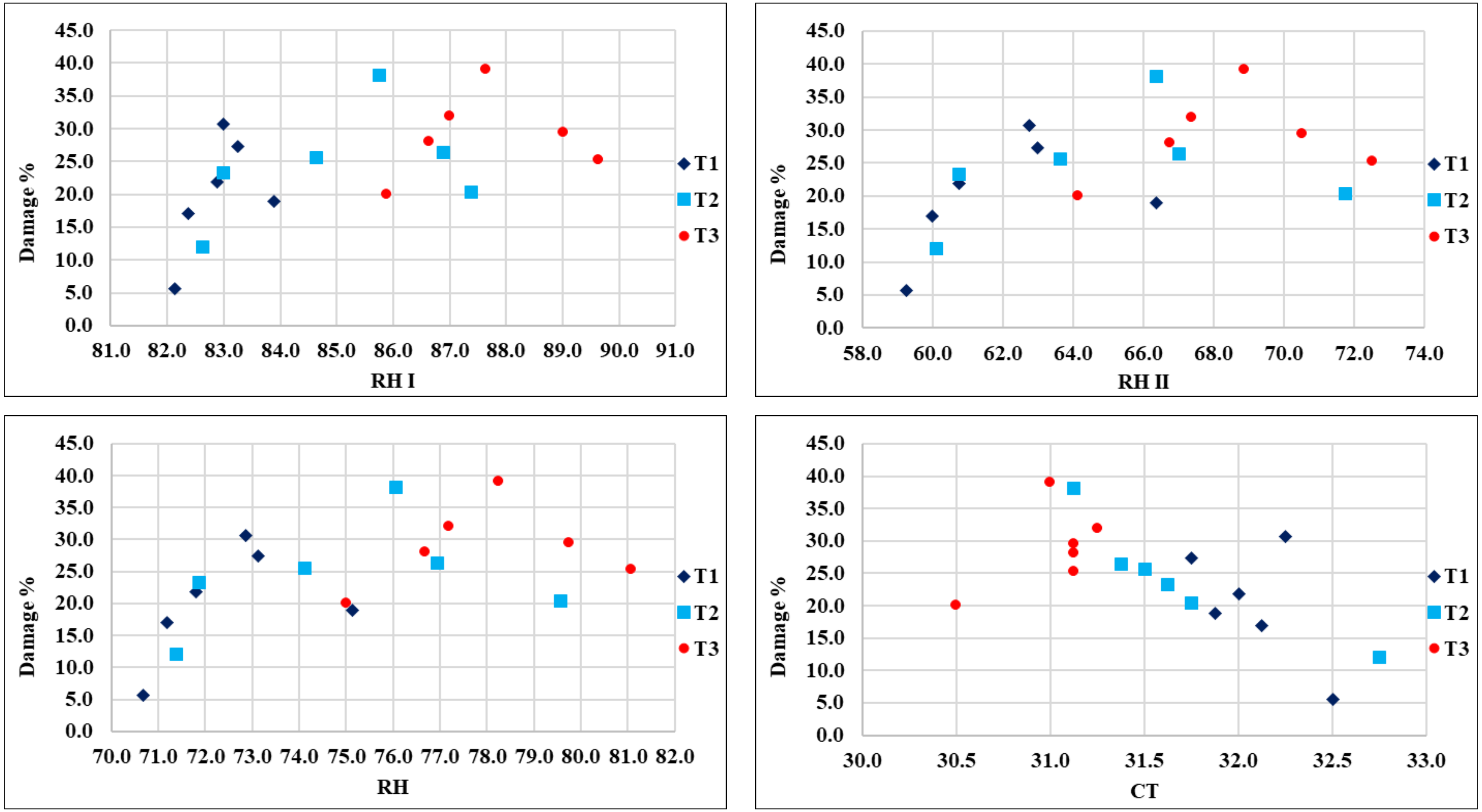
The relationship between damage caused by yellow stem borer with respect to dead hearts formed during the active tillering phase and white ear heads formed during the panicle initiation phase and the recorded micrometeorological parameters *viz*.

relative humidity and canopy temperature in all three treatments was portrayed by scatter plot diagrams that are presented in Figures 23-26.

The analysis of the diagram revealed that, during the *rabi* season, the highest per cent dead hearts (above 30%) was noticed at the forenoon relative humidity range of 85-89 per cent, afternoon relative humidity range of 65-72 per cent, average relative humidity range of 75-80 per cent and canopy temperature range of 31-32.5^{0}C. During *kharif* season, it occurred at forenoon, afternoon, average relative humidity and canopy temperature ranges of 87.5-89 per cent, 74.5-77 per cent, 81-82.5 per cent, and 29.5-31^{0}C. In both seasons, all the observations recorded within this humidity range were from direct sowing. The relative humidity observations recorded from paired row planting and normal transplanting were lower than this range, clearly indicating the role of higher relative humidity in increased pest damage. During *kharif* season, the canopy temperature recorded in paired row planting and normal transplanting were higher than the favourable range. At the same time, during *rabi* season, it was found that most of the canopy temperature observations recorded fell within this favourable range irrespective of the systems. During both seasons, at active tillering phase, the dead heart damage recorded in paired row planting was statistically on par with that of normal transplanting and significantly less than that in direct sowing (Tables 14 a. and Table 14 b.). This indicates the prevalence of favourable microclimate in direct sowing for dead heart damage compared to that in paired row planting and normal transplanting.

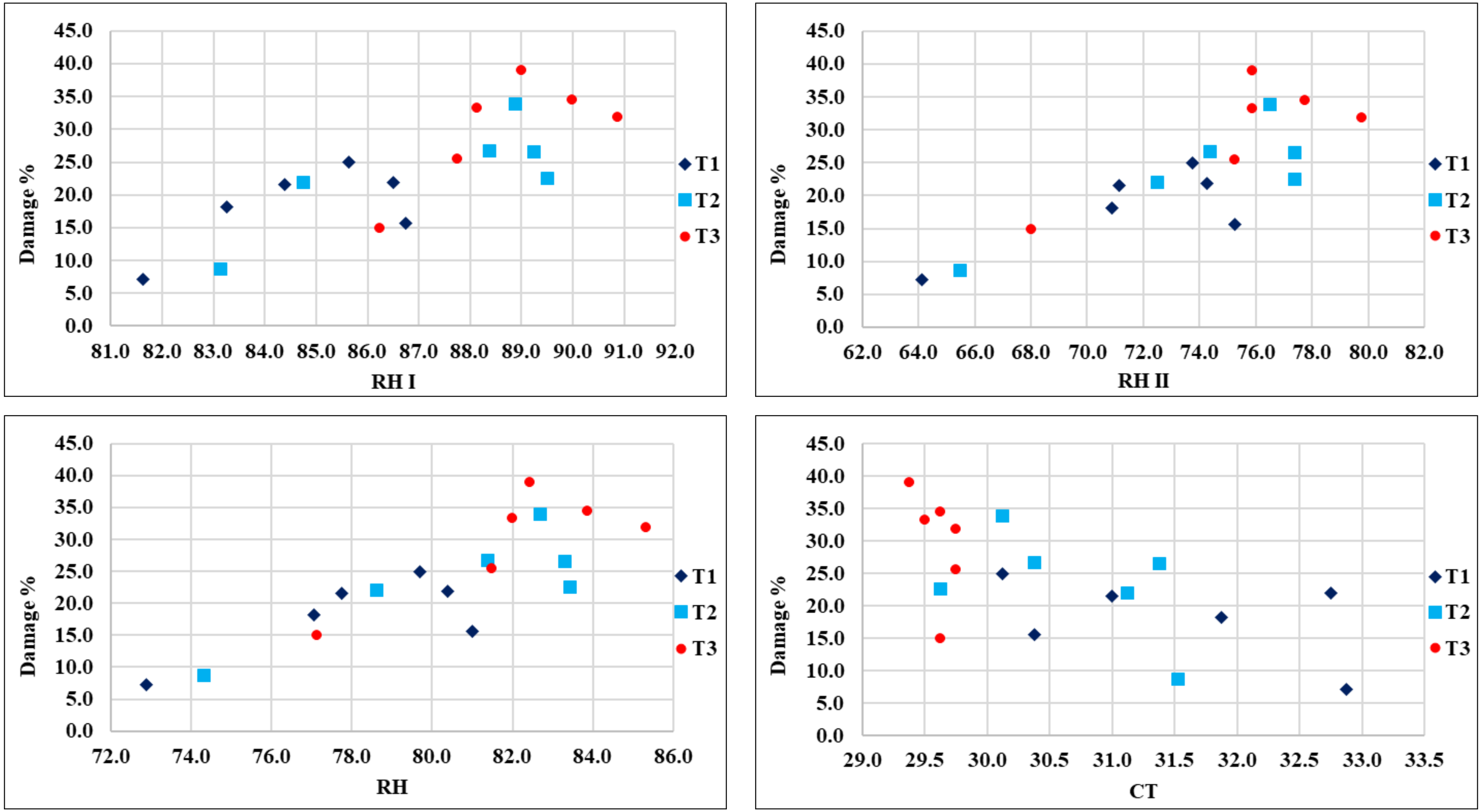
The yellow stem borer damage during the panicle initiation phase was recorded with respect to per cent white ear head formation. When this data was correlated with that of micrometeorological observations, it was found that the highest per cent white ear head was noticed at forenoon relative humidity of 85-90 per cent, afternoon relative humidity of 70-80 per cent, average relative humidity of 79-85 per cent and canopy temperature of 30.5-32^{0}C. Similarly, the highest damage per cent (WEH) was noticed during *kharif* season at forenoon, afternoon, average relative humidity and canopy temperature ranges of 87.5-92 per cent, 75.5-79 per cent, 82-84 per cent and 29-31^{0}C. In both seasons, the highest number of observations recorded within this range of data were from direct sowing and normal transplanting compared to paired row planting. The recorded relative humidity in paired row planting were lower and canopy temperature was higher than the range derived. Also, during both seasons, at the panicle

Figure 21. Correlation between incidence of leaf folder and micrometeorological parameters (*Rabi* season)



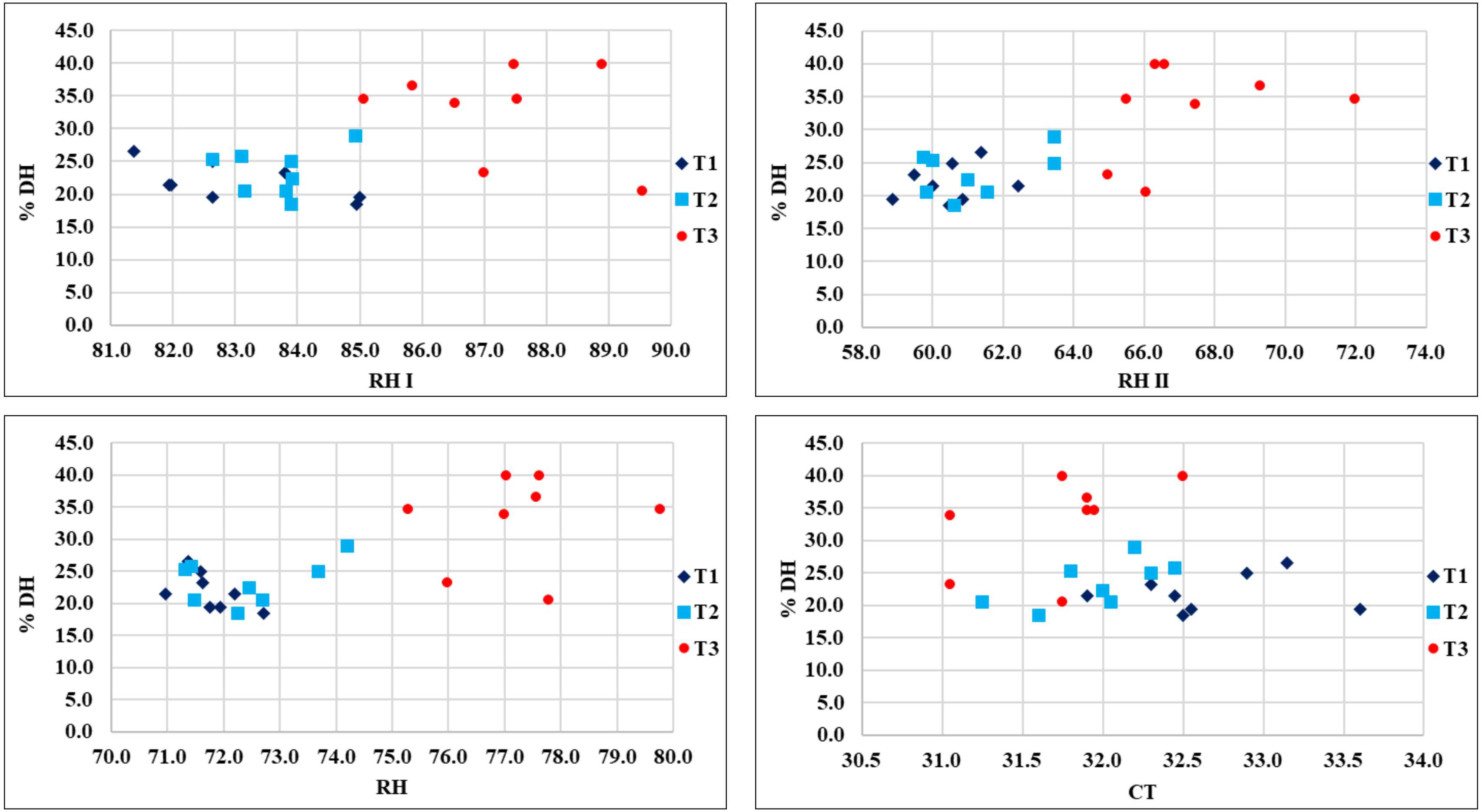
RH I: Forenoon relative humidity; RH II: Afternoon relative humidity; RH: Average relative humidity; CT: Canopy temperature; T1: Paired row planting; T2: Normal transplanting; T3: Direct sowing

Figure 22. Correlation between incidence of leaf folder and micrometeorological parameters (*Kharif* season)



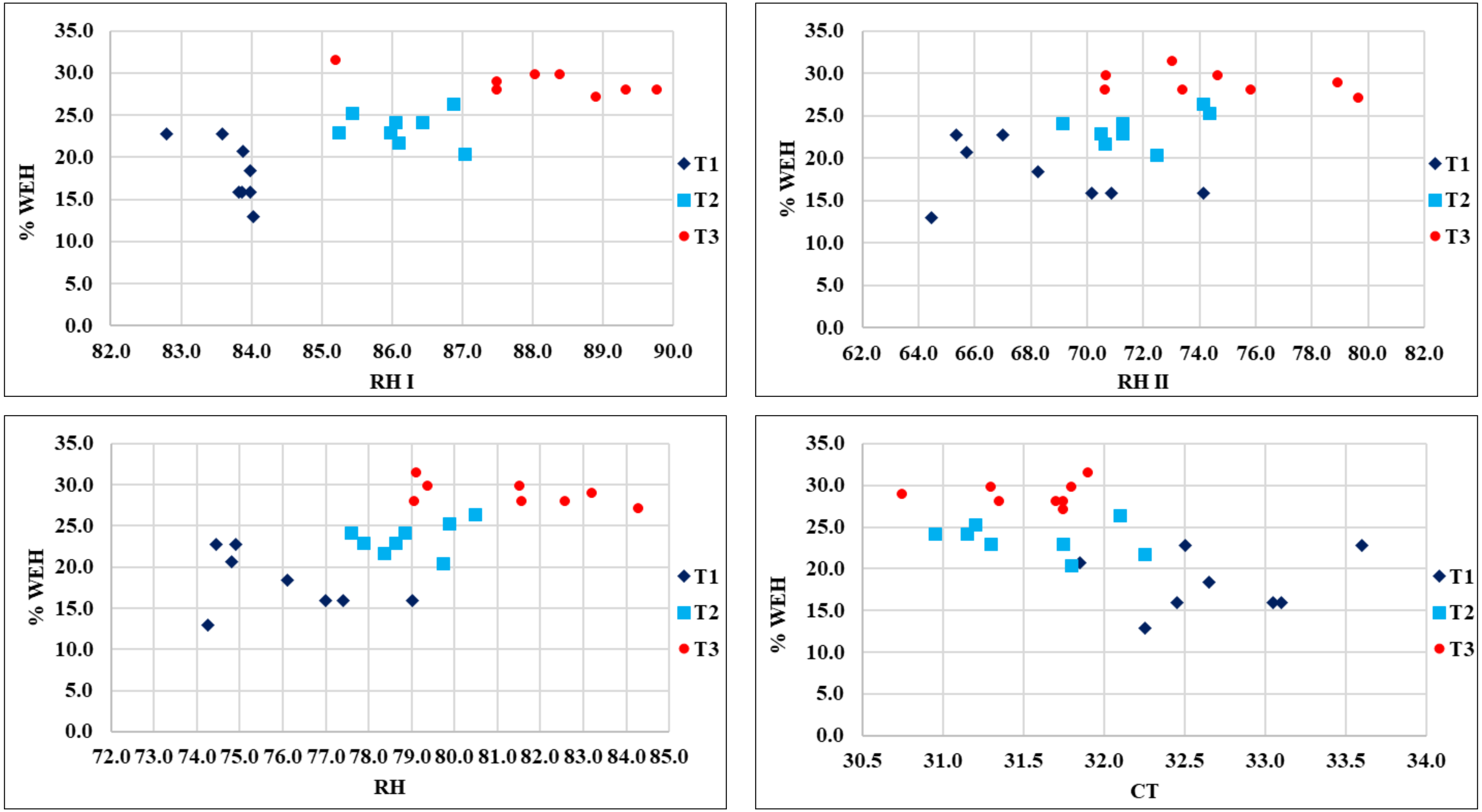
RH I: Forenoon relative humidity; RH II: Afternoon relative humidity; RH: Average relative humidity; CT: Canopy temperature; T1: Paired row planting; T2: Normal transplanting; T3: Direct sowing

Figure 23. Correlation between incidence of yellow stem borer (% DH) and micrometeorological parameters (*Rabi* season)



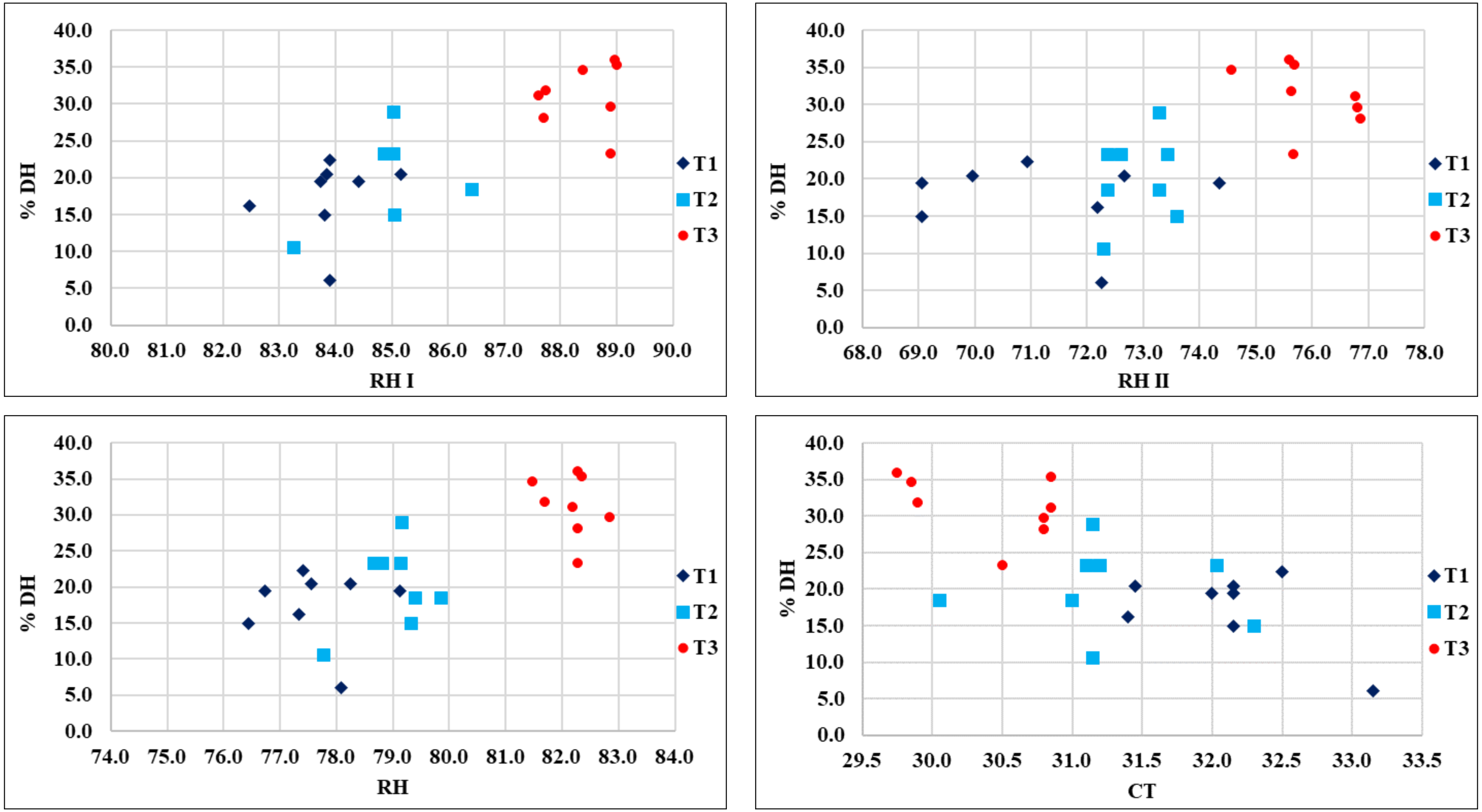
% DH: Per cent dead heart; RH I: Forenoon relative humidity; RH II: Afternoon relative humidity; RH: Average relative humidity; CT: Canopy temperature; T1: Paired row planting; T2: Normal transplanting; T3: Direct sowing

Figure 24. Correlation between incidence of yellow stem borer (% WEH) and micrometeorological parameters (*Rabi* season)



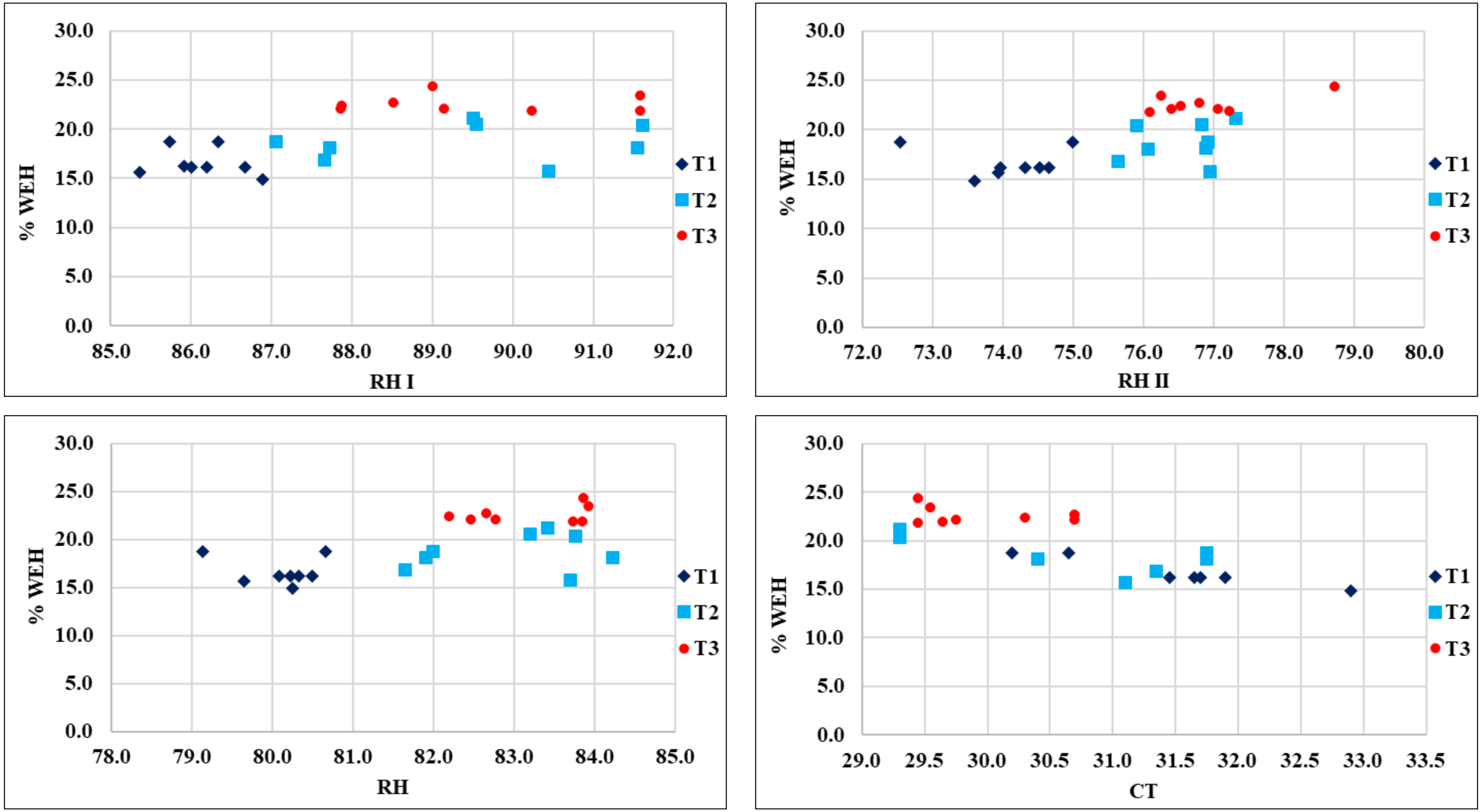
% WEH: Per cent white ear head; RH I: Forenoon relative humidity; RH II: Afternoon relative humidity; RH: Average relative humidity; CT: Canopy temperature; T1: Paired row planting; T2: Normal transplanting; T3: Direct sowing

Figure 25. Correlation between incidence of yellow stem borer (% DH) and micrometeorological parameters (*Kharif* season)



% DH: Per cent dead heart; RH I: Forenoon relative humidity; RH II: Afternoon relative humidity; RH: Average relative humidity; CT: Canopy temperature; T1: Paired row planting; T2: Normal transplanting; T3: Direct sowing

Figure 26. Correlation between incidence of yellow stem borer (% WEH) and micrometeorological parameters (*Kharif* season)



% WEH: Per cent white ear head; RH I: Forenoon relative humidity; RH II: Afternoon relative humidity; RH: Average relative humidity; CT: Canopy temperature; T1: Paired row planting; T2: Normal transplanting; T3: Direct sowing initiation phase, the white ear head damage recorded in paired row planting was significantly lower compared to normal transplanting and direct sowing (Tables 14 a. and Table 14 b.). This indicates that the microclimate associated with paired row planting is less conducive for the white ear head damage compared to other two systems.

4.3.2.4 Influence of microclimate on incidence of rice bug

The effect of microclimate on the incidence of rice bug was investigated. The micrometeorological parameters *viz.* relative humidity and canopy temperature were correlated with the per cent damaged grains caused due to rice bug and the data was portrayed in scatter diagram for a quick comprehension (Figures 27 and 28).

The correlation analysis indicated that the highest per cent damage (25%) due to rice bug during the *rabi* season was noticed at forenoon relative humidity of 90.5-94 per cent, afternoon relative humidity of 75-79 per cent, average relative humidity of 83.5-85.5 per cent and canopy temperature of 30.5-32.5^{0}C. Similarly, during the *kharif* season, it was highest (20%) at respective forenoon, afternoon and average relative humidity and canopy temperature ranges of 91.5-94.5 per cent, 78-83 per cent, 85.5-88 per cent and 27-29.5^{0}C. The highest number of observations corresponding to this range were recorded from direct sowing. The relative humidity recorded from normal transplanting and paired row planting were lower than this range, whereas canopy temperature was higher than the range derived. The relative humidity recorded in paired row planting was lower than that in normal transplanting. At the same time, canopy temperature recorded in paired row planting was higher. During both seasons, the rice bug damage recorded in paired row planting was significantly lower than that in normal transplanting and direct sowing (Table 15.). This indicates that the microclimate associated with paired row planting might not be conducive for the rice bug infestation compared to other two systems.

4.4 ENUMERATION OF RHIZOSPHERE MICROFLORA

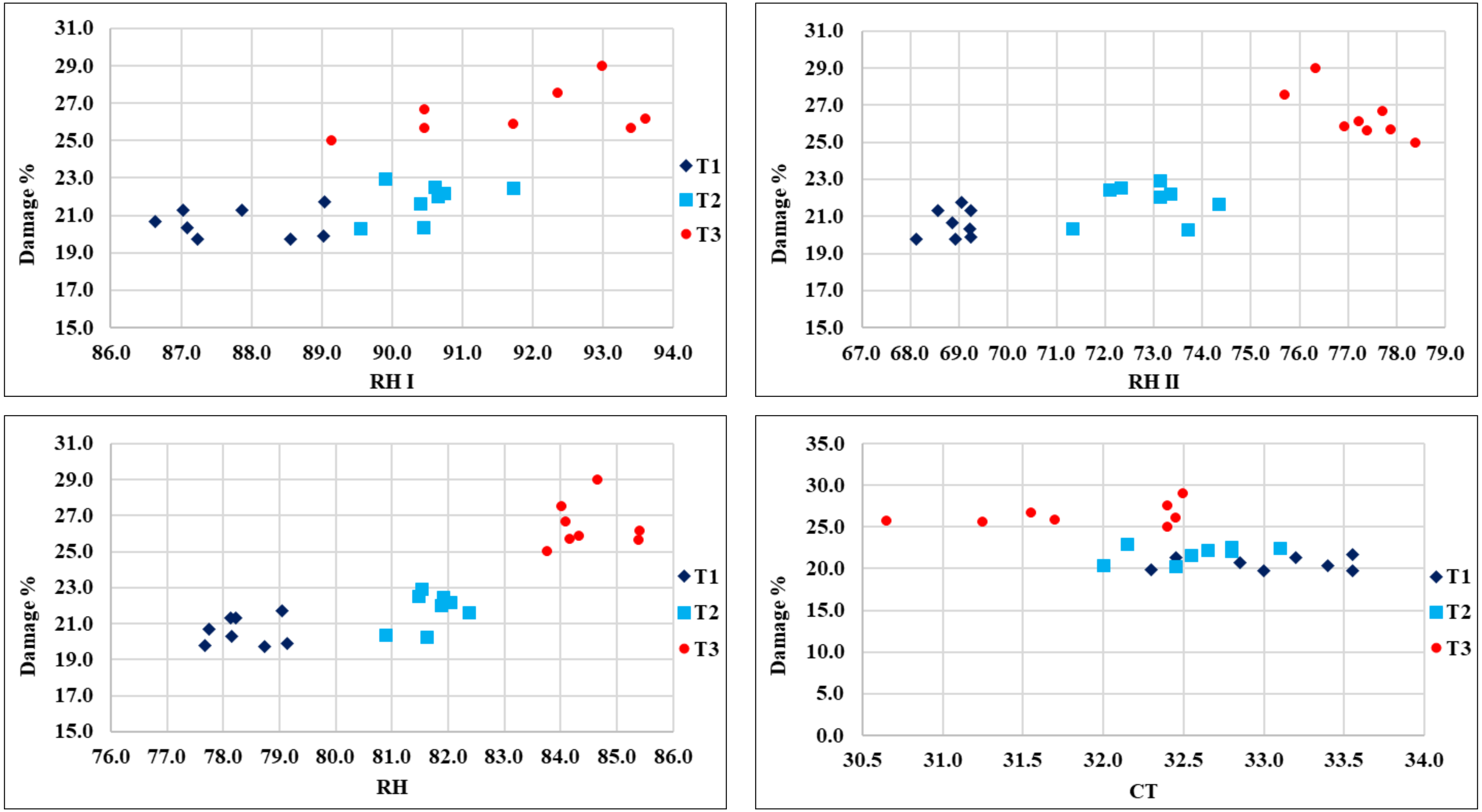
Enumeration of rhizosphere microflora was performed using serial dilution and plating techniques at 20, 50 and 75 days after sowing (Plates 15-17). The dilutions used respectively for bacteria, actinomycetes and fungi were 10^{-4}, 10^{-5} and 10^{-7}. The corresponding observations are presented in Table 18.

From the data, it is evident that the fungal population in the rhizosphere increased significantly from the initial growth stage to the active tillering stage and then decreased. During the first observed interval (20 DAS), no significant difference was observed between the fungal population in direct sowing (4.30×10^4 cfu g^{-1}), paired row planting (3.30×10^4 cfu g^{-1}) and normal transplanting (3.40×10^4 cfu g^{-1}). In the next observed interval, i.e., during the active tillering stage, the fungal population enumerated in direct sowing, normal transplanting and paired row planting increased to 27.00×10^4 cfu g^{-1}, 16.00×10^4 cfu $g^{-}1$, 15.00×10^4 cfu g^{-1} respectively. This decreased as the crop passed the booting stage. In the final observed interval (75 DAS), The fungal population in paired row planting, normal transplanting and direct sowing decreased respectively to 4.00×10^4 cfu g^{-1}, 3.00×10^4 cfu g^{-1} and 5.00×10^4 cfu g^{-1}. No significant difference was noticed between the systems with respect to the fungal population in all these observed intervals.

During the first observed interval, the enumerated bacterial population in the rhizosphere of paired row planting, normal transplanting and direct sowing were 13.30×10^7 cfu g^{-1}, 12.00×10^7 cfu g^{-1} and 11.00×10^7 cfu g^{-1} respectively. The values increased as the crop reached the active tillering stage. In this stage, the bacterial population recorded in direct sowing, normal transplanting and paired row planting were 110.00×10^7 cfu g^{-1}, 88.00×10^7 cfu g^{-1}, and 93.00×10^7 cfu g^{-1} respectively. In the next observed interval, however, the values decreased. In this stage, the bacterial population observed in the rhizosphere of paired row planting, normal transplanting and direct sowing were 4.60×10^7 cfu g^{-1}, 4.10×10^7 cfu g^{-1}, and 1.80×10^7 cfu g^{-1} respectively. A significant difference was absent between the in all the intervals considered with respect to the bacterial population in the rhizosphere.

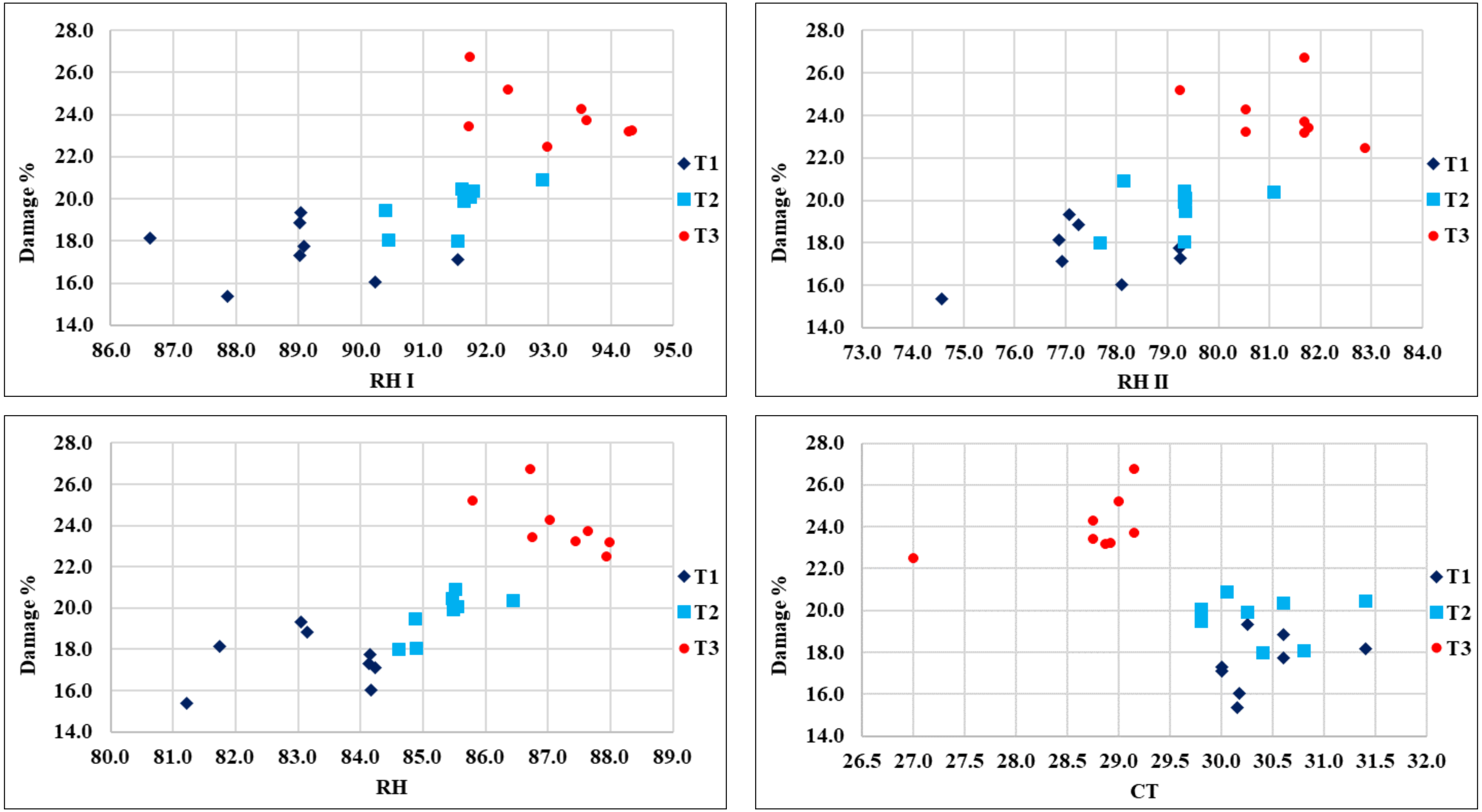
A similar trend was noticed in the population of actinomycetes also. During the initial interval, it was 9.60×10^5 cfu g^{-1} in paired row planting, 8.00×10^5 cfu g^{-1} in normal transplanting and 8.70×10^5 cfu g^{-1} in direct sowing. In the next observed interval, it increased to 12.60×10^5 cfu g^{-1}, 13.00×10^5 cfu g^{-1}, and 10.00×10^5 cfu g^{-1} respectively in the rhizosphere of paired row planting, normal transplanting and direct sowing. In the successive interval (75 DAS), the population of actinomycetes in paired row planting, normal transplanting and direct sowing decreased respectively to 4.00×10^5 cfu g^{-1}, 3.80×10^5 cfu g^{-1}, and 3.60×10^5 cfu g^{-1}. In this case also, no significant difference was noticed between the systems.

Figure 27. Correlation between incidence of rice bug (% damaged grains) and micrometeorological parameters (*Rabi* season)

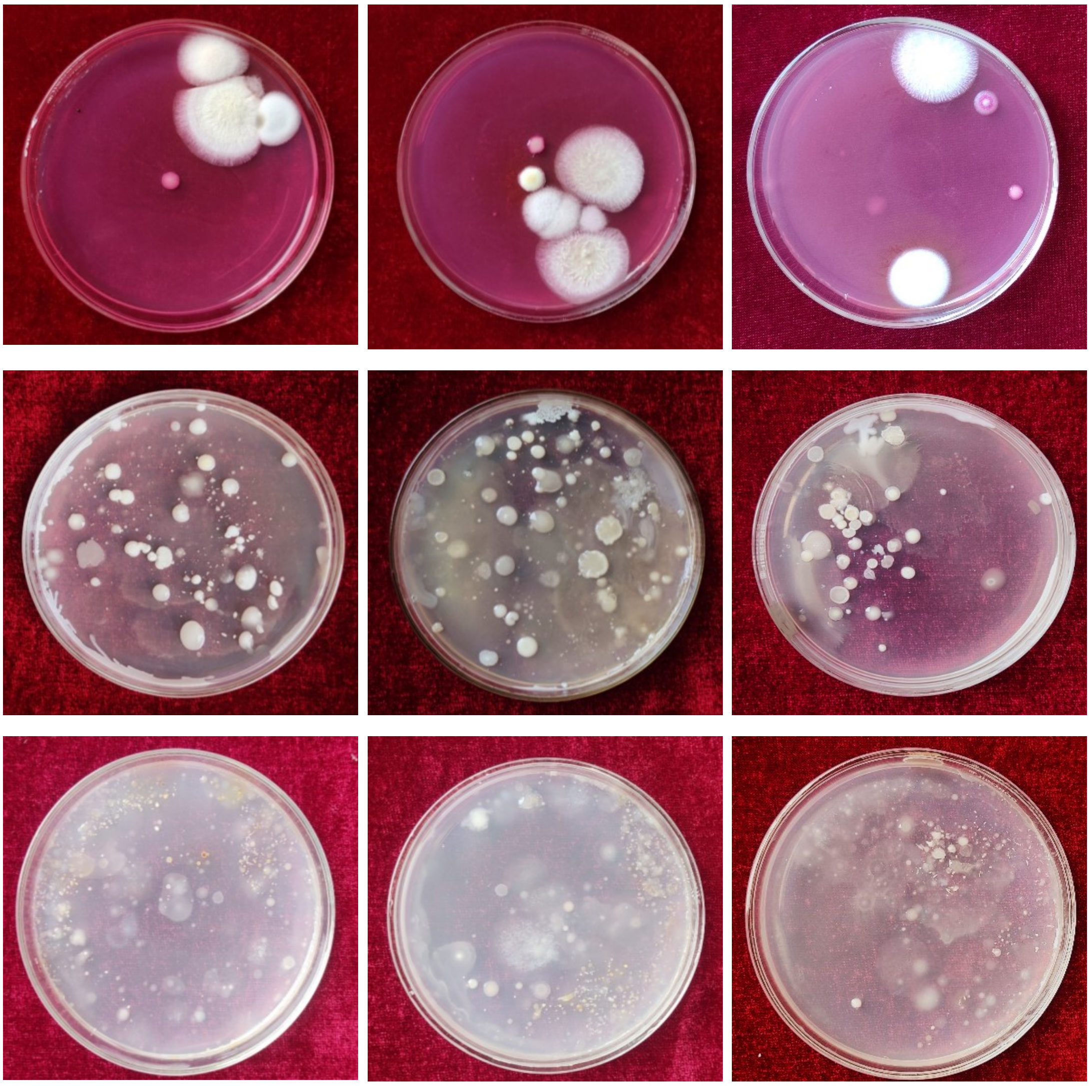


RH I: Forenoon relative humidity; RH II: Afternoon relative humidity; RH: Average relative humidity; CT: Canopy temperature; T1: Paired row planting; T2: Normal transplanting; T3: Direct sowing

Figure 28. Correlation between incidence of rice bug (% damaged grains) and micrometeorological parameters (*Kharif* season)

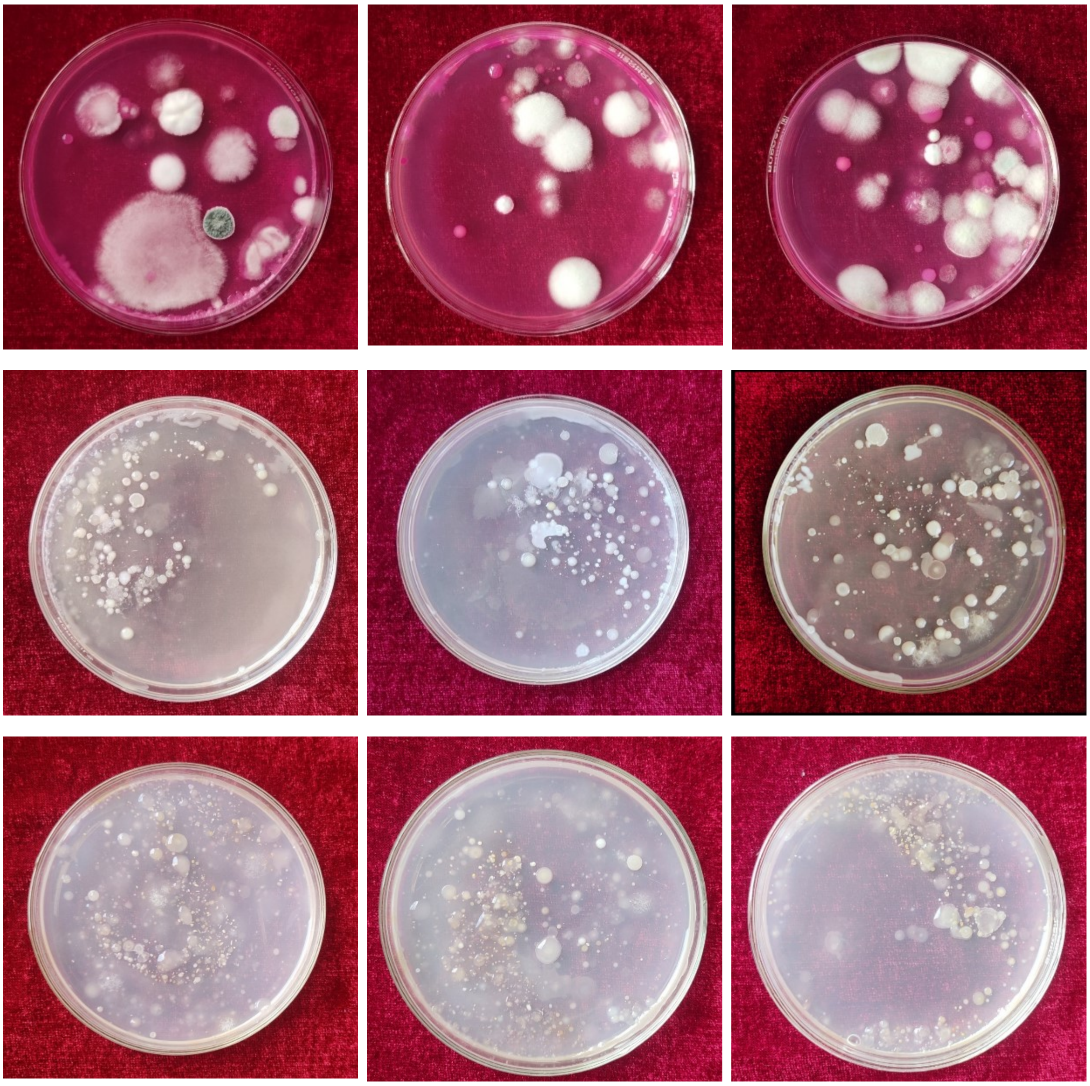


RH I: Forenoon relative humidity; RH II: Afternoon relative humidity; RH: Average relative humidity; CT: Canopy temperature; T1: Paired row planting; T2: Normal transplanting; T3: Direct sowing



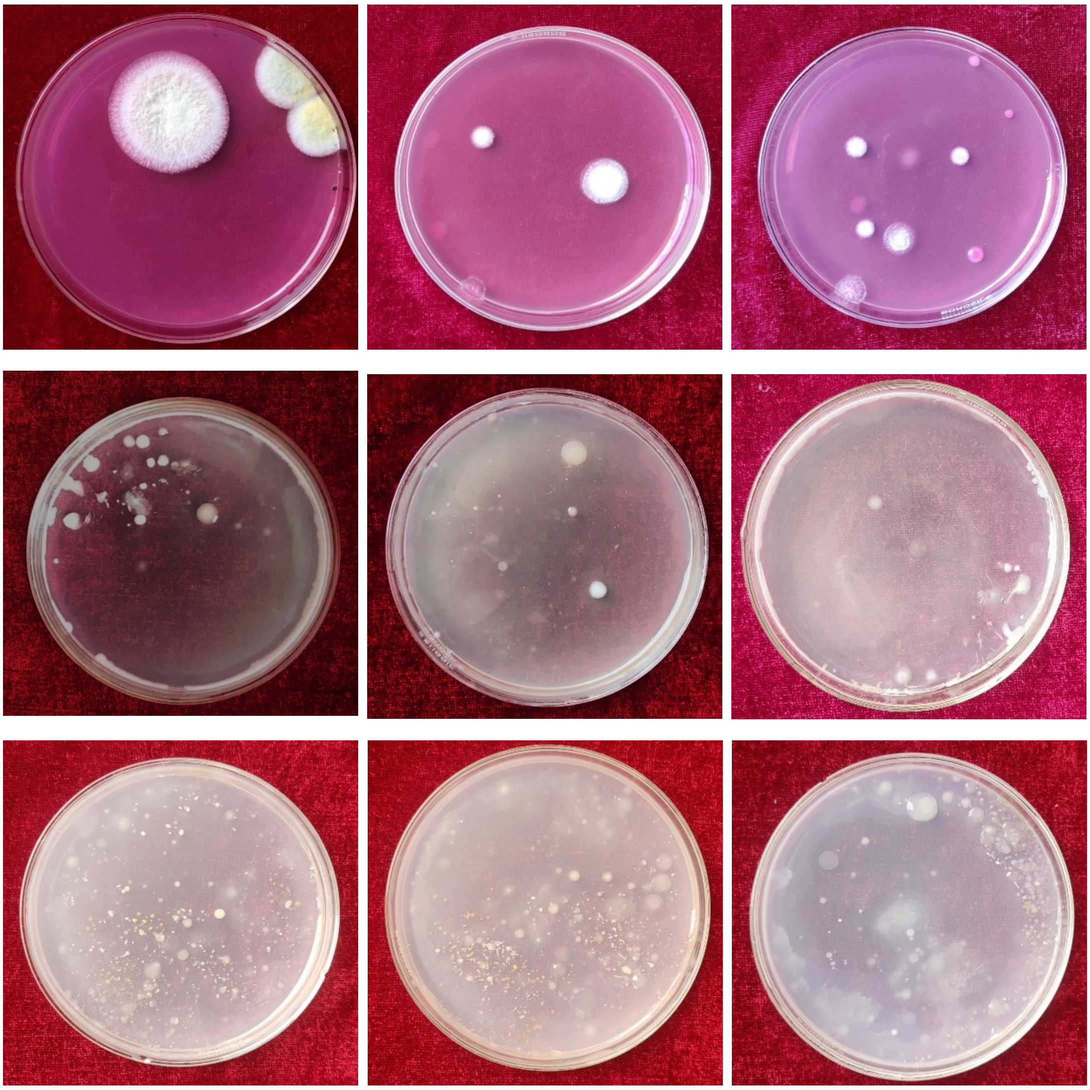
T1 **T2** **T3**

Plate 15. Enumeration of rhizosphere microflora (20 DAS)



T1 T2 T3

Plate 16. Enumeration of rhizosphere microflora (50 DAS)



T1 T2 T3

Plate. 17 Enumeration of rhizosphere microflora (75 DAS)

Table 18. Rhizosphere microbial population in different planting systems

Sl. No.	Treatments	Fungi			Bacteria			Actinomycetes		
		(× 10^4 cfu g^{-1} soil)			(× 10^7 cfu g^{-1} soil)			(× 10^5 cfu g^{-1} soil)		
		20 DAS	50 DAS	75 DAS	20 DAS	50 DAS	75 DAS	20 DAS	50 DAS	75 DAS
1.	T1-Paired row planting	3.30	15.00	4.00	13.30	93.00	4.60	9.60	12.60	4.00
2.	T2-Normal transplanting	3.40	16.00	3.00	12.00	88.00	4.10	8.00	13.00	3.80
3.	T3-Direct sowing	4.30	27.00	5.00	11.00	110.00	1.80	8.70	10.00	3.60
CD (0.05)		NS	NS	NS	NS	NS	NS	NS	NS	NS

cfu: colony forming units

Table 19 a. Number of tillers per hill in different planting systems of rice (*rabi* season)

Sl. No.	Treatments	No. of tillers per hill							
		30 DAS	40 DAS	50 DAS	60 DAS	70 DAS	80 DAS	90 DAS	100 DAS
				AT	PI	B	H	F	PM
1.	T1-Paired row planting	3.13^b	4.13^c	7.75^a	8.00^a	8.13^a	8.25^a	8.63^a	9.38^a
2.	T2-Normal transplanting	3.38^b	4.50^b	5.88^b	6.38^b	6.75^c	6.50^c	6.75^c	6.25^b
3.	T3-Direct sowing	5.13^a	6.00^a	7.50^a	7.63^a	7.75^b	7.50^b	7.63^b	6.63^b
CD (0.05)		0.50	0.36	0.82	0.73	0.87	0.64	0.74	0.97

DAS: Days after sowing; AT: Active tillering; PI: Panicle initiation; B: Booting; H: Heading; F: Flowering; PM: Physiological maturity

From the observed results, it can be concluded that the rhizosphere population increased significantly from the initial growth stages to the active tillering stage and subsided gradually as the crop approached the maturing stages. However, a significant difference with respect to the rhizosphere population was not noticed between the three treatments in any of the observed intervals.

4.5 BIOMETRIC PARAMETERS OF RICE IN DIFFERENT PLANTING SYSTEMS

Biometric observations *viz*. number of tillers per hill, number of leaves per hill, plant height and leaf area were taken at ten days intervals over both seasons (*rabi* and *kharif*) and compared statistically to find the effect of planting geometry on biometric observations of rice.

4.5.1 Biometric observations of rice during *rabi* season

4.5.1.1 Number of tillers

The number of tillers per hill recorded from different planting systems is given in Table 19 a. During the initial stages (30 DAS, 40 DAS), the number of tillers was significantly higher in direct sowing (5.13, 6.00) than that in paired row planting (3.13, 4.13) and normal transplanting (3.38, 4.50). The trend changed as the crop reached the active tillering phase. In the active tillering and panicle initiation phase, the number of tillers recorded in paired row planting (7.75, 8.00) was on par with that recorded in direct sowing (7.50, 7.63) and was significantly higher than that in normal transplanting (5.88, 6.38). However, from the booting phase onwards, a significantly higher number of tillers were observed in paired row planting compared to the other two treatments. During the physiological maturity phase, wherein the highest number of tillers was recorded in all three treatments, the same trend was repeated. In this stage, the number of tillers observed in paired row planting (9.38) was significantly higher than that in normal transplanting (6.25) and direct sowing (6.63).

4.5.1.2 Number of leaves

The number of leaves per hill recorded from different planting systems is given in Table 19 b. Through the study, it was observed that the number of leaves per hill during the initial growth stages (30 DAS, 40 DAS) was significantly higher in direct sowing (21.75, 25.00) than in normal transplanting (14.63, 20.25) and paired row planting (13.75, 18.13). However in the active tillering phase, the number of leaves recorded in paired row planting (39.63) was significantly higher compared to normal

Table 19 b. Number of leaves per hill recorded in different planting systems (*Rabi* season)

Sl. No.	Treatments	No. of leaves per hill							
		30 DAS	40 DAS	50 DAS	60 DAS	70 DAS	80 DAS	90 DAS	100 DAS
				AT	PI	B	H	F	PM
1.	T1-Paired row planting	13.75[b]	18.13[c]	39.63[a]	40.88[a]	41.00	41.88[a]	43.50[a]	47.50[a]
2.	T2-Normal transplanting	14.63[b]	20.25[b]	31.25[b]	33.13[b]	36.50	34.13[b]	35.63[c]	33.75[b]
3.	T3-Direct sowing	21.75[a]	25.00[a]	38.75[a]	40.38[a]	39.50	38.50[a]	39.25[b]	34.38[b]
CD (0.05)		1.75	1.30	4.06	3.02	NS	3.83	3.37	2.08

Table 19 c. Plant height recorded in different planting systems (*Rabi* season)

Sl. No.	Treatments	Plant height (cm)							
		30 DAS	40 DAS	50 DAS	60 DAS	70 DAS	80 DAS	90 DAS	100 DAS
				AT	PI	B	H	F	PM
1.	T1-Paired row planting	47.13[b]	60.00[b]	67.25[b]	80.13[b]	89.63[b]	94.13	99.75	99.88
2.	T2-Normal transplanting	49.00[b]	59.13[b]	66.50[b]	80.13[b]	90.50[b]	93.75	97.25	99.88
3.	T3-Direct sowing	59.63[a]	69.38[a]	75.25[a]	91.88[a]	98.88[a]	97.00	99.00	100.50
CD (0.05)		1.96	1.89	2.61	5.16	4.20	NS	NS	NS

DAS: Days after sowing; AT: Active tillering; PI: Panicle initiation; B: Booting; H: Heading; F: Flowering; PM: Physiological maturity

transplanting (31.25) and was statistically on par with that of direct sowing (38.75). This trend repeated till the heading stage with an exception noticed in the booting stage, wherein no significant difference was noticed between the three systems. However, in the flowering and the physiological maturity stages, it was noticed that the number of leaves recorded in paired row planting (43.50, 47.50) was significantly higher than that noticed in direct sowing (39.25, 34.38) and normal transplanting (35.63, 33.75).

4.5.1.3 Plant height

The plant height recorded from different systems of planting is presented in Table 19 c. From the data, it is evident that plant height measured from the initial tillering stages till the booting phase was significantly higher in direct sowing compared to other treatments. In all these observed intervals, there was no significant difference observed between the normal transplanting and paired row planting. In the active tillering phase and panicle initiation phase, the plant height recorded in direct sowing (75.25, 91.88) was significantly higher than normal transplanting (66.50, 80.13) and paired row planting (67.25, 80.13). Similarly, during the booting stage, the plant height observed in the direct sown plot was 98.88 cm which was significantly higher than normal transplanting (90.50 cm) and paired ow planting (89.63 cm). After the booting stage (70 DAS), no significant difference was observed between the treatments with respect to plant height (Table 24 c.).

4.5.1.4 Leaf area

The leaf area recorded from different planting systems are given in Table 19 d. Leaf area was found to be significantly higher in the direct sown plot till the active tillering (50 DAS) phase than in the other two systems compared. During the first two observed intervals, the leaf area recorded was found to be significantly higher in direct sowing (28.08 cm^2, 32.96 cm^2) compared to the other two treatments. In these stages, it was also noticed that the leaf area measured from paired row planting (18.01 cm^2, 27.03 cm^2) was significantly lower than that from normal transplanting (21.85 cm^2, 24.87 cm^2). In the active tillering phase also, the measured leaf area in direct sowing (43.52 cm^2) remained significantly higher than normal transplanting (29.22 cm^2) and paired row planting (31.71 cm^2). However, no significant difference was noticed between the latter two. In the successive stages, a significant difference with respect to leaf area was found to be absent between the three treatments (Table 24 d).

Table 19 d. Leaf area recorded in different planting systems (*Rabi* season)

Sl. No.	Treatments	Leaf area (cm^2)							
		30 DAS	40 DAS	50 DAS	60 DAS	70 DAS	80 DAS	90 DAS	100 DAS
				AT	PI	B	H	F	PM
1.	T1-Paired row planting	18.01b	27.03c	31.71b	33.28	32.37	23.99	31.79	29.84
2.	T2-Normal transplanting	21.85b	24.87b	29.22b	32.32	32.08	23.44	29.37	28.83
3.	T3-Direct sowing	28.08a	32.96a	43.52a	33.42	29.87	25.61	30.95	28.44
CD (0.05)		2.54	1.34	3.87	NS	NS	NS	NS	NS

Table 20 a. Number of tillers per hill in different planting systems of rice (*Kharif* season)

Sl. No.	Treatments	No. of tillers per hill							
		30 DAS	40 DAS	50 DAS	60 DAS	70 DAS	80 DAS	90 DAS	100 DAS
				AT	PI	B	H	F	PM
1.	T1-Paired row planting	4.00b	5.25b	7.38a	7.75a	8.00a	8.25a	8.38a	9.50a
2.	T2-Normal transplanting	4.13b	4.88b	5.63b	6.00b	6.25c	6.38c	6.63c	6.88c
3.	T3-Direct sowing	5.50a	6.00a	6.88a	7.00a	7.13b	7.25b	7.75b	7.88b
CD (0.05)		0.43	0.48	0.68	0.55	0.60	0.52	0.34	0.96

DAS: Days after sowing; AT: Active tillering; PI: Panicle initiation; B: Booting; H: Heading; F: Flowering; PM: Physiological maturity

4.5.2 Biometric observations of rice during *kharif* season

4.5.2.1 Number of tillers

The number of tillers per hill recorded from different planting systems is given in Table 20 a. From the data, it is evident that during the initial stages (30 DAS, 40 DAS), the number of tillers was found to be significantly higher in direct sowing (5.50, 6.00) than that in normal transplanting (4.13, 4.88) and paired row planting (4.00, 5.25). However, in the active tillering phase and the panicle initiation phase, the number of tillers counted from paired row planting (7.38, 7.75) was significantly higher than normal transplanting (5.63, 6.00) and was statistically on par with direct sowing (6.88, 7.00). But in the booting stage, it was observed that the number of tillers recorded in paired row planting (8.00) was significantly higher than in normal transplanting (6.25) and direct sowing (7.13). This trend repeated till the physiological maturity phase. The number of tillers during the physiological maturity stage was significantly higher in paired row planting (9.50) compared to direct sowing (7.88) and normal transplanting (6.88).

4.5.2.2 Number of leaves

The number of leaves per hill recorded from different planting systems is given in Table 20 b. The results revealed that the number of leaves per hill recorded during the initial growth stages (30 DAS, 40 DAS) in paired row planting (16.63, 21.63) was statistically on par with that of normal transplanting (17.75, 21.13) and was significantly higher in direct sowing (22.88, 25.25). In the active tillering phase, the number of leaves per hill was significantly higher in paired row planting (39.38) compared to normal transplanting (30.00) and direct sowing (34.38). This trend repeated in the successive observation intervals till the crop reached the flowering stage (Table 25 b.). In the flowering stage, the number of leaves recorded in paired row planting (41.88) was significantly higher than that in normal transplanting (34.88) and was on par with that of direct sowing (39.38). The highest number of leaves was recorded during the physiological maturity phase, wherein the number of leaves in paired row planting (47.88) seemed to be significantly higher than that from direct sowing (40.63) and normal transplanting (36.00). No significant difference was noticed between normal transplanting (36.00) and direct sowing (40.63).

Table 20 b. Number of leaves per hill recorded in different planting systems (*Kharif* season)

Sl. No.	Treatments	No. of leaves per hill							
		30 DAS	40 DAS	50 DAS	60 DAS	70 DAS	80 DAS	90 DAS	100 DAS
				AT	PI	B	H	F	PM
1.	T1-Paired row planting	16.63[b]	21.63[b]	39.38[a]	40.50[a]	40.88[a]	42.50[a]	41.88[a]	47.88[a]
2.	T2-Normal transplanting	17.75[b]	21.13[b]	30.00[c]	31.00[c]	31.63[c]	32.63[c]	34.88[b]	36.00[b]
3.	T3-Direct sowing	22.88[a]	25.25[a]	34.38[b]	36.13[b]	35.63[b]	37.25[b]	39.38[a]	40.63[b]
CD (0.05)		1.44	1.91	3.56	2.16	2.49	3.43	1.83	4.90

Table 20 c. Plant height recorded in different planting systems (*Kharif* season)

Sl. No.	Treatments	Plant height (cm)							
		30 DAS	40 DAS	50 DAS	60 DAS	70 DAS	80 DAS	90 DAS	100 DAS
				AT	PI	B	H	F	PM
1.	T1-Paired row planting	50.75[b]	62.88[b]	70.75[b]	84.88[b]	92.63[b]	97.25	101.50	101.63
2.	T2-Normal transplanting	52.38[b]	62.50[b]	69.88[b]	83.75[b]	93.25[b]	96.63	99.00	101.50
3.	T3-Direct sowing	62.88[a]	72.13[a]	78.63[a]	95.50[a]	99.75[a]	100.88	101.63	102.25
CD (0.05)		1.77	1.85	2.60	5.75	4.11	NS	NS	NS

DAS: Days after sowing; AT: Active tillering; PI: Panicle initiation; B: Booting; H: Heading; F: Flowering; PM: Physiological maturity

4.5.2.3 Plant height

The results on plant height recorded from different planting systems are given in Table 20 c. From the data, it is clear that till the booting phase, plant height in direct sowing was significantly higher compared to other two systems. In all these observed intervals, there was no significant difference observed between normal transplanting and paired row planting. The plant height recorded in active tillering and panicle initiation phase was found to be significantly higher in direct sowing compared to that in normal transplanting (69.88 cm, 83.75 cm) and paired row planting (70.75 cm, 84.88 cm). During the booting stage, the plant height recorded in paired row planting (92.63 cm) was statistically on par with normal transplanting (93.25 cm) and was significantly lower than that of direct sowing (99.75 cm). After the booting phase, no significant difference was observed between the treatments with respect to plant height.

4.5.2.4 Leaf area

The leaf area recorded from different planting systems are given in table 20 d. Until active tillering stage, the leaf area recorded in paired row planting (18.42 cm^2, 26.86 cm^2, 30.91 cm^2) was statistically on par with that recorded in normal transplanting (21.72 cm^2, 24.56 cm^2, 29.41 cm^2). During these three intervals, the plant height was significantly higher in direct sowing (27.91 cm^2, 33.18 cm^2, 43.48 cm^2) compared to the other two systems. From panicle initiation onwards, there was no significant difference in leaf area between these three systems.

4.6 YIELD ATTRIBUTES AND YIELD OF RICE IN DIFFERENT PLANTING SYSTEMS OF RICE

Yield attributes *viz*. number of hills per m^2, number of panicles per hill, number of grains per panicle, number of chaffy grains per panicle and 1000 grain weight and grain yield recorded during *rabi* and *kharif* season are given in Table 21 a and Table 21 b. respectively.

4.6.1 Yield attributes and yield of rice during *rabi* season

4.6.1.1 Number of hills per m^2

The results on number of hills per m^2 are given in Table 26 a. The number of hills per m^2 was found to be significantly lower in paired row planting (40.00) compared to normal transplanting (66.00) and direct sowing (69.50).

Table 20 d. Leaf area recorded in different planting systems (*Kharif* season)

Sl. No.	Treatments	Leaf area (cm^2)							
		30 DAS	40 DAS	50 DAS	60 DAS	70 DAS	80 DAS	90 DAS	100 DAS
				AT	PI	B	H	F	PM
1.	T1-Paired row planting	18.42[b]	26.86[b]	30.91[b]	33.22	32.30	23.91	31.74	29.89
2.	T2-Normal transplanting	21.72[b]	24.56[b]	29.41[b]	32.26	31.95	23.54	29.07	28.67
3.	T3-Direct sowing	27.91[a]	33.18[a]	43.48[a]	33.32	30.30	25.65	31.02	28.54
CD (0.05)		2.34	2.45	4.55	NS	NS	NS	NS	NS

DAS: Days after sowing; AT: Active tillering; PI: Panicle initiation; B: Booting; H: Heading; F: Flowering; PM: Physiological maturity

Table 21 a. Yield attributes and yield of rice (*Rabi* season)

Sl. No.	Treatments	No. of hills per m^2	No. of panicles per hill	No. of grains per panicle	No. of chaffy grains per panicle	Grain yield per hectare (kg ha^{-1})	1000 grain weight (g)
1.	T1-Paired row planting	40.00[c]	8.50[a]	102.63	11.38	3406.38[a]	26.75
2.	T2-Normal transplanting	66.00[b]	7.00[ab]	97.88	16.00	2944.38[b]	26.38
3.	T3-Direct sowing	69.00[a]	5.50[b]	90.25	18.00	2108.75[c]	26.88
CD (0.05)		3.28	1.76	NS	NS	271.03	NS

Table 21 b. Yield attributes and yield of rice (*Kharif* season)

Sl. No.	Treatments	No. of hills per m^2	No. of panicles per hill	No. of grains per panicle	No. of chaffy grains per panicle	Grain yield per hectare (kg ha^{-1})	1000 grain weight (g)
1.	T1-Paired row planting	40.00^c	11.50^a	128.63	10.18	3717.88^a	26.73
2.	T2-Normal transplanting	66.00^b	7.50^b	118.50	11.14	3049.13^b	26.90
3.	T3-Direct sowing	71.00^a	5.50^b	110.63	11.95	2404.13^c	27.31
CD (0.05)		3.57	3.51	NS	NS	251.47	NS

4.6.1.2 Number of panicles per hill

The number of panicles per hill recorded in paired row planting (8.50) was statistically on par with that of normal transplanting (7.00) and significantly higher than that of direct sowing (5.50).

4.6.1.3 Number of grains per panicle

Even though the number of grains per panicle recorded in paired row planting (102.63) was higher than that of normal transplanting (97.88) and direct sowing (90.25), there was no significant difference between treatments.

4.6.1.4 Number of chaffy grains per panicle

There was no significant difference between the number of chaffy grains per panicle recorded in paired row planting (11.38), normal transplanting (16.00) and direct sowing (18.00).

4.6.1.5 1000 grain weight

The 1000 grain weight recorded in paired row planting, normal transplanting and direct sowing were 26.75 g, 26.38 g and 26.88 g respectively. There was no significant difference between the treatments in 1000 grain weight.

4.6.1.6 Grain yield

The grain yield was significantly higher in paired row planting (3406.38 kg ha^{-1}) than normal transplanting (2944.38 kg ha^{-1}) and direct sowing (2108.75 kg ha^{-1}).

4.6.2 Yield and yield attributes of rice during *kharif* season

4.6.2.1 Number of hills per m^2

The results on number of hills per m^2 are given in Table 26 b. The number of hills per m^2 was significantly lower in paired row planting (40.00), compared to normal transplanting (66.00) and direct sowing (71.13).

4.6.2.2 Number of panicles per hill

The number of panicles per hill was significantly higher in paired row planting (11.50) compared to normal transplanting (7.50) and direct sowing (5.50). No significant difference was noticed between normal transplanting and direct sowing with respect to the number of panicles per hill.

4.6.2.3 Number of grains per panicle

Even though the number of grains per panicle was higher in paired row planting (128.63), followed by normal transplanting (118.50) and direct sowing (110.63), there was no statistically significant difference between the three treatments.

4.6.2.4 Number of chaffy grains per panicle

There was no significant difference observed in the number of chaffy grains per panicle recorded in paired row planting (10.18), normal transplanting (11.14) and direct sowing (11.95).

4.6.2.5 1000 grain weight

There was no significant difference in 1000 grain weight recorded in paired row planting (26.73 g), normal transplanting (26.90 g) and direct sowing (27.31 g).

4.6.2.6 Grain yield

The grain yield was significantly higher in paired row planting (3717.88 kg ha^{-1}) than the other two systems. Similarly, the yield obtained from normal transplanting (3049.13 kg ha^{-1}) was significantly higher than direct sowing (2404.13 kg ha^{-1}).

Discussion

5. DISCUSSION

A field experiment was conducted over two seasons (*rabi* 2021 and *kharif* 2022) to study the influence of paired row planting on disease and pest incidence in rice at the Regional Agricultural Research Station, Pattambi. During the *rabi* season the diseases observed were bacterial blight, sheath blight, brown spot and false smut. In the *kharif* season, in addition to these diseases, sheath rot was also observed. Infestation of case worm, leaf folder, yellow stem borer and rice bug were also noticed in the field.

5.1 INFLUENCE OF PLANTING GEOMETRY ON INCIDENCE OF DISEASES IN RICE

5.1.1 Incidence of bacterial blight in different planting systems of rice

The disease incidence and severity of bacterial blight were found to be significantly less in paired row planting when compared to normal transplanting and direct sowing in both *rabi* and *kharif* seasons. The difference in planting geometry, plant population and associated microclimate can be considered as the contributing factors responsible for this difference in incidence of bacterial blight. Meah (1987) also reported results supporting this finding. He observed that closest plant spacing showed a significant increase of disease severity than wider plant spacing. Rashid *et al*. (2019) while analyzing the effect of row spacing as a strategy to manage bacterial leaf blight, also observed that wider row spacing significantly reduced bacterial leaf blight severity. They attributed the change in microclimate within the closely spaced crop stands as the reason for the increased severity of bacterial blight. Similarly, in this study, paired row planting with wider space between the paired rows might have developed a less humid microenvironment within the crop canopy as well as restricted the movement of the pathogen thereby reducing the spread of the disease. However, in normal transplanting, the spacing is uniform and there is no wide gap as in the case of paired row planting. The closer spacing and higher plant density in normal transplanting and direct sowing might have contributed to the development of a humid and shady microclimate that is considered ideal for the growth and development of pathogen.

The role of microclimate associated with different planting geometry in the development of bacterial blight was analyzed to support this assumption. While analyzing the micrometeorological observations, it was found that the highest disease incidence and severity recorded during the *rabi* season were at the forenoon relative humidity range of 87-91 per cent, afternoon relative humidity range of 67-77 per cent, average relative humidity range of 77-84 per cent and canopy temperature range of 30.5-31.5^{0}C and the same during the *kharif* season were at forenoon relative humidity range of 88-93 per cent, afternoon relative humidity range of 76-82 per cent, average relative humidity range of 82-87 per cent and canopy temperature range of 29-30^{0}C. From the scatter plot diagram, it became clear that the maximum observations corresponding to this humidity and temperature range were recorded in direct sowing followed by normal transplanting. This indicates the presence of a more congenial microenvironment with respect to relative humidity and canopy temperature for the development of bacterial blight in direct sowing and normal transplanting. On the other hand, observations corresponding to this micrometeorological range were not recorded in paired row planting.

When the three treatments were compared, the relative humidity was found to be lower in paired row planting, followed by normal transplanting and direct sowing and this might have acted as the factor behind the low incidence and severity of bacterial blight in paired row planting compared to normal transplanting and direct sowing. In accordance with this finding, Mew (1987) also reported that low relative humidity affects both lesion development and appearance negatively. Dossa *et al.* (2016) also confirmed this observation by reporting that bacterial blight severity increased with increased relative humidity. These reports justify the results obtained from the correlation analysis conducted between relative humidity and disease variables.

According to Saha *et al*. (2015), bacterial blight infection is favoured by a temperature range of 25-30^0 C, high humidity, shading, and high dose of nitrogenous fertilizers. The studies conducted by Horino *et al*. (1982) also discussed the possible role of increased temperature on bacterial blight development. Most of the canopy temperature observations recorded from the treatments were within or higher than the optimum range of 25-30^{0}C and so a significant difference in temperature associated with the canopy architecture of each treatment on DI and PDI was not observed. This might be the factor responsible for the higher disease incidence and severity recorded in direct sowing even under lower canopy temperatures than paired row and normal transplanting.

We can conclude that paired row planting with wider spacing and modified microclimate characterized with low relative humidity compared to normal transplanting and direct sowing would be a better crop establishment method for the management of bacterial blight of rice.

5.1.2 Incidence of sheath blight in different planting systems of rice

Similar to bacterial blight, the incidence and severity of sheath blight observed during each interval after the first notice of symptom in the field, i.e., the panicle initiation phase, were significantly lower in paired row planting, followed by normal transplanting and direct sowing. The absence of disease symptoms during the initial tillering stages could be attributed to the less favourable microclimate observed within the plant stands due to the incomplete canopy cover. Similar findings were made by Koshkdaman *et al.* (2020) who stated that the development of the disease in infected tillers at the initial tillering stage was suppressed due to the undeveloped canopies and less favourable microclimate associated with them.

Wu *et al.* (2015) reported that high plant density favoured sheath blight epidemics. In this study, the higher plant density observed in direct sowing and normal transplanting might have resulted in more plant-to-plant contacts that eventually resulted in the spread of *Rhizoctonia solani*, the soil borne pathogen causing sheath blight. The wide gap of 35 cm between the paired rows might have acted as a barrier for the spread of pathogen from infected to healthier plants. Even under equal probability of receipt of primary inoculum, the paired row could thus manage the spread of pathogen more effectively than other two systems due to this specific spatial configuration. Castilla *et al*. (1996) also suggested that the higher frequency of leaf-to-leaf contacts in closer planting played an important role in horizontal spread of sheath blight. They also discussed the requirement of contacts between infected and healthy tissues for the spread of disease by acting as 'bridges' for the mycelial hyphae to progress.

Willocquet *et al*. (2000) came up with a similar finding when the effect of different crop establishment methods in sheath blight epidemics was analyzed. They pointed out that greater contact frequency favoured rice sheath blight epidemics. They also compared the speed of within-hill spread and between-hill spread of sheath blight and concluded that the former takes place much faster than the latter. The difference in aggregation of tillers attained due to different crop establishment methods was considered as the major attributing factor. In this study, the aggregation of tillers was found to be higher in direct sowing followed by normal transplanting leading to increased spread of sheath blight between hills.

Apart from the contact frequency and aggregation pattern, the microclimate also might have influenced sheath blight incidence and severity. Kaur *et al.* (2015) mentioned that mean temperature around 25 °C and humidity range of 80 to 95 per cent were optimum for sheath blight development. Belmar *et al*. (1987) also discussed the role of temperature, relative humidity along with the quantity of sclerotia per unit of field area as major factors regulating the horizontal development of sheath blight in rice.

The correlation analysis conducted between micrometeorological parameters and disease variables showed that the disease incidence and severity were increased at forenoon relative humidity of 89-92 per cent, afternoon relative humidity of 72-78 per cent, average relative humidity of 81-84 per cent and canopy temperature of 30.5-32.5^{0}C during the *rabi* season. Similarly, the forenoon relative humidity of 90-93 per cent, afternoon relative humidity of 79-81 per cent, average relative humidity of 84-87 per cent and canopy temperature of 28-30^{0}C favoured sheath blight development during the *kharif* season. Pal *et al.* (2017), in favour of the obtained results, analyzed the effect of weather parameters on initiation and progression of sheath blight of rice and concluded that a maximum temperature range of 31-34^0 C and minimum temperature range of 17-23^{0}C coupled with 70-83 per cent evening relative humidity were critical to the disease development.

The detailed and comprehensive analysis of scatter diagrams correlating micrometeorological observations and disease variables corresponding to sheath blight revealed that the humidity observations recorded in this favourable range were higher in direct sowing than in normal transplanting. In both seasons, observations lower to this humidity range were recorded in paired row planting. These observations were in consistent with the assumption that paired row planting with wider spacing and less humid microclimate provided a less humid microclimate unfavourable for the sheath blight disease. On the other hand, direct sowing and normal transplanting with closer spacing provided a more humid and congenial microclimate favouring incidence and development of sheath blight when compared to paired row planting. Biswas *et al.*

(2012) after analyzing the effect of microclimatic modifications through cultural alternatives, came up with a similar finding. According to the study conducted by them, the sheath blight severity was significantly less in wider spacing with lower relative humidity compared to closer spacing. The results obtained by Khaing *et al.* (2015) also confirm the present findings. They reported that increased plant density in closer spacing increased incidence of sheath blight. Kumar *et al.* (2009) also reported that square planting characterized by high plant density increased sheath blight development than those planting systems with sparse population.

The scatter diagrams also revealed that most of the canopy temperature observations recorded in direct sowing during the disease observed intervals fell within the favourable range in which highest DI and PDI were recorded during *kharif* season and these were lower than that recorded in paired row planting. These results were in consistent with that reported by Biswas *et al*. (2012). They summarized that the lower canopy temperature observed in closer spacing led to increased sheath blight severity when compared to wider spacing with higher canopy temperature. Koshkdaman *et al.* (2020) also suggested that planting at closer spacing, by increasing relative humidity and reducing canopy temperature, promoted disease development. However, such a relationship could not be obtained during *rabi* season. The higher air temperature experienced during the summer months coinciding with the observed intervals might have masked the effect of microclimate in different canopy architecture associated with each planting geometry. Giesler *et al.* (1996) gave a similar indication by stating that certain extreme weather conditions might mask the influence of microclimate.

By analyzing the observed results and the related previous reports, it can be summarized that paired row planting with wide space between the paired rows facilitated in building a less humid microclimate with high canopy temperature and less plant-to-plant contacts that is not conducive for sheath blight disease development and spread. Even though the plant-to-plant spacing in a row is similar to normal transplanting, there is a wide space after each paired row in paired row planting and this might have created a break in the spread of the pathogen.

5.1.3 Incidence of brown spot in different planting systems of rice

During *rabi* season, the brown spot incidence was observed in all three systems at the initial tillering stages itself. However, during *kharif* season, the disease was initiated only after the active tillering stage. The incidence and severity of brown spot recorded during the *kharif* season were lower compared to the *rabi* season. Sunder *et al.* (2014) also mentioned similar results stating that brown spot incidence decreased during those seasons characterized by regular rainfall and increased in seasons with limited rainfall, drought like conditions and heavy dew. Similar reports were given by other researchers as well (Barnwal, *et al*., 2013; Abrol *et al.*, 2022).

When the disease variables that were recorded in each system were compared statistically, it was found that during *rabi* season, the incidence and severity recorded in paired row planting remained significantly less in all stages of the crop from tillering to physiological maturity. During *kharif* season, no significant difference was noticed between paired row planting and normal transplanting during the initial stages. From booting stage onwards, the incidence and severity of brown spot was significantly less in paired row planting compared to normal transplanting and direct sowing. In all the observed stages, the disease incidence and severity remained higher in direct sowing irrespective of the seasons.

The wider spacing and the associated microclimate in paired row planting were observed to be less conducive to the development and spread of brown spot disease. Hegde *et al.* (2000) also confirmed the influence of the planting method on the incidence of brown spot and reported that disease incidence was lower in row seeding and line transplanting compared to broadcasting of pre-germinated seeds. A similar observation was made by Berger (1975), who reported that leaf spot disease spread faster in closely spaced plots when compared to widely spaced ones and he attributed the modified microclimatological effect as the possible cause. According to him, the distance between plants within and between rows alter the microclimate and eventually the disease spread. Unlike in the case of sheath blight, contact frequency between plant tissues was assumed to play little role in brown spot spread. The involvement of wind dispersed conidia might have reduced the significance of the difference in the distances between plants in different geometry.

The influence of microclimate associated with varying planting geometry on the spread of brown spot disease was analyzed in different studies. According to Sunder *et al.* (2014), successful inoculation by conidia required a relative humidity of more than 89 per cent at 25°C and infection was favoured by free water on leaf surface. Studies carried out on conidial production have also shown that a temperature range of 21-26^{0}C was optimum and a relative humidity of 92 per cent and above was associated with higher production of conidia with maximum at 100 per cent relative humidity. Barnwal *et al.* (2013) reported that temperature interacted with humidity to influence leaf wetness which was positively correlated with disease development. Percich *et al.* (1997) also provided similar results. They suggested that high plant density led to closer canopy development and thus longer leaf wetness duration. This could be the reason behind the significantly higher DI and PDI recorded in direct sowing and normal transplanting with higher plant density when compared to paired row planting.

