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Improving water efficiency and crop yield of drip-irrigated onions through the application of deficit irrigation, mulching, and fertigation

Shrankhla Mishra, SK Pyasi, MK Awasthi and RN Shrivastava

Abstract
Water plays a pivotal role in our lives, serving various purposes, including irrigation and domestic use. Moreover, all ecosystems on Earth rely on water for their survival. Currently, agriculture accounts for 70 percent of worldwide freshwater withdrawals (according to the FAO Water Report, 2011). Drip irrigation is recognized as an efficient method for conserving water and increasing water productivity because it can deliver precise and controlled water amounts (Shock *et al*., 2000).
Onion cultivation, being a valuable cash crop in India, covers approximately 8.05 lakh hectares and is steadily expanding. In the state of Madhya Pradesh alone, onion cultivation spans about 1.8 lakh hectares. The primary objective of this research is to examine the combined impact of deficit irrigation, fertigation, and mulching in drip-irrigated onion fields. This study aims to calculate parameters like water conservation percentage, water productivity, fertigation efficiency, onion yield, and the economic viability of different treatment strategies.
The field trial was conducted using a drip irrigation system with six main treatments (T_1 to T_6) and three sub-treatments (F1 to F3). The results revealed variations in the number of leaves, plant height, bulb diameter, canopy temperature, onion yield, water conservation, and water productivity. Specifically, the range for these parameters fell within the following values: 5-13 leaves, 19.5-68 cm plant height, 3.1-7.9 cm bulb diameter, 29-45 °C canopy temperature, and 14.0-18.9 tons per hectare onion yield. The maximum water conservation of 574 mm was observed in T_1, while water productivity ranged from 3.03 to 6.00 kg/m3.
In summary, deficit irrigation and fertigation levels significantly influenced the number of leaves, plant height, bulb diameter, and onion yield. The highest yield was achieved in T_4 (18.9 tons/ha), with water savings of 104 mm in T_3. The Benefit-Cost Ratio (BCR) in the study was notably affected by the level of deficit irrigation and the cost of mulching. The straw mulch treatment consistently yielded the highest BCR under all treatments, ranging from 1.67 to 1.19. Meanwhile, the crop without mulch treatment in all main treatments yielded a BCR ranging from 1.63 to 1.08. In conclusion, farmers can achieve better yields and economic profitability by adopting 80% deficit irrigