PERFORMANCE EVALUATION OF DRIP IRRIGATION IN PADDY CULTIVATION

BY

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TAVANUR- 679573, MALAPPURAM

KERALA, INDIA

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PROJECT REPORT

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KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND FOOD TECHNOLOGY

TAVANUR- 679573, MALAPPURAM, KERALA, INDIA

2025

DECLARATION

We hereby declare that this project entitled **"PERFORMANCE EVALUATION OF DRIP IRRIGATION IN PADDY CULTIVATION"** is a Bonafide record of project work done by us during the course of study and that the report has not previously formed the basis for the award to us of any degree, diploma, associateship, fellowship or other similar title of another university or society.

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Dedicated to Climate Resilient Agriculture

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SYMBOLS AND ABBREVIATIONS

WUE	:	Water use efficiency
DI	:	Drip irrigation
CF	:	Conventional flooding
T1	:	Treatment 1
T2	:	Treatment 2
T3	:	Treatment 3
HP	:	Horsepower
GHG	:	Greenhouse gas
CH_4	:	Methane
CO_2	:	Carbon dioxide
N_2O	:	Nitrous oxide
IPCC	:	Intergovernmental panel on climate change
FAO	:	Food and agriculture organization
PVC	:	Polyvinyl chloride
HDPE	:	High-density polyethylene
lph	:	Litres per hour
DAT	:	Days after transplantation
IQR	:	Interquartile range
B:C Ratio	:	Benefit-cost ratio
MOP	:	Muriate of potash
NPK	:	Nitrogen-phosphorus-potassium
NUE	:	Nutrient use efficiency
AWD	:	Alternate wetting and drying
SA	:	Saturation irrigation
SP	:	Sprinkler irrigation
Eq	:	Equation
AC	:	Alternating current
PMKSY	:	Pradhan Mantri Krishi Sinchayee Yojana
PDMC	:	Per Drop More Crop
SRI	:	System of Rice Intensification

CHAPTER 1
INTRODUCTION

Water has always been a very important natural resource. One of the most important agricultural inputs is water. Despite the limited production resources, consumption needs are increasing day by day and it is getting harder to meet the demand of human beings. The world population is expected to increase by more than one-third approximately 2.3 billion people between 2009 and 2050 (FAO, 2009). In order to overcome this problem, people are looking for ways to make more production with the scarce resources. Water scarcity is a pressing global issue, especially in areas where water resources are limited and particularly in agricultural sectors where water-intensive crops like rice are cultivated and also it impacts directly or indirectly towards the global climate change by emitting greenhouse gases and contributes about 16% of the total greenhouse gas emissions in the country (Pradhanand Goswami, 2019). In the agricultural sector, livestock and rice cultivation are significant sources of methane emissions, accounting for approximately 37% and 11% of total anthropogenic methane emissions, respectively (Smith *et al*., 2008). The competition for water among agriculture, municipal needs, and environmental requirements is already significant and is expected to intensify further as the global population grows and the impacts of climate change become more pronounced. Since agriculture uses from 70 to 90% of the developed water supply, it will be the first source exploited to meet the competing demands for water (Postel, 1999). It is important to remember that nearly 40% of the world food supply comes from irrigated agriculture and there will be additional pressure in the future to meet increased food demands (Postel, 1999). To meet the twin challenges of conserving water and increasing the food supply, irrigated agriculture will have to improve water productivity, e.g. “more crop per drop” (Ayars *et al.,*2015).

Rice is the staple food crop of Kerala, but Kerala has always experienced rice shortages. During 1960–1961, the peak period for rice production, the shortage of rice was 40.12% of the total demand and this increased to 83.45% in 2009–2010 (Karunakaran, 2014). Since the 1980s rice cultivation in Kerala has been in steady decline, from 8,500,000 hectares in 1980–1981 to 1,980,000 hectares in 2017 (GoK,2017). The traditional rice growing areas in Kerala, Palakkad and Alappuzha, have, experienced 49.93% and 56.97% declines in the areas cultivated for rice between 1960–1961 and 2009–2010 (Karunakaran, 2014). The Palakkad district, which is considered the rice bowl of Kerala, has lost 1,03,980 hectares of paddy fields in the last four decades (Athira & Kumar, 2016). A number of factors have been identified as contributing to this decline, including: competition from other crops, such as rubber and coconut the difficulties involved in rice cultivation, such as biotic stress caused by diseases and weeds, low levels of productivity, uneven rainfall, land degradation, ground water depletion, chemical pollution and labour shortages (Athira and Kumar, 2016; Fox, 2017; Kannan, 1998; Kannan & Pushpangadan, 1990; Kumar,2005; Mani, 2009). A study of traditional rice cultivation in the Palakkad, Malappuram and Wayanad districts, representing 47% of the total rice paddy area in Kerala (Krishnakutty *et al.*,2019).

Rice (*Oryza sativa*) is the staple food of about 50% of the global population and more so for the Asian population. The crop is also important from the global food security point of view, as it is consumed by a majority of the global poor living in Asia, more than two billion people get 60-70% of their food energy from rice and its derivatives (Tas, 2021). In the past, the rice demand in Asia and South America was met by the green revolution (Hossain *et al.*, 2003; Pingali, 2012; Samal *et al.*, 2022). Nutrition is a fundamental prerequisite for all living beings to perform essential functions like growth, development, and production. Rice is the second most consumed grain in the world. If the worldwide population growth rate continues, rice production should be increased by 50% all over the world in order to meet the demand in 2030 (FAO, 2022). Paddy, the third most-produced grain after corn (1116.34 million metric tons) and wheat (764.49 million metric tons), produced 496.40 million metric tons in 2020. Therefore, it is one of the most consumed grains and is a basic food item for many countries. 90% of the rice production in the world takes place in Asia.

The most important limiting factor in rice cultivation is the supply and management of irrigation water. Traditional rice farming practices, such as flood irrigation, have significant environmental consequences, including high water usage, methane emissions, and soil degradation (Linquist *et al.*, 2015). According to the Intergovernmental Panel on Climate Change (IPCC), greenhouse gases such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) are major contributors to global warming (IPCC,2021). The concentration of GHGs such as methane (CH_4), carbon dioxide (CO_2), and nitrous oxide (N_2O) has been increased by 150%, 40%, and 20%, respectively, since the pre-industrial time. The energy sector accounts for approximately 73% of global CO_2 emissions, with transportation contributing around 14%, and agriculture and land use making up about 18% of total emissions, with significant methane and nitrous oxide contributions (IPCC, 2021). The GWP of rice crop is 467 and 169% higher compared to that of wheat and maize, respectively (Linquist *et al*., 2012). In rice cultivation, methane is the primary greenhouse gas emitted, with a global warming potential estimated to be about 25 times higher than that of CO_2 over a 100-year period. Methane emissions from flooded rice fields are particularly significant due to anaerobic conditions promoting methanogenesis. Additionally, paddy fields emit other greenhouse gases such as nitrous oxide (N_2O) and carbon dioxide (CO_2). Nitrous oxide emissions arise from microbial processes such as nitrification and denitrification in the soil, particularly in flooded conditions with the application of nitrogen fertilizers. Nitrous oxide has a global warming potential approximately 298 times greater than CO_2 over a 100-year period (IPCC, 1997). Although nitrous oxide concentrations are lower than methane emissions, their global warming potential is much higher, emphasizing the need to address and reduce nitrous oxide emissions. Around 30% and 11% of global agricultural CH_4 and N_2O, respectively, are emitted from rice fields (Gupta *et al*., 2021). Flood irrigation has low water use efficiency (WUE), with significant losses due to evaporation, percolation, and runoff, resulting in inefficient water use and lower productivity (Tuong *et al*., 2005). However, this method consumes a significant portion of the world's freshwater resources, leading to challenges in water-scarce regions. This method of cultivation of rice utilizes more than 30 to 45% of the world’s fresh water resources (Humphreys et al., 2010). High water and energy requirements make flood irrigation costly for farmers, particularly in water-scarce regions (Bouman *et al*., 2007).

Pressurized irrigation systems have potential to increase water productivity by providing water to match crop requirements, reducing runoff, deep drainage losses, generally keeping soil drier reducing soil evaporation and increasing the capacity to capture rainfall. Application efficiency of different surface and pressurized irrigation methods varies and depends on design, management and operation (Bardowicks *et al.*, 2006). The drip irrigation treatment had more effective tillers, more roots in topsoil, higher WUE, and greater economic benefit in rice (He, Ma, Yang, Chen, & Jia, 2013) and high yield compare with conventional flooding irrigation. Considering the conservative amount of fertilizer application, less than the amount of fertilization in normal paddy field, the yield potential of rice could be improved by increasing the amount of fertilizer as top application in drip irrigation system (Adekoya *et al*., 2014). Drip irrigation (DI) has emerged as a potential solution to address these challenges by providing precise, efficient, and controlled water delivery directly to the plant's vicinity. It minimizes runoff, improving water use efficiency (Bouman *et al*., 2002) and is gaining attention as a sustainable alternative to flood irrigation, particularly in water-scarce regions (Lamm *et al*., 2012). Drip irrigation provides substantial savings from irrigation water, fertilizer, pesticide/herbicide and labour costs as well as soil cultivation, planting, maintenance, harvesting, field rent and other costs. The most important problems in paddy production with drip irrigation are weed control and initial investment cost. Taha, 2020 reports that the drip irrigation method is beneficial in reducing or eliminating the effects of nematodes that cause significant damage to plants. In the surface drip irrigation system (DI), since the lateral pipes are located on the soil surface, they cause problems in the passage of the machines.

In light of escalating water scarcity caused by climate change, rapid urbanization, and increasing competition for water resources across sectors, there is a pressing need to identify alternative irrigation strategies that are both water-efficient and yield-effective. This promoted us to look for the performance evaluations of drip irrigation systems in paddy cultivation. Recognizing the potential in this field, the Government of India too have launched supportive schemes like the Pradhan Mantri Krishi Sinchayee Yojana (PMKSY) and its component, Per Drop More Crop (PDMC), to encourage the adoption of micro irrigation. These initiatives aim to boost water use efficiency, promote sustainable agriculture, and enhance farmers’ resilience to water-related challenges, making the topic of this study both relevant and timely. In this context this study is planning to conduct with the following main objectives:

1. To evaluate performance of drip irrigation in paddy cultivation.
2. To assess the feasibility of different drip line spacings for efficient water management in paddy cultivation.
3. To evaluate cost economics of drip irrigation system in paddy cultivation.

REVIEW OF LITERATURE

CHAPTER 2
REVIEW OF LITERATURE

Micro irrigation is an effective irrigation system, which applies water at a very slow rate, to the root system of the crop. This makes more water available to the growing plant. The adoption of micro irrigation improves the irrigation efficiency considerably over the surface irrigation and thereby reduce the wastage of water. This chapter deals with the concepts and literature available on various parameters compared between Drip and Flood irrigation from agricultural sector especially from rice cultivation.

2.1 WATER REQUIREMENT OF PADDY:

Indian farmers are using as much as 15,000 litres of water to produce one kilogram of rice when the maximum requirement is only 4,000 litres (Kanmony, 2001). Water requirement to produce one kilogram of rice is about two to three times more than the water required to produce one kilogram of other cereals such as maize or wheat. Until recently, this amount of water has been taken for granted. Now, however, the water crisis threatens the sustainability of irrigated rice ecosystems. To safeguard food security and preserve precious water resources, ways must be explored to grow rice using less water (Belder *et al*., 2002). Because of the continuous presence of ponded water, there are huge losses of water by evaporation, seepage, and percolation out of the root zone (Casteneda *et al*., 2002).

The water requirement for rice cultivation varies significantly based on factors such as soil type, irrigation practices, and climate (Bouman *et al*., 2007). For wet land preparation, water input can range from 100–150 mm when transplanting follows soaking within a few days, but can reach up to 940 mm in large-scale irrigation systems with poor water control. Once the crop is established, fields are typically kept flooded until just before harvest. Water inputs for rice cultivation are generally two to three times higher than those required for other cereals. Xue *et al*., 2007 reported an average yield of aerobic rice was 4.1 t ha^{-1} with 688 mm of total water input in 2003 and 6.0 t ha^{-1} with 705 mm of water input.

Mandal *et al*., 2019 examined that continuous submergence (farmers' practice) of conventional puddle transplanted rice consumes a large volume of water (~2000 mm) with low water productivity.

2.2 MICRO IRRIGATION IN PADDY:

Bucks and Davis (1986), later outlined several potential advantages of micro irrigation, including increased beneficial use of water, enhanced plant growth and yield, reduced salinity hazard, improved efficiency of fertilizers and chemicals, limited weed growth, decreased energy requirements, and improved cultural practices.

Westcott and Vines (1986), conducted an experiment on sprinkler irrigation of rice (Oryza sativa) in U.S. production areas, aiming to reduce water use where flood irrigation was dominant. Although this method saved water, it resulted in lower yields and increased fungicide requirements compared to flood irrigation.

Agriculture is the largest consumer of water, but the overall efficiency of the traditional flood irrigation system is only 25–40%. As a result, there is an increasing need for water conservation and improved water-use efficiency to achieve 'more crop per drop'. Micro irrigation offers a solution, as it minimizes water wastage and reduces the movement of contaminants to surface and groundwater. It allows for precise, timely delivery of water and nutrients to avoid plant stress and enhance productivity.

Alternate Wetting and Drying (AWD) irrigation began gaining attention as a method not only for conserving water but also for reducing greenhouse gas emissions. In continuously flooded rice fields, anaerobic conditions promote methane (CH_4) production. AWD introduces dry periods that disrupt methane generation. Bouman and Tuong, 2005 found AWD improved water productivity to 0.96 kg/m^3 compared to continuous flooding.

In Bangladesh, several on-farm trials demonstrated the effectiveness of AWD using perforated PVC pipes for irrigating boro rice. This method achieved a grain yield of 5.8 t/ha—about 8% higher than that of farmers using continuous ponding—and reduced water use by around 30% (Husain *et al*., 2009).

Sriphirom *et al*., 2019 evaluated AWD in different agro-climatic regions. Their study found that AWD irrigation reduced water use by up to 30% while maintaining rice yields similar to continuous flooding.

Khamarunneesa (2022), highlighted the importance of drip irrigation as a highly efficient system that delivers water uniformly and directly to the root zone at low flow rates using drippers. This technique ensures precise application of water and nutrients, optimizing their use for better crop growth.

Spanu *et al*., 2024 tested Sprinkler Irrigation (SP) for rice using low-flow-rate sprinklers or centre pivots. SP resulted in up to 70% water savings while maintaining similar yields. It also eliminated the need for soil levelling, saving time and tillage costs.

2.2.1 Moisture distribution pattern in drip irrigation system in paddy:

Thabet and Zayani (2008), conducted research into wetting patterns under trickle source irrigation in loamy sand soil in Tunisia, using two emitter discharge rates: 1.5 and 4 lph. The study observed that vertical movement of soil moisture was greater with the higher discharge rate—52.5 cm at 4 lph after 6 hours of water application—compared to 40 cm at 1.5 lph. However, after 3 hours of water application, the maximum wetted radius (30 cm) was observed with the lower discharge rate (1.5 lph), while the minimum (22 cm) occurred at the higher discharge rate (4 lph).

Aineeche *et al*., 2009 reported that as the volume of water applied increases, both the wetted width and depth also increase. Among soil types, the maximum wetted width and depth were found in sandy soil, followed by silt clay loam and loam soils, for all volumes of irrigation water applied.

Salwa *et al*., 2010 studied the wetting front in sandy and clayey soils. The vertical wetting front was 36.07% greater in sandy soil compared to clayey soil, while the horizontal wetting front was 13.08% greater in clayey soil than in sandy soil.

Nafchi *et al*., 2011 reported the shape and volume of wetted soil under trickle irrigation. The average diameter of wetted soil for clay, loam, and sandy loam soils was 49.12, 42.92, and 22.29 cm at 2 lph; 62.58, 49.08, and 40.22 cm at 4 lph; 66.50, 58.74, and 48.11 cm at 8 lph; and 71.75, 68.07, and 50.12 cm at 12 lph, respectively. The wetted soil volume was greater in fine-textured soils compared to coarse-textured ones.

Ragheb *et al*., 2011 highlighted that several factors—such as emitter discharge rate and irrigation volume—significantly influence the water distribution pattern under drip emitters. Increased discharge rate led to enhanced horizontal and vertical water movement under the same irrigation volume, especially in loamy sand soil. In contrast, a lower discharge rate favoured primarily vertical movement.