The correlation analysis conducted between micrometeorological parameters and disease variables showed that the forenoon relative humidity range of 89-92 per cent, afternoon relative humidity range of 72-77 per cent, average relative humidity range of 81-84 per cent and canopy temperature range of 30.5-32.5^{0}C favoured brown spot infection during *rabi* season and the forenoon relative humidity range of 89-93 per cent, afternoon relative humidity range of 77-81 per cent, average relative humidity range of 83-87 per cent and canopy temperature range of 28-30^{0}C favoured the same during the *kharif* season in this study. The analysis of scatter diagram depicting the correlation between these variables recorded during *kharif* season indicated that maximum observations falling within this range of micrometeorological data were recorded from direct sowing, followed by normal transplanting and paired row planting. The closer spacing in direct sowing followed by normal transplanting might have created a humid microclimate with low temperature which became conducive for the development of brown spot disease when compared to the paired row planting with wider spacing and a lesser humid microclimate. Dhaliwal *et al.* (2018) studied the effect of canopy temperature and relative humidity on incidence of brown spot under different planting systems in rice and came up with similar results. They stated that the higher relative humidity and lower canopy temperature associated with the dense canopy in higher plant populations increased incidence of brown spot when compared to lower plant populations. These observations were in consistent with that reported by Percich *et al.* (1997) who stated that decrease in minimum temperature increased the brown spot epidemics. During *rabi* season, however, this trend varied with respect to canopy temperature. All the observations pertaining to canopy temperature recorded from the three systems during the observed intervals fell within the range of 30.5-32.5^{0}C. The higher air temperature existed during this season might have caused an impact on canopy temperature, nullifying the variations between the different planting geometry.

It can be concluded that the increased relative humidity and duration of leaf wetness associated with closer planting favour incidence of brown spot. The altered microclimate within paired row planting with wider spacing can overcome this disadvantage to an extent.

5.1.4 Incidence of sheath rot in different planting systems of rice

Sheath rot incidence was observed in the field only during the *kharif* season. The higher number of rainy days in *kharif* season might have accelerated the disease development. Bigirimana *et al.* (2015) also reported that rainy season favoured sheath rot disease. The disease symptoms were first observed during the heading stage. The booting to harvesting stage of the *kharif* planting was exposed to higher relative humidity and low temperature coupled with less number of sunshine hours and this might have resulted in the increased incidence of sheath rot in *kharif* season after the booting phase in rice. Similar findings were reported by Reddy *et al.* (2001) as well.

The DI recorded in paired row planting was statistically on par with that of normal transplanting and significantly lower than that of direct sowing until the physiological maturity stage. At the physiological maturity stage, the DI recorded in paired row planting was significantly lower compared to normal transplanting and direct sowing. However, PDI recorded in all three observed stages in paired row planting were significantly lower than the other two systems. In all these stages, PDI remained significantly higher in direct sowing.

This low incidence of sheath rot may be due to the less plant population in paired row planting compared to normal transplanting and direct sowing. The increased plant density in direct sowing, followed by normal transplanting might have increased the incidence and severity of sheath rot disease. Singh and Dodan (1995) also reported that disease severity increased in densely planted situations. Supporting this observation, Bigirimana *et al.* (2015) commented that crop intensification practices such as increased plant density, favoured the susceptibility of rice to sheath rot like diseases. Sakthivel (2001) also reported that avoiding dense planting might prevent the predisposition factors favouring the sheath rot disease. He also suggested that sheath rot infection occurred after the plant got weakened by other diseases and infestations of pests like stem borers, which, in this study, were more in direct sowing followed by normal transplanting. The bore holes at panicles were reported as ideal infection sites for the fungus. Pearce *et al.* (2001) also made similar observations and reported that severe infections occurred in densely planted rice fields where the stem borers made their significant infestation. They also reported that *Sarocladium oryzae,* causal agent of sheath rot disease, could be isolated from the bodies and eggs of tarsonemid mites, indicating their role in mode of entry of pathogen. Bigirimana *et al*. (2015) also discussed the role of insects like stem borer, leaf hoppers, tarsonemid mites and rice ear head bugs as facilitators of entry of pathogen into the host tissue. Similar findings were reported by Singh and Dodan (1995). Closely spaced plants in direct sowing and normal transplanting, by shading each other might have altered the microclimate within the crop canopy, making rice plants more vulnerable to insect pests. The stem borer damage recorded during this study also confirms this assumption. The increased stem borer damage reported in direct sowing and normal transplanting might have contributed to the development of more primary injury spots in the plants and these might have acted as the points of entry of sheath rot pathogen.

The modified microclimate might have also influenced the incidence and severity of sheath rot disease. Sakthivel (2001) reported that hot and humid weather with temperature of 20-30^0 C and relative humidity in the range of 65-85 per cent favoured the development of sheath rot. Correlation analysis conducted between micrometeorological parameters and disease variables indicated that incidence and severity of sheath rot disease were favoured by the microclimate with 90.5-92.5 per cent forenoon relative humidity, 78.5-81 per cent afternoon relative humidity, 84.5-87 per cent average relative humidity and canopy temperature of 28-30^{0}C.

A closer analysis of the scatter diagram also revealed that the micrometeorological observations recorded in paired row planting did not fall within this favourable range. The maximum number of observations falling within this ideal microclimatological range were recorded from direct sowing, followed by normal transplanting. These findings gave implications about the more congenial microclimatic conditions that existed in densely planted direct sowing and normal transplanting compared to that of paired row planting for the development of sheath rot disease. The decreased relative humidity and increased canopy temperature within the paired row planting might have reduced the disease development. The findings of Reddy *et al.* (2001) were also in accordance with the present results. They reported a positive correlation of sheath rot incidence with relative humidity and a negative correlation with sunshine hours.

However, contrary to the obtained results, Kashid *et al.* (2021) reported that canopy temperature exhibited a positive correlation and evening relative humidity exhibited a negative correlation with disease incidence. But, the morning relative humidity, like in this case, was positively correlated with disease incidence. Mehta *et al.* (2022) reported that maximum and minimum temperatures showed a negative and morning relative humidity showed a positive correlation with incidence of sheath rot. These findings are in favour of the present results. However, they also reported that evening relative humidity showed a negative correlation with disease development. Therefore, other microclimatological factors might have also acted synergistically or antagonistically with the factors dealt in the present study to produce such an outcome of the disease and these also have to be addressed in the future studies.

Sheath rot, caused by *S. oryzae* is influenced by several factors. For the management of sheath rot, the modified planting geometry in paired row planting can play a significant role mainly because of the changes in plant density as well as by reducing other predisposing factors such as pest incidence.

5.1.5 Incidence of false smut in different planting systems of rice

False smut is an important emerging disease of rice. Historically an uncommon disease, false smut has recently increased in importance throughout the rice growing regions of the world. An attempt was made to assess the influence of planting geometry on the incidence of false smut in rice.

The incidence of false smut was observed in the field during both seasons in all three systems. The incidence and severity of false smut were found to be significantly less in paired row planting, followed by normal transplanting and direct sowing.

The role of microclimate associated with each planting geometry on the incidence of false smut was analyzed. From the micrometeorological data collected during this study, it is evident that the relative humidity reported in paired row planting during the flowering period is lower than that of normal transplanting and direct sowing. Canopy temperature, on the other hand, was lower in direct sowing and normal transplanting when compared to paired row planting. Also, the correlation analysis conducted between micrometeorological parameters and disease variables revealed that the false smut infection was favoured by a microclimate with a forenoon relative humidity of 88-95 per cent, afternoon relative humidity of 71-77 per cent, average relative humidity of 80-85 per cent and canopy temperature of 28.5-33^{0}C during the *rabi* season. Similarly, during the *kharif* season, an increased false smut infection was noticed at a forenoon relative humidity range of 89-96 per cent, afternoon relative humidity range of 78-82 per cent, average relative humidity range of 83.5-88 per cent and canopy temperature range of 29-30.5^{0}C. The number of observations recorded within this range was higher in direct sowing, followed by normal transplanting and paired row planting. Most of the observations recorded in paired row planting were found to be lower than this relative humidity range and higher than the canopy temperature range. This decrease in the relative humidity and increase in the canopy temperature might have acted as the cause of decreased infection in paired row planting.

Supporting this finding, several researchers have reported that the false smut incidence was favoured by relatively low temperature and high relative humidity during the flowering stage (Singh *et al*., 1987; Bhargava *et al.*, 2018; Mohapatra *et al*., 2018; Lore *et al.*, 2021). Bag *et al*. (2021), in favour of the obtained results, reported that the ideal stage of infection in the rice plant coincided with an environmental condition of 90 per cent relative humidity. There are similar reports justifying the role of relative humidity in increasing false smut infection (Bhagat and Prasad, 1996; Chaudhari *et al*., 2019). Jiehui *et al.* (2022) also observed that higher relative humidity and more moderate temperatures increased the severity of rice false smut disease and the germination rate of conidia of *U. virens* in the rice–crayfish coculture when compared to rice monoculture. Mohapatra *et al*. (2018) also reported that the conditions leading to the development of higher humidity below the crop canopy create an environment favourable for the development of false smut disease. They also commented that light can inhibit the formation of secondary spores from chlamydospores. Therefore, in addition to the role of reduced relative humidity and increased canopy temperature, an increased light interception in paired row planting, might have also influenced the secondary spread of false smut negatively.

By comparing the obtained results with that of the reported ones, it can be concluded that the closer spacing noticed in direct sowing and normal transplanting might have created a microclimate with higher relative humidity and low canopy temperature, conducive to the development of false smut disease compared to paired row planting with wider spacing.

Since the symptoms of false smut will appear only after the flowering stage, where the curative application of fungicides will not give satisfactory results particularly in rainy season, there is a requirement to prevent the incidence beforehand to minimize the associated yield loss. Modifying the microclimate to restrict the growth and development of the fungi responsible can be considered a cultural control measure. The present study provides indications regarding the advantages of adopting paired row planting, with modified microclimate, in managing false smut incidence in rice to an extent. A few more trials in the future may provide results confirming this indication.

5.2 INFLUENCE OF PLANTING GEOMETRY ON INCIDENCE OF PESTS IN RICE

5.2.1 Incidence of caseworm in different planting systems of rice

The influence of planting geometry on incidence of caseworm in rice was analyzed. The damage caused by caseworm was recorded with respect to per cent damaged leaves and the obtained results showed that the caseworm damage was observed during the initial tillering stages, irrespective of the systems.

From the data collected over two seasons, it is evident that high incidence of caseworm took place during the initial tillering stages and reduced significantly thereafter. The caseworm infestation was not observed after the active tillering stage. This trend repeated in all plots, irrespective of the systems. Supporting this observation, Singh and Singh (2010) reported that rice at seedling and tillering stages act as the preferred hosts for caseworm infestation and the same disappears after the maximum tillering stage. While analyzing the incidence pattern of rice caseworm, Haq *et al.* (2006) also came up with similar observation and reported that caseworm mostly damaged the rice plants 2 to 4 weeks after transplanting.

In both observed intervals, the caseworm damage recorded in paired row planting was statistically on par with that of normal transplanting and higher than that of direct sowing. The significant increase in caseworm infestation noticed in paired row planting and normal transplanting during the observed intervals may not be due to the effect of the planting geometry itself. The difference in biometric characters between direct sown and transplanted crops can be considered a potential cause for this peculiar observation. In direct sowing, due to the absence of transplanting shock, the establishment of rice took place earlier than that in transplanted plots as reported by Nwokwu *et al.* (2016). Hence, the susceptible stage of the direct sown crop might have surpassed that of normal transplanting and paired row planting beforehand.

The role of microclimate in the incidence of caseworm was also analyzed. Analyzing the data, it was observed that, the highest per cent damage due to caseworm (above 30%) was recorded at forenoon relative humidity of 81.25-83.5 per cent, afternoon relative humidity of 59-62 per cent, average relative humidity of 70.75-72.25 per cent and canopy temperature of 31.75-34.25^{0}C during *rabi* season. Similarly, during the *kharif* season, it was recorded at forenoon, afternoon, and average relative humidity and canopy temperature ranges of 81.75-85 per cent, 62.5-70 per cent, 73-76.5 per cent and 31-33^{0}C respectively.

From the data, it is also evident that caseworm damage above 30 per cent was recorded in both paired row planting and normal transplanting in these microclimatic conditions. In direct sowing, however, the earlier establishment of plant stands might have helped to surpass the susceptible stage by the time first observations were taken after transplanting seedlings in paired row and normal transplanted plots. So, it may not be appropriate to idealize a planting geometry with respect to the microclimatic conditions in managing caseworms, considering the susceptibility stage and duration of its attack.

5.2.2 Incidence of leaf folder in different planting systems of rice

The influence of planting geometry on leaf folder infestation in rice was assessed during this study. The data thus obtained revealed that the per cent damaged leaves due to leaf folder infestation increased gradually from the initial tillering stages to the panicle initiation stage. After this stage, a further increase in damage was not noticed. During the panicle initiation phase, where the highest leaf folder damage was noticed in all three systems, a significant reduction in leaf folder damage was recorded in paired row planting compared to other two systems.

The decreased leaf folder damage in paired row planting could be attributed to the difference in spacing, plant density and associated microclimate. Kushwaha and Sharma (1981) proposed an inverse relationship between spacing and leaf folder incidence, which supports the present findings. Also, the closer spacing in direct sowing compared to normal transplanting might have led to more leaf-to-leaf contact in the former, creating a more favourable situation for the movement of leaf folder larvae. A similar observation was made by Sarao and Mahal (2013) who reported that the clumpy growth of plants in direct sowing leads to the intermingling of leaves, which provides favourable conditions for the folding of leaves and easy leaf-to-leaf movement of the larvae than that in conventional transplanting. This observation can be conveniently extended to include paired row planting also. In paired row planting, a wide space of 35 cm between the paired rows might have acted as a hindrance for the larvae movement compared to comparatively closely, but regularly arranged plants in normal transplanting. Chapagain *et al.* (2011) also gave an indication that the widely spaced crop establishment system with reduced plant density could escape leaf folder infestation. According to them, the larvae of the rice leaf folder required sufficient number of leaves to feed upon, and the fewer number of leaves present during the peak period of infestation could limit pest activity in widely spaced plots.

The influence of the associated microclimate on the incidence of leaf folder was also evaluated. Behera *et al*. (2013) reported that the leaf folder needs a temperature of 25-32^0 C and a high relative humidity of 83-90 per cent for better development. The increase in relative humidity observed in direct sowing and normal transplanting might have resulted in increased leaf folder damage. The data revealed that the highest per cent damage caused by leaf folders in *rabi* season was at forenoon relative humidity of 85.5-88 per cent, afternoon relative humidity of 66-69 per cent, average relative humidity of 76-78.5 per cent and canopy temperature of 31-31.5^{0}C during *rabi* season. Similarly, during the *kharif* season, it was recorded at forenoon, afternoon, and average relative humidity and canopy temperature ranges of 88-91 per cent, 75-80 per cent, 82-86 per cent and 29-30.5^{0}C respectively.

A detailed analysis of the scatter diagram also showed that the highest number of observations recorded within this range were from direct sowing followed by normal transplanting. Most of the observations recorded in paired row planting were lower than the relative humidity range derived. Similarly, the canopy temperature observations recorded in the same were higher than this range. This indicates that the microclimate associated with paired row planting is not conducive to leaf folder damage compared to normal transplanting and direct sowing.

The decreased relative humidity and increased canopy temperature might have contributed to less leaf folder damage in paired row planting with wide spacing compared to normal transplanting and direct sowing. Supporting the present finding, other researchers have conducted a correlation analysis of the leaf folder population and/or its damage with abiotic factors and reported the existence of a significant positive correlation with relative humidity variables and a negative correlation with the temperature variables (Zainab *et al.*, 2017; Sharma *et al*., 2018; Rasul *et al*. 2019; Priyadharsan and Muthukumaran, 2020; Tiwari *et al*., 2021)

However, observations contrary to the present findings have also been reported. Some of them reported a decrease in relative humidity (Chakraborty and Deb, 2011; Tiwari *et al*., 2021) whereas, others reported an increase in canopy temperature as the cause of increased pest damage (Baskaran *et al*., 2017; Jasrotia *et al*., 2019). Contrary to all these reports, Sulagitti *et al.* (2017) and Morshed *et al*. (2020) reported that the leaf folder population didn't get affected by morning relative humidity and temperature. Therefore, more trials have to be conducted in the future including more micrometeorological parameters to get a better understanding of the role of complex interactions of these variables in the microclimate associated with the planting geometry on incidence and damage caused by leaf folder.

It can be concluded that the less relative humidity, high canopy temperature and less leaf-to-leaf contact in paired row planting might have resulted in less incidence of leaf folder compared to other two systems. However, the higher relative humidity, lower canopy temperature and more leaf-to-leaf contact attained in the closely spaced direct sowing and normal transplanting favoured leaf folder damage.

5.2.3 Incidence of yellow stem borer in different planting systems of rice

The damage caused by yellow stem borer was analyzed in terms of per cent dead hearts at the active tillering stage and per cent white ear heads during the panicle initiation stage in all three systems with an objective of deriving a relationship between the change in planting geometry and pest damage.

In both seasons, the per cent dead hearts recorded in paired row planting and normal transplanting did not show any significant difference. However, the per cent white ear heads noticed in paired row planting during the panicle initiation stage was significantly lower than in the other two systems. In both cases, per cent damage due to yellow stem borer was significantly higher in direct sowing compared to other treatments. This might be due to the congenial conditions offered by more closely arranged plants in direct sowing for the spread of yellow stem borer.

The lack of significant difference between the stem borer damage observed in paired row planting and normal transplanting during the active tillering stage might be due to the common element of transplanting shock and so the establishment time taken by plants in these systems. Also, the canopy development in both paired row planting and normal transplanting would not be completed by this stage and the incomplete coverage of the crop canopy might have reduced the influence of the planting geometry of these systems on the spread of the pest. Therefore, both paired row planting and normal transplanting might have provided similar conditions for pest development during the initial growth stages. However, by the panicle initiation stage, the canopy development reached its final lap, showcasing differences in canopy architecture and thus the conditions favouring yellow stem borer. These differences became visible in the per cent white ear heads recorded from these systems. In this stage, paired row planting experienced significantly lower yellow stem borer damage than normal transplanting.

On the other hand, in direct sowing, crop establishment took place earlier as there was no transplanting shock. This possibly helped it to exhibit the characteristic canopy architecture from the initial stages itself. For instance, during the active tillering phase, it was noticed that the plants in direct sowing were comparatively taller than that in the other two treatments. These taller plants might have created an environment favourable for the moths to rest, increasing the rate of infestation. A finding similar to this was reported by Baloch and Abdullah (2011), who proposed that moths of yellow stem borer prefer taller plants for resting. They also suggested that rice stem borers, being nocturnal insects, prefer shady green foliage to rest. Direct sowing, with higher plant density, might have contributed to the preferable shady atmosphere for the pests to rest.

Behera *et al.* (2013) also stated that wider spacing is unfavourable to pests like yellow stem borer, explaining the increased stem borer damage in closely spaced direct sowing and normal transplanting compared to widely spaced paired row planting. Oyediran and Heinrichs (2001), supporting the present results, observed that the stem borer damage increased with an increase in planting density. The increased plant density in direct sowing and normal transplanting reduced the distance between the host plants, facilitating easy movement of yellow stem borer larvae. These observations are in line with the findings of Sarao and Mahal (2013), who reported that close proximity of plants in direct sowing assists in the movement of larvae from one plant to another, causing severe damage.

The role of microclimate in the difference in yellow stem borer infestation was analyzed and the results revealed that, during the *rabi* season, the highest per cent dead hearts was noticed at the forenoon relative humidity range of 85-89 per cent, afternoon relative humidity range of 65-72 per cent, average relative humidity range of 75-80 per cent and canopy temperature range of 31-32.5^{0}C. During *kharif* season, the highest dead heart damage was recorded at the forenoon, afternoon, average relative humidity and canopy temperature ranges of 87.5-89 per cent, 74.5-77 per cent, 81-82.5 per cent, and 29.5-31^{0}C respectively. In both seasons, all the observations recorded within this humidity range were from direct sowing. The relative humidity observations recorded from paired row planting and normal transplanting were lower than this range, clearly indicating the role of high relative humidity in increased pest damage. During the *kharif* season canopy temperature recorded in paired row planting and normal transplanting were higher than this range. This similarity in the experienced relative humidity during the active tillering phase, also explains the non-significance between the recorded per cent dead hearts in paired row planting and normal transplanting. At the same time, the canopy temperature plotted in the diagram against pest damage during the rabi season, fell within this favourable range irrespective of the systems.

When the per cent ear head damage was correlated with that of micrometeorological observations, it was found that the highest per cent white ear head was noticed at forenoon relative humidity of 85-90 per cent, afternoon relative humidity of 70-80 per cent, average relative humidity of 79-85 per cent and canopy temperature of 30.5-32^{0}C. Similarly, the highest damage was noticed during *kharif* season at forenoon, afternoon, average relative humidity and canopy temperature ranges of 87.5-92 per cent, 75.5-79 per cent, 82-84 per cent and 29-31^{0}C. In both seasons, the highest number of observations recorded within this range of data were from direct sowing and normal transplanting compared to paired row planting. The recorded relative humidity in paired row planting was lower and canopy temperature was higher than the favourable range derived.

In a nutshell, it can be stated that an increase in forenoon, afternoon and average relative humidity and a decrease in canopy temperature observed in direct sowing and normal transplanting positively influenced yellow stem borer damage. Supporting this finding, several researchers reported that morning and evening relative humidity favoured the yellow stem borer population in rice (Nag *et al*., 2018; Singh *et al*., 2020). Morshed *et al*. (2020) also reported that temperature showed a significant negative and relative humidity showed a significant positive impact on yellow stem borer damage with respect to white ear head and dead heart damage respectively. The present results are also in favour of the findings reported by Sharma *et al.* (2018) stating that average temperature and average relative humidity showed a significant negative and positive correlation respectively with per cent dead heart damage. They explained that the drop in mean temperature in association with a prolonged spell of rainy days was most congenial for pest growth and multiplication. Justin and Preetha (2013) also came up with similar observations.

However, findings contrasting with the present results have also been reported. A few among them reported the positive influence of temperature variables (Behera *et al.*, 2013; Nag *et al*., 2018; Sing *et al.*, 2020;), whereas others reported negative influence of one or more relative humidity variables on yellow stem borer damage (Sharma *et al*., 2018).

It can be summarized that the decreased planting density and increased spacing in paired row planting, by creating a conducive microenvironment and reducing plant-to-plant contact, prevent the yellow stem borer infestation to an extent compared to other systems.

5.2.4 Incidence of rice bug in different planting systems of rice

The effect of planting geometry on the incidence of rice bug infestation, which was recorded in terms of damaged grains per panicle, was assessed during this study.

The results showed that the rice bug damage was significantly less in paired row planting compared to normal transplanting and direct sowing in both seasons. The closer planting and increased plant density in direct sowing and normal transplanting might have created a shady microenvironment favouring the rice bug population. The preference for shaded areas by adult bugs for resting was also reported by Paikra *et al.* (2021). Therefore, it can be assumed that the wide space in between the paired rows might have created conditions not conducive for the rice bug population in paired row planting.

The influence of microclimate associated with the different planting geometry considered on the difference in rice bug damage was also analyzed. The correlation analysis indicated that the highest per cent damage due to rice bugs during the *rabi* season was noticed at forenoon relative humidity of 90.5-94 per cent, afternoon relative humidity of 75-79 per cent, average relative humidity of 83.5-85.5 per cent and canopy temperature of 30.5-32.5^{0}C. Similarly, during the *kharif* season, it was highest at respective forenoon, afternoon and average relative humidity, and canopy temperature ranges of 91.5-94.5 per cent, 78-83 per cent, 85.5-88 per cent and 27-29.5^{0}C. The highest number of observations corresponding to this range were recorded from direct sowing, indicating the possibility of a more favourable microclimate for rice bug infestation.

The relative humidity observations recorded from the other two systems were lower than this favourable range, whereas canopy temperature observations were higher than this range. The relative humidity recorded in paired row planting was lower than that in normal transplanting. Also, the canopy temperature recorded in paired row planting was significantly higher than that of normal transplanting. This difference in microclimate within the canopy of the three systems might have reflected in the damage caused by rice bugs. As per this study, the rice bug activity is favoured by an increased relative humidity and decreased canopy temperature and thus any canopy architecture providing these congenial microenvironmental characteristics might have encouraged more infestation. This finding, to an extent, explains the decreased rice bug damage in paired row planting.

Supporting this finding, Sulagitti *et al.* (2017) and Kalita *et al.* (2020) reported that rice bugs showed a positive correlation with morning relative humidity and a negative correlation with temperature. Other researchers have also reported a negative correlation between temperature variables and the rice bug population (Bhatnagar and Saxena, 1999; Sharma *et al*., 2019; Mohanta *et al*., 2020; Paikra *et al*., 2021). The findings of Gupta *et al*. (2018), who reported a significant positive association of the rice bug population with morning and evening relative humidity, are also in line with the obtained results.

However, some of the earlier researchers have reported results contrasting with the present observations. It includes studies revealing the negative influence of relative humidity variables (Bhatnagar and Saxena, 1999; Sharma *et al*., 2019; Mohanta *et al*., 2020; Paikra *et al*., 2021) and the positive influence of temperature variables (Gupta *et al*., 2018) on the rice bug population and/or the damage caused by them. Therefore, it is required to include more micrometeorological parameters under study to elucidate the complex interactions of these variables in creating a conducive microclimate for the rice bug population.

The results of the study revealed that the incidence and severity of major diseases in rice *viz.* bacterial blight, sheath blight, brown spot, sheath rot and false smut and the damage caused by pests *viz*. leaf folder, yellow stem borer and rice bug were significantly lower in paired row planting compared to normal transplanting and direct sowing. The difference in planting geometry and associated microclimate can be considered as the contributing factors responsible for this difference in incidence of diseases. The decrease in pest and disease incidence in paired row planting can also be attributed to the proposed theory of trophobiosis. The theory states that the susceptibility of a crop plant to pests and diseases depends on its nutritional state. According to this theory, it is not just any plant which is attacked by pests and diseases, but only those which could serve as food for the insect or pathogen (Chaboussou, 2004). Therefore, the factors which affect plant physiology can lessen or increase its susceptibility to pest and disease attacks. Padmavathi *et al.* (2009) also reported that rice plants that grow rapidly and vigorously with accelerated tillering and root growth, are less attractive to insects, bacteria, fungi and viruses because of their nutritional dynamics attributing theory of trophobiosis as the possible reason. In paired row planting, the wider spacing between the paired rows enabled the plants within to reduce the competition successfully for the resources like nutrients, space, air, water and sunlight and develop into healthy plants with more tillers, leaves, and root development. Such relatively healthier plants, with vigorous growth and improved tillering, observed in paired row planting might have resisted the pest and disease incidence.

5.3 RHIZOSPHERE MICROFLORA IN DIFFERENT SYSTEMS OF ESTABLISHMENT IN RICE

Plants shape their rhizosphere microbial communities through changes in soil temperature, moisture, physical structure, litter quality, and root exudates. Soil microbial communities, in turn, influence plant community structure by altering plant performance and functional traits (Hortal *et al*., 2017). Holding this as the background data, the difference in the abundance of rhizosphere microflora with a difference in planting geometry was analyzed by performing serial dilution and plating techniques.

From the data, it is evident that the maximum population of fungi, bacteria and actinomycetes was reported during the active tillering phase, irrespective of the treatments. The same declined as the crop approached the maturing phases. The exhaustion of nutrients in the rhizosphere, due to the active intake by the plants might have resulted in such a reduction in the microorganism population. Supporting this observation, Aslam *et al.* (2013) reported that bacterial communities were different at certain growth stages of rice. According to their study, a group of Actinobacteria remained almost constant till the vegetative phase but decreased thereafter during the reproductive and ripening stages in soils. They attributed the changes in nutrient balance and pH with the changes in crop growth stages as the possible reasons for the corresponding finding. Ghoshal and Singh (1995) also reported that the microbial biomass decreased sharply from the seedling to the flowering stage and then increased slightly. The less competition for nutrients by the plants, resulting in the availability of nutrients for rhizosphere microorganisms was considered the factor responsible for the increase in microbial biomass during the initial growth phases whereas, the accelerated nutrient uptake by the plants followed in the successive stages resulted in the decline of the same.

The results revealed that the rhizosphere population showed no significant difference between treatments at all the stages considered. The uniformity maintained with respect to soil properties, nutrient and water management and variety used in all the plots might be the reason behind this observation. The only difference that existed between the treatments was in the spacing and plant density, which might not be sufficient enough to cause a change in the number of rhizosphere microflora. Aslam *et al*. (2013), in favour of the present results, commented that the change in bacterial communities during different rice growth stages was similar irrespective of field conditions, although diversity varied. It has been shown that plant species have a greater effect on the rhizosphere microflora than the plant's developmental stage, which is a constant factor here. Similarly, Wieland *et al*. (2001) reported that the plant development stages played a less significant role in the shifts of microorganism communities compared to the soil type and plant species. Between the latter two, the effect of the soil type was considered higher than that of the plant species. Latour *et al.* (1996) also concluded that the diversity of the fluorescent Pseudomonas population in the rhizosphere was influenced mainly by the soil type, which was also a constant factor in this particular study. Lay *et al*. (2018), in favour of the obtained results, observed that seeding density did not influence significantly the composition of bacterial, fungal, or archaeal assemblages associated with canola roots. These previous reports indicate that the major factors that are reported to contribute significantly to the variation in rhizosphere microflora, *viz*. variety, soil type, management practices, and nutrition were maintained constant between the treatments. This explains the lack of significant difference in rhizosphere population of fungi, bacteria and actinomycetes.

However, this observation cannot be accepted as a conclusive one, considering the limitations of media-based techniques in completely revealing the diversity and abundance of rhizosphere microorganisms. There are reports stating that responses to the competition between plants, possibly alter the quantity, quality and availability of resources supplied by a host plant to its microbiome (Hortal *et al*., 2017). Similarly, Anas *et al*. (2011) reported that a reduced seeding rate enhances the growth rate and root development of plants. They also reported that plants with larger root systems as well as bigger canopies contribute more root exudates (carbohydrates, amino acids, etc.) to the rhizosphere, where they act as substrates for soil organisms. The role of soil aeration in promoting root growth and thereby the biodiversity and abundance of soil organisms that enhance plant health and performance was also discussed. All these previous reports revealed a possible interaction between the distinct plant density and the rhizosphere microflora associated with each planting geometry. Therefore, metagenomic approaches can be undertaken in the future to get a better understanding of the relationship between planting geometry and the rhizosphere population.

5.4 INFLUENCE OF DIFFERENT PLANTING GEOMETRY ON GROWTH OF RICE

Biometric observations *viz*. number of tillers per hill, number of leaves per hill, plant height and leaf area were taken at ten days intervals and compared statistically to elucidate the influence of planting geometry on biometric characters of rice.

From the data obtained during the course of the study, it is evident that during the initial stages, the number of tillers was found significantly higher in direct sowing than that in the other two treatments. The trend changed as the crop reached the active tillering phase. From the active tillering phase onwards, the number of tillers recorded in paired row planting was significantly higher followed by direct sowing and normal transplanting except in the active tillering and panicle initiation stage, where the number of tillers recorded in paired row planting was statistically on par with that of direct sowing.

It was also observed that, like the number of tillers, the number of leaves per hill during the initial growth stages was significantly higher in direct sowing than in normal transplanting and paired row planting. From the active tillering stage onwards, the number of leaves per hill recorded in paired row planting was higher compared to other two treatments.

From the data, it is also evident that plant height from the initial tillering stages till the booting stage was significantly higher in direct sowing compared to other treatments. In all these observed intervals, there was no significant difference observed between the normal transplanting and paired row planting. After the booting stage, no significant difference was observed between the treatments with respect to plant height.

Leaf area was found to be significantly higher in the direct sown plots till the active tillering phase than in the other two systems compared. In the successive stages, there was no significant difference in leaf area between the three systems.

The significantly higher number of tillers, leaves and leaf area observed during the initial stages might be due to the early establishment of rice plants in direct sown plots. The lack of transplanting shock might have assisted the directly sown rice plants to establish strong stands earlier than the transplanted crop. A similar finding was reported by Naklang *et al.* (1996) who stated that avoidance of transplanting shock in direct sowing led to increased biomass production compared to transplanting. They also observed that transplanting of seedlings damages the root system, and the development of new roots in the top layer may be impaired. The lack of such a disadvantage resulted in faster growth and early attainment of maturity in direct sowing, which explains the increase in tiller number with respect to paired row planting during the initial growth stages and to normal transplanting throughout the growth period. The increased tiller number obviously increased the number of leaves. Iwuagwu *et al*. (2017) also supported the observed results by conferring that direct sowing resulted in good stand establishment, high tillering, stable growth and reduced transplanting shock compared to transplanting. However, the vigour of the plants and the associated yield observed in normal transplanting was higher than that of direct sowing.

The increase in plant height noticed in direct sowing till the booting phase can also be attributed to the same reason. By this stage, the successful establishment of the crop was taken place in all the treatments, nullifying the advantage experienced by the plant stands in direct sown plots during the initial growth stages. The plant height recorded in direct sowing during the physiological maturity stage remained higher than in the other two treatments. Gautam *et al.* (2008), in favour of this finding, showed that narrow spacing maintained its significant superiority in producing comparatively taller plants. Kumar (2001) also reported that higher plant densities tended to produce taller plants than lower plant densities. The lack of significant difference between the treatments after the booting stage implies that the spacing did not affect the plant height significantly during this study. This finding is in line with that of Zhimomi *et al*. (2021), who reported that different spacing of seedlings had no significant influence on plant height. The findings of Iwuagwu *et al*. (2017) also support this observation. However, contrary to the observed results, they also stated that plant height tends to decrease in direct sown plots compared to transplanted ones.

The significant increase in the tiller and leaf number in paired row planting, with wider spacing, since the active tillering phase can be attributed to a multitude of reasons. Supporting the obtained results, Zhimomi *et al*. (2021) also observed profuse tillering under wider spacing compared to closer spacing. The wider spacing maintained in paired row planting compared to the other two systems might have reduced the intraspecific competition between the plants and population pressure on individual plants for space, solar radiation, light, nutrients, air and moisture, resulting in better growth and development of individual plants with improved tillering. Results supporting these observations have been reported in previous studies (Rautaray, 2007; Gautam *et al*., 2008). Verma *et al.* (2012) also reported the role of increased resource availability in planting geometry with wider spacing in the better development of individual plants.

The notable reduction in pests and diseases might have also resulted in increased number of tillers in paired row planting. The closer canopy with increased relative humidity build-up and decreased canopy temperature attracted various pests and diseases, that have been discussed above, resulting in poor growth characteristics in relatively closely spaced direct sowing and normal transplanting.

From the observed results, it can be concluded that the paired row planting with wider planting geometry encouraged profuse tillering compared to other systems of crop establishment.

5.5 INFLUENCE OF DIFFERENT PLANTING GEOMETRY ON YIELD AND YIELD ATTRIBUTES

Grain yield per hectare and yield attributes *viz*. number of hills per m^2, number of panicles per hill, number of grains per panicle, number of chaffy grains per panicle and 1000 grain weight were taken from each plot.

The number of hills per m^2 was significantly lower in paired row planting followed by normal transplanting and direct sowing. The distinct spacing adopted in the former two transplanted systems during both seasons explains the variation with respect to treatments and the similarity with respect to the season in the corresponding observations. The number of hills per m^2 recorded in paired row planting with wider spacing (35-15cm ×10 cm) was 40, whereas that in normal transplanting with narrow spacing (15 cm × 10 cm) was 66. In direct sowing, a specific spacing was not maintained and thus the number varied between 69 - 71. Direct sowing led to an increased plant density and thus to an increased number of hills per m^2.

The number of panicles per hill was significantly higher in paired row planting, followed by normal transplanting and direct sowing. There was no significant difference between the systems with respect to the number of grains per panicle, number of chaffy grains per panicle and 1000 grain weight. However, contrary to the observed results, Gautam *et al.* (2008) reported that a significant increase in 1000 grain weight was registered at wider spacing as compared to closer spacing.

The increased number of tillers observed in paired row planting explains the increase in the number of panicles in it. However, the number of tillers observed in direct sowing and normal transplanting showed no significant difference during the physiological maturity phase and an explanation only with respect to the number of tillers may not be sufficient to justify the increased number of panicles in normal transplanting compared to direct sowing. The increased planting density in direct sowing might have led to increased competition between the plants, affecting the number of panicles. Similar results have been reported by various researchers, stating that an increased planting density associated with closer planting results in increased competition for resources *viz*. light, air, nutrients, space, moisture, and thus the reduced tillering and number of panicles per hill (Rautaray, 2007; Bezbaruha *et al.*, 2011; Sihag *et al*., 2015). Iwuagwu *et al*. (2017), in support of obtained results, reported that reduced plant-plant competition in transplanted crops led to the production of vigorous plants, a greater number of panicles and higher yield than direct sowing. This satisfactorily justifies the increased number of panicles in normal transplanting compared to direct sowing in spite of the increased number of tillers observed in the latter compared to the former.

The appreciable role of planting geometry associated with wider spacing, as in the case of paired row planting, in favouring yield parameters can be attributed to the decreased competition and effective source-sink relationship achieved. Supporting this observation, Verma *et al*. (2012) observed that all the growth and yield attributing characters were maximum with wider crop geometry and minimum with closer crop geometry due to more availability of resources for the development of the individual plant. The better partitioning of photosynthates from source to sink and less competition for resources led to the better development of yield attributes under wider crop geometry. Zhimomi *et al*. (2021), in support of the present results, reported that competition for resources in closer planting results in the development of skinny and fragile plants, producing lesser yield and the vigorous growth of plants in wider cropping geometry makes them focus more on the source than the sink, resulting in improved panicle length and consequently the number of grains per panicle. They also extended that better root development and more sunlight interception in wider cropping geometry may lead to more nutrient uptake to the source and ultimately to greater grain yield.

Also, there are reports stating that closer planting results in high dry matter production (Gautam *et al.*, 2008; Sihag *et al.*, 2015). This might have restricted the diversion of photosynthates toward reproductive parts in direct sowing, resulting in a lower number of panicles and grains, as reported by Gautam *et al.* (2008). Smith *et al.* (2018) also observed that a plant intercepts light, converts intercepted radiation to biomass and partitions this biomass into the harvested product at a greater efficiency only when the given crop is grown in ideal conditions where ample nutrients, water and all biological stresses are controlled. In the present study, it was also observed that the biological stresses, pest and disease incidence, showed a decrease in paired row planting compared to the other two treatments. The same recorded in direct sowing was higher than that of normal transplanting. All these factors might have contributed to the increased number of panicles per hill, increased grains per panicle and decreased number of chaffy grains per panicle noticed in paired row planting, followed by normal transplanting and direct sowing. This ultimately affected the grain yield per hectare.

The grain yield was significantly higher in paired row planting than in the other two systems. The yield recorded in normal transplanting was significantly higher compared to direct sowing. The increased number of panicles might have contributed to the increased yield observed in it. The same reason justifies the increased yield in normal transplanting compared to direct sowing. The number of panicles per hill was higher in the former compared to the latter. Iwuagwu *et al*. (2017), supporting the results, also reported that the yield obtained from normal transplanting showed a significant increase compared to direct sowing.

Supporting the increased yield observed in paired row planting, Moossa *et al*. (2017) reported that paired row planting with 35 - 15 cm × 10 cm spacing produced 23% higher yield over others by exploiting the border effect. According to them, the border effect was distributed throughout the field under paired row planting without compromising the plant population, resulting in a yield increase over the general system of planting. Wang *et al*. (2013) attributed the yield advantage of the border row mainly to more solar energy, good ventilation, and less competition for nutrients, which resulted in more panicles, higher biomass production, and consequently higher grain yields, justifying the obtained results.

In conclusion, it can be stated that paired row planting remained superior over the other two treatments with respect to the yield and yield attributing characteristics.

Summary

6. SUMMARY

A field experiment was conducted over two seasons (*rabi* 2021 and *kharif* 2022) to study the influence of paired row planting, a new planting geometry on disease and pest incidence in rice at the Regional Agricultural Research Station, Pattambi. The experiment was laid out in randomized block design with three treatments and seven replications using the rice variety, Jyothi. The treatments were paired row planting (35-15 cm × 10 cm), normal transplanting (15 cm × 10 cm) and direct sowing.

Disease incidence and severity were recorded at ten day interval from the first notice of the symptom in the field. During the *rabi* season the diseases observed were bacterial blight, sheath blight, brown spot and false smut. In the *kharif* season, in addition to these diseases, sheath rot was also observed. The incidence and severity of diseases *viz*., bacterial blight, sheath blight, brown spot, sheath rot and false smut were significantly lower in paired row planting followed by normal transplanting and direct sowing. The difference in planting geometry, plant population and associated microclimate can be considered as the contributing factors responsible for this difference in incidence of diseases. In paired row planting, a wide space of 35 cm between the paired rows is maintained and this might have developed a less humid microenvironment within the crop canopy as well as restricted the movement of the pathogen by creating a barrier to the spread of the disease. The less plant to plant contacts in paired row planting compared to other two systems might have also added to its advantage in managing the horizontal spread of the diseases to an extent.

However, in normal transplanting, the spacing is uniform and there is no wide gap as in the case of paired row planting. The closer spacing and higher plant density in normal transplanting and direct sowing might have contributed to the development of a humid and shady microclimate that is considered ideal for the growth and development of pathogens. It might have also resulted in increased contact frequency in these systems compared to paired row planting facilitating the accelerated spread of the diseases.

In addition to diseases, pest damage was also recorded at every ten days interval. Infestation of case worm, leaf folder, yellow stem borer and rice bug were noticed in the field. The damage due to the infestation of major pests, leaf folder, yellow stem borer and rice bug was significantly lower in paired row planting when compared to the other two systems. Like disease incidence, pest incidence was also significantly higher in direct sowing, followed by normal transplanting. The less humid microenvironment in paired row planting with wide spacing might not have encouraged the spread of pests as in the case of diseases. At the same time, closely spaced plants in normal transplanting and direct sowing might have shaded each other creating a humid microclimate, making them more vulnerable to pests. The increased plant to plant contacts observed in these systems might have also facilitated the easy movement of pest larvae. The increased activity of pests like yellow stem borer in direct sowing and normal transplanting might have also acted as the predisposing factors for complex diseases like sheath rot. However, a significant difference in caseworm incidence was not observed between the different establishment systems of rice. The results indicated that the susceptibility stage of the crop played a more significant role than the difference in planting geometry in the incidence of caseworm.

The role of microclimate associated with different planting geometry in the incidence of diseases and pests was also analyzed during this study. The results revealed that the relative humidity recorded in the paired row planting was lower compared to normal transplanting and direct sowing. However, the canopy temperature recorded in paired row planting was higher than that of other two systems. This indicates that the low relative humidity and high canopy temperature in paired row planting provided a microenvironment unfavourable for disease and pest development.

The decrease in pest and disease incidence in paired row planting can also be attributed to the proposed theory of trophobiosis which states that the susceptibility of a crop plant to pests and diseases depends on its nutritional state. The factors which affect plant physiology can lessen or increase its susceptibility to pest and disease attacks. In paired row planting, the wider spacing between the paired rows might have enabled the plants within to reduce the competition successfully for the resources like nutrients, space, air, water and sunlight and develop into healthy plants with more tillers, leaves, and root development. Such relatively healthier plants, with vigorous growth and improved tillering, observed in paired row planting might have resisted the pest and disease incidence.

The influence of planting geometry on the rhizosphere microflora was analyzed using serial dilution and plating technique. However, a significant difference between the systems was not observed. The uniformity maintained with respect to soil properties, nutrient and water management and variety used might be the reason behind this observation.

The biometric observations *viz.,* number of tillers, number of leaves, plant height and leaf area were recorded at every ten-day interval. The number of tillers in paired row planting was significantly higher followed by direct sowing and normal transplanting. Yield and yield attributes were also recorded. No significant difference was noticed between the systems with respect to number of grains per panicle, number of chaffy grains per panicle and 1000 grain weight. However, the number of panicles per hill and yield obtained from paired row planting was significantly higher than other two systems.

The wider spacing maintained in paired row planting compared to the other two systems might have reduced the intraspecific competition between the plants and population pressure on individual plants for space, solar radiation, light, nutrients, air and moisture, resulting in better growth and development of individual plants with improved tillering. Also, the better partitioning of photosynthates from source to sink and less competition for resources might have led to the better development of yield and yield attributes under paired row planting with wider crop geometry. Also, in paired row planting, the border effect is distributed throughout the field resulting in a yield increase over the general system of planting.

The incidence of diseases and pests in paired row planting was significantly lower compared to normal transplanting and direct sowing. This reduction in pest and disease incidence might have also contributed significantly to the yield advantage in paired row planting. So, it can be summarized that the unique spatial configuration of paired row planting helps to manage disease and pest incidence to an extent, reduces the plant competition for resources and exploits border effect resulting in a significant yield improvement over the conventional systems of rice establishment without utilizing any additional inputs.

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Appendices

APPENDIX – I

Composition of Martin's Rose Bengal Agar Medium

a. Dextrose	-	10.0 g
b. Peptone	-	5.0 g
c. KH_2PO_4	-	1.0 g
d. $MgSO_4$	-	0.5 g
e. Agar	-	20.0 g
f. Rose Bengal		
g. Distilled Water	-	1000 ml
h. pH	-	7.2

APPENDIX – 2

Composition of Nutrient Agar Medium

a. Peptone	-	5.0 g
b. Beef extract	-	3.0 g
c. NaCl	-	5.0 g
d. Agar	-	20.0 g
e. Distilled Water	-	1000 ml
f. pH	-	6.5-7.0

APPENDIX – 3

Composition of Kenknight Agar Medium

a. Dextrose	-	1.0 g
b. KH_2PO_4	-	0.1 g
c. $NaNO_3$	-	0.1 g
d. KCl	-	0.1 g
e. $MgSO_4$	-	0.1 g
f. Agar	-	20.0 g
g. Distilled Water	-	1000 ml
h. pH	-	7.0

INFLUENCE OF NEW PLANTING GEOMETRY- PAIRED ROW PLANTING ON INCIDENCE OF DISEASES IN RICE

By

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(2020-11-100)

ABSTRACT OF THE THESIS

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Abstract

ABSTRACT

Rice is the most important food crop in the world and the staple food of more than half of the world's population including India. However, the productivity of rice in Kerala is comparatively lower than other states. There is a requirement to develop technologies that can increase the yield from the limited land resources. Paired row planting is a modified planting geometry developed at the Regional Agricultural Research Station, Pattambi which utilizes the border effect to enhance yield of rice and this method is getting wide acceptance among the farmers. The intensity and spread of diseases are greatly influenced by plant density, spacing and associated microclimatic conditions. In this context, the present study was undertaken to assess the incidence of diseases in new planting geometry, paired row planting.

A field experiment was conducted at the Regional Agricultural Research Station, Pattambi over two seasons (*rabi* 2021 and *kharif* 2022). The experiment was laid out in randomized block design with three treatments and seven replications using the rice variety, Jyothi. The treatments were paired row planting (35-15 cm × 10 cm), normal transplanting (15 cm × 10 cm) and direct sowing.

Disease incidence and severity were recorded at ten days interval from the first notice of the symptom in the field. During the *rabi* season, the diseases observed were bacterial blight, sheath blight, brown spot and false smut. In the *kharif* season, in addition to these diseases, sheath rot was also observed. The incidence and severity of diseases were significantly lower in paired row planting compared to normal transplanting and direct sowing. The highest disease incidence and severity were noticed in direct sowing. In addition to diseases, pest damage was also recorded at every ten days interval. Infestation of case worm, leaf folder, yellow stem borer and rice bug were noticed in the field. The damage due to the infestation of major pests, leaf folder, yellow stem borer and rice bug was significantly lower in paired row planting when compared to the other two systems. Like disease incidence, pest incidence was also significantly higher in direct sowing, followed by normal transplanting. The difference in planting geometry, plant population and associated microclimate can be considered as the contributing factors responsible for the difference in diseases and pests incidence.

When the micrometeorological parameters *viz*., relative humidity and canopy temperature were considered, it became evident that relative humidity was significantly lower in paired row planting compared to normal transplanting and direct sowing. The canopy temperature recorded in paired row planting was higher than the other two systems. This might have added to its advantage in managing pest and disease incidence. On the other hand, the significantly higher relative humidity and lower canopy temperature observed in normal transplanting and direct sowing might have acted as the contributing factor for the higher pest and disease incidence.

The influence of planting geometry on the rhizosphere microflora was analyzed using serial dilution and plating technique. However, a significant difference between the systems was not observed. The uniformity maintained with respect to soil properties, nutrient and water management and variety used might be the reason behind this observation.

The biometric parameters *viz.* number of tillers, number of leaves, plant height and leaf area were recorded at every ten days interval. The results showed that the number of tillers in paired row planting was significantly higher followed by direct sowing and normal transplanting. Yield and yield attributes *viz.*, number of hills per metre square, number of panicles per hill, number of grains per panicle and number of chaffy grains per panicle and thousand grain weight were also recorded. The number of panicles per hill and grain yield recorded in paired row planting was significantly higher than other two systems. The wider spacing in paired row planting might have reduced the plant competition for resources and resulted in better growth and development of plants that led to profused tillering and improved yield. The reduction in pest and disease incidence might have also contributed significantly to the yield advantage.

The study also implies that the alterations in planting geometry can have a significant influence on pest and disease incidence. From the results, we could infer that in addition to the yield advantage, paired row planting also contributes significantly towards disease and pest management and therefore it can be considered as a promising planting geometry over the existing systems.