



Maximizing Yield and Water Productivity of Garlic (*Allium sativum* L.) by Adopting Sprinkler Irrigation System

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ABSTRACT

An experiment on sprinkler irrigation system was conducted to improve yield and water productivity of garlic. The field experiment was conducted during three consecutive *rabi* seasons from 2022–23 to 2024–25. The data on yield, yield attributing parameters, water productivity, economics, soil moisture distribution and water saving of treatment (T₂) *i.e.* Sprinkler irrigation system were calculated and compared with the corresponding farmer's practice (T₁) *i.e.* Conventional flood irrigation system. The study revealed that the sprinkler irrigation system (T₂) increased bulb yield by 15.24% and water productivity by 71.17%. Compared with the conventional flood irrigation system (T₁), with bulb yield increasing from 92.5 to 107.1 q/ha and water productivity from 1.36 to 2.31 kg/m³. The treatment T₂ also showed average water saving of 31.41% over the T₁. In economic terms, the treatment T₂ performed better with a benefit-cost ratio of 2.76 as compared with T₁ (2.46). Higher yield due to uniform moisture distribution, negligible water stagnation condition and suppress thrips population along with higher returns and water saving over the farmer's practice created greater awareness and motivated the other farmers to adopt this irrigation technology.

Keywords: Garlic, Sprinkler irrigation system, Water productivity, Water saving, Yield.

INTRODUCTION

In India, Garlic is the most important bulb crop after onion. Total area under Garlic cultivation in India was 3,82,610 ha in 2023-24 which led to production of 3213.93 thousand tonnes. India, although rank second by area and production, but India's garlic productivity is low compared to the global average, but there is potential to increase it through many practices such as mechanization, Improved cultivation techniques, developing high-yielding, disease-resistant varieties, precision farming and innovations in irrigation practices such as micro irrigation system, which ensure nutrient managements and more efficient use of irrigation water with 90 per cent of irrigation efficiency as compared to 40-60 percent for conventional surface irrigation (Bhosle, 2024; Vijayakumar, 2024). In Madhya Pradesh, overall stage of groundwater extraction is 58.75 %. Some district of madhya pradesh under Malwa Plateau such as Indore, Mandsaur, Ratlam, Shajapur and Ujjain shows very high stage of ground water extraction *i.e.* > 100%. Indore (119.38%) is the second highest groundwater extraction districts after Ratlam (135.14 %) district (GWRA-2023). This showed that in these districts the annual ground water

consumption is more than annual extractable groundwater resources. There are several reasons for ground water extraction but for irrigated agriculture it contributed significantly (Rajkhowa, 2024). Sprinkler irrigation system has a capability to save significant amounts of irrigation water with greater soil moisture distribution uniformity, to improve yield, water productivity and fertilizer use with less leaching effects and to save amount of irrigation water applied as compared with other surface irrigation methods (Chauhdary *et al*, 2024). Therefore, this study focus on maximizing the yield and water productivity of Garlic by adopting sprinkler irrigation system.

MATERIALS AND METHODS

Site Description

The experiments were conducted for three consecutive years during Rabi season 2022–23, 2023–2024 and 2024–25 at farmers' fields of Village Tilaur Khurd, Tehsil Bicholi Hapsi, District Indore to validate impact of demonstration on sprinkler Irrigation system to improve yield and water productivity of Garlic (Fig.1). Geographically Indore is situated in western

region of Madhya Pradesh (Latitude 22° 44' N, Longitude 75° 50' E.), on the southern edge of the Malwa plateau at an average elevation of 553 m above mean sea level with an average annual rainfall of 952 mm. The location lies on a borderline between a humid subtropical climate and a tropical climate. The soil of the farmer's fields was black soil in texture with very low in available nitrogen, medium in available phosphorus and higher in available potassium.

The treatment was comprised of sprinkler irrigation (T2) along with surface irrigation (conventional flood irrigation, T1). The conventional flood irrigation system was being followed on the field for irrigating garlic from last 15 years. Each trial was of 0.25 ha area and secondary filtration system of sprinkler irrigation system i.e. screen filter and other safety devices was provided as critical input.

Layout of experimental field

Tubewell was used as a water source for irrigation. Main line was of PVC pipes with 90 mm in diameter (OD) to convey the water from the source to the main control points in the field. Irrigation water was delivered through mini sprinklers with discharge of 500 lph at the spacings of 30 ft in LDPE laterals of 32 mm (OD at 2.5 bar operating pressure). The layout details of the experimental design are shown as in Fig. 2.

Sowing of crop and Irrigation and fertigation scheduling

Field preparation including primary and secondary tillage operations were carried out before sowing of the Garlic. Recommended dose of well decomposed cow dung (10 t/ha) was applied to increase organic content of soil. Seed rate for garlic were 400-500kg/ha. Garlic cloves (variety :Ooty) were planted on last week of September to first week of October for all three years (2022-23, 2023-24, 202-25) of experiment with plant to plant spacing of 10 cm and row to row spacing of 15 cm via 21 tynes Garlic planter. Depending upon climatic conditions and soil type decide irrigation amount and frequency. First irrigation was applied immediately after sowing then depending upon need irrigation was applied with interval of 10-12 days. Crop was harvested manually, when almost 50% leaves start yellowing and drying. It was occurred 140-145 days after sowing. Irrigation has stopped 15 days before harvesting. Plants are pull out or uprooted, then tied into small bundle and kept in field or shade for 2-3 days. After proper drying, dry stalks are removed and bulbs were cleaned.

Water productivity: The total yield obtained under each treatment (kg.ha^{-1}) was divided by the amount of irrigation water applied ($\text{m}^3.\text{ha}^{-1}$) for each treatment to obtain water productivity (kg.m^{-3}) (Eq. 1).

$$\text{Water productivity (kg.m}^{-3}\text{)} = \frac{\text{Crop yield (kg.ha}^{-1}\text{)}}{\text{Amount of irrigation water applied (m}^3\text{.ha}^{-1}\text{)}} \dots (1)$$

Uniformity coefficient (CU)

The important parameter developed by Christiansen (1942), which is widely used to evaluate micro-sprinkler uniformity. A measurable index of degree of uniformity obtains of any size of micro-sprinkler operating under given condition, is known as uniformity coefficient. This calculation is based on determining average amount of water in the catch can and deviation from this amount (Fig. 3). This results were expressed as percentage. The better the uniformity smaller the deviation and value will approaches to 100 per cent. For determination of uniformity coefficient, catch cans was placed on level surface. The system was operated for 20 min, immediately after termination of irrigation, the volume of water collected in each catch cans were measured with the help of graduated cylinder. Equation 2 was used for computing for the uniformity coefficient.

$$Cu = 100 \left(1.0 - \frac{x}{m} \right) \dots (2)$$

Where, m= average observations (average application rate), mm

n= total number of observation points

x = numerical deviation of individual observations from the average application rate, mm

Soil moisture distribution under sprinkler irrigation system

For the measurement of soil moisture distribution under the sprinkler irrigation system soil samples was collected after 24hrs of irrigation and soil moisture content was measure by standard oven dry method (FAO, 2023).

Yield-attributing characters of garlic

At harvest, garlic bulbs were collected from each farmer's field from representative plants selected at random. Bulb diameter was measured by wrapping a thread around the widest portion of the bulb and measuring its length using a graduated scale. Fresh bulb weight was recorded using an electronic balance. Number of cloves per bulb was counted manually after separating the cloves. Average clove weight was

Maximizing Yield and Water Productivity of Garlic (*Allium sativum* L.)



(a) Year 2022-23



(b) Year 2023-24

Fig.1: Field photographs showing the Garlic crop grown under Sprinkler Irrigation system

calculated by dividing total clove weight per bulb by the number of cloves.

Economic Analysis:

Economic analysis was carried out by considering the working life of sprinkler irrigation as 8 years. Seasonal cost of cultivation of garlic was computed by considering the cost of land development and preparation, seed cost, seed treatment, sowing, manure and fertilizers, Irrigation charges, Chemical, electricity charges, Hired human labour, Machine labour, harvesting cost, Marketing expenses and additional processing costs. The gross returns (GR) included income from sale of garlic. The average selling price of garlic was for year 2022-23, 2023-24 and 2024-25 was Rs. 5900 /q in the Indore district of Madhya Pradesh. Net return from both treatments was calculated after subtracting total cost i.e cost of cultivation (Fixed cost +variable costs) from the calculated gross return. Economic viability of sprinkler irrigation system was evaluated by computing benefit-cost ratio (B:C ratio) by dividing gross returns by total seasonal cost. The results were compared with B:C ratio of T1 (Conventional flood irrigation system) treatment.

