The Mechanization Trend and Economic Prospects of Micro Irrigation in India

Abstract

Agriculture plays a crucial role in the Indian economy, contributing nearly 16 percent to the total GDP, with farm mechanization serving as the backbone of agricultural GDP. This study analyzes the growth trend in agricultural mechanization in India by examining the shift from traditional human and animal-powered equipment to mechanically powered farm equipment like tractors and power tillers, which are vital for farm mechanization. Secondary data from 2004-2005 to 2021-2022 were used, and the compound annual growth rate (CAGR) and correlation analyses were performed to assess trends. The study found a 6.78 percent annual growth in tractor purchases, with a linear trend equation showing a 0.93 coefficient of determination (R^2) at a 1 percent significance level, and a Pearson correlation coefficient of 0.76, indicating a strong correlation between tractor and power tiller purchasing trends. Precision farming, a type of farm management that uses information technology to optimize crop and soil health and productivity while minimizing production costs, is increasingly adopted due to advancements in mechanization. In India, precision farming techniques like drip and sprinkler micro-irrigation, covering 13,476,804 hectares with 46.90 percent under drip and 53.09 percent under sprinkler, have proven beneficial, especially in water-scarce areas. Precision farming is practiced mainly by medium to large progressive farmers, often experimentally or commercially, and offers profitable returns when applied to high-value crops such as fruits, vegetables, flowers, and medicinal plants.

Key Words: Farm mechanization, mechanically powered equipment Precision farming Micro-irrigation, Agricultural GDP

Introduction:

Agriculture is a key sector of the Indian economy, contributing nearly 16 percent to the total GDP (Economic Survey, 2022). The sector has shown consistent growth over the past several years, with an average annual growth rate of 4.6 percent and achieving 3.0 percent growth in 2021-2022. During this period, India produced 315.7 million tonnes of food grains, highlighting the sector's critical role in ensuring food security and economic stability. A significant driver of this growth is farm mechanization, which serves as the foundation of agricultural productivity by enhancing the efficiency and effectiveness of farm operations. The shift from traditional human and animal-powered tools to mechanically powered farm machinery, such as tractors and power tillers, has been instrumental in this transformation. The *Sub Mission on Agricultural Mechanization (SMAM)* has been a key initiative supporting this transition by providing assistance to state governments to establish Custom Hiring Centers (CHCs), Hi-Tech hubs and farm machinery banks. As of December 2022, 21,628 CHCs, 467 Hi-Tech hubs, and 18,306 farm machinery banks have been established, facilitating access to modern agricultural equipment (Agriculture Statistics at a Glance, 2021).

Farm mechanization not only reduces the drudgery associated with traditional farming methods but also increases productivity by enabling the timely and efficient use of inputs and natural resources while reducing cultivation costs. However, with the increasing fragmentation of farm holdings in India: from an average size of 1.23 hectares in 2005-2006 to 1.08 hectares in 2015-2016, there is a growing need for machines that are both viable and efficient for small farms (Agriculture Statistics at a Glance, 2021). This trend towards mechanization has also accelerated the adoption of precision farming practices, which leverage information technology to optimize crop and soil management for maximum health and productivity. Precision farming is increasingly seen as a way to reduce production costs and increase returns, especially when applied to high-value crops such as fruits, flowers, vegetables and medicinal and aromatic plants.