Shan *et al.*, 2011 investigated wetting patterns in overlap zones under double point sources of drip irrigation. The wetting front increased with shorter emitter spacings. At 30 cm and 40 cm emitter spacings, the average volumetric water content was 0.17, 0.15, and 0.12 cm^3/cm^3; and 0.16, 0.13, and 0.11 cm^3/cm^3 at 10 cm, 20 cm, and 30 cm distances from the drip line, respectively. The wetting dimensions for 10 L and 20 L irrigation volumes were 60.5 and 57 cm, and 60.4 and 61 cm, in the horizontal and vertical directions, respectively. The study recommended shorter emitter spacing to enhance the wetted area and improve water use efficiency.

Parthasarathi *et al.*, 2013 conducted a field study to assess the effect of varying lateral spacings (0.6 m, 0.8 m, and 1.0 m) and dripper discharge rates (0.6 and 1.0 lph) on rice performance. The results indicated that a lateral spacing of 0.8 m coupled with 1.0 lph emitters provided optimal moisture distribution, leading to improved physiological traits and higher grain yield.

Huang *et al.*, 2015 examined the effect of emitter spacing in drip-irrigated sugarcane. At a spacing of 30 cm, the wetted depth was 33.5 cm, while it was 31.5 cm at 40 cm spacing. The study recommended a 30 cm emitter spacing with a 1.38 lph discharge rate for sugarcane in latosols.

Aiswarya *et al.*, 2024 reported on soil moisture content estimation using gravimetric methods and mapped the values using "Surfer 15" software. After 2 hours of irrigation, the highest moisture content was found near the emitter. At a 10 cm depth, moisture at 30 cm horizontal distance was higher than at 20 cm due to overlapping of emitter wetting patterns. Lateral water movement was found to be greater than vertical. After 24 hours, moisture content was highest at 30 cm depth, likely due to evaporation loss at the surface and plant uptake from intermediate depths. The study on 4 lph emitters operated for 20 minutes concluded that a logarithmic model best predicts horizontal wetted radius, while a polynomial model is suited for vertical wetted depth prediction.

2.2.2 Effect of drip irrigation on water use efficiency in paddy:

Parthasarathi *et al.*, 2013 conducted a study on evaluation of drip irrigation system for water productivity and yield of rice and concluded that drip irrigation improved the water savings by 50% in aerobic rice. Irrigated water used decreased in the surface drip irrigation method (545.1 mm) compared with control irrigation method (730 mm). Irrigation water input in drip irrigated aerobic rice was 513 mm ha^{-1} (the average for two years 2013–2014) and saved 60–80% compared with that consumed under flooded conditions. Water requirements under aerobic condition were decreased by reducing water losses due to seepage, percolation, and evaporation. In addition, under drip irrigation was found to create better conditions for growth and yield of aerobic rice. Thus, it can be concluded that drip irrigation has greater water saving capacity compared with the flooding irrigation, and therefore is a better water-saving technology in areas of water scarcity (Kruzhilin *et al*., 2015).

Sarkar *et al*., 2018 conducted the field experiment at the Instructional Farm of Faculty of Agricultural Engineering, BCKV, Nadia, West Bengal during the year of 2016–17. The study was conducted with the objectives to determine the water requirements of summer rice under drip irrigation, to compare the water requirements of summer rice under drip and conventional (flooding) irrigation, and concluded that water use efficiency in the surface drip irrigation method (55.36 kg/m^3) compared with conventional irrigation method (12.40 kg/m^3). Bozkurt Çolak (2021) carried out research work of rice in surface drip systems in 2019 and 2020 in the Mediterranean Region of Turkey in comparison with conventional flooding (CF), and concluded that water saving in the year of 2019 in the surface drip irrigation method (56%) compared with conventional irrigation method and water saving in the year of 2020 in the surface drip irrigation method (66%) compared with conventional irrigation method.

Sasmita *et al*., 2022 carried research out at the Sukamandi Experimental Station, Subang, West Java in July – October 2019; this study aims to determine the performance of drip irrigation technology as compared to conventional farming, and concluded that water use efficiency in the surface drip irrigation method (45%) compared with conventional irrigation method. Sasmita *et al*., 2022 carried research out at the Sukamandi Experimental Station, Subang, West Java in July – October 2019; this study aims to determine the performance of drip irrigation technology as compared to conventional farming, and concluded that water saving in the surface drip irrigation method (45%) compared with conventional irrigation method.

2.2.3 Effect of drip irrigation on yield of paddy:

Parthasarathi *et al.*, 2013 conducted a study between February to June during summer 2012 and December to April during summer 2013 at Tamil Nadu Agricultural University, Coimbatore, India concluded that drip irrigation improved the aerobic rice yield by 29 %. Grain yield significantly increased in the surface drip irrigation method laid out at 0.8 m lateral distance and in 1.0 lph discharge rate (5169 kg/ha) compared with control irrigation method (4181 kg/ha).

Rao *et al.*, 2017 carried out research work on effects of drip irrigation system for enhancing rice (Oryza sativa) yield under system of rice intensification management at the Central Institute of Agricultural Engineering, Bhopal, concluded that grain yield significantly increased in the surface drip irrigation method with 30 cm emitter spacing (7070 kg/ha) compared with control irrigation method (3140 kg/ha).

Bozkurt Çolak (2021), carried out a research work of rice in surface drip systems in 2019 and 2020 in the Mediterranean Region of Turkey in comparison with conventional flooding (CF), concluded that grain yield in the year of 2019 in the surface drip irrigation method (7461 kg/ha) compared with conventional irrigation method (9577 kg/ha) and grain yield in the year of 2020 in the surface drip irrigation method (6557 kg/ha) compared with conventional irrigation method (8247 kg/ha).

Sasmita *et al.*, 2022 carried research out at the Sukamandi Experimental Station, Subang, West Java in July - October 2019, this study aims to determine the performance of drip irrigation technology as compared to conventional farming, concluded that grain yield in the surface drip irrigation method (4910 kg/ha) compared with conventional irrigation method (5260 kg/ha).

2.2.4 Effect of drip irrigation on paddy plant parameters:

Rao *et al.*, 2017 carried out research work on effects of drip irrigation system for enhancing rice (Oryza sativa) yield under system of rice intensification management at the Central Institute of Agricultural Engineering, Bhopal, concluded that plant height and number of tillers after 60 days of transplanting significantly increased in the surface drip irrigation method with 30 cm emitter spacing (76.45 cm and 240.75 no's respectively) compared with conventional irrigation method (73.45 cm and 217.25 no's respectively).

Bozkurt Çolak (2021), carried out a research work of rice in surface drip systems in 2019 and 2020 in the Mediterranean Region of Turkey in comparison with conventional flooding (CF), concluded that plant height and number of panicle in the year of 2019 had significantly increased in the surface drip irrigation method (90.9 cm and 275 panicle/m^2 respectively) compared with conventional irrigation method (111.3 cm and 273 panicle/m^2 respectively) and in the year of 2020 he found out the plant height and number of panicle in the surface drip irrigation method as 86.4 cm and 267 panicle/m^2 respectively and in conventional irrigation method as 96.3 cm and 310 panicle/m^2 respectively.

Sasmita *et al*., 2022 carried research out at the Sukamandi Experimental Station, Subang, West Java in July - October 2019, this study aims to determine the performance of drip irrigation technology as compared to conventional farming, concluded that number of panicle had significantly increased in the surface drip irrigation method (307 panicle/m^2) compared with conventional irrigation method (242 panicle/m^2).

2.2.5 Effect of drip irrigation on nutrient uptake and NUE in paddy:

Hussain *et al*., 1989 noticed that tillers per hill and straw yield increased with each increment of nitrogen fertilizers. Belton and Goh (1992) found that increasing urea fertigation raised exchangeable Fe and Mn but reduced exchangeable Ca and Mg due to acidification. Dahatonde (1992) reported that panicle length and number of grains per panicle increased with higher nitrogen levels up to 150 kg N/ha. Bohra and Doerfling (1993) revealed that increasing levels of potassium application improved plant height, tiller number, and shoot dry weight at flowering.

Kiittad *et al*., 1995 observed increased nutrient uptake and higher fertilizer use efficiency under drip irrigation compared to traditional methods. Hebbar et al. (2004) also reported significantly higher uptake of N, P, and K (142.1, 13.3, and 94.3 kg/ha, respectively) and higher fertilizer use efficiency (205.5 kg/kg NPK) under drip irrigation than furrow irrigation (170 kg/kg NPK), attributed to better moisture and nutrient availability throughout the crop growth stages.

Singh and Singh (2005), reported increased grain yield and yield attributes like number of productive tillers, grains per panicle, and test weight with increasing nitrogen levels up to 180 kg/ha. Tripathi and Jaishwal (2006) observed improvements in yield and its components (panicles/m², panicle weight, and test weight) with nitrogen levels up to 150 kg N/ha.

Solaimalai *et al*., 2005 stated that fertigation typically results in significantly better performance (up to 90%) in nutrient use efficiency and plant nutrient recovery compared to other fertiliser methods. The benefits include improved fertiliser distribution in the root zone, flexibility in splitting doses based on plant uptake at different stages, and reduced nitrogen losses through leaching due to direct nutrient delivery to the root zone.

Shaymaa *et al*., 2009 observed greater NPK uptake and recovery under drip irrigation compared to furrow irrigation, highlighting the role of water delivery systems in nutrient efficiency.

Hashem (2019), conducted a field experiment in Egypt during the 2017 and 2018 summer seasons and found that using NPK 19:19:19 at 2.5 kg/ha during active tillering and panicle initiation, along with recommended fertilizer doses, significantly increased grain yield.

Khamarunneesa (2022), noted that drip irrigation enhances nutrient efficiency by maintaining soil moisture at field capacity, ensuring consistent nutrient availability throughout plant growth.

Mallick *et al*., 2023 carried out an experiment on boro rice variety "Satabdi (CR 146-7027-224)" over the 2021 and 2022 seasons. They concluded that using NPK 10:26:26 or NPK 19:19:19 in combination with recommended fertilizers during panicle initiation and grain filling stages resulted in higher grain yield.

2.2.6 Effect of drip irrigation on cost analysis in paddy:

Parthasarathi *et al*., 2013 conducted a study between February to June during summer 2012 and December to April during summer 2013 at Tamil Nadu Agricultural University, Coimbatore, India concluded that drip irrigation improved the aerobic rice yield by 29 %. Cost of cultivation, Gross return, Net return and Benefit: Cost ratio significantly increased in the surface drip irrigation method laid out at 0.8 m lateral distance and in 1.0 lph discharge rate (24,217.5 Rs/ha,67621.49 Rs/ha,43659.78 Rs/ha and 238.76) compared with control irrigation method (29845.55 Rs/ha,53380.90 Rs/ha,23535.35 Rs/ha and 152.64).

Rao *et al.*, 2017 carried out research work at the Central Institute of Agricultural Engineering, Bhopal, concluded that Annual cost of cultivation, Gross monetary return, Net monetary return and Benifit:Cost ratio significantly increased in the surface drip irrigation method with 30 cm emitter spacing (70094.41 Rs/ ha /year, 407775.49 Rs/ ha /year, 337681.08 Rs/ ha /year and 495.44) compared with conventional irrigation method (95932.13 Rs/ ha /year, 185042.41 Rs/ ha /year, 89110.29 Rs/ ha /year and 163.72).

2.3 EFFECT OF VARIOUS TREATMENTS OF DRIP IRRIGATION IN PADDY CULTIVATION:

Rao *et al.*, 2017 carried out research work at the Central Institute of Agricultural Engineering, Bhopal. He considered five treatments in the study: T1: Conventional practices with continuous flooding, T2: System of Rice Intensification (SRI) crop and water management methods, T3: SRI management with drip irrigation emitters spaced at 20 cm, T4: SRI with drip emitters spaced at 30 cm and T5: SRI with drip emitters spaced at 40 cm. Among the drip-irrigated treatments, there was no significant difference in grain yield between the T3 and T4 treatments which indicate that spacing drippers at 30 cm can be recommended as the cost of installing a drip system would be relatively cheaper with more widely-spaced drippers. The greatest average plant height was recorded with treatment T3 (76.45 cm) possibly. Similarly, the greatest number of tillers m^{-2} area was also recorded under T3 (240.75), followed by T4 (232.50) and T5 (223.50). The lowest number of tillers was recorded with T1 (217.25). T3 gave the highest number of productive tillers at maturity (264.75 m^{-2}), also the highest number of grains per panicle (161.75), longest panicle length (27.52 cm), and highest panicle weight (3.41 g). T3 gave the highest grain yield, 7.07 t/ha, while conventional practices (T1) with flood irrigation resulted in the lowest grain yield, 3.14 t/ha. Water productivity was found highest under T3 (0.90 kg/m^3) followed by T4 (0.86 kg/m^3). The lowest water productivity was recorded under T1 (0.16 kg/m^3), with no difference between T4 and T3 in terms of water productivity. The highest net return (Rs 209036.79/ha/year) and B:C (3.23) ratio can be obtained under T3, followed by T4. The lowest net return (Rs 73017.35/ha/year) and lowest Benifit: Cost (2.18) ratio was obtained with conventional practice of paddy cultivation.

MATERIALS AND METHODS

CHAPTER 3
MATERIALS AND METHODS

This chapter provides a description of the study area Materials used for the study and the methodology adopted for achieving the objectives and the methodology adopted for the study.

3.1 DETAILS OF THE STUDY AREA

The study was carried out in the Instructional Farm of KCAEFT Campus which is situated in Tavanur village of Malappuram District. The site is situated on the cross point of 10° 51'18" N latitude and 75 °59' 11" E longitude at an altitude of 8.54 m above mean sea level. Agro climatically, the area straddles the border between the northern and central zone of Kerala. The average annual rainfall varies from 2500 mm to 2900 mm. The average maximum temperature of the study area is 34.2°C and the average minimum temperature is 22.4°C. Average relative humidity and average light intensity are 71% and 30,000 lx respectively. Table 3.1 shows the description of the land selected. The overall experiment period was carried out from January 2025 to May 2025.

Table 3.1 Description of the land

Area	50 m^2
Length	10 m
Breadth	5 m
Soil type	Laterite
Soil texture	Sandy loam

Plate 3.1 Site selection

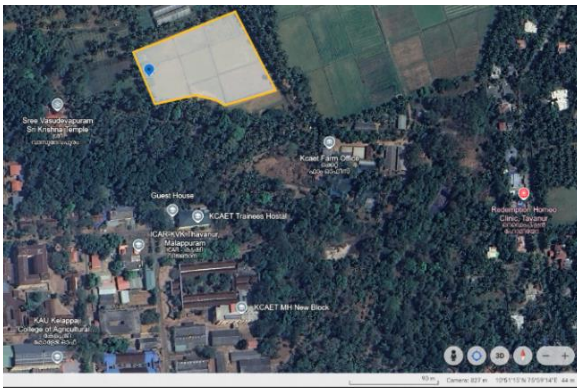

Fig. 3.1 Location of study area

3.2 SEEDLING PREPARATION

3.2.1 Rice variety

The Harsha variety which is a short to medium duration crop matures within a manageable timeframe of about 4 months (Approx. 100–110 days), which aligns perfectly with our project duration. This ensures you can complete the full crop cycle from transplanting to harvesting within our project timeline.

Plate 3.2 Seed

3.2.2 Soaking of seeds

1.5 Kg of seeds of Harsha variety were soaked in water for 8–12 hours. Water was drained and kept them in a moist jute sack for 1–2 days to sprout.

Plate 3.3 Soaking

Plate 3.4 Sprouted seed

3.3 LAND PREPARATION

3.3.1 Nursery land preparation

A suitable flat lowland area of 0.5 (5cm x 4cm) cent was selected near a water source for nursery. The land preparation was carried out by ploughing and the plot was separated by bund. The field was levelled after irrigating and made into flood condition.

Plate 3.5 Bund formation

Plate 3.6 Tilling

Plate 3.7 Levelling

Plate 3.8 Flood condition

3.3.2 Treatment land preparation

Two plots measuring 1 cent (10 m x 4 m) was demarcated and bunded for the control irrigation treatment and drip irrigation treatment. Prior to soil tillage, both plots were amended with 1 kg of lime per cent and 7 kg of cow dung per cent, as per standard agronomic practices. Subsequently, both plots were tilled using a power tiller. Control irrigated treatment was tilled under flooded conditions to simulate conventional paddy cultivation methods. In contrast, Drip irrigated treatment was tilled under moist (non-flooded) conditions suitable for drip irrigation. After tillage, drip irrigated treatment was subdivided into three raised beds, each measuring 10 m x 1 m. Finally, both plots were levelled using a manual leveller to ensure proper field gradient and water distribution.