Statistical Analysis

The data were analysed year-wise and pooled over three years using completely randomized design (CRD), considering farmers as replications. Analysis of variance (ANOVA) was carried out and treatment means were compared using critical difference (CD) at 5% probability level.

RESULTS AND DISCUSSION

Christiansen Uniformity Coefficient

It was computed by using equation 2. Uniformity coefficient from the observed discharge values in the experimental system at 2.5 kg/cm² pressure was observed as 83.5%, 83.1% and 82.2%, respectively for the year of 2023, 2024 and 2025. Similar results were reported by Bhagwat and Keskar (2024).

Soil moisture distribution

The soil moisture distribution, contours maps were plotted by kriging technique using software named “Surfer version 28.2.275.0” to assess the variation in the soil moisture within root zone of crop. For computing soil moisture distribution, soil samples were taken 24 hours after irrigation at two depths of 0-15 cm and 15-30 cm. Contour map showed that soil moisture distribution near to the effective root zone area of garlic (0-30 cm) was almost uniform, and close to the beneficial condition (field capacity) of the plant. Similarly, in the traditional flood method, upper surface was found to be close to the saturated state. Here soil moisture distribution under sprinkler irrigation system is shown in Fig. 4.

Under the sprinkler irrigation system, average volumetric soil moisture content (cm³cm⁻³) was observed as 30.9 and 26.2 cm³cm⁻³ in soil depth of 0-15 and 15-30 cm respectively, while it was 27.1 and 38.4 cm³cm⁻³ in soil depth of 0-15 and 15-30 cm, respectively. So, the overall percentage variation in

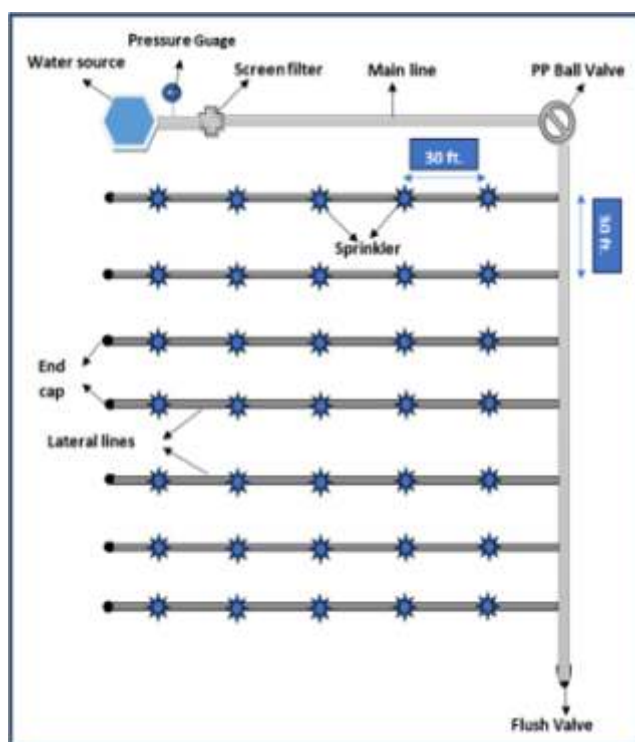


Fig. 2: Layout of experimental field

average volumetric soil moisture content between two sprinkler in upper soil profiles (0-300 mm) was minimum under Sprinkler Irrigation (i.e. 15.24%), while it was higher under conventional flood irrigation (29.27 %). Micro-irrigation systems maintain a uniform soil moisture regime within the effective root zone, thereby enhancing water and nutrient uptake by garlic plants. Bajpai and kaushal (2020) reported similar results.

Effect of irrigation methods on yield

Garlic yield for three years and average pooled yield under two treatments is shown in Fig. 5, Table 1. Garlic yield was significantly influenced by irrigation methods during all the three years. In 1st Year, sprinkler irrigation recorded a significantly ($P=0.05$, $CD=4.5$) higher yield T_2 (103.2 q ha⁻¹) compared to flood irrigation T_1 (88.4 q ha⁻¹). A similar trend of significantly ($P=0.05$, $CD=3.8$) higher yield was observed in 2nd Year i.e. T_1 (82.5 q ha⁻¹) and T_2 (93.7 q ha⁻¹) and for 3rd year, similarly yield was significantly ($P=0.05$, $CD=5.82$) higher under T_2 (124.4 q ha⁻¹) as compared to T_1 (106.6) q ha. The interaction between year and irrigation method was also significant, indicating differential yield response across years.

The pooled mean yield under sprinkler irrigation (107.1 q ha⁻¹) was significantly higher

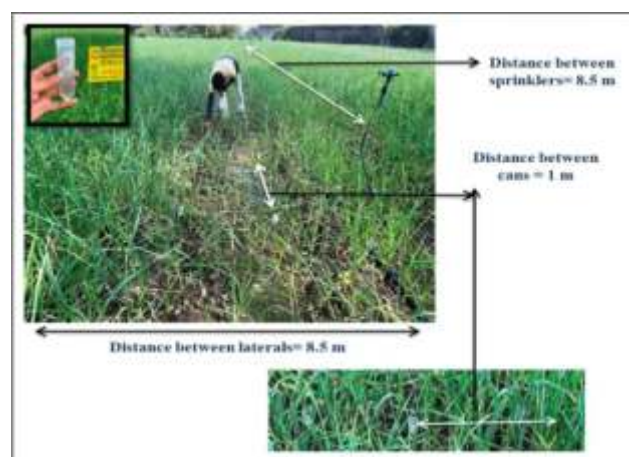


Fig.3: Uniformity measurement of sprinkler irrigation system by catch cans method

($P=0.05$, $CD=4.65$) than flood irrigation (92.5 q ha⁻¹), representing an increase of about 15.78%. This confirms the earlier findings of Rao *et al* (2022) who also recorded higher marketable bulb yield of garlic under sprinkler irrigation system. This may be due to the uniform soil moisture distribution near to the crop root zone area of garlic and reduced water stress during critical growth stages, which enhanced bulb development. Under conventional flood irrigation system, it has been observed that saturated soil moisture conditions in upper soil profile (0-30 cm) during crop growth stages, deep percolation losses and uneven distribution of irrigation water, all these conditions lead to development of diseases and resulted lower yield. These results are in line with the findings of Bajpai *et al* (2023).

Effect of irrigation methods on Plant Parameters

Bulb Diameter (cm) and Bulb Weight (gm)

Bulb equatorial diameter and bulb weight showed a significant response to irrigation methods in all the three years as well as in pooled analysis Fig 5 and Table 1. Sprinkler irrigation produced significantly larger bulbs diameter and bulb weight compared to flood irrigation across years. The pooled mean bulb diameter and bulb weight under sprinkler irrigation (5.21 cm, 28.09 gm) was significantly higher ($CD=0.13$, $CD=0.35$ at $P=0.05$) than flood irrigation (4.36 cm, 24.06 gm) respectively. Improved bulb diameter and bulb weight under sprinkler irrigation may be attributed to uniform and optimal soil moisture availability throughout the root zone, which

Maximizing Yield and Water Productivity of Garlic (*Allium sativum* L.)

