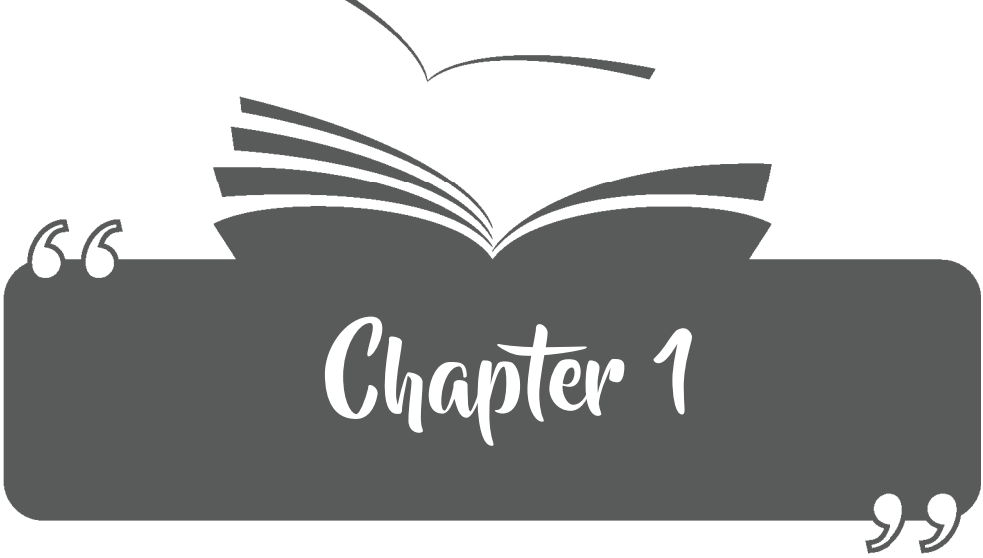


DRIP IRRIGATION IN RICE CULTIVATION: ENHANCING WATER EFFICIENCY AND CROP YIELD

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1. Introduction to Drip Irrigation and Rice Cultivation

Efficient water management is very important, especially due to drought or water scarcity in a region. On the one hand, water use efficiency (WUE) and increased water productivity per unit area must be promoted (Nkya et al., 2015). On the other hand, low-cost, effective, and sustainable methods should be selected. The studies showed that drip hose or pipe irrigation systems can potentially improve water use efficiency in agro-systems, and they can be adapted and used in greenhouse and open-field vegetable cultivation. Reported that irrigation technologies form the most adapted sustainable land management tools because irrigation may increase soil fertility with the addition of manure and or more phosphorus that may be added, which are found in irrigation water.

On the other hand, in arid regions, water scarcity has a remarkable role in crop productivity and agricultural activities. Due to the abundance of water or low-cost factors, farmers widely preferred flood or sprinkler methods instead of drip irrigation methods in their practices. However, this irrigation technology is insufficient only to increase productivity in arid and semi-arid regions. Consequently, advanced technologies should be directed to farmers. In regions where water is very scarce, the quantities applied to irrigation through these methods are limited, so crop growth is affected negatively. On the other hand, in the abovementioned regions, the future of food and feed production becomes a serious problem with the increase in the population working in the agricultural sector.

Water scarcity is a significant issue today, especially in agriculture. With growing industrialization and urbanization, cultivation is being affected severely. Modern techniques of irrigation should be practiced for an efficient use of water. Drip irrigation is one of the modern irrigation techniques that is very useful in saving water and fertilizers and reducing labor costs. Improving the existing irrigation methods or finding alternative methods that save water, power, fertilizers, and human labor is necessary. Sustainable and profitable crop production is essential for the development of agriculture as well as for meeting food requirements.

There is substantial evidence that the production of rice has declined in many parts of the world, including major rice-growing countries of Asia, due to less availability of water for irrigation and less productivity of the rice crop. To get the towering yield of rice, a copious supply of water is a pre-requisite. The availability of water for irrigation is not sufficient for the rice crop.

2. Historical Background of Drip Irrigation in Agriculture

Irrigation has a long and complex history in agricultural development (Pardossi et al., 2009). Ancient irrigation systems that include canals and embankments have been found in land terraces and other forms such as groundwater wells and artesian pressure systems. Even in terms of ductile clay pipes, ancient farmers have used a method similar to present-day drip irrigation by making clay pots of different sizes that leak holes at the roots of plants. Continuation, improvements, and modernization of this method can be seen throughout historical development in various parts of the world.

Ancient civilizations such as Mesopotamians, Persians, Egyptians, Chinese, Indians, and Romans established irrigation systems. The Persian underground canals merely affected the ground level and disappeared with the advent of modern surface water transmission systems. Similarly, pot-type underground irrigation systems were practiced by the Chinese to close the spacing of horticulture crops. Among the ancient irrigation systems, the one developed by the Indians and captured in the Arthasastra is historically rich and a scientific methodology of irrigation (Sharma et al., 2018).

Almost two billion hectares of land are currently irrigated, producing 40 % of the world's food (Pardossi et al., 2009). Rapid advances in irrigation technology have occurred in past decades, leading to the development of modern drip irrigation systems which have revolutionized the way water is delivered to crops. Throughout the 1960s and 1970s, many advances were made in crop management, including the development and improvement of center pivot and linear move irrigation systems. Additionally, the design and precision of spray heads and booms were refined, enabling an even water distribution across large areas. Design capabilities were also improved, with the incorporation of computer programs that could derive an irrigation schedule due to input variables. These monumental advances in technology, paired with a better understanding of soil, water, and crop response to irrigation, have greatly increased the efficiency of water used in agriculture. Technological advancements over the past 20 years have formed the foundation of present-day irrigation practices.

3. Importance of Water in Rice Cultivation

Water plays a vital role in agricultural productivity all over the world. Fresh water is essential for life. It is also required for various sectors such as industry, energy and agriculture for economic development. Most ancient civilizations emerged and developed in river basins where water was

abundant. For thousands of years, water has been the lifeblood of agriculture to ensure food security. The world population is expected to reach 8.5 billion by 2030, 9.7 billion by 2050 and exceed 11.2 billion by 2100. The ever-growing population will need food and water. In addition to these factors, there is a growing concern about water scarcity due to the increasing competition for shrinking freshwater resources. Globally, agriculture is the largest consumer of water and as the world population grows, the pressure to provide safe and affordable food for all in the face of decreasing water availability will increase further (H. Ali, 2018, M. Sreeman et al., 2018). Therefore, over the past few years, the scientific community has advanced the development of water management and irrigation strategies to enhance crop resilience in low-water environments.

Rice is considered one of the world's most important cereal crops due to its essential value and the area used for cultivation (Setiobudi & Sembiring, 2009). It is a staple food, providing a significant portion of the daily calories of approximately 3.5 billion people, especially in developing countries. Southeast Asia ranks first in the world with 145 million hectares of rice cultivation area.

Rice cultivation requires a significant amount of water compared to other crops. More than 80% of the fresh water resources in Asia are used for agriculture, of which about half of the total irrigation water is used for rice production (Dawe et al., 2003) .It is estimated that up to 3,000 liters of water are needed to produce 1 kg of rice(Satyanarayana et al.,2007). If water is insufficient in rice cultivation, the plant will yield lower yields due to poor root development, limited nutrient uptake, and difficulty in extracting enough water to meet the transpiration needs of the plants. Conversely, if there is too much water, the plants are expected to have limitations in their ability to transpiration as their roots cannot access sufficient oxygen, increasing the likelihood that the nutrients required for plant survival and growth will not be efficiently taken up (Setiobudi & Sembiring, 2009). Irrigation is essential for water conservation and the sustainability of agriculture with the rapid development of new irrigation technologies. Although drip irrigation, which is based on the drip delivery of water close to the root zone of plants, is widely used worldwide (Pardossi et al., 2009), it is used only in a small part of rice-growing areas. Therefore, it is necessary to develop drip irrigation technology specifically adapted to the specific conditions of rice cultivation.

4. Traditional Irrigation Methods

The replacement of traditional flood/furrow irrigation (FFI) by drip irrigation (FFI) is one of the main ways to modernize traditional irrigation

systems (Pluquellec, 2002). In the Mediterranean, traditional irrigation systems that have operated stably since ancient times include the irrigated terraced fields of Andalusia (Spain, 711–1492 CE), the Gutta of Damascus (Syria, ca. 2000 BCE), the khettara systems of Tafilalt and Ziz (Morocco, Middle Ages) or the Timimoun oases (Algeria, >1000 CE) (Barceló, 1989, Bianquis, 1989, Lightfoot, 1996, Remini et al., 2011). DI uptake is expected to increase water efficiency, crop yields and irrigation systems modernization in rural areas, ensuring its sustainability in the current context (García-Ruiz et al., 2011, Iglesias et al., 2010, Playán and Mateos, 2006, Wallace, 2000).

From a technological point of view, DI delivers a constant amount of water directly to the plant roots through line sources (emitters) established at or below the soil surface, mostly at low operating pressures (20–200 kPa) and low discharge rates (1–30 l/h) .Since DI uptake requires the removal of hydraulic infrastructure (e.g. channels, basins) and the suspension of some of the tasks associated with traditional irrigation (e.g. fertilization, leveling, ridge and channel maintenance), DI and FI are opposing systems in field applications.

Following the increase in world population, the global demand for crops has increased significantly, leading to a tremendous increase in agricultural practices associated with food production systems. In developing countries, the agricultural sector is the socio-economic sector that employs the majority of the population. Among many crops, rice is one of the most important staple foods chosen for cultivation. It is the staple food responsible for feeding almost half of the world's population, but a large portion of it is grown in a well-planned irrigated ecosystem. Cultivating rice with the following traditions requires a significant amount of water (Dattatraya Vibhute et al., 2017). Rice can be produced in both rain-fed upland and lowland rain-fed ecosystems, but most rice is produced through flood irrigation, most often through some form of irrigation system. The age-old tradition of rice cultivation practiced by many rice farmers uses surface and flood irrigation; water is applied directly to the foot of each plant or ridge on which the plant is grown. Various types of conventional irrigation practices such as Border, Furrow and Basin Irrigation Systems (e.g. Control, Wild Flood, Ridge Bed, Conventional Bed) are widely used in rice farming to achieve maximum yield. These conventional methods are old practices with some cultural backgrounds and are a vital part of local food production techniques. Direct irrigation to the plant or ridges is a centuries-old design created by farmers, which is low cost but has a very low water use efficiency gamma (γ) level ranging from 20-30%. As climate and agricultural practices have evolved, irrigation methods have also advanced, starting with basic furrow irrigation

and moving to flood type methods commonly used to apply water to the fields. Continuous flood is the most commonly used irrigation method in the world's major rice producing countries. Generally, water flows evenly along the toe of the plant ridges and is evenly distributed throughout the field. This conventional practice not only wastes time and energy, but also 30-40% of the applied water is lost through infiltration or runoff. More water left in the field for 6-10 days during the peak crop season also results in more weeds in the field. The practice requires manual labor as workers have to push water to each location along the length of the field up to 5 times per crop. Of all irrigation requirements, plant or ridge irrigation is known to be one of the weakest systems. This results in huge water losses either through runoff or direct evaporation from stagnant water at the foot of the crop ridges. This age-old irrigation process, which has been practiced for decades in many food basket areas around the world, is well known and regularly and timely applied.

5. Benefits of Drip Irrigation in Rice Cultivation

Drip irrigation in rice cultivation offers various benefits:

a) Improved water efficiency—less water is used while maintaining the same yield level;

b) Less weed growth—their growth is more restricted due to precise watering, so the amount of herbicides required is also less;

c) Better crop health—consistent moisture reduces plant stress, damp conditions decrease the severity of rice blast, and steady moisture levels result in greater grain quality with less chalkiness;

d) Money savings—as a result of the matters mentioned above, cost savings for farmers include water, herbicides, and health remedies, in addition, higher or more stable production means more revenues as well;

e) Reduced runoff due to controlled water applications-in contrast, drought events are more severe in fields with traditional irrigation;

f) Enhanced production—a number of further test results have shown that drip irrigation can increase rice yields, both the filled grain percentage and 1000-grain weight is higher, moreover, drip fertigation (along with special fertilizers that will not clog the emitters) can boost yields immensely (Setiobudi & Sembiring, 2009). At the same time, the nutrients it provides are utilized more efficiently, so leaching is significantly reduced. Furthermore, drip irrigation has been proven to promote higher rice production in areas with insufficient water resources (Manuel Gonçalves et al., 2022), and thus, this technology could help farmers weather changes

due to global warming. Besides climate change, progression in society is also a threat to food safety; population growth and the swift expansion of urban areas lead to continuous land degradation. Balancing these threats and demand for heightened production is not an easy task by any means. All in all, the real-life application of these benefits may differ, but they form a key foundation for understanding drip irrigation's influence on sustainability and production.

6. Challenges and Limitations of Drip Irrigation in Rice Cultivation

Though drip irrigation has immense potential to improve water efficiency and productivity, its implementation in rice is surrounded by numerous challenges and constraints.

a) In comparison to flooding irrigation and low lift pump sprinkler systems, the initial investment cost of drip systems is significantly higher, which is inevitable for their effective operation. This higher capital cost outlay can deter farmers from installing such systems at their farms, especially resource-poor farmers.

b) A drip system requires technical knowledge of its components and proper system installation, operation, and maintenance. Farmers without this technical know-how may feel uncomfortable using such technologies (Belder et al., 2007).

c) Emitters and filters are the basic components of a drip irrigation system. Emitters are prone to clogging due to suspended matters, which affects water discharge from the emitters. Besides emitters, clogging could also occur in filters, valves, tubes, and screens due to organic and inorganic particles present in irrigation water. Once the filters and emitters are damaged due to clogging, the cost of repairing or replacing them is not economical for resource-poor farmers.

d) Unlike the other irrigation methods, drip irrigation is a capital-intensive technology and it requires frequent maintenance throughout the irrigation season and after the harvest. An interruption in the water flow damages the crop by creating dry and wet patches within the field. Therefore, a regular inspection of on-farm devices is necessary (Nkya et al., 2015).

e) Drip irrigated water is not only sensitive to the soil and crop but it is also sensitive to climatic factors. Low humidity and high temperature in the drip irrigated field increase the evaporation loss of water.

f) Dry wind affects the uniformity of water applied to the crops by moving the droplets away from the target area. Rain with high intensity and wind speed could damage the drip irrigation system. On the other hand, high frequency and intensity rain reduces the requirement for supplementary water and affects the system's optimum scheduling.

Therefore, water for a drip system should be managed considering both crop water requirements and other agro-physical conditions of the crop-growing environment. Since the potential for expansion is high, especially in water-scarce areas, there should be more support and incentives from the government to overcome these physical and awareness-related constraints. Similarly, more research on crop suitability and emission devices is warranted areas.

Many Asian countries are experiencing a water crisis due to increasing needs for food production; water availability is now closely associated with food security. To counteract this potential water crisis, China intends to execute irrigation facility replacement and improvement in order to efficiently manage irrigation water. For sustainable management of irrigation water, one potential alternative approach for states is the drip irrigation technique instead of surface or overhead irrigation systems. Many efforts in this direction are made in various agricultural land irrigations, but freshwater rice land irrigation is a function of maintaining a water layer in which rice obfuscates air inputs. Thus, air penetration in the field is impeded.

Drip irrigation offers a positive alternative to typical rice irrigation. Drip irrigation could offer spatial and temporal management advantages compared to surface irrigation for rice. To enhance social well-being and strive to create sustainability in rice agriculture, opportunities for drip irrigation in rice cultivation were addressed. Moreover, drip irrigation has advantages in growing other crops in rotations, which could be an additional option, particularly in relatively large farms. This could be extremely vital in countries where water has been scooped up and large farms are seeking to expand the value of crops produced. However, existing limitations restricted the popularization of drip irrigation for rice cultivation. This raises a number of challenges for drip irrigation adoption on a wide scale that refers to the research interest. The challenges faced in the conversion of traditional rice cultivation techniques to modern agriculture are comprehensive. There are engineering challenges, issues of the environment, and the mindset of farmers.

7. Initial Investment Costs

Many farmers in various parts of the world, especially in Indonesia, still use manual irrigation systems - an outdated and labor-intensive method. Another issue in the field is that the water level is not equal throughout the field. The soil in the rice fields is not flat. If it is not leveled properly, some of the rice may dry out due to evaporation of water and water seeping into areas outside the field. The current traditional irrigation system uses surface irrigation, which causes high evaporation. This cultivation method will increase the amount of weeds in the rice plants. The growth of the rice plants will be inhibited due to the rise of the water and the covering of the upper part of the plant with water (Wilbourn, 2013). To overcome these difficulties, rice irrigation should be done automatically and efficiently. The initial investment cost of drip irrigation is usually high, and farmers, especially small farmers, are reluctant to adopt it. However, the focus should be on switching to a more efficient irrigation system for rice cultivation. A non-stationary economic model of the yield response factor to water input was derived and used to evaluate the net benefits of a hypothetical drip irrigation adoption strategy for a canal-based irrigation system in the Ayeyarwady Delta, Myanmar. The capital costs of the hypothetical adoption strategy included the costs of pump installation, filter installation, lateral lines, drip irrigation pipes, and unskilled labor costs for excavation and filter cleaning. More financially viable drip irrigation adoption strategies could include portable drip irrigation systems or other configurations, including non-canopy drip irrigation methods. Mobile subsidies, financing, and assistance in switching to front-panel or multiline drip irrigation by government and non-governmental organizations could accelerate the adoption of more financially viable drip irrigation adoption strategies. It is important for both farmers and stakeholders to keep in mind that investing in sustainable irrigation practices can result in beneficial long-term economic returns. The initial investment costs associated with switching from traditional flood or furrow irrigation to drip irrigation appear to be one of the largest individual risk factors for farmers that may limit adoption. When considering the ease of access to drip irrigation equipment, the cost of the kit, including the pump, filtration system, piping, and proper installation of these components, should be taken into account. In the context of a small-scale upland farming operation from the Kilimanjaro region, the cost of a complete system that can effectively irrigate 1 acre of land ranges from $1000 to $3000 (Nkya et al., 2015). Although initial investment costs can be a barrier to switching to efficient irrigation methods, it is emphasized that long-term costs are generally lower, and total profits are often greater compared to traditional methods. For example, in the Lower Rio Grande Valley in the United

States, investment in a drip irrigation system pays for itself through seed, labor, and water savings as well as increased fruit yields (Wilbourn, 2013). Given the potential for drip irrigation to significantly increase water efficiency and, generally, yields, it is critical to increase awareness of how the payback period for the systems can be achieved. In the context of net return cash flow analysis in this region, it has been shown that producers can recoup their capital investment after 5 to 10 cropping seasons. Providing access to grants or microcredit loans for those wishing to switch to drip farming can facilitate a quicker transition and buffer the high initial costs that farmers must invest in one go.

8. Drip Irrigation Adoption in Rice-Growing Regions

Drip irrigation has traditionally been associated with high value crops such as fruit, grapes and cotton. However, recent trials have shown that it can also be used in rice production - with very significant water savings. In addition, the increasing scarcity of water resources has led to long-term water use regulations in some south-east Asian countries and a shift in emphasis towards improving the efficiency of water use. A drip irrigation system placed along crop rows uses between 0.2-0.300 m^3 of water per hectare (Belder et al., 2007).

With the shift of farmers who grow rice from classical paddy cultivation to the drop irrigation system, the loss of irrigation will decrease and will be saved between 23 % and 50 % of the amount of water used in cultivation (Howell et al., 2015).

Currently, more data is needed about the rate and location of real demand for irrigation technologies that save water. The perceptions of the farmers to adopt drop irrigation vary depending on cultural and economic contexts. Because the technology is inadequate and drip irrigation request is still more expensive than the widespread irrigation system is still located. However, especially young breeders switch to drop irrigation system faster.

Like never before, fresh water has become crucial for agricultural activities around the world; facing this challenge, improving water management is no longer an alternative. Growing needs for food production due to an expanding population and increased water scarcity because of continuous pollution and global warming have posed water management as one of the most critical problems in many places on the Earth.

9. Future Prospects and Innovations in Drip Irrigation Technology

Most of the countries in the South Asian region are agriculture dependent and scarcity of irrigation water for cultivation is a common phenomenon. There is an increasing interest to adopt new crops, cultivation methods and technologies for increasing crop yield. Drip irrigation is a new technology in these countries requiring less amount of water. It is well known that almost 90% of the root zone can be exploited when water and nutrients are delivered using Drip Irrigation Systems (DIS) . Also small amount of water can be directly supplied to the root zone by Drip Irrigation Pipe (DIP). Rice is a major food crop in these countries. The aim of this research is to suggest better water distribution pattern and arrangement of DIP for maximizing crop yield in rice cultivation. Improving crop yield and decreasing consumption of water are the need of the time. In the extensive experimental work presented here, a completely new micro layout has been developed. In the developed micro layout rice cultivation performed effectively using Drip Irrigation Pipes (DIP). Conversely, results show that the functionality is lower in traditional practice.

The following emerging trends and advancements in drip irrigation technology that have the potential are promising for maximizing crop yield in cultivation and enhancing efficient use of water are reported next. The smart drip irrigation technology refers to a system that helps farmers manage their respective drip irrigation system that eventually makes the system intelligent. Various factors for making the system smart are discussed. The main emphasis is on the potential research and development of the drip irrigation technology. That highlights the research trend in smart drip irrigation. The existing and smart technologies in the detection of soil moisture for irrigation based on the use of different devices and sensors as well as automation of the control system also be presented. After the smart drip irrigation technologies, a framework or structure for the development or design of workers for smart drip irrigation and automation of in-field operations. A strong emphasis on future perspectives is made that advances would give the potential for smart drip irrigation for widespread use in different crops and cultivation practices. As such, the adaptive drip irrigation and also the irrigation scheduling method for more deeply studied to help farmers for frequent irrigation practices, increase crop yield, and improve water efficiency. Emerging trends promote the latest information to develop more advanced and efficient drip irrigation equipment and materials that can be used in the adaptiveness and scheduling while maintaining the adoption and sustainability of the practice. Furthermore, water resources situation for the cultivation is worsening and reflects on new drip irrigation practices and scheduling

is predicted to adapt to future situation against challenges, opportunities and constraints.

The 21st century is the age of technology and speed. The emerging technologies have brought a revolution in every field. Drip irrigation coupled with a device that senses the availability of moisture and automatically applies the desired amount of water at the required time is relatively new in the field of agriculture compared to the local irrigation systems which have been in use for quite a long time. Currently proposed to enhance the implication of modern drip irrigation systems, would allow recording advantages and span the range of issues related to crop growth. The modern irrigation system could be computer-controlled through special software, capable of adjusting water automatisms within the set of critical environmental conditions for the growth of crops. In the creation of modern irrigation systems, of advanced technology, a very significant role to be played by predicting the rising demand for irrigation markets, to analyze drive forces and implement an adapted perspective policy (Porras Binayao et al., 2024).

Perhaps no two words more aptly describe the state of today's agriculture and no two words are more ominous to agriculture's ability to meet the increasing demand for food and fiber, than "sustainability" and "irrigation". This is unfortunate and may well be undeserved. There are many reasons for the undeserved reputation of unsustainability when it comes to irrigation. First and foremost is the rapid rate of innovation and new technologies being incorporated in irrigation systems. Innovations come in new material for parts and pipes, sprinkler packages with flow triggering intensity, or changes in water conveyance. Design of water irrigation systems, particularly in developing countries, are inconsistent with crop water requirements which mean over-irrigation, with quantified losses of tens of water and energy. Since the water supply is the same for both countries, only the increase of crop evapotranspiration or the indirect decrease in the production and food chain, leads the countries to their optimum irrigation path. In either scenario, possible sustainability is directly related to changes in irrigation practices. Furthermore, the innovation in material means that the irrigation networks when it's getting older facing loss of pressure and as a result reduction in the area that the water passes, creating system failures.

Though design and on-farm performance often fall short of expectation, new, more-precisely designed systems can be very water conserving. Aside from equipment factors, there are many policy trends that are leading toward the more efficient use and management of water resources in agriculture. These trends involve political agendas both domestically

and abroad and are directly likely to influence irrigation practices in the future. Finally, a critical analysis of the inevitability of the continuation of the problem of unsustainable irrigation development and practice and some observations are provided regarding the likely future. Overall, these systems may prove innovative, encourage adoption and enhance the sustainability of future systems. Will collaborate with an array of interested parties to develop even better systems and of necessity better strategies in the management of irrigation technology.

To summarize the issue briefly, the problem of water scarcity is one of the most important problems of today's world, and therefore it is of great importance to use water efficiently, including the cultivation of rice fields. Rising economies such as India are known for their different and specific features in water resources management. On the one hand, there is an evolution in the use of innovative and high -tech methods in water resources management. This enabled India to overcome the famine in the water sources to a certain extent. Meanwhile, there are opposite characteristics in various regions of India to the successful adoption of water management practices. In recent years, the Indian economy has witnessed a huge increase in the adoption of drop irrigation practices, especially in rice fields.

Rice fields can be efficiently irrigated by using the integrated drop irrigation system with fertilization. Rice is famous for its dense water, so significant amounts of water require water to irrigate the fields.

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