Plate 3.9 Bund Formation

Plate 3.10 Tilling

Plate 3.11 Added Cow Dung

Plate 3.12 Added Lime

Plate 3.13 Levelling

Plate 3.14 Formed Three Bed

3.4 SOWING OF SEED

After three days of soaking the sprouted seeds were separated from the wet sack and detached from each other and was evenly spread on the wet beds by broadcasting method. The beds were kept moist (not too wet) until the seeds started to germinate. After a week, we maintained a small amount of water (2–3 cm) in the nursery.

Plate 3.15 Separating sprouted seed from jute bag

Plate 3.16 Sprouted seed

Plate 3.17 Broadcasted seed to nursery

3.5 DESIGN AND INSTALLATION OF DRIP IRRIGATION SYSTEM

3.5.1 Design of drip irrigation system

For the performance evaluation of drip irrigation in comparison with the conventional method of irrigation for paddy cultivation, two separate field setups were prepared. The conventional flooding method was carried out in a plot of 1 cent area, measuring 10 meters in length and 4 meters in width. In this setup, paddy plants were transplanted at a spacing of 15 cm between plants and 20 cm between rows. For the drip irrigation method, the field was divided into three distinct treatment plots, each measuring 10 meters in length and 1 meter in width. The first treatment (T1) included four rows of plants, each row equipped with a dedicated lateral line, with row-to-row spacing of 20 cm and plant-to-plant spacing of 15 cm. The second treatment (T2) featured a row-to-row spacing of 10 cm and a plant-to-plant spacing of 30 cm, with a lateral placed at the center of the 10 cm spaced rows. The third treatment (T3) consisted of six rows of paddy plants with a row-to-row spacing of 15 cm and plant-to-plant spacing of 15 cm, with a 35 cm buffer space between each set of rows; a single lateral line was placed centrally between the closely spaced rows. These configurations were designed to evaluate the impact of varying lateral placements and planting geometries on the performance of drip irrigation in paddy cultivation. Table 3.2 shows the various treatments.

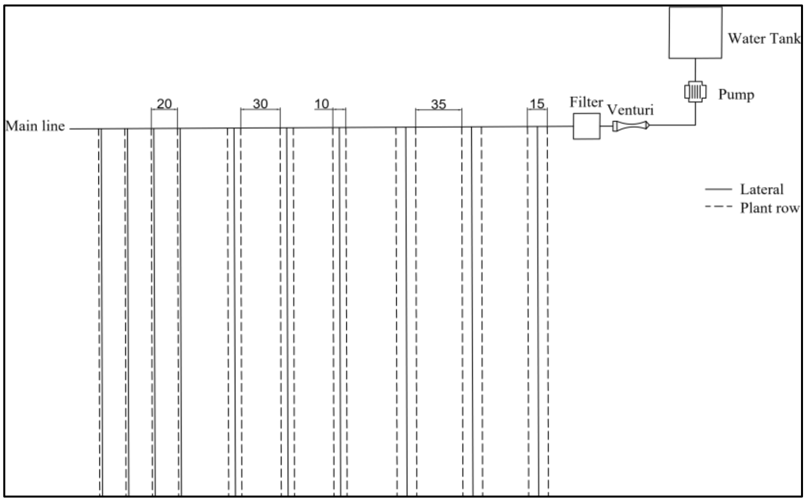

Fig. 3.2 Layout of drip irrigation system

Table 3.2 Description of treatments

TREATMENT	SPACING BETWEEN DOUBLE ROWS	ROW –ROW SPACING (cm)	PLANT – PLANT SPACING (cm)
T1 (10m x 1m)	0	20	15
T2 (10m x 1m)	30	10	15
T3 (10m x 1m)	35	15	15
Control (10m x 4m)	0	20	15

3.5.2 Components of drip irrigation system

3.5.2.1 Water source

The water required for drip irrigation was sourced from a filter point well located within the farm premises. Water from the well was pumped into a storage tank installed near the experimental plot. This intermediate storage allows for regulated supply, maintains consistent pressure in the system, and facilitates the use of filtration and fertigation units if needed. A water tank with a capacity of 1000 litres was used.

Plate 3.18 Water source

3.5.2.2 Tank

A tank of 1000 litres was installed in the field.

Plate 3.19 Tank

Plate 3.20 Tank cleaning

3.5.2.3 Pump

A 0.5 HP centrifugal AC pump is a mechanical apparatus crafted to transfer fluids by harnessing the rotational power of an alternating current (AC) motor, typically with a 0.5 horsepower capacity, and converting it into hydrodynamic force. Its fundamental components comprise an impeller, casing or volute, motor, shaft, and inlet/outlet ports. Table 3.3 shows the specifications of the pump we used.

Table 3.3 Specifications of pump

Model	MSTD
Head range	16-21 m
Capacity	12.5 mfd
Overall efficiency	20%
KW/HP	0.37/0.5
T/Head	20 m
Size	25*25
Rated discharge	1 lps
Rated speed	2880 rpm
Maximum current	4 A

Plate 3.21 Pump

3.5.2.4 Filter

A screen filter is a type of mechanical filtration system that uses a screen or mesh to filter out debris, particles, and contaminants from water. The screen acts as a barrier that captures larger particles, allowing clean water to pass through. Screen filters are commonly used in irrigation, water treatment, and industrial applications.

Plate 3.22 Screen filter **Plate 3.23 Filter cleaning**

3.5.2.5 Pressure regulator

Maintains uniform pressure throughout the system to ensure even water distribution. Installed after the filter unit, to ensure clean water enters the regulator and to avoid clogging/damage. Maintains consistent pressure output (usually 1–2 kg/cm²) to match drip emitter requirements. Protects emitters from damage due to high inlet pressure.

Plate 3.24 Pressure regulator

3.5.2.6 Fertigation System

Fertigation typically produces significantly better performance (up to 90%) than other fertiliser application methods in terms of nutrient use efficiency and plant nutrient recovery. The major benefits of fertigation are improved fertiliser distribution in the root zone, increased flexibility in splitting fertiliser doses based on plant uptake rates during its different growth stages and the ability to maintain a low (but constant) nutrient content in the soil solution. Drip fertigation had the advantages like higher water and fertilizer use efficiency, less nitrogen losses through leaching and provide nutrients directly to the root zone. The system consisted of a venturi connected to the mainline, which uses the pressure difference in the pipeline to draw and mix the fertilizer solution with irrigation water.

Plate 3.25 Fertigation system

3.5.2.7 Mainline

Carries water from the source to the sub-main or laterals; usually made of PVC or HDPE pipes. In our drip irrigation system incorporates a high-quality HDPE pipe (40 mm, Class 3, IS:4984) as the mainline/sub-main, capable of withstanding up to 6 kg/cm² pressure, ensuring reliable water distribution to the inline emitter-equipped laterals.

Plate 3.26 Mainline

3.5.2.8 Inline Laterals

Laterals are the network of small-diameter pipes in a drip irrigation system that distribute water from the mainline to emitters near plant roots. Inline laterals are specialized drip irrigation pipes with drippers pre-installed at 30 cm spacing along their length. They are typically made from UV-stabilized polyethylene and we used a lateral of 16 mm diameter.

Plate 3.27 Laterals **Plate 3.28 Emitters**

3.5.2.9 Grommet and take-off

These are used to connect the lateral to submain. A hole is punched with hand drill of predetermined size in submain. Grommet is fixed into the hole on submain. Take-off is pressed into the grommet with take-off punch up to step provided. Grommet acts as a seal. The sizes are different for 12 mm,16 mm and 20 mm lateral diameter.

Plate 3.29 Grommet **Plate 3.30 Take-off**

3.5.2.10 End Caps

End caps are used to seal the ends of drip lateral or main lines. They prevent water leakage and allow easy system maintenance. Made from UV-stabilized plastic, they are available in sizes like 12 mm, 16 mm, and 20 mm.

Plate 3.31 End cap

3.5.3 Installation

The drip irrigation system was installed. This included establishing a secure power supply connection to operate the motor and control unit, laying out the mainline and connecting lateral lines fitted with emitters for uniform water distribution. We also ensured that filters, valves, and pressure regulators were properly installed to maintain consistent flow and prevent clogging, resulting in a fully functional and well-organized irrigation setup.

Plate 3.32 Setting of tank and motor

Plate 3.33 Making holes on mainline to insert grommet

Plate 3.34 Laying of venturi, filter and mainline **Plate 3.35 Laying of laterals**

Plate 3.36 Priming **Plate 3.37 Drip laid in different treatments**

3.6 IRRIGATION SCHEDULING

The proposed irrigation schedule for the experiment involves maintaining a water depth of 5 cm in the control irrigation treatment for 30 days, with each irrigation event delivering approximately 500 liters of water. For the drip-irrigated treatments, water is applied through drip emitters for duration of 15 minutes per irrigation cycle for 83 days, with each irrigation event delivering approximately 68 liters of water. In the initial stage, following transplantation, the drip field is proposed to be irrigated on alternate days for a period of 1–2 weeks to allow the plants to establish and develop a stronger root system. This approach ensures optimal moisture availability tailored to the specific requirements of both irrigation methods.

3.7 FERTIGATION SCHEDULING

The proposed fertigation schedule for the experiment includes distinct nutrient application methods for the nursey, control and drip-irrigated treatments.

3.7.1 Nursery

To control early infestations of sucking pests such as aphids, thrips, and leafhoppers confider (Imidacloprid) was applied, which can damage tender seedlings. On the 13th day, bleaching powder was applied to the nursery water to help prevent the spread of fungal and bacterial diseases by disinfecting the water and soil surface. On the 20th day, Urea was applied as a nitrogen source to promote healthy, green growth of seedlings, ensuring they are strong and vigorous for transplanting. Along with urea, Ferterra (Chlorantraniliprole) was also applied to protect the seedlings from early-stage stem borers and other chewing pests that could affect plant establishment after transplanting also from discolouration.

Plate 3.38 Confidor application

Plate 3.39 Mixture of urea and ferterra

Plate 3.40 Application of urea and ferterra

3.7.2 Treatments

Urea was applied for prevention of uneven growth, nitrogen deficiency. MOP (Muriate of Potash) was applied to promote grain filling and strengthen the stem, factamfos was applied to promote root growth, crop quality and is considered as a good starter fertilizer for basal application in paddy fields and 19:19:19 helps in balanced nutrient supply during vegetative and reproductive phases, helps in enhancing growth and quick panicle initiation. In the control irrigation field factamfos are applied through the irrigation channel during each application. MOP (Muriate of Potash) and Urea is proposed to be applied by broadcasting. In the drip-irrigated treatments, fertilizers are applied through fertigation system. In table 3.4 the fertigation scheduling in control and treatments are given. This fertigation schedule is designed to ensure timely and efficient nutrient delivery tailored to the specific needs of the crop under both irrigation methods.

Table 3.4 Fertigation scheduling

FERTILISER	TREATMENTS	MODE OF APPLICATION	DOSE PER APPLICATION (g)
19:19:19	T1,T2,T3	4 days interval	163
Factomfos	Control	Single time	500
MOP	T1,T2,T3	4 days interval	18
	Control	20 days interval	90
Urea	T1,T2,T3	4 days interval	12
	Control	14 days interval	60

Plate 3.41 Fertilizers

Plate 3.42 Fertilizer measurement

Plate 3.43 Fertilizer application to various treatments

3.8 TRANSPLANTATION

Seedlings raised in the nursery were transplanted into the treatments after 15 days of sowing, with the assistance of farm labourers. In control irrigation, transplanting was carried out with a row-to-row spacing of 15 cm and plant-to-plant spacing of 20 cm.

In T1, T2 and T3, transplanting was done on three raised beds, each adopting a different lateral and plant spacing configuration to evaluate water distribution efficiency and plant response:

- T1: Row-to-row spacing was maintained at 15 cm, and plant-to-plant spacing was 20 cm. A drip lateral was provided for each column of plants, ensuring individual plant access to water.
- T2: Two columns of plants with 10 cm spacing between columns. After these two columns, a 30 cm gap was maintained, followed by another section of plants spaced at 10 cm apart within columns.
- T3: Two columns of plants with 15 cm spacing between columns. This was followed by a 35 cm gap, then another segment of plants spaced at 10 cm within columns.


Plate 3.44 Transplantation

Plate 3.45 Transplanted field (T1, T2, T3)

Plate 3.46 Transplanted field (Control)

3.9 WEED MANAGEMENT AND PROTECTION

In T1, T2 and T3, heavy weed growth was observed, primarily due to the moist micro-environment created along the drip lines. Although mechanical weeding tools were initially considered, manual weeding proved to be more effective in our field conditions. Manual removal allowed for precise targeting of weed-infested areas, especially around the drip lines and crop root zones, without disturbing the irrigation setup or damaging young paddy plants.


Plate 3.47 Mechanical and manual weed removal

To safeguard the paddy crop from animal interference, a protective shade net barrier was installed around the perimeter of the surface drip irrigated field and flood irrigated field in paddy cultivation.

Plate 3.48 Shade net installation

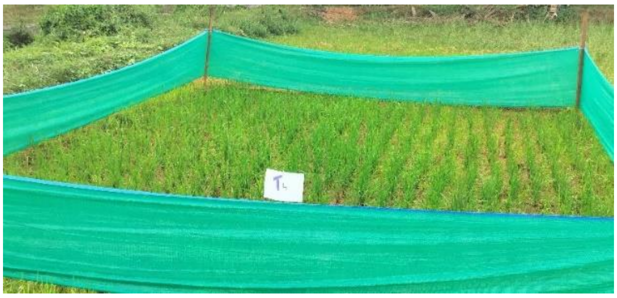

Plate 3.49 Shade net installed around control irrigation

Plate 3.50 Shade net installed around T1,T2,T3

3.10 PERFORMANCE EVALUATION OF DRIP IRRIGATION SYSTEM

3.10.1 Spatial Variation Of Soil Moisture Content

To evaluate the uniformity of soil moisture distribution, soil samples were collected from plot of T1, T2 and T3 over two consecutive days. Irrigation was applied for 15 minutes, and samples were collected 30 minutes after irrigation. The sampling locations were strategically selected to assess both vertical and lateral distribution of moisture. Soil samples were collected from the following positions relative to the emitter:

- At the surface near the emitter
- 10 cm depth from the surface
- 20 cm depth from the surface

- 7.5 cm lateral distance from the emitter
- 15 cm lateral distance from the emitter

From T1, T2 and T3, five samples were taken, resulting in a total of 15 samples.

Procedure:

1. Collection of can:

A total of 15 aluminum moisture cans were collected from the soil laboratory. The empty weight of each can (without lid) was recorded using a digital weighing balance.

Plate 3.51 Weighing of can

2. Collection of Soil Samples:

Soil was collected from the predetermined positions and placed into the respective cans. The wet weight of each can with the soil sample (without lid) was measured and recorded.

Plate 3.52 Soil sample collection

3. Oven Drying:

The cans were placed in a hot air oven and dried at 115°C for 24 hours to remove all moisture content from the samples.

Plate 3.53 Soil sample placed for drying

4. Final Weighing

After drying, the cans were removed from the oven and allowed to cool. The dry weight of each can with the dried soil sample (without lid) was measured and recorded.

Plate 3.54 Weighing of dried Soil sample

Calculation of Soil Moisture Content:

The gravimetric method was used to determine the soil moisture content using the following formula:

$$\boxed{\text{Soil Moisture Content (\%)}=\frac{Ww-Wd}{W_d}\times 100} \quad - \quad \text{Eq. 3.1}$$

Where:

W_w = Wet weight of the sample with can (g)

W_d = Dry weight of the sample with can (g)

3.10.2 Measurement of plant growth parameters

The data collection in the experiment includes periodic observation of key plant growth parameters such as plant height, number of leaves, number of tillers, and number of panicles. These parameters are to be recorded at regular intervals of 10 days after transplantation (DAT), with the first observation scheduled for March 4. From T1, T2 and T3, data is to be collected from five representative plants, and the average value for each parameter will be calculated for comparative analysis and plotting the graph. In the control irrigation, observations will be recorded from fifteen randomly selected plants, and their average values will be used for comparative analysis and for plotting graph. The graph was plotted using excel software. Also, box plot was plotted using orange software, which is a visual programming and data analysis tool and the statistical analysis was done using one way ANOVA.

Plate 3.55 Measurement of plant parameters

RESULTS AND DISCUSSION

CHAPTER 4
RESULTS AND DISCUSSION

In this study we have evaluated the performance of Drip irrigation and Flood irrigation in paddy cultivation, assessed the feasibility of different drip line spacings for efficient water management in paddy cultivation and evaluated the cost economics of drip irrigation system in paddy cultivation. In this chapter, the observations and results recorded during our study are presented and discussed under the following subheads.