Micro-irrigation, particularly drip and sprinkler systems, is a key component of precision farming, offering a more sustainable approach to water management. Drip irrigation delivers water directly to the plant roots through a network of emitters, pipes, and valves, significantly reducing water wastage and evaporation. This system has become one of the most valued innovations in agriculture, especially in water-scarce regions, due to its efficiency in water and nutrient use. As of the financial year 2020-2021, India had 6,320,945 hectares under drip irrigation, with Andhra Pradesh leading with 1,388,126 hectares, followed by Maharashtra (1,349,979 hectares) and Gujarat (865,959 hectares). Drip irrigation is widely adopted in areas with acute water scarcity, such as farms, commercial greenhouses, and residential gardens. Similarly, sprinkler irrigation mimics natural rainfall, distributing water through a system of pipes and sprinklers, making it suitable for a variety of soil types and slopes. In India, 7,155,859 hectares are under sprinkler irrigation, with Rajasthan leading due to its sandy soil and undulating topography, covering 1,730,876 hectares, followed by Karnataka with 1,304,281 hectares (Agriculture Statistics at a Glance, 2021). These micro-irrigation techniques have proven highly effective in improving water use efficiency, reducing input costs, and enhancing crop yields, particularly in water-scarce and arid regions. During the financial year 2020-2021, India had a total of 13,476,804 hectares under micro-irrigation, with drip and sprinkler systems contributing 46.90 percent and 53.09 percent, respectively.

Overall, the convergence of farm mechanization and micro-irrigation practices presents a promising pathway for sustainable agricultural growth in India. The economic benefits of adopting these technologies are substantial, offering higher productivity, better water management, and increased profitability, particularly for high-value crops. With continued support from government policies and programs, such as the *Pradhan Mantri Krishi Sinchayee Yojana (PMKSY)* and *Sub Mission on Agricultural Mechanization (SMAM)*, the adoption of these practices is expected to expand, contributing to a more sustainable and resilient agricultural sector in India (PMKSY, 2021; NABARD, 2021; Directorate of Economics and Statistics, 2022).

Methodology

Source of data: Data on the state-wise area covered under micro-irrigation (in hectares) is primarily collected from the *Ministry of Agriculture and Farmers Welfare* (2022-2023), which provides comprehensive statistics in its reports. Additional insights into the adoption of micro-irrigation systems, such as drip and sprinkler irrigation across various states, are

obtained from the *Agricultural Statistics at a Glance (2021-2022)* and reports under the *Pradhan Mantri Krishi Sinchayee Yojana (PMKSY)*. Other sources include the reports from *National Bank for Agriculture and Rural Development (NABARD)* and the *Directorate of Economics and Statistics* (2021-2022).

The purchasing trend of tractors in India was computed based on the high R^2 (coefficient of determination) and low Root Mean Square Error (RMSE) values, this linear model function was evaluated. The analysis of growth rate was explained using the best-fitted model (Linear trend Equation), one of the growth model functions.

Linear function

$Y = a_0 + a_1 x_1 + \ldots + a_n x_n$

Where,

Y = Purchasing of Tractor

a_0 = Constant

β_1=Coefficient factor

x_1 = Year factor

The annual linear growth rate was computed as follows

$$r = \frac{\beta 1}{\underline{y}} X\ 100$$

After fitting the first linear trend function by the least-square method, we get the estimate of β1.

Correlation between the purchasing trend of tractor and power tiller was also computed by using the following formula

$$r = \frac{\sum (xi - x)(yi - y)}{\sqrt{\sum (xi - x)^2 (yi - y)^2}}$$

r= Correlation coefficient

Xi = Values of X- variable in the sample

X = mean of the value of x variable

Yi = Values of Y- variable in the sample

Y = mean of the value of Y variable

RESULT AND DISCUSSION

Tractors are a fundamental requirement of farming since they supply the machine power needed to carry out farm tasks. Tractors are used to pull a range of agricultural equipment for plowing, planting, harvesting, and growing crops, in addition to normal landscape maintenance, grass care, removing brush, and fertilizer application. During the year 2004-2005, 248 thousand tractors were purchased in India and it was 842 thousand in number during the year 2020-2021. Uttar Pradesh stands on first position in purchasing of

tractor with 117563 in number. This is followed by Maharashtra and Madhya Pradesh with 104301 and 100551 respectively. In 2020-2021, 899000 tractors were purchased in India that shows purchasing peak of the tractors. In this study purchasing trend of tractors was computed for 18 years of data from 2004-2005 to 2021-2022. For this annual growth computation linear trend equation was best with a 0.93 coefficient of determination (R^2) at a 1 percent level of significance. This equation shows 6.78 percent annual growth in the purchasing pattern of tractors in India. Pearson correlation coefficient was also computed for find out the correlation between the sale of a tractor and a power tiller. Pearson correlation coefficient was found 0.76, which shows the purchasing trend of tractors and power tillers are highly correlated and significant at a 1 percent level of significance.

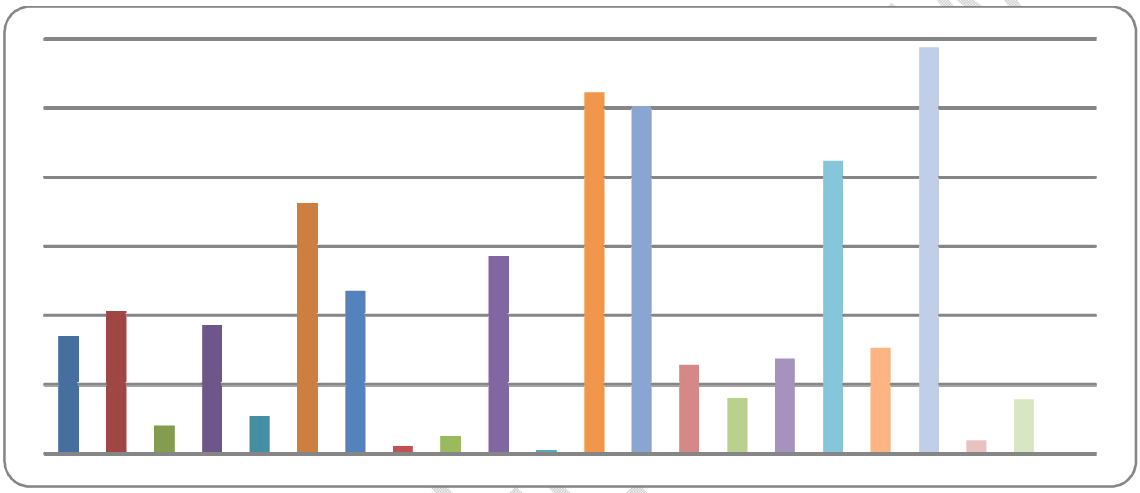

Fig. 1 State-wise Sales of Tractors in India during 2021-2022 (No's)
Source: Agriculture statistics at a glance (2022)

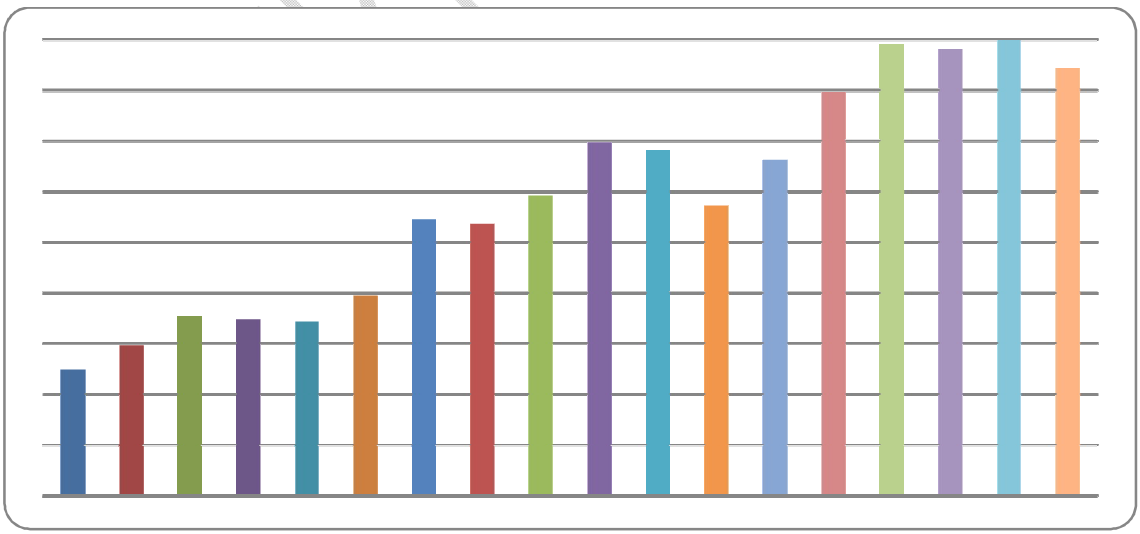

Fig. 2 Year-wise sale of tractors in India (No's)
Source: Agriculture statistics at a glance (2022)

Power tiller is an agricultural implement, fitted with rotary tillers, that is fast gaining traction in the Indian agricultural scene for its multi-purpose uses. Power tillers may be used on both small and big farms, but they are especially suggested for farms with tiny plots of land or rocky, uneven terrain that would make maneuvering a tractor difficult. Power tillers can be used for a variety of tasks in addition to tilling the ground, including plowing, sowing seeds, planting seedlings, adding fertilizer, spraying fertilizer, herbicides, and water, pumping water, harvesting, threshing, and conveying crops. In India during the year 2004-2005, 17000 power tillers were purchased; it was purchased 54000 in number during the year 2020-2021. 2011-2012 was the peak year for purchasing of power tillers *i.e.* 60 thousand.

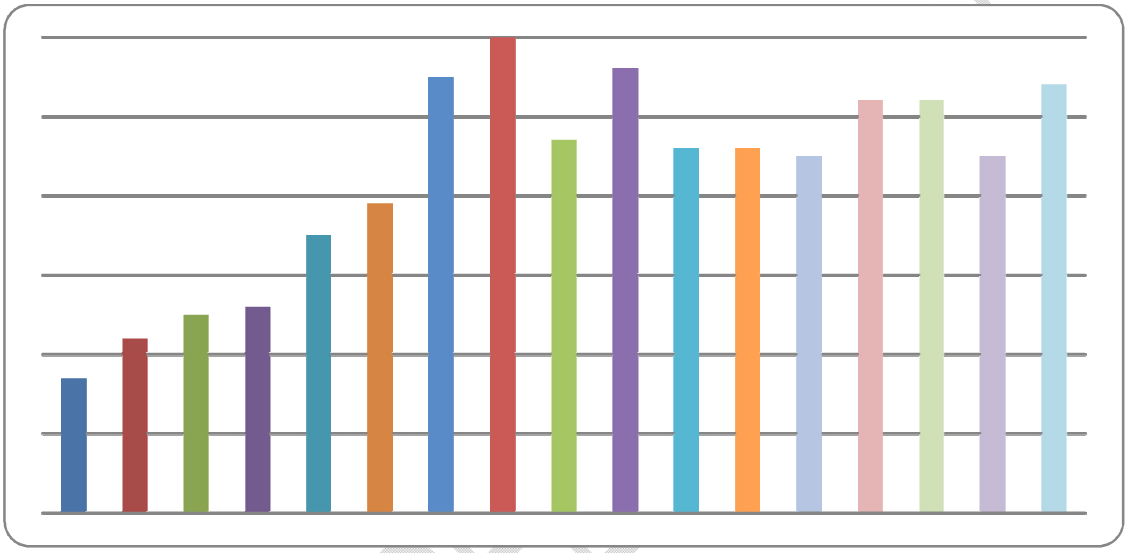

Fig. 3 Year wise sale of Power Tiller in India (No's)
Source: Agriculture statistics at a glance (2022)

Micro Irrigation

Precision farming, also known as site-specific farming, has emerged as a potential combination of technologies that might boost agricultural output while practicing environmental stewardship. With the use of precision farming, farmers can precisely apply the right quantity of seeds, water, pesticides, fertilizer, and other inputs when and where they're needed for the best crop development. Precision farming can boost yields, lower costs, minimize pollution, and improve economic efficiency. It will improve control production process and lead to more efficient use of labour hours, which will raise profits. Micro irrigation is a modern method of irrigation; by this method water is irrigated through drippers, sprinklers, foggers and by other emitters on surface or subsurface of the land. During the financial year 2020-21, India hada 13476804-hectare area under micro irrigation, in which 46.90 and 53.09 percent were contributions made by drip and sprinkler respectively. In India, Karnataka standsin first position with 2093262 hectare area under micro irrigation followed by Rajasthan, Maharashtra, and Andhra Pradesh with 2018495, 1926304, and 1907291 hectare area respectively.

Table 1: State-wise Area Covered under Micro Irrigation in Hectare (as of 31.03.2021)

State	Drip irrigation	Sprinkler irrigation	Total Micro irrigation
Andhra Pradesh	1388126	519165	1907291
Arunachal Pradesh	4017	3494	7511
Assam	4208	16217	20425
Bihar	13763	106979	120742
Chhattisgarh	31311	331283	362594
Goa	1386	1346	2732
Gujarat	865959	764933	1630892
Haryana	40018	600461	640479
Himachal Pradesh	7934	6403	14337
Jammu & Kashmir	1779	280	2059
Jharkhand	17713	17713	43399
Karnataka	788981	1304281	2093262
Kerala	24168	9096	33264
Madhya Pradesh	330335	258600	588935
Maharashtra	1349979	576325	1926304
Manipur	358	7039	7397
Meghalaya	308	307	615
Mizoram	5551	1744	7295
Nagaland	3589	6210	9799
Odessa	29425	115396	144821
Punjab	36416	14055	50471
Rajasthan	287619	1730876	2018495
Sikkim	6667	7943	14610
Tamil Nadu	805282	348010	1153292
Telangana	203279	74871	278150
Tripura	444	1651	2095
Uttar Pradesh	41273	227897	269170
Uttrakhand	12737	10300	23037
West Bengal	10347	92984	103331
Total	**6320945**	**7155859**	**13476804**

Source: Ministry of Agriculture and Farmers Welfare (2022-2023)

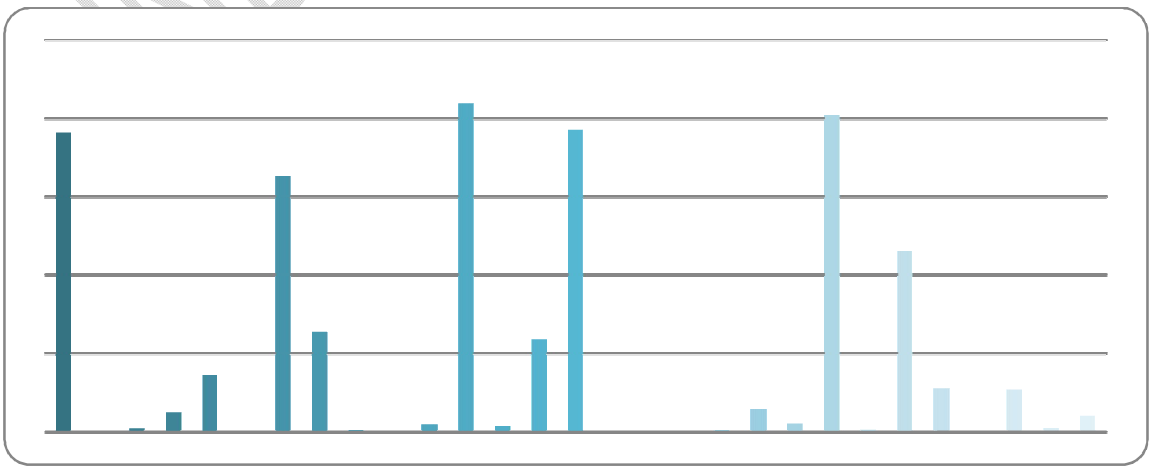

Fig 4: State-wise Area Covered under Micro Irrigation
Ministry of Agriculture and Farmers Welfare (2022-2023)

Drip Irrigation

A paradigm change in agricultural watering is represented by drip irrigation. India has 6320945 hectare area under drip irrigation in the financial year 2020-21. Andhra Pradesh is the leading state with 1388126 hectare area under drip irrigation and this is followed by Maharashtra and Gujarat with 1349979 and 865959 hectare area. Drip systems are based on management units including integrated valves and mains and sub-main pipes to control and distribute water to individual plots. Valve-piping combinations can be designed to irrigate pre-determined management zones based either on soil-landscape properties or on plant properties including yield and yield quality following seasonal history of monitoring spatial variability and a subsequent re-designing of the drip system. It has been suggested that, in orchards, irrigation systems should be designed, based on soil variability, from the beginning to achieve variable rate irrigation. The zonal separation criteria are suggested to be soil texture and soil elevation (Gemtos*et al*., 2011).

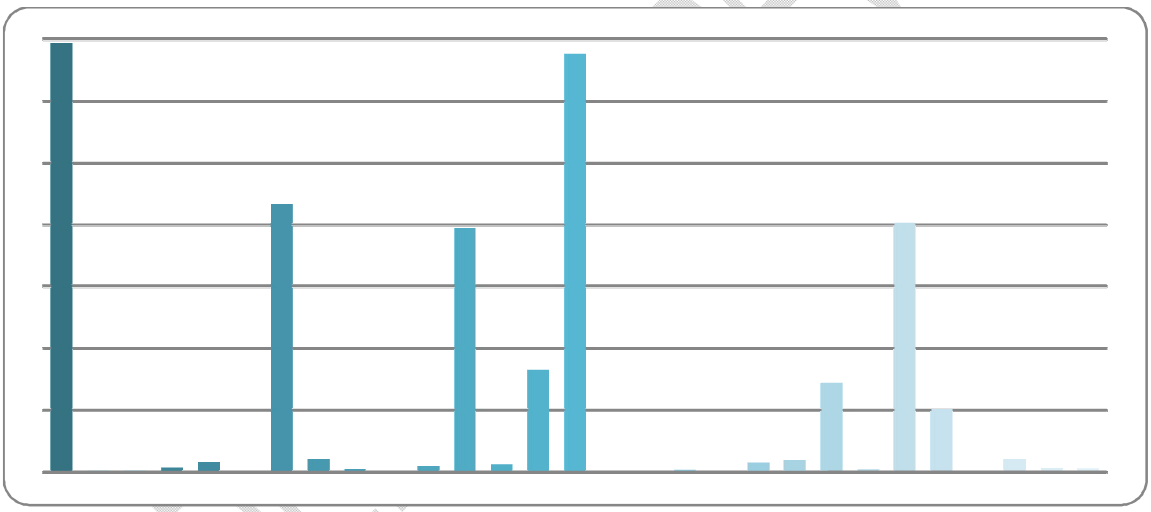

Fig. 5 State-wise Area covered under drip Irrigation (2021)
Source: Ministry of Agriculture and Farmers Welfare (2022-2023)

Installation cost of Drip system in India

A 1-hectare area requires 10,000 square meters of LLDP plain lateral pipe. Farmers mostly use 16 mm drip pipes with 2 kg pressure. In-line (emitting pipe) drip pipes come with pre-installed emitters spaced at 30 to 40 cm intervals, and the cost of this pipe is 8.50 rupees per meter. On the other hand, on-line (LLDP plain lateral pipe) drip pipes require farmers to install emitters manually, based on their specific crop needs. The cost of these pipes is 7.20 rupees per meter. Farmers typically need to invest between 1.35 to 1.50 lakh rupees per hectare to install a drip irrigation system in their fields. After installation, the Government of India provides a subsidy of up to 50-65 percent on the cost of the drip system.

Sprinkler System

Precision irrigation meets the demands of plants by enabling the delivery of water and nutrients without wastage, at the proper time, in the proper location, and in the proper quantity. India has a 7155859-hectare area under a sprinkler system. Sprinkler system is used, in large proportion in Rajasthan state due to sandy soil and undulating topography. For what Rajasthan stand on first position with 1730876 hectare area under the sprinkler system, followed by Karnataka with 1304281 hectare area during the financial year 2020-21.Sprinkler irrigation was initially invented for home lawn care and garden water use.But while spray irrigation technology was originally about personal use, it is such helpful technology that it was rapidly adopted into agriculture as one of the most common types of irrigation systems.

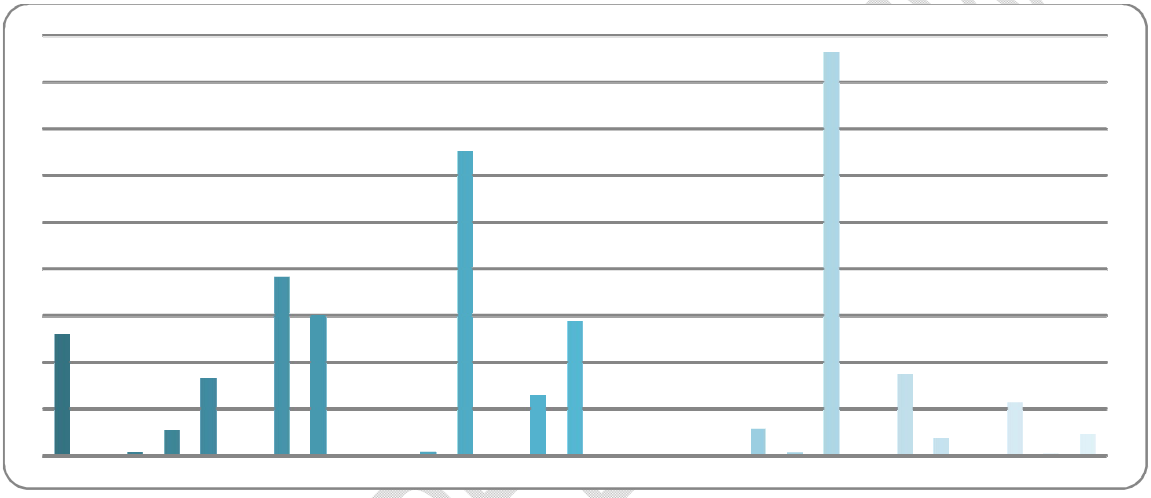

Fig. 6 State-wise Area Covered under Sprinkler Irrigation (2021)

Installation cost of Basic Sprinkler system in India

Sprinkler system of irrigation is most popular system in India as well as Rajasthan. Rajasthan standsin first position in the area under irrigation through the sprinkler system. The sprinkler system is an economic system for the farmer as well as an environment for saving 40 per cent of water as compare to traditional approaches. Installation cost of this system is also low. 56.74 percent of Installation cost is occupied by pipes and a nearby 20 percent cost is spenton Sprinkler Nozzles. The range of this installation cost may vary according to non-availability of the pump set and main pipe line. Use of a presser gauge filter chamber and water tank also variesfrom region to region.

Table 2: Installation cost of Basic Sprinkler system in India

Component of Sprinkler	Number of Components	Amount of per component in Rupees	Total Amount	Percentage share of Component
Pipe with coupler 6 m. long	20	570	11400	56.74

Sprinkler Nozzles	10	400	4000	19.91
Rizer Pipe	10	110	1100	5.48
Sprinkler coupler with Foot baton	10	225	2250	11.20
Connecting nipple	1	150	150	0.75
Bend with coupler	2	250	500	2.49
T- with coupler	2	275	550	2.74
End Plug	2	70	140	0.70
Basic System cost per Hectare	-	-	20090	100

Source: Ministry of Agriculture and Farmers Welfare, PMKSY reports

Irrigated area under principal crops

Irrigation is the artificial application of water to land. Some land requires irrigation before it is possible to use it for any agricultural production. Some land has to be irrigated before it can be used for any type of agricultural output. In other regions, irrigation primarily helps to boost productivity and supplement rainfall. Total cereals crops have the largest area under irrigation. According to the year 2018-19, out of the total area under cereals cultivation, 63 percent area was irrigated. Sugarcane is long duration crop, so it has a strong need for irrigation throughout the year. Out of the total area under sugarcane, 96.6 percent area was irrigated during the year 2018-19. Although most of the pulses are grown in the monsoon season even then 23.2 percent area of total pulses was irrigated. 31.4 per cent area of oilseed, 45.1 per cent of area of cotton and 67.9 per cent area of tobacco were also irrigated during the year 2018-19. If we go for general, 52 percent that is more than half of the total area were irrigated in the same period.

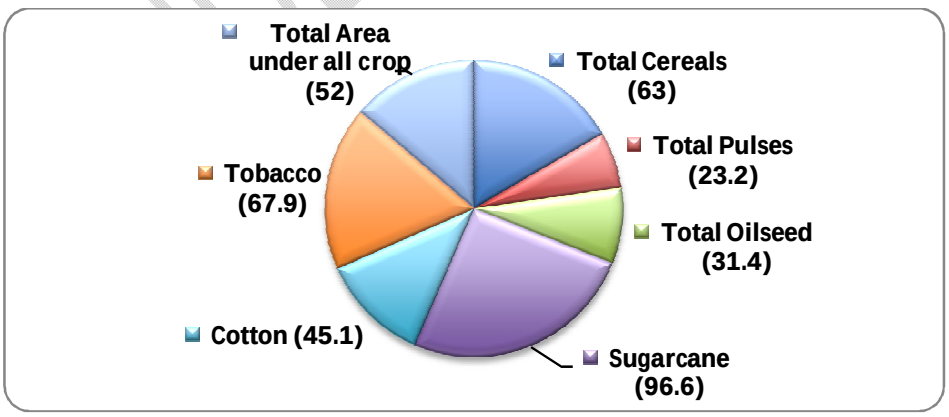

Fig. 7 Percent Coverage of Irrigated Area under Principal Crops (2019-20)

Conclusion

Micro-irrigation is crucial for water conservation and enhancing agricultural productivity, proving its versatility across all soil types and a wide range of agronomic and horticultural crops. This method not only reduces labor and field preparation costs but also optimizes water usage, making it ideal for diverse farming needs. Effective irrigation system design, tailored to soil variability, is essential for achieving optimal results in orchards and other specialized crops. Implementing robust extension programs will accelerate the adoption of precision farming techniques, with subsidies playing a key role in making these systems more accessible to farmers. The analysis reveals a 6.78 percent annual growth in tractor purchases in India, with a Pearson correlation coefficient of 0.76, indicating a strong and statistically significant relationship between the purchasing trends of tractors and power tillers. India's widespread adoption of precision micro-irrigation technique (drip and sprinkler system) has significantly impacted water-scarce regions. In the financial year 2020-21, India had 13,476,804 hectares under micro-irrigation, with drip and sprinkler systems contributing 46.90 percent and 53.09 percent, respectively. Andhra Pradesh led with 1,388,126 hectares under drip irrigation, followed by Maharashtra and Gujarat. Additionally, the country had 7,155,859 hectares under sprinkler systems, with Rajasthan and Karnataka being the top users. The installation cost of a drip system ranges from 1.35 to 1.50 lakh rupees per hectare, while the basic sprinkler system installation costs approximately 20,000 rupees per hectare. These advancements underscore the transformative impact of precision irrigation on enhancing productivity and sustainability in Indian agriculture.

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