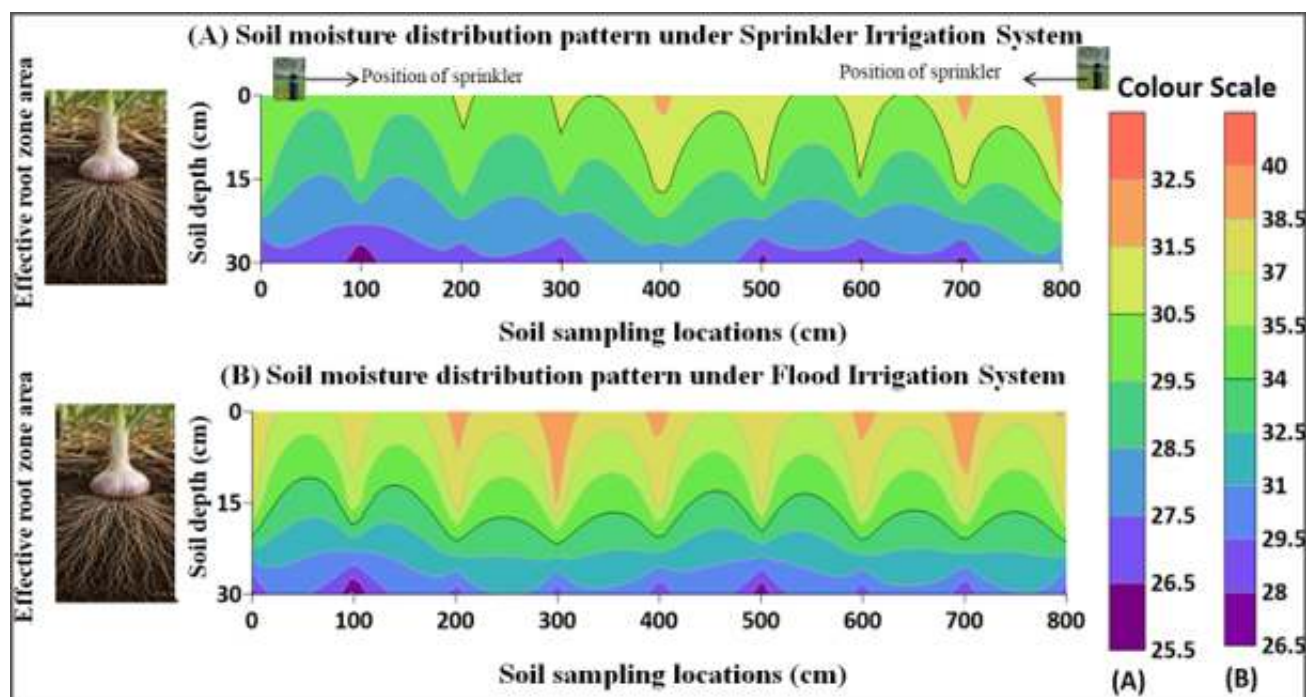


Fig.4: Soil moisture distribution pattern after 24 hrs of irrigation under Flood and Sprinkler Irrigation system

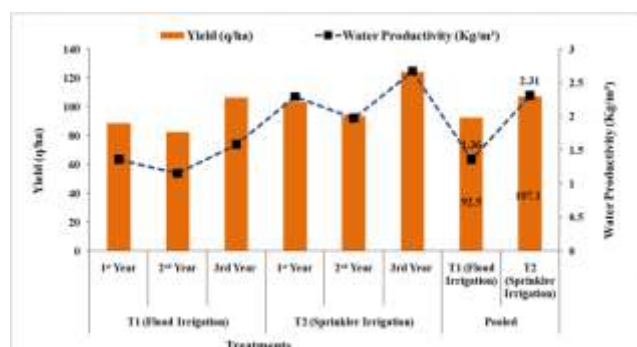


Fig. 4 : Year wise and pooled impact of irrigation methods on yield (q/ha) and Water Productivity (Kg/m³) of garlic.

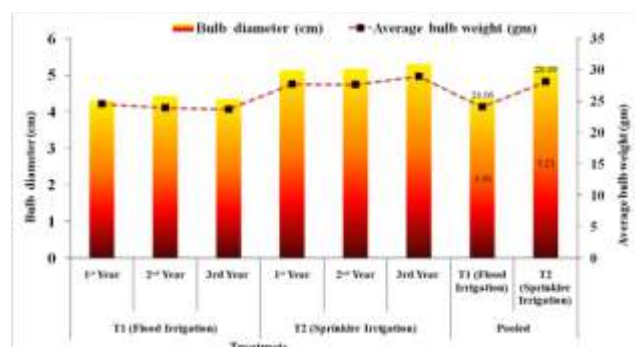


Fig. 5: Year wise impact of irrigation methods on bulb diameter (cm) and bulb weight (gm)

promotes cell expansion, efficient assimilate translocation, and enhanced photosynthetic activity. The uniform wetting pattern under sprinkler irrigation minimizes soil moisture fluctuations, leading to better nutrient uptake and improved bulb development, indicating that bulb growth in garlic is highly responsive to efficient irrigation management. These findings agreed with those obtained by Latif and Abdelshafy (2017).

Cloves per bulb (No) and Average clove weight (gm)

Unlike yield and bulb size parameters, the

number of cloves per bulb did not differ significantly between irrigation methods in any of the years or in pooled analysis. The pooled mean number of cloves per bulb was 15.93 under flood irrigation and 16.1 under sprinkler irrigation, with the difference being statistically non-significant (Fig. 6 Table 1). The non-significant response of clove number suggests that this trait is largely governed by genetic factors rather than irrigation management. Similar observations have been reported earlier, where irrigation influenced bulb size and clove weight but had little effect on the number of cloves per bulb.

Average clove weight was significantly affected by irrigation methods in all three years.

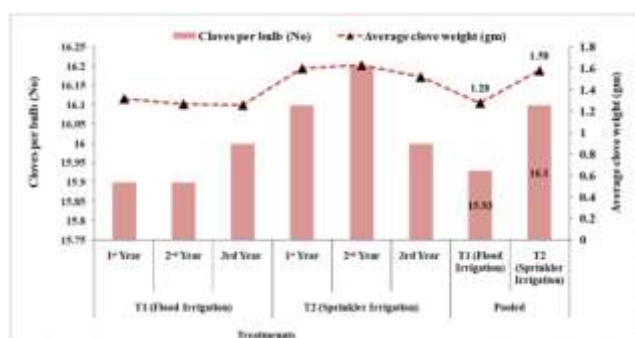


Fig. 6 : Year wise impact of irrigation methods on Cloves per bulb (No) and Average clove weight (gm)

Sprinkler irrigation (T_2) recorded higher clove weight compared to flood irrigation (T_1) during each year. In pooled analysis, sprinkler irrigation resulted in a significantly higher ($P=0.05$, $CD=0.04$) average clove weight (1.58 g) compared to flood irrigation (1.28 g). The increase in clove weight under sprinkler irrigation can be explained by improved bulb development, where fewer or similar numbers of cloves were formed but with greater individual clove size. This indicates better partitioning of assimilates under favorable moisture conditions created by sprinkler irrigation. These findings agreed with those obtained by Sable *et al* 2025.

Irrigation water applied (mm), water productivity (kg m^{-3}) and water saving (%)

Irrigation Water Applied (mm) and Water Saving (%)

Flood irrigation required 650–700 mm water, whereas sprinkler irrigation required only 450–475 mm across years. Sprinkler irrigation resulted in 30.8–32.1% water saving compared to flood irrigation (Fig. 7). Consistent reduction in irrigation water under sprinkler irrigation clearly demonstrates its water-efficient nature without compromising productivity. Reduced irrigation water application under sprinkler irrigation resulted in substantial water saving ($\approx 31.41\%$) and significantly higher water productivity. Mangat *et al* (2024) and Singh *et al* (2024) observed similar results.

Water productivity was significantly higher ($P=0.05$, $CD=0.16$) under sprinkler irrigation compared to flood irrigation in all three years and in pooled analysis (Table 1, Fig 4). In

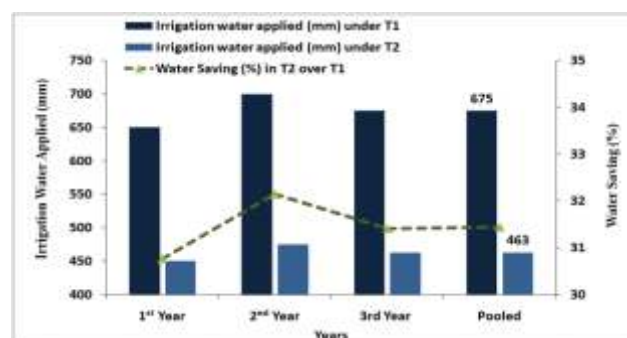


Fig.7: Irrigation water applied and Water saving in garlic for year 2022-23, year 2023-24 and average under T1 and T2 treatments

pooled analysis, sprinkler irrigation T_2 recorded a water productivity of 2.31 kg m^{-3} , which was about 69.85% higher than flood irrigation T_1 (1.36 kg m^{-3}). The substantial improvement in water productivity under sprinkler irrigation was primarily due to reduced irrigation water application (463 mm) combined with higher yield. Rao *et al* (2016) and Bajpai *et al* (2023) reported similar results as better management of irrigation water under sprinkler irrigation would lead to high water productivity and significant savings in irrigation water. In a field condition, it has been also observed that, sprinkler irrigated garlic plants may suppress the thrips population as compared with flood irrigated plants (Fig 8). Bankar *et al* (2022) observed similar results. They reported that the water jet from sprinklers disturbs the growth and reproduction of thrips.