4.1 INTERPRETATION OF SPATIAL VARIATION OF SOIL MOISTURE CONTENT

The data collection includes the soil sample collected at the surface near the emitter, at 10 cm depth from the surface, at 20 cm depth from the surface, at 7.5 cm lateral distance from the emitter and at 15 cm lateral distance from the emitter from different treatments (T1, T2 and T3) and the contour diagrams of soil moisture content (%) of various soil samples collected at different location were generated in Surfer software.

4.1.1 At the surface near the emitter:

The soil moisture variation at the surface near emitters was assessed for different treatments (T1, T2, T3) using contour maps generated in Surfer software (Fig 4.1). The data revealed that soil moisture content was consistently higher around the emitter zones, confirming the effectiveness of the surface drip irrigation system in delivering water precisely where it is needed. In treatment T3, moisture levels ranged from approximately 24.2% to 25.7%, while T2 showed a almost similar moisture gradient between 24.2% and 26%. T1 displayed the highest surface moisture among the treatments, ranging from 27.3% to 28.05% because of presence of four laterals in the plot. Last graph represents a cumulative representation of all three treatment, demonstrated a uniform distribution with values from 24.2% to 28.2%, further supporting the effectiveness of emitter placement and system uniformity. The moisture contours indicate minimal lateral movement of water beyond the emitter zone, emphasizing the localized wetting pattern typical of drip systems. This distribution is beneficial for minimizing weed growth between rows and reducing water losses due to evaporation and percolation, thereby enhancing overall water use efficiency in paddy cultivation under surface drip irrigation.

Kwon *et al.,* 2020 from his study published in Horticultural Science and Technology examined soil water flow pattern and observed that the moisture is concentrated near the emitter at surface (29%) and diminishes with distance.

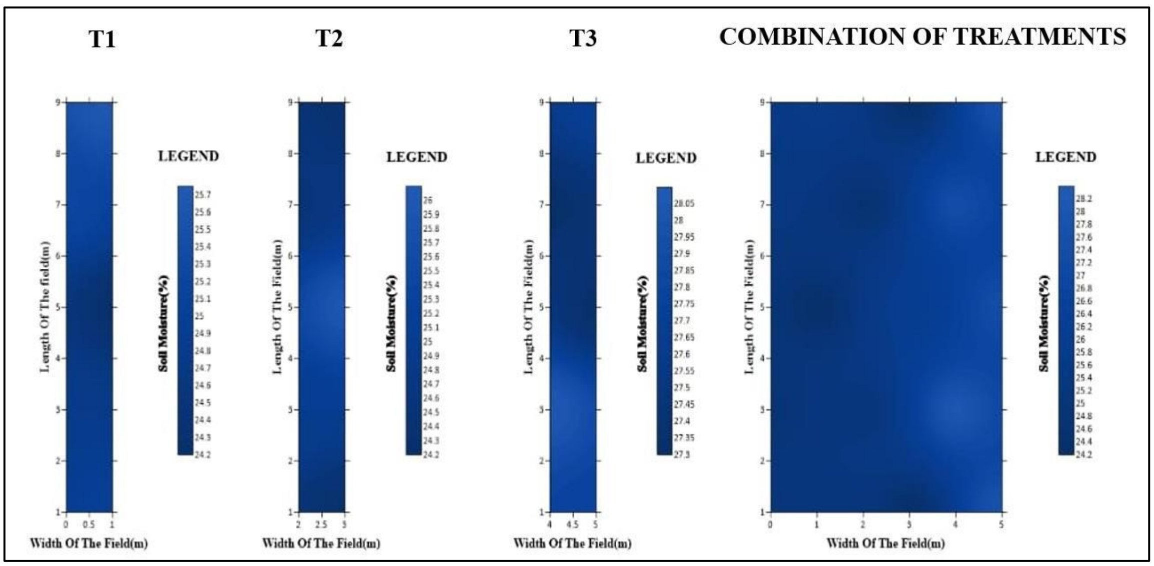

Fig. 4.1 Spatial variation of soil moisture content at the surface near the emitter generated in Surfer software

4.1.2 At 10 cm depth from the surface:

The soil moisture variation at a depth of 10 cm from the emitter was analyzed for different treatments (T1, T2, T3) using contour maps generated in Surfer software (Fig 4.2). The data shows that the moisture content decreased with depth compared to surface values. In treatment T3, the moisture content ranged from 20.0% to 21.7%, while T2 showed slightly improved moisture retention with values from 19.9% to 21.8%, indicating consistent distribution. T1 recorded the highest moisture levels among the treatments, ranging from 24.56% to 25.06% because of presence of four laterals in the plot. Last graph represents a cumulative representation of all three treatment, showed a broader moisture distribution ranging from 20.0% to 25.2%, reinforcing the system's effectiveness in maintaining adequate moisture at the root zone. The contour patterns show a well-defined moisture bulb near the emitters, confirming that the drip system successfully targets the crop root zone, minimizing losses and promoting efficient water use. This enhanced moisture availability at 10 cm depth is crucial for early root development and nutrient uptake, contributing positively to crop establishment and growth under surface drip irrigation in paddy cultivation.

Kwon *et al*., 2020 from his study published in Horticultural Science and Technology examined soil water flow pattern and observed that the moisture content at 10 cm was 21.8 %.

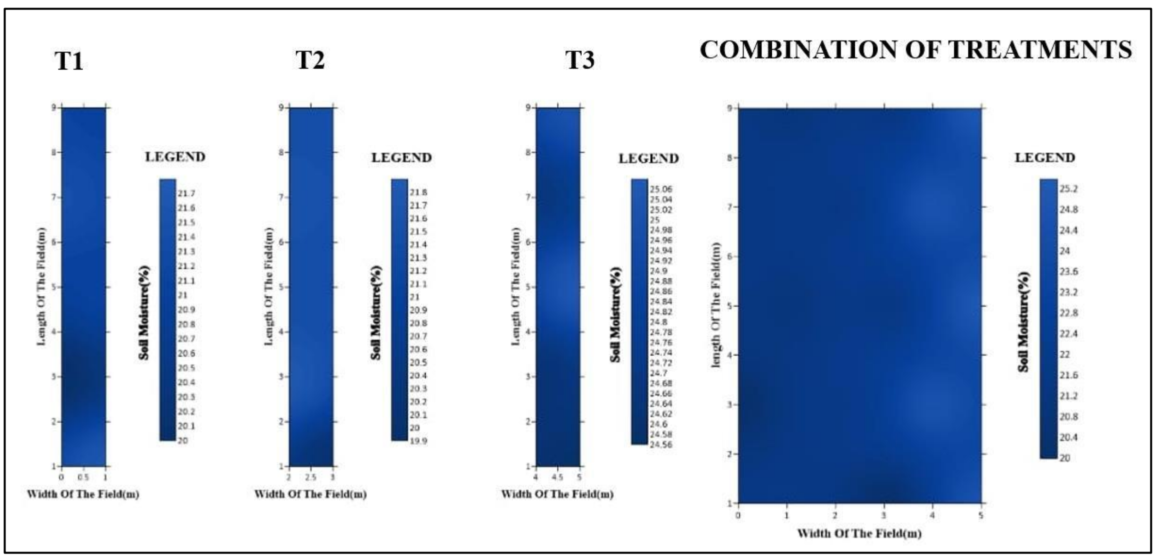

Fig. 4.2 Spatial variation of soil moisture content at 10 cm Depth from Emitters generated in Surfer software

4.1.3 At 20 cm depth from the surface:

The soil moisture variation at a depth of 10 cm from the emitter was analyzed for different treatments (T2, T3, T4) using contour maps generated in Surfer software (Fig 4.3). In T2, the moisture content ranged from 19.65% to 20.55%, indicating minimal water loss and good moisture availability at root depth. T3 showed similar moisture levels, varying between 19.8% and 20.85%, reflecting stable water distribution and limited variation across the lateral span. T4 demonstrated higher moisture retention, with values from 20.98% to 21.44%, because of presence of four laterals in the plot. Last graph represents the entire field of all three treatment, recorded moisture values ranging from 19.6% to 21.5%, further confirming uniform water distribution and adequate moisture levels in the deeper root zone. The contour patterns display smooth gradients, indicating consistent irrigation efficiency with minimal dry patches. This stable moisture profile at 20 cm depth plays a vital role in supporting root elongation, nutrient absorption, and plant anchorage, contributing significantly to the overall health and productivity of paddy under drip irrigation. The average value of vertical spatial variation of soil moisture content is given in Table 4.1.

Nisha, 2007 reported in the study of surface drip irrigation of ladies' finger in sandy loam soil, Kerala Agricultural University, Thrissur, Kerala, the moisture content at 20 cm depth was 22%. The results confirm that surface drip irrigation is not only effective at the surface and shallow depths but also ensures sufficient water availability at deeper levels, enhancing the water-use efficiency of the system.

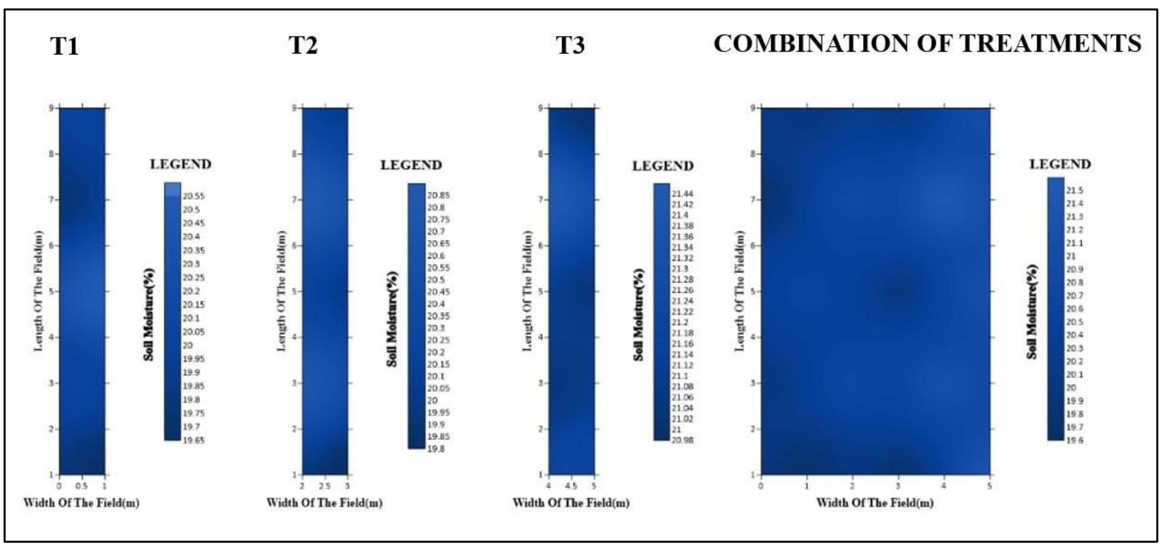

Fig. 4.3 Spatial variation of soil moisture content at Depth of 20cm from Emitters generated in Surfer software

Table 4.1 Vertical spatial variation of soil moisture content

Depth	T1	T2	T3
At surface near emitter	27.796	24.914	25.022
At 10cm depth	24.822	20.954	21.2
At 20cm depth	21.15	20.296	19.994

4.1.4 At 7.5 cm lateral distance from the emitter:

The soil moisture variation at 7.5 cm lateral distance from the emitter was analyzed for different treatments (T2, T3, T4) using contour maps generated in Surfer software (Fig 4.4). The soil moisture distribution at a lateral distance of 7.5 cm from the emitters reflects the horizontal spread of water from the drip point, which is crucial for understanding the wetting pattern and root zone coverage in surface drip irrigation for paddy. In treatment T2, the soil moisture ranged from 21.95% to 23.35%, indicating adequate lateral movement of water and suggesting good coverage for near-emitter root zones. T3 exhibited a similar range, with values between 22.56% and 23.02%, showing uniform lateral spread and minimal variability across the length of the field. In contrast, T4 demonstrated significantly higher moisture levels, ranging from 25.15% to 26.55%, because of presence of four laterals in the plot. Last graph represents the entire experimental field, showed a broader moisture range from 22.0% to 26.6%, indicating a reasonably uniform lateral spread throughout the plot. Notably, areas closer to emitters show slight increases in moisture intensity, confirming the effectiveness of the emitter spacing and discharge rate in wetting the lateral root zone adequately.

Aiswarya *et al*., 2024 conducted a study at Central Farm, AEC & RI , Kumulur, Tamil Nadu, from the study observed reduced moisture content at distances away from the emitter. The uniformity in moisture distribution at this lateral distance also implies that drip irrigation can efficiently wet the effective root zone, reducing water losses and enhancing water-use efficiency in surface drip-irrigated paddy systems.

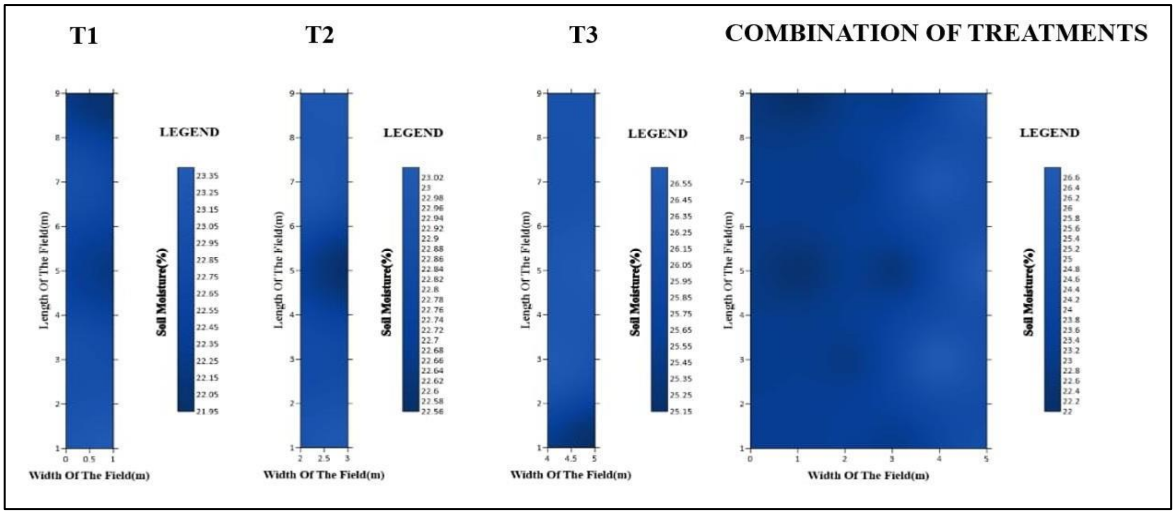

Fig. 4.4 Spatial variation of soil moisture content at 7.5cm Distance from Emitter generated in Surfer software

4.1.5 15 cm lateral distance from the emitter:

The soil moisture variation at 15 cm lateral distance from the emitter was analyzed for different treatments (T2, T3, T4) using contour maps generated in Surfer software (Fig 4.5). It offers critical insight into the horizontal wetted perimeter of the drip irrigation system and its capability to effectively cover the paddy crop root zone. In treatment T2, soil moisture ranged from 19.3% to 20.35%, showing a moderate level of water availability at this distance. The distribution appears relatively uniform but suggests slight moisture depletion compared to areas closer to the emitter. T3 had a similar pattern, with values between 19.25% and 20.55%, indicating consistent performance. Significantly higher soil moisture levels were observed in T4, ranging from 23.3% to 25.0%, because of presence of four laterals in the plot. Last graph represents the full experimental layout, soil moisture ranged from 19.2% to 24.8%, with noticeable gradients but overall sufficient moisture coverage. The average value of lateral spatial variation of soil moisture content is given in Table 4.2.

Kwon *et al*., 2020 from his study published in Horticultural Science and Technology examined soil water flow pattern and observed that the soil moisture content was highest near the emitter and decreased with horizontal distance.

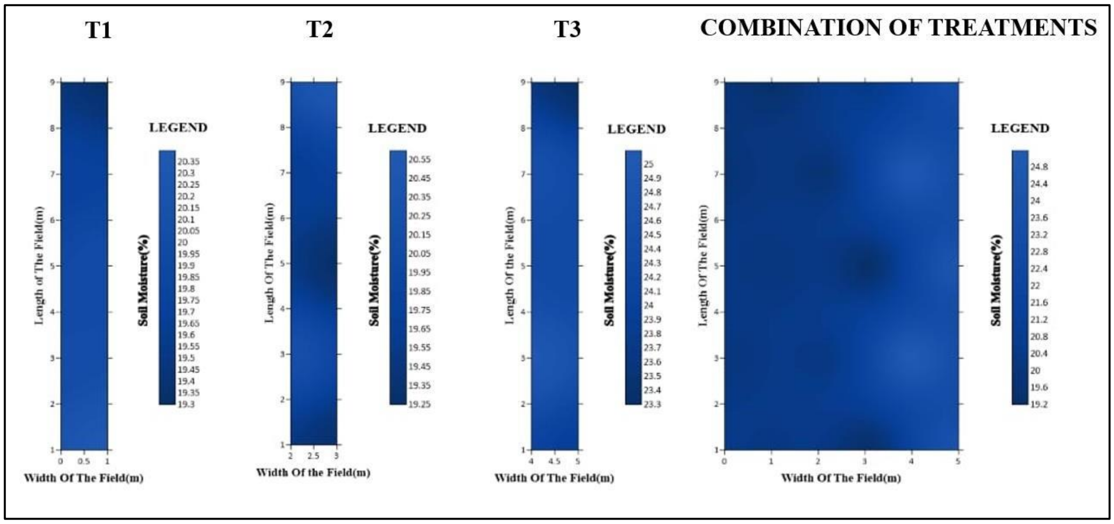

Fig. 4.5 Spatial variation of soil moisture content at 15cm distance from emitter generated in surfer software

Table 4.2 Lateral spatial variation of soil moisture content

Lateral distance	T1	T2	T3
At surface near emitter	27.796	24.914	25.022
At 7.5cm distance from emitter	26.176	22.884	22.71
At 15cm distance from emitter	24.21	19.8	19.874

4.2 PLANT GROWTH PARAMETER

The data collection includes periodic observation of key plant growth parameters such as plant height, number of leaves, number of tillers, and number of panicles. These parameters are recorded at regular intervals of 10 days after transplantation (DAT). From T1, T2 and T3 data was collected from five representative plants in each of the three treatment plots, and the average value for each parameter was calculated for comparative analysis and plotting graph. In the control irrigation, observations were recorded from 15 randomly selected plants, and their average values were used for comparative analysis and for plotting graph.

4.1.6 Graph

The average values of various plant parameters measured was used for comparative analysis and it was plotted in Excel software as shown in Fig 4.6, Fig 4.7, Fig 4.8 and Fig 4.9 shows the graph plotted. The average values are given in table 4.3, table 4.4, table 4.5 and table 4.6.

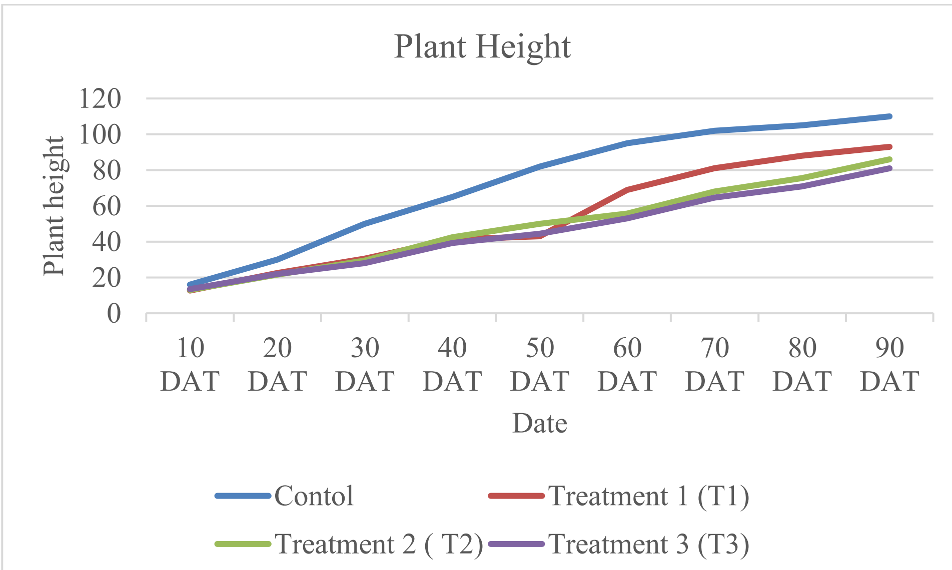

Fig. 4.6 Graph showing the variation in plant height in various treatments

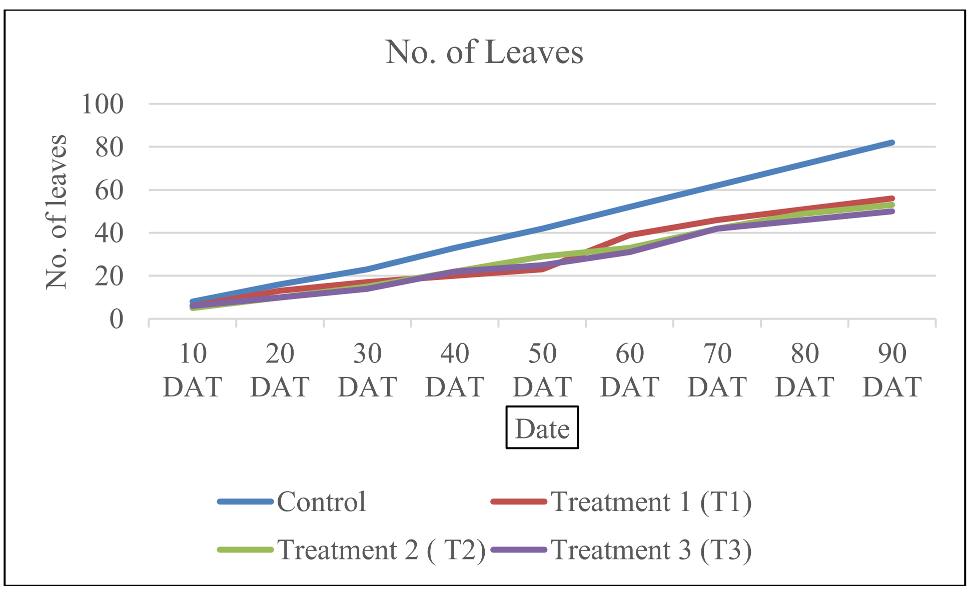

Fig. 4.7 Graph showing the variation in no. of leaves in various treatments

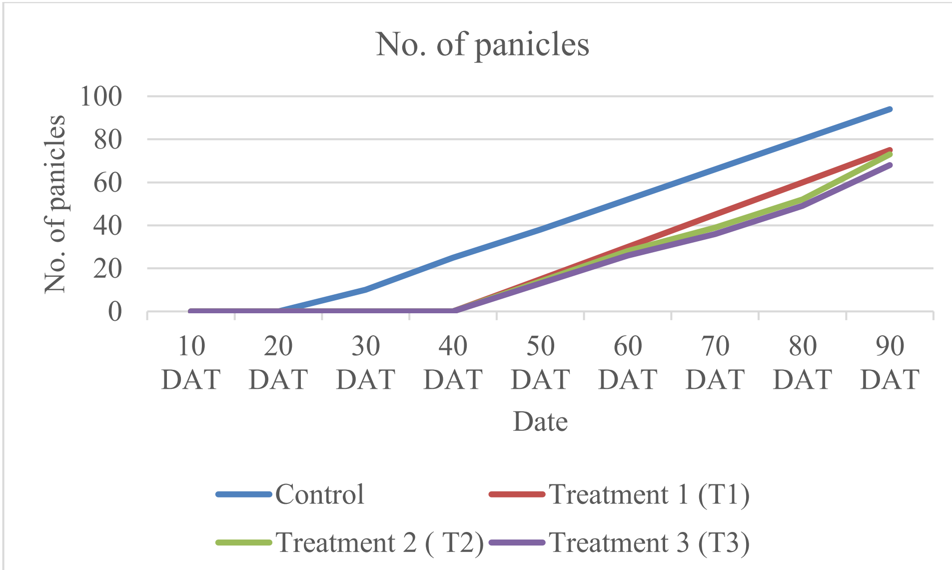

Fig. 4.8 Graph showing the variation in no. of panicles in various treatments

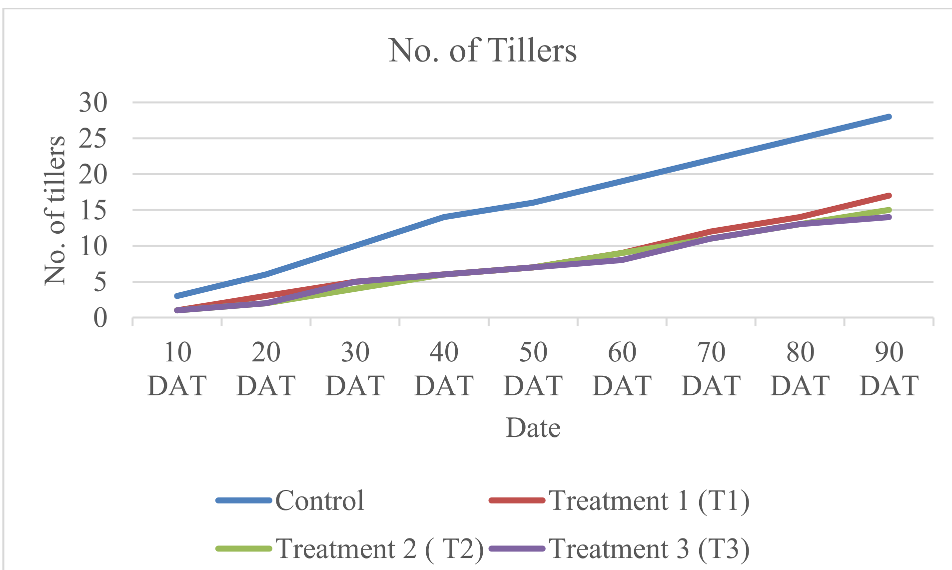

Fig. 4.9 Graph showing the variation in no. of tillers in various treatments

The results showed that rice plants grew best under Control irrigation, with taller plants, more leaves, and a higher number of panicles and tillers. By the end of the season, control irrigation plants reached over 110 cm in height and produced more than 80 leaves, 90 panicles, and around 27 tillers. Among the drip irrigation methods, T1 performed the best, coming close to control irrigation in plant growth and yield-related traits. T2 and T3 showed slightly lower growth. This means that while flooding gives the highest growth, a well-managed drip system, especially like T1, can still give good results while saving water.

Merza *et al*., 2023 found that plant height was enhanced in flood irrigation due to constant moisture availability and nutrient solubility. The study emphasized the limitations of drip irrigation in uniformly wetting the root zone in paddy fields, especially during critical growth phases.

Kumar *et al*., 2021 also observed that although surface drip irrigation could improve root length and water productivity, it could not match the overall physiological performance and yield stability provided by traditional flood irrigation in heavy clay soils.

Table 4.3 Average value of plant height in various treatments

Date	Control	T1	T2	T3
10 DAT	16	12.69	13	13.5
20 DAT	30	22.48	21.5	22
30 DAT	50	30.52	29.5	28
40 DAT	65	41.22	42.5	39.3
50 DAT	82	43	50	44.4
60 DAT	95	69	55.7	53
70 DAT	102	81	68	64.7
80 DAT	105	88	75.5	70.9
90 DAT	110	93	86	81

Table 4.4 Average value of no. of panicles in various treatments

Date	Control	T1	T2	T3
10 DAT	0	0	0	0
20 DAT	0	0	0	0
30 DAT	10	0	0	0
40 DAT	25	0	0	0
50 DAT	38	15	14	13
60 DAT	52	30	28	26
70 DAT	66	45	39	36
80 DAT	80	60	52	49
90 DAT	94	75	73	68

Table 4.5 Average value of no. of tillers in various treatments

Date	Control	T1	T2	T3
10 DAT	3	1	1	1
20 DAT	6	3	2	2
30 DAT	10	5	4	5
40 DAT	14	6	6	6
50 DAT	16	7	7	7
60 DAT	19	9	9	8
70 DAT	22	12	11	11
80 DAT	25	14	13	13
90 DAT	28	17	15	14

Table 4.6 Average value of no. of leaves in various treatments

Date	Control	T1	T2	T3
10 DAT	8	6	5	6
20 DAT	16	13	10	10
30 DAT	23	17	15	14
40 DAT	33	20	22	22
50 DAT	42	23	29	25
60 DAT	52	39	33	31
70 DAT	62	46	42	42
80 DAT	72	51	49	46
90 DAT	82	56	53	50

4.1.7 Box plots of plant growth parameters

The average values of various plant parameters measured was used for comparative analysis and for plotting the box plot using orange software and from fig 4.10 – fig 4.25 shows the graph plotted.

4.2.2.1 Plant height:

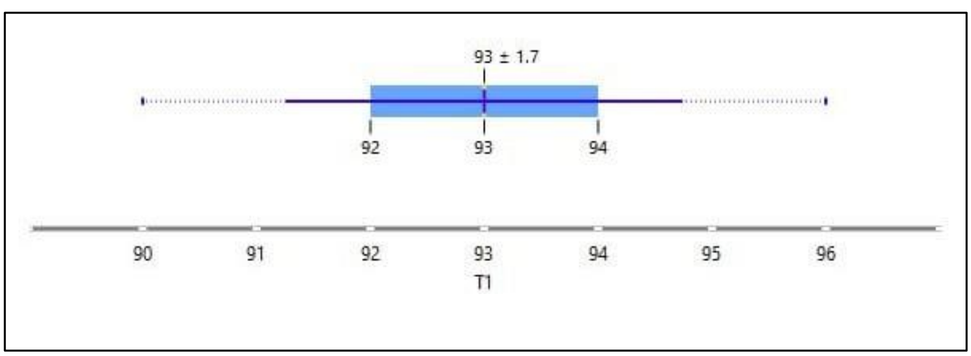

Fig. 4.10 Box plot for plant height of T1

Median=93

Inter Quartile Range (IQR)=q3-q1

=94-92=2

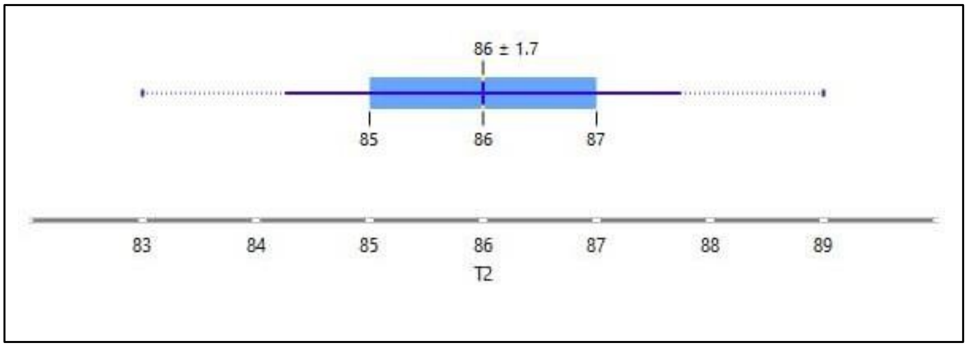

Fig. 4.11 Box plot for plant height of T2

Median=86

Inter Quartile Range (IQR)=q3-q1

=87-85=2

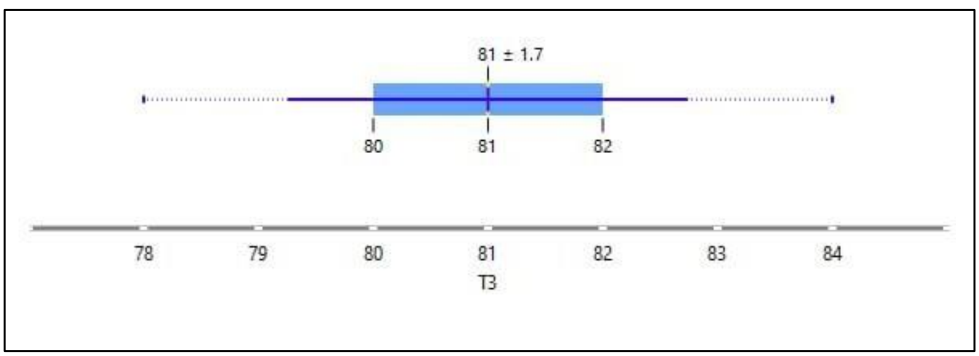

Fig. 4.12 Box plot for plant height of T3

Median=81

Inter Quartile Range (IQR)=q3-q1

=82-80=2

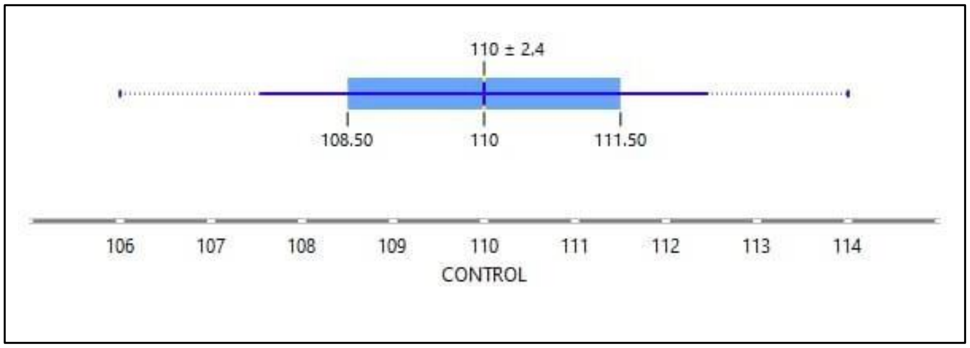

Fig. 4.13 Box plot for plant height of control

Median=110

Inter Quartile Range (IQR)=q3-q1

=111.50-108.50=3

The box plots representing plant height under different treatments (T1, T2, T3, and Control) reveal noticeable differences in growth performance. The treatment T1 showed the highest median plant height of 93 cm with an interquartile range (IQR) of 2 cm, indicating a relatively consistent performance among plants. T2 followed with a median of 86 cm and the same IQR of 2 cm. Treatment T3 recorded a slightly lower median of 81 cm, again with an IQR of 2 cm, showing uniformity but reduced height compared to T1 and T2. The Control plot had the highest variation with an IQR of 3 cm and a median of 110 cm, suggesting more diverse plant height outcomes in the absence of treatment. Overall, while the Control recorded the tallest plants, T1 displayed a balanced combination of good plant height and minimal variability, which could be indicative of more reliable growth under that treatment condition.

4.2.2.2 No. of leaves:

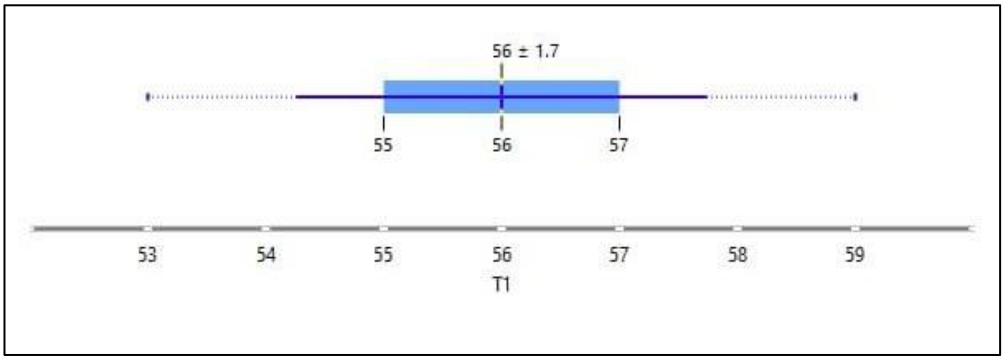

Fig. 4.14 Box plot for no. of leaves of T1

Median=56

Inter Quartile Range (IQR)=q3-q1

=57-55=2

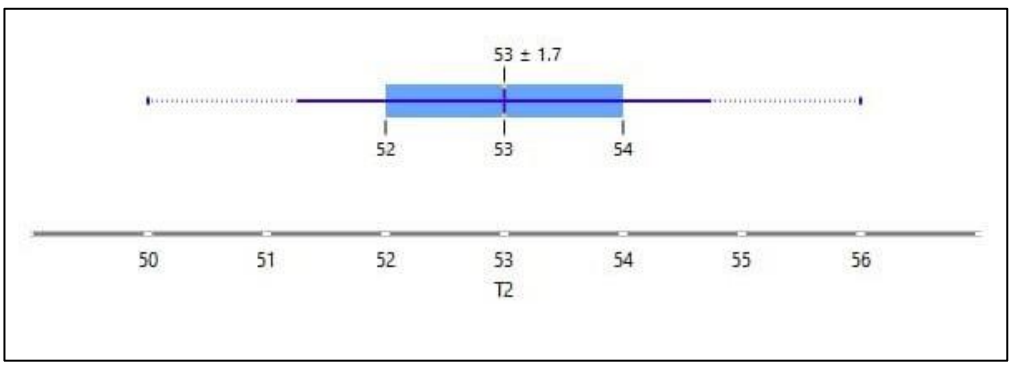

Fig. 4.15 Box plot for no. of leaves of T2

Median=53

Inter Quartile Range (IQR)=q3-q1

=54-52=2

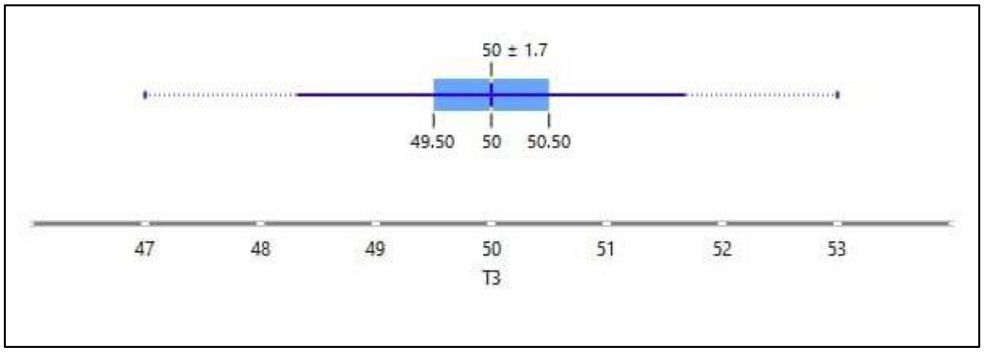

Fig. 4.16 Box plot for no. of leaves of T3

Median=50

Inter Quartile Range (IQR)=q3-q1

=50.50-49.50=1

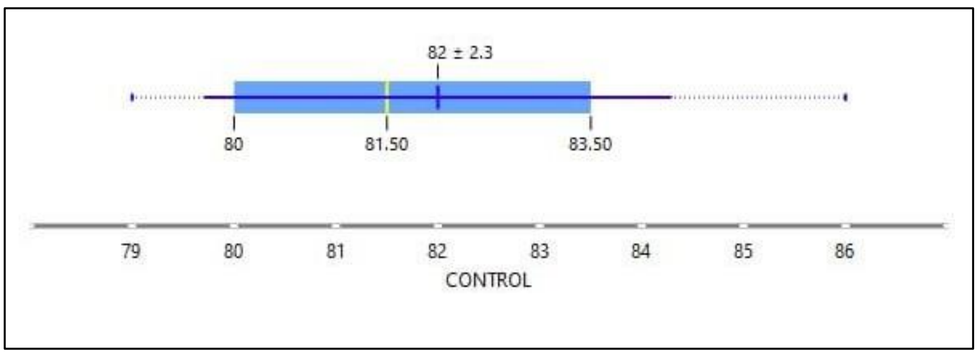

Fig. 4.17 Box plot for no. of leaves of control

Median=81.50

Inter Quartile Range (IQR)=q3-q1

=83.5-80=3.5

The box plot analysis of the number of leaves across four treatments reveals notable differences in plant performance. Treatment T1 recorded the highest median number of leaves at 56, along with a relatively narrow interquartile range (IQR) of 2, indicating both high central tendency and consistency. This was closely followed by the second treatment, which had a median of 53 and an identical IQR of 2, though slightly lower in overall performance compared to T1.The third treatment showed a further decline in leaf number, with a median of 50 and the smallest IQR of 1, signifying the most consistent but lowest performance among the treatments. Interestingly, the fourth treatment (possibly a control or reference group) also presented a median of 53 and IQR of 2, similar to T2, indicating comparable outcomes.

Overall, the data suggest that Treatment T1 is the most effective in promoting leaf growth, as evidenced by its highest median and a tightly grouped data spread. On the other hand, T3, while consistent, showed the least number of leaves, making it the least favorable option among those studied. This comparative insight helps identify the most beneficial treatment for optimal plant leaf development

4.2.2.3 No. of panicles:

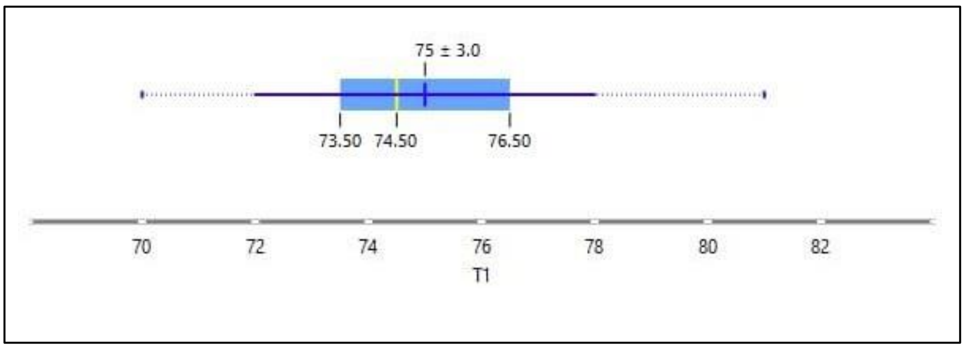

Fig. 4.18 Box plot for no. of panicles of T1

Median=74.50

Inter Quartile Range (IQR)=q3-q1

=76.50-73.50=3

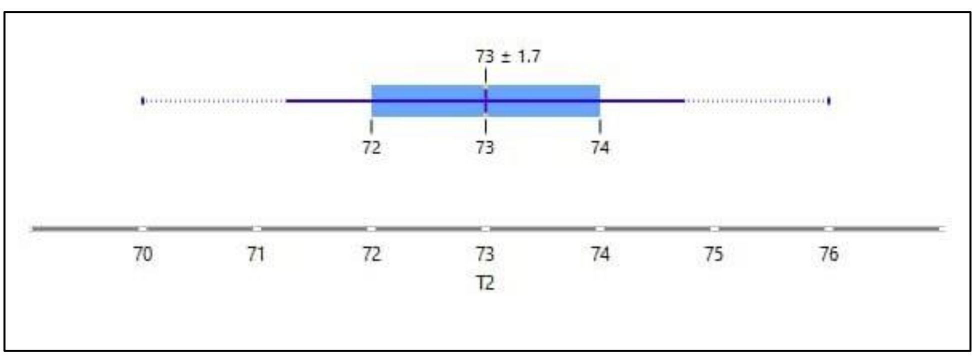

Fig. 4.19 Box plot for no. of panicles of T2

Median=73

Inter Quartile Range (IQR)=q3-q1=74-72=2

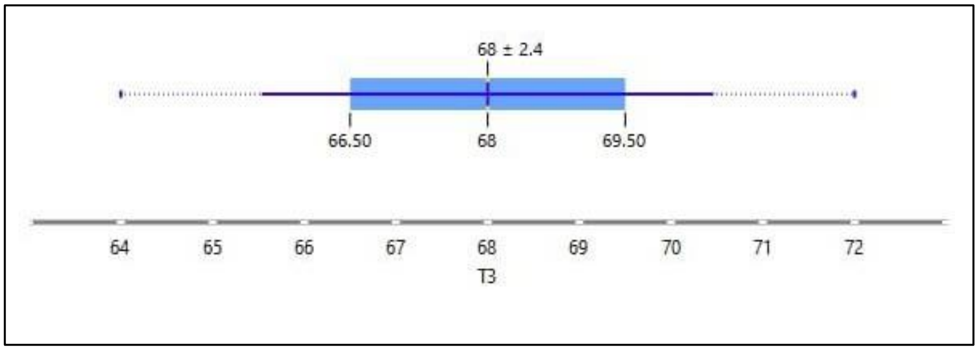

Fig. 4.20 Box plot for no. of panicles of T3

Median=68

Inter Quartile Range (IQR)=q3-q1

=69.50-66.50=3

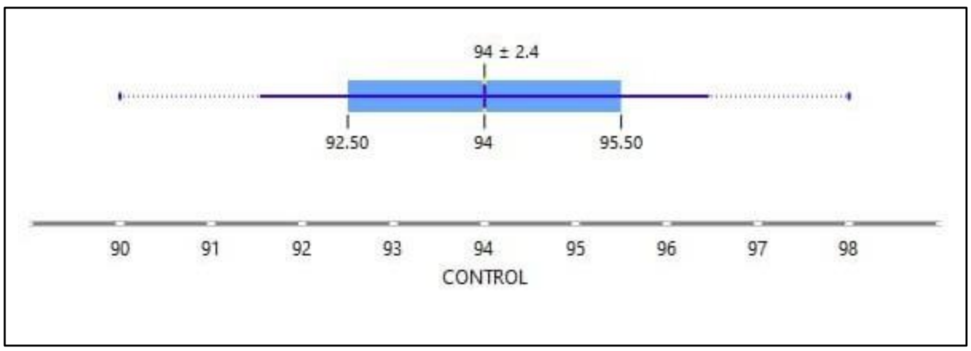

Fig. 4.21 Box plot for no. of panicles of control

Median=94

Inter Quartile Range (IQR)=q3-q1

=95.50-92.50=3

The comparison of the number of panicles across the four treatments (T1, T2, T3, and Control) reveals noticeable variation in median values and interquartile ranges (IQR). The Control group exhibited the highest median (81.5) and the widest spread (IQR = 3.5), indicating greater variability and overall performance. T1 followed with a median of 74.5 and an IQR of 3.0, suggesting relatively high and consistent panicle development. T2 showed a slightly lower median of 73 with a narrower IQR of 2.0, reflecting more uniform results but slightly reduced output. T3 had the lowest median value of 68 and an IQR of

2.0, indicating comparatively less panicle formation and moderate variability.

Overall, the Control group performed best, followed by T1, while T3 exhibited the least favorable results for this plant parameter.

4.2.2.4 No. of tillers:

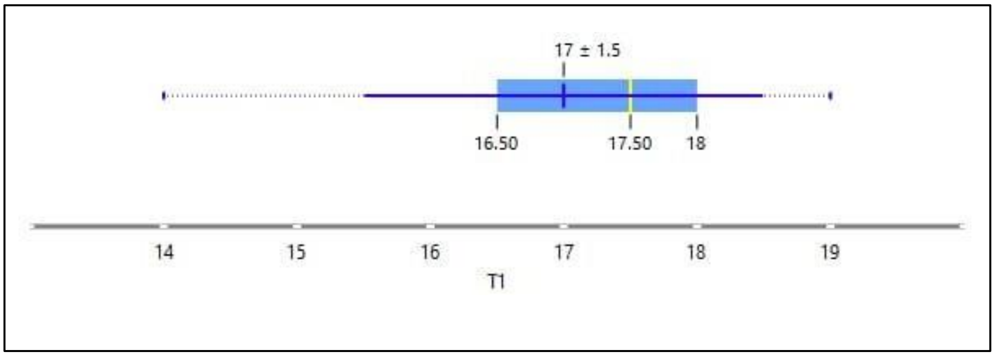

Fig. 4.22 Box plot for no. of tillers of T1

Median=17.50

Inter Quartile Range (IQR)=q3-q1

=18-16.5=1.5

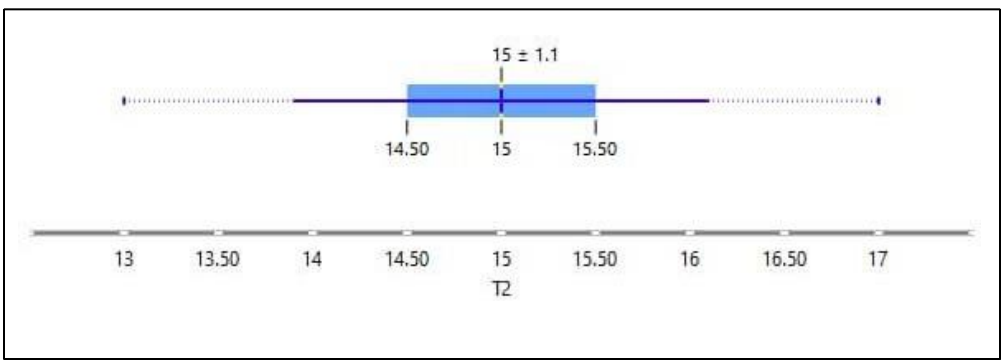

Fig. 4.23 Box plot for no. of tillers of T2

Median=15

Inter Quartile Range (IQR)=q3-q1

=15.5-14.5=1

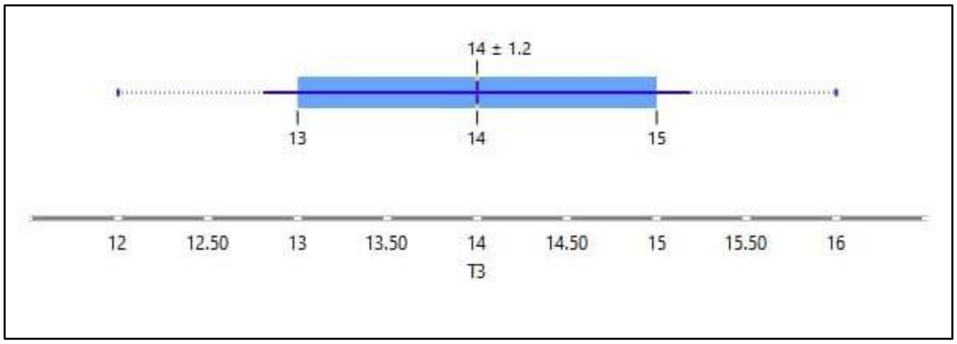

Fig. 4.24 Box plot for no. of tillers of T3

Median=14

Inter Quartile Range (IQR)=q3-q1

=15-13=2

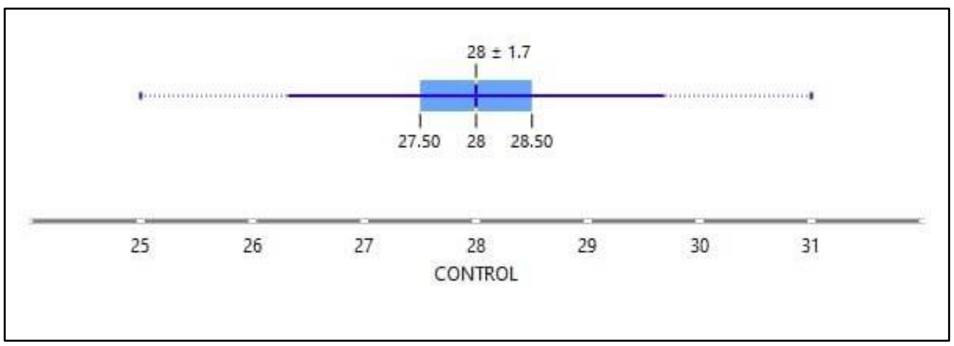

Fig. 4.25 Box plot for no. of tillers of control

Median=28

Inter Quartile Range (IQR)=q3-q1

=28.5-27.5=1

Among the four treatments, the Control (flood-irrigated plot) shows the highest median number of tillers at 28, with a narrow interquartile range (IQR) of 1, indicating consistent tiller production. T1 follows with a median of 17.5 and an IQR of 1.5, showing slightly more variation but still relatively stable performance under drip conditions. T2 records a lower median tiller count of 15 with the smallest IQR of 1, suggesting uniformity but reduced tiller formation compared to T1 and Control. T3 has the lowest median tiller number at 14 and the widest IQR of 2, indicating both reduced and more variable tiller development. Overall, the data clearly reflect that Control irrigation supports the highest and most consistent tiller production, while among the drip treatments, T1 performs better than T2 and T3.

4.1.8 Statistical analysis of plant parameters in Control, T1, T2 and T3

The plant parameters values collected from various treatments (T1, T2, T3 and control) was used for the statistical analysis using one way ANOVA and the table 4.1, table 4.2, table 4.3 and table 4.4 shows the results.

4.2.3.1 Plant height:

Table 4.7 ANOVA table on plant height in Control, T1, T2 and T3

SUMMARY						
Groups	Count	Sum	Average	Variance		
CONTROL	10	1100	110	6.666667		
T1	10	930	93	3.333333		
T2	10	860	86	3.333333		
T3	10	810	81	3.333333		
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	4810	3	1603.333	384.8	2.16E-27	2.866266
Within Groups	150	36	4.166667			
Total	4960	39				

With the F-value (384.8) substantially higher than the critical value (2.866266) and a very low P-value (2.16E-27), it is evident that plant height significantly differs among Control, T1, T2, and T3 treatments. This confirms that the treatments had a real impact on plant height under different treatments.

Gomez, K.A., and Gomez, A.A. 1984, stated that if the F value > F-critical value and p value < 0.05, then there is significant difference between the means and if the F value < F-critical value and p value > 0.05, then there is no significant difference between the means.

4.2.3.2 No. of leaves:

Table 4.8 ANOVA table on no. of leaves in Control, T1, T2 and T3

SUMMARY						
Groups	Count	Sum	Average	Variance		
CONTROL	10	820	82	5.77778		
T1	10	560	56	3.33333		
T2	10	530	53	3.33333		
T3	10	500	50	3.11111		
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	6487.5	3	2162.5	556.071	3.39308E-30	2.86627
Within Groups	140	36	3.88889			
Total	6627.5	39				

With the F-value (556.071) substantially higher than the critical value (2.86627) and a very low P-value (3.39308E-30), it is evident that no. of leaves significantly differs among Control, T1, T2, and T3 treatments. This confirms that the treatments had a real impact on no. of leaves under drip irrigation methods.

Gomez, K.A., and Gomez, A.A, stated that if the F value > F-critical value and p value < 0.05, then there is significant difference between the means and if the F value < F-critical value and p value > 0.05, then there is no significant difference between the means.

4.2.3.3 No. of panicles:

Table 4.9 ANOVA table on no. of panicles in Control, T1, T2 and T3

SUMMARY				
Groups	Count	Sum	Average	Variance
FLOOD	10	940	94	6.66667
T1	10	750	75	10
T2	10	730	73	3.33333
T3	10	680	68	6.66667

ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	3890	3	1296.67	194.5	2.71256E-22	2.86627
Within Groups	240	36	6.66667			
Total	4130	39				

Since the F-value (194.5) is much greater than the F critical value (2.87) and the P-value (2.71256E-22) is significantly lower than 0.05, it clearly indicates that there are statistically significant differences in the number of panicles among the treatments Control, T1, T2 and T3. This means the variation observed in panicle number is not due to random chance but due to the treatments applied.

Gomez, K.A., and Gomez, A.A. 1984, stated that if the F value > F-critical value and p value < 0.05, then there is significant difference between the means and if the F value < F-critical value and p value > 0.05, then there is no significant difference between the means.

4.2.3.4 No. of tillers:

Table 4.10 ANOVA table on no. of tillers in Control, T1, T2 and T3

SUMMARY						
Groups	Count	Sum	Average	Variance		
CONTROL	10	280	28	3.11111		
T1	10	170	17	2.44444		
T2	10	150	15	1.33333		
T3	10	140	14	1.55556		
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	1250	3	416.667	197.368	2.11696E-22	2.86627
Within Groups	76	36	2.11111			
Total	1326	39				

Again, the F-value (197.368) is much higher than the F critical value (2.86627), and the P-value (2.11696E-22) is close to zero. This strongly suggests that the number of tillers varies significantly across treatments Control, T1, T2 and T3. The treatment effect on tiller production is statistically significant and not attributed to random variation.

Gomez, K.A., and Gomez, A.A. 1984, stated that if the F value > F-critical value and p value < 0.05, then there is significant difference between the means and if the F value < F-critical value and p value > 0.05, then there is no significant difference between the means.

The results showed that rice plants grew best under Control irrigation, with taller plants, more leaves, and a higher number of panicles and tillers. This variation maybe because of the difficulty in weed management, use of upland variety in lowland condition, attacks from animals, flooding of water helps in the uniform dilution of fertilizers and its availability uniformly to all plants. Among the drip irrigation methods, T1 performed the best, coming close to control irrigation in plant growth and yield- related traits. T2 and T3 showed slightly lower growth. This means that while flooding gives the highest growth, a well-managed drip system, especially like T1, can still give good results while saving water.

4.1.9 Statistical analysis of plant parameters in T1, T2 and T3

The plant parameters values collected from T1, T2 and T3 treatments was used for the statistical analysis using one way ANOVA and the table 4.5, table 4.6, table 4.7 and table 4.8 shows the results.

4.2.4.1 Plant height:

Table 4.11 ANOVA table on plant height in T1, T2 and T3

SUMMARY				
Groups	Count	Sum	Average	Variance
T1	10	930	93	3.33333
T2	10	860	86	3.33333
T3	10	810	81	3.33333

ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	726.667	2	363.333	109	1.174E-13	3.35413
Within Groups	90	27	3.33333			
Total	816.667	29				

P-value (1.17×10^{-13}) is much less than 0.05. This indicates a statistically significant difference between the mean plant heights of the different treatment groups. F (109) is much greater than F crit (3.354131). This confirms the significant difference. There is strong evidence to suggest that the various drip treatments (T1, T2, T3) have a significant effect on plant height. Looking at the summary, T1 resulted in the highest average plant height, followed by T2, and then T3.

Gomez, K.A., and Gomez, A.A. 1984, stated that if the F value > F-critical value and p value < 0.05, then there is significant difference between the means and if the F value < F-critical value and p value > 0.05, then there is no significant difference between the means.

4.2.4.2 No. of leaves:

Table 4.12 ANOVA table on no. of leaves in T1, T2 and T3

SUMMARY				
Groups	Count	Sum	Average	Variance
T1	10	560	56	3.33333
T2	10	530	53	3.33333
T3	10	500	50	3.11111

ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	180	2	90	27.6136	2.95595E-07	3.35413
Within Groups	88	27	3.25926			
Total	268	29				

P-value (2.96×10−7) is much less than 0.05. This indicates a statistically significant difference between the mean number of leaves across the treatment groups. F (27.61364) is greater than F crit (3.354131). This confirms the significant difference. There is strong evidence that the different drip treatments significantly influence the number of leaves. T1 appears to result in the highest average number of leaves, followed by T2, and then T3.

Gomez, K.A., and Gomez, A.A. 1984, stated that if the F value > F-critical value and p value < 0.05,then there is significant difference between the means and if the F value < F-critical value and p value > 0.05,then there is no significant difference between the means.

4.2.4.3 No. of panicles:

Table 4.13 ANOVA table on no. of panicles in T1, T2 and T3

SUMMARY						
Groups	Count	Sum	Average	Variance		
T1	10	750	75	10		
T2	10	730	73	3.33333		
T3	10	680	68	6.66667		
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	260	2	130	19.5	5.74867E-06	3.35413
Within Groups	180	27	6.66667			
Total	440	29				

P-value (5.75×10−6) is much less than 0.05. This indicates a statistically significant difference between the mean number of panicles among the treatment groups. F (19.5) is greater than F crit (3.354131). This confirms the significant difference. There is strong evidence that the different drip treatments have a significant impact on the number of panicles. T1 shows the highest average number of panicles, followed by T2, and then T3.

Gomez, K.A., and Gomez, A.A. 1984, stated that if the F value > F-critical value and p value < 0.05, then there is significant difference between the means and if the F value < F-critical value and p value > 0.05, then there is no significant difference between the means.

4.2.4.4 No. of tillers:

Table 4.14 ANOVA table on no. of tillers in T1, T2 and T3

SUMMARY						
Groups	Count	Sum	Average	Variance		
T1	10	170	17	2.44444		
T2	10	150	15	1.33333		
T3	10	140	14	1.55556		
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	46.6667	2	23.3333	13.125	0.0001	3.35413
Within Groups	48	27	1.77778			
Total	94.6667	29				

P-value (0.000104) is much less than 0.05. This indicates a statistically significant difference between the mean number of tillers across the different treatment groups. F (13.125) is greater than F crit (3.354131). This confirms the significant difference. There is strong evidence to suggest that the various drip treatments (T1, T2, T3) have a significant effect on the number of tillers. Similar to the previous variables, T1 appears to result in the highest average number of tillers, followed by T2, and then T3.

Gomez, K.A., and Gomez, A.A. 1984, stated that if the F value > F-critical value and p value < 0.05, then there is significant difference between the means and if the F value < F-critical value and p value > 0.05, then there is no significant difference between the means.

Among the drip irrigation treatments, T1 performed the best, coming close to control irrigation in plant growth and yield-related traits. T2 and T3 showed slightly lower growth.

This means that a well-managed drip system, especially like T1, can still give good results while saving water. This maybe because, since T1 is having 4 laterals as compared to T2 and T3, the amount of water applied is more in case of T1, also T1 has reduced weed growth as compared to T2 and T3.

4.2 YIELD OF VARIOUS TREATMENTS

The control irrigation recorded the highest yield at 926.63 kg/ha. Among the drip-irrigated treatments, T1 performed best with a yield of 728.95 kg/ha. The declining trend in yield from T1 to T3 under drip irrigation could be attributed to reduced water supply or nutrient uptake, affecting crop vigor and grain filling. Since T1 is having 4 laterals as compared to T2 and T3, the amount of water applied is more in case of T1, also T1 has reduced weed growth as compared to T2 and T3. The reduction in yield between drip and control irrigation maybe because of the difficulty in weed management, attacks from animals, flooding of water helps in the uniform dilution of fertilizers and its availability uniformly to all plants. Table 4.9 and fig 4.26 shows the yield from each treatment along with yield from control irrigation.

Fig. 4.26 Yield obtained from the treatments

Bozkurt Çolak, Y, 2021 conducted a study on comparison of aerobic rice cultivation using drip system with conventional flooding concluded that control produced significantly greater yield than both Drip. Although drip systems saved 49 –60.5% of water compared to Control, yield reductions of 15–29% (for Drip) were observed under drip irrigation compared to flood irrigation.

Table 4.15 Yield from different treatments and control

Treatment	No. of Plants	Yield (kg/cent)	Yield (kg/ha)
T1	1320	2.95	728.95
T2	1188	2.58	637.52
T3	1188	2.41	595.51
Control	1340	3.75	926.63

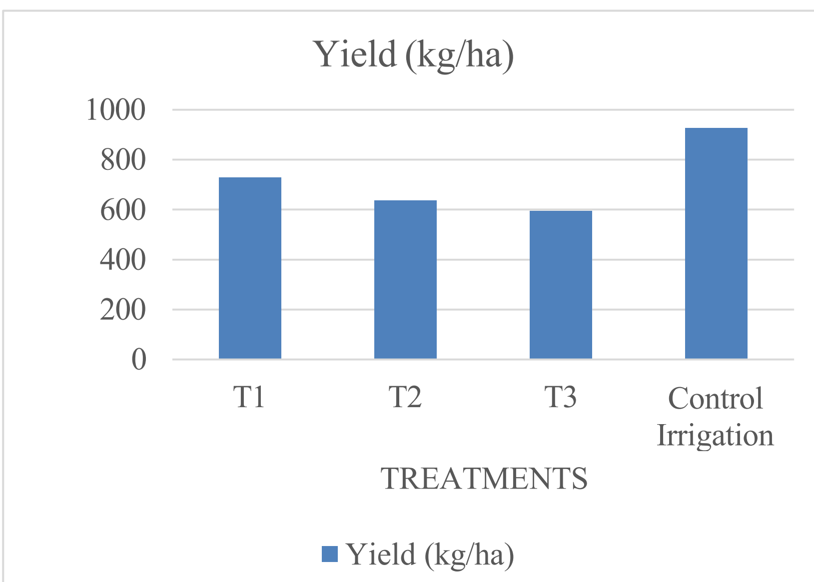

Fig. 4.27 Graph showing the variation in yield from different treatments

4.3 WATER USE EFFICIENCY

Plot Size per treatment =1 cent = 10 m × 5 m = 50 m²

Emitters of 4 LPH (litres per hour), spaced at 30 cm

Number of laterals =10 (T1+T2+T3)

Spacing between emitters = 30 cm (≈34 emitters per lateral in 10 m)

Total emitters = 10 laterals × 34 emitters = 340 emitters

Irrigation duration: 15 minutes/day (0.25 hours)

1. Drip Irrigation Water Applied

Daily Water Output from Each emitter = 4 × 0.25 = 1 litre/day

So, for 170 emitters =340 × 1 = 340 litres/day = 0.34 m³/day

Total No of irrigation days = 83 days;

Total amount of water supplied=0.34 × 83 = 28.22 m³ /cent of plot

Total amount of water supplied =28.22 × 200 = 5644 m³ /ha

[1 hectare = 10000 m²; 1 cent = 50 m²; 1 ha = 200 plots of 1 cent]

$$\textbf{Water use efficiency} = \frac{\textbf{Grain yield(kg/ha)}}{\textbf{Water applied(m}^3\textbf{/ha)}} \qquad \text{-Eq. 3.2}$$

$$= \frac{\mathbf{728.95}}{\mathbf{5644}}$$

$$\mathbf{= 0.13\ kg/m^3}$$

2. Flood Irrigation Water Applied

We maintain Flooding of 5 cm depth = 0.05 m

Water Applied for 27 minutes per irrigation cycle; and it's done once every 3 days over 90 days (≈ 30 irrigations)

Volume per irrigation = Area *Depth

= 50 * 0.05=2.5 m^3

Total volume of water =2.5 * no. of irrigation

=2.5 * 30

=75 m^3/cent

Total amount of water supplied =75 *200

= 15,000 m^3 /ha

$$\textbf{Water use efficiency} = \frac{\textbf{Grain yield(kg/ha)}}{\textbf{Water applied(m}^3\textbf{/ha)}}$$

$$= \frac{\textbf{926.63}}{\textbf{15000}} = \textbf{0.06 kg/m}^3$$

Parthasarathi *et al*., 2013 conducted a study between February to June during summer 2012 and December to April during summer 2013 at Tamil Nadu Agricultural University, Coimbatore, India concluded that drip irrigation improved the water savings by 50% in aerobic rice. Irrigated water used decreased in the surface drip irrigation method (545.1 mm) compared with control irrigation method (730 mm).

Irrigation water input in drip irrigated aerobic rice was 513mm ha^{-1} (the average for two years 2013–2014) and saved 60–80% compared with flooded conditions. Water requirements under aerobic condition were decreased by reducing water losses due to seepage, percolation, and evaporation. Under drip irrigation was found to create better conditions for growth and yield of aerobic rice. Thus, it can be concluded that drip irrigation has greater water saving capacity compared with the flooding irrigation, and therefore is a better water-saving technology in areas of water scarcity (Kruzhilin *et al.*, 2015).

Table 4.16 Cost analysis of drip irrigation

Sl. No.	Component	Quantity	Unit Cost (₹)	Total Cost (₹)
1	Inline Laterals (16 mm diameter)	150 m	16.5	2475
2	Mainline Pipe (HDPE 29.21 mm)	2 no.	250	500
4	Pump (0.5 HP AC)	1 unit	1800	1800
5	Filter (Screen type)	1 unit	250	250
6	Venturi Injector for Fertigation	1 unit	300	300
7	Pressure Regulator	1 unit	150	150
8	Grommets and Take-offs	15 sets	5	75
9	End Caps	15 units	10	150
10	Miscellaneous (Tapes, gum, etc.)	-	-	115
	Total			5815

Table 4.17 Cost analysis between drip and control irrigation

Sl. No.	Particulars	Drip Irrigation (₹)	Control Irrigation (₹)
1	Land Preparation	460	220
2	Seed Cost (1.5 kg Harsha Variety)	45	45
3	Nursery & Transplanting Labor	2000	2000
4	Irrigation Setup Materials	5815	0
5	Pump Operation (electricity)	800	1600
6	Power tiller	1200	2400
7	Fertilizers (MOP, Factamfos, 19:19:19, Urea)	285	50
8	Organic Inputs (Cow dung, Lime)	225	225
9	Plant Protection Chemicals (Ferterra, Bleaching powder, Confidor)	20	20
10	Shade Net	500	500
	Total Cost	11350	7060

Table 4.18 Cost analysis of various treatments

ITEM	COST OF TREATMENT PER HECTARE			
	CONTROL	T1	T2	T3
Fixed cost for drip (Rs./ha)	0	30,000	22,000	22,000
Cultivation cost (Rs.)	20000	10000	10000	10000
Pumping charge (Rs.)	18000	2000	2000	2000
Labour cost (Rs.)	2000	6000	8000	8000
Total cost /ha/season	48000	48,000	42000	42000
Yield Rs/ha/season	50964.65	40092.25	35063	32753.05
Straw yield Rs/ha/season	7114.72	6596.92	5894.83	5572.36
Gross return/ha/season	58079.37	46689.17	40957.83	38325.41
Net return/ha/season	10079.37	4311	3042.17	3674.59
Benefit-cost ratio	**1.2**	**1**	**0.97**	**0.91**

The cost analysis revealed that the benefit-cost ratio was highest for the control (1.2), followed by T1 (1.0), T2 (0.97), and T3 (0.91). Although the total cost per hectare was comparable or even lower for the drip treatments, the net returns and gross return were significantly lower in T1, T2, and T3. This was primarily due to reduced yield under drip irrigation, which was adversely affected by unexpected attacks during the cropping season. These biotic stresses led to a noticeable decline in productivity in the drip treatments, ultimately resulting in a lower benefit-cost ratio despite the potential input savings.

Ismail Tas,2021 in his study reported that the cost of producing one kilogram of paddy was 30 rupees under drip irrigation, compared to 37.71 rupees under flood irrigation. Additionally, water savings of 50–74.6% were achieved with drip irrigation, depending on various factors

SUMMARY AND CONCLUSION

CHAPTER 5

SUMMARY AND CONCLUSION

The project was undertaken to evaluate the performance of drip irrigation in paddy cultivation, with specific focus on its feasibility, efficiency in water usage, and economic viability. A short to medium duration paddy variety, Harsha, was selected for the experiment. The experimental design included a control irrigation and three drip irrigation treatments (T1, T2, and T3) laid out in raised beds with varying configurations of plant and lateral spacing. A comprehensive methodology was followed, starting from seed selection and nursery raising, followed by land preparation with soil amendments including lime and cow dung. The fields were tilled, bunded, and levelled accordingly under flooded conditions for the control and under moist conditions for drip-irrigated treatments.

The drip irrigation system was designed and installed with a 1000 litre tank as the water source, powered by a 0.5 HP centrifugal pump. Essential components such as screen filters, pressure regulators, mainlines (HDPE), inline laterals with emitters, and end caps were installed for effective water distribution. Fertigation was done using a venturi to deliver nutrients like Urea, MOP, and NPK formulations directly to the root zone in the drip treatments, while traditional broadcasting and channel application of Urea, MOP, Factomfose were followed in the control irrigation. Transplantation was carried out maintaining specific plant spacing for each treatment.

To assess the performance of the system, several parameters were evaluated. Soil moisture content was measured spatially at various depths (surface, 10 cm, 20 cm) and lateral distances (7.5 cm, 15 cm) from the emitters using the gravimetric method. These samples were analysed after irrigation to map wetting patterns using Surfer software. Plant growth parameters such as height, number of leaves, number of tillers, and number of panicles were recorded at regular 10 DAT. These values were averaged and graphically represented using Excel and Orange software to visualize trends and variation through line graphs and box plots. Additionally, ANOVA statistical analysis was conducted to assess the significance of differences observed between treatments. The economic aspects were also recorded and analysed to determine the viability of drip irrigation over control irrigation.

Soil moisture analysis revealed a localized wetting pattern around emitters, with the highest moisture retention observed in treatment T1 due to the presence of four laterals. T1 consistently maintained better moisture levels across all measured depths and lateral distances, ensuring adequate water availability throughout the root zone. Treatments T2 and T3 also showed satisfactory moisture distribution, though slightly less uniform compared to T1.

Plant growth observations supported the effectiveness of the drip system, especially treatment T1, which showed performance nearly comparable to the control irrigation. The control irrigation produced the highest plant height, number of leaves, panicles, and tillers. Treatments T2 and T3 followed closely with slightly reduced growth parameters. Box plots confirmed that T1 not only achieved higher median values but also exhibited low variability, suggesting consistent performance across sampled plants. The ANOVA results indicated significant differences between treatments in terms of panicle number, tiller count, and leaf production, underlining the importance of irrigation design in influencing crop performance. Economically, drip irrigation demonstrated a favourable outlook. Treatment T1 achieved higher water productivity, reduced water input, and enhanced nutrient use efficiency through fertigation. Although initial investment in drip system installation is higher, operational costs were significantly lower due to reduced labour, water, and fertilizer requirements. The benefit-cost ratio in drip treatments, especially T1, was on par with control irrigation, highlighting its potential for wider adoption in water-scarce regions. Moreover, the environmental advantages of reduced methane emissions and better nutrient management further position drip irrigation as a sustainable alternative for future paddy cultivation.

In conclusion, while control irrigation remains slightly superior in maximizing plant growth and yield, drip irrigation particularly with optimized lateral spacing as in T1 provides a viable, sustainable, and water-efficient method of rice cultivation. With government support through schemes like PMKSY and increasing pressure to conserve water and reduce emissions, transitioning to drip systems in paddy could play a pivotal role in achieving both agricultural and environmental goals.

FUTURE SCOPE OF WORK

Based on the results obtained from the various treatments under drip irrigation in paddy cultivation, Treatment T1 proved to be the most effective. It outperformed other treatments in terms of yield, water use efficiency, and overall plant health. This indicates that T1 can be recommended to farmers as a sustainable irrigation practice, especially in areas facing water scarcity.

However, it is important to consider that the present study was conducted using an upland paddy variety in a lowland field condition. This mismatch may have led to a reduction in potential yield. To better understand the treatment's actual performance, it is suggested that similar experiments be conducted in true upland conditions using appropriate upland varieties.

There were several challenges in the drip irrigation field. One of the key issues was difficulty in carrying out intercultural operations such as weeding, primarily due to the close spacing of drip laterals. Therefore, optimizing lateral spacing is essential to ensure better field access and ease of operations without disturbing the irrigation layout. Due to the concentrated wetting pattern around emitters, weed growth was localized and more difficult to control using conventional methods. In this context, mulching stands out as a highly effective complementary practice. It can suppress weed emergence by blocking sunlight, maintain soil moisture for longer periods, and regulate soil temperature, also organic mulches like rice straw, dry leaves, or biodegradable films not only support sustainable farming practices but also improve soil structure and nutrient availability over time. By incorporating mulching along with drip irrigation, farmers can reduce labour requirements for weeding and improve overall crop health. This makes the system more practical and productive, especially for small and marginal farmers. Also, since the methane emission is lower in drip irrigated treatments it contributes to global efforts in reducing greenhouse gas emission.

In summary, the study demonstrates that micro-irrigation, particularly Treatment T1, can be successfully adopted in paddy cultivation with proper field design and support practices like mulching. This integrated approach not only helps conserve water but also improves crop management, paving the way for sustainable and efficient rice farming.

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Appendix I

Spatial variation of soil moisture content at the surface near the emitter:

Sl.No.	Weight of can with wet soil (g)	Weight of can with dry soil (g)	Moisture content (%)
1	30.5	26.36	25.31
2	34	29.2	25
3	36.5	31.2	25.02
4	27.5	24.03	24.7
5	31.5	27.19	25.08
6	34	29.58	24.62
7	29.5	25.6	25.05
8	36.5	31.03	26
9	28	24.47	24.33
10	28	24.45	24.57
11	34.5	29.05	28.57
12	30.5	26.01	28
13	38	31.91	27.77
14	33	28.11	27
15	39.5	33.11	27.64

Spatial variation of soil moisture content at 10 cm Depth from emitters:

Sl.No.	Weight of can with wet soil(g)	Weight of can with dry soil(g)	Moisture content (%)
1	28.5	20.68	21.63
2	20.5	18.75	20
3	30	26.52	21.05
4	25	22.35	21.42
5	27	23.94	21.9
6	28	25	20
7	24.5	22.09	19.9
8	24.5	21.94	21.42
9	24	21.51	21.57
10	24	21.48	21.88
11	24.5	21.64	24.57
12	21.5	19.23	24.62
13	23	20.39	25.05
14	30	26.04	24.67
15	23	20.38	25.2

Spatial variation of soil moisture content at Depth of 20cm from emitters:

Sl.No.	Weight of can with wet soil(g)	Weight of can with dry soil(g)	Moisture content (%)
1	26.5	23.78	19.67
2	14.5	13.75	20
3	31	27.42	20.54
4	26	23.36	19.76
5	26.5	23.75	20
6	29	25.85	19.81
7	28.5	25.32	20.72
8	27.5	24.58	20.05
9	29.5	26.14	20.83
10	31.5	27.9	20.07
11	26.5	23.6	21.22
12	23.5	21.15	21.05
13	25.5	22.8	21.05
14	30	30.17	21.43
15	26.5	23.63	21

Spatial variation of soil moisture content at 7.5cm Distance From emitter:

Sl. No.	Weight of can with wet soil (g)	Weight of can with dry soil (g)	Moisture content (%)
1	22.3	20.03	23.33
2	23.03	21.5	23
3	24.07	22.6	22.22
4	25.9	23.09	23
5	27.08	24	22
6	28.4	25.05	23
7	29.6	26.06	22.85
8	30.04	27.8	22.57
9	32.04	28.1	23
10	33.07	29.3	23
11	35.03	30	25.16
12	36.5	31.08	26.57
13	37.05	32.8	26.57
14	39	33.04	26.25
15	40.02	34.3	26.33

Spatial variation of soil moisture content at 15cm Distance From emitter:

Sl.No.	Weight of can with wet soil(g)	Weight of can with dry soil(g)	Moisture content (%)
1	24	21.63	20.33
2	14.5	13.75	20
3	23.5	21.25	20
4	26	23.36	19.71
5	21.5	19.64	19.33
6	20	18.38	19.33
7	20.5	18.73	20.22
8	20	18.38	19.28
9	22	20.03	19.67
10	21	19.13	20.5
11	32.5	28.16	23.92
12	28.5	24.81	24.92
13	35.5	30.51	24.3
14	36	30.87	24.58
15	30.5	26.62	23.33

Data collected from Control Irrigation:

DATE	PLANT HEIGHT (cm)	NO OF TILLERS (no.)	NO OF LEAVES (no.)	NO OF PANICLES (no.)
10DAT	16	3	8	0
20DAT	30	6	16	0
30DAT	50	10	23	10
40DAT	65	14	33	25
50DAT	82	16	42	38
60DAT	95	19	52	52
70DAT	102	22	62	66
80DAT	105	25	72	80
90DAT	110	28	82	94

Data collected from Drip Irrigation (T1):

DATE	PLANT HEIGHT (cm)	NO OF TILLERS (no.)	NO OF LEAVES (no.)	NO OF PANICLES (no.)
10DAT	12.69	1	6	0
20DAT	22.48	3	13	0
30DAT	30.52	5	17	0
40DAT	41.22	6	20	0
50DAT	43	7	23	15
60DAT	69	9	39	30
70DAT	81	12	46	45
80DAT	88	14	51	60
90DAT	93	17	56	75

Data collected from Drip Irrigation (T2):

DATE	PLANT HEIGHT (cm)	NO OF TILLERS (no.)	NO OF LEAVES (no.)	NO OF PANICLES (no.)
10DAT	13	1	5	0
20DAT	21.5	2	10	0
30DAT	29.5	4	15	0
40DAT	42.5	6	22	0
50DAT	50	7	29	14
60DAT	55.7	9	33	28
70DAT	68	11	42	39
80DAT	75.5	13	49	52
90DAT	86	15	53	73

Data collected from Drip Irrigation (T3):

DATE	PLANT HEIGHT (cm)	NO OF TILLERS (no.)	NO OF LEAVES (no.)	NO OF PANICLES (no.)
10DAT	13.5	1	6	0
20DAT	22	2	10	0
30DAT	28	5	14	0
40DAT	39.3	6	22	0
50DAT	44.4	7	25	13
60DAT	53	8	31	26
70DAT	64.7	11	42	36
80DAT	70.9	13	46	49
90DAT	81	14	50	68

PERFORMANCE EVALUATION OF DRIP IRRIGATION IN PADDY CULTIVATION

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ABSTRACT

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DEPARTMENT OF IRRIGATION AND DRAINAGE ENGINEERING

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ABSTRACT

Paddy cultivation, traditionally reliant on flood irrigation, is a significant consumer of freshwater resources and a contributor to greenhouse gas emissions. With growing concerns about water scarcity, environmental sustainability, and the need for efficient agricultural practices, alternative irrigation methods such as drip irrigation have gained attention. This study evaluates the performance of drip irrigation in paddy cultivation in comparison with the conventional flood irrigation method. Three drip irrigation treatments (T1, T2, T3), each with varying lateral spacings and plant arrangements, were designed and compared with the control irrigation using flood irrigation.

Key performance indicators such as spatial variation of soil moisture content, plant growth parameters (such as plant height, number of tillers, leaves, and panicles), yield, water use efficiency, and cost economics were assessed. Soil moisture content was analysed at various depths and lateral distances using the gravimetric method and visualized through contour mapping. Results showed that soil moisture was effectively retained in the root zone under drip irrigation, with higher concentration near emitters and limited lateral movement, ensuring efficient water utilization. Among the treatments, T1 demonstrated the most promising results in terms of plant growth, showing performance closest to the control irrigation. While the control irrigation yielded the highest growth and productivity. Moreover, the cost-benefit analysis revealed that drip irrigation, although initially more expensive, becomes economically viable through savings in water.

In conclusion, the study highlights that drip irrigation, particularly when properly designed and managed, can serve as a sustainable and efficient alternative to flood irrigation in paddy cultivation. It offers a viable approach to address water scarcity, improve water productivity, and reduce environmental impact, making it a promising solution for climate-resilient agriculture.