Economic analysis

Pooled economic analysis for three years of garlic (cost of cultivation, gross return, net return and B:C ratio) is show in Table 2 and Fig. 9. Sprinkler irrigation recorded a consistently higher benefit–cost (B:C) ratio compared to flood irrigation during all the three years of study. The pooled analysis also revealed a clear economic advantage of sprinkler irrigation, with a mean B:C ratio of 2.55, which was significantly higher ($P=0.05$, $CD=0.12$) to 2.29 under flood irrigation.

It showed 11.84 % higher B:C under T_2 (Sprinkler irrigation) as compared with T_1 (Conventional flood irrigation) treatment. The higher B:C ratio under sprinkler irrigation can be attributed to improved yield, higher water productivity, and efficient utilization of irrigation water, resulting in

Maximizing Yield and Water Productivity of Garlic (*Allium sativum* L.)



T₁ (Conventional flood Irrigation system)



T₂ (Sprinkler Irrigation system)

Fig. 8: Field view of thrips population under treatment T₁ (conventional flood irrigation system) and T₂ (sprinkler irrigation system)

Table: 2 Pooled economic Analysis (year of 2022-23, 2023-24 and 2024-25) of Garlic under T₁ and T₂ treatments.

Cost of cultivation (Rs/ha)		Gross income (Rs/ha)		Net return (Rs/ha)		B:C	
T ₁	T ₂	T ₁	T ₂	T ₁	T ₂	T ₁	T ₂
225400	235400	515007	599760	289607	364360	2.28	2.55
CD (P=0.05)						0.12	

greater net returns despite slightly higher initial investment.

CONCLUSION

The present investigation demonstrated that sprinkler irrigation resulted in 15.78 % higher crop yields, 69.85% higher water productivity and was more profitable with B:C of 2.55. Higher grain yield with sprinkler irrigated Garlic was mainly attributable to minimum variation in the percentage of moisture distribution (i.e. 15.24% under sprinkler irrigation whereas 29.27% under conventional flood irrigation) in effective root zone area of garlic (0–300 mm), which in turn increased water productivity. Increased irrigation water productivity might result in reduced withdrawal of groundwater, and prevent groundwater declining problem in Indore district of Madhya Pradesh. In addition to this, with the saving of 31.41% (212 mm) of irrigation water under T₂ treatment, farmer can irrigate additional 0.4 ha (approximate) under sprinkler irrigation system. Higher yield and water productivity due to uniform moisture distribution, negligible water stagnation condition and

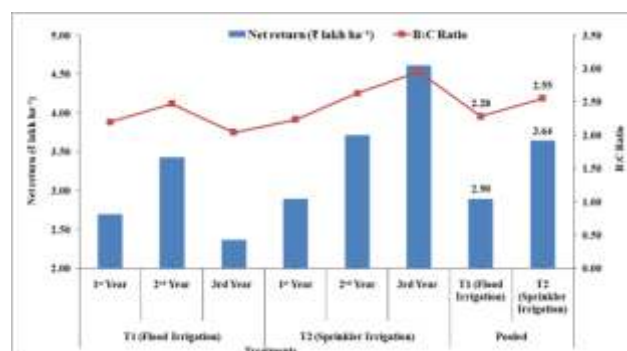


Fig. 9: Year-wise economic performance of garlic in terms of benefit–cost ratio under different irrigation methods

suppress thrips population along with higher returns and water saving in the on farm testing over the farmer's practice created greater awareness and motivated the other farmers to adopt this irrigation technology. The consistent performance of sprinkler irrigation across years highlights its potential as a water-efficient irrigation strategy for garlic cultivation, capable of enhancing both productivity and resource-use efficiency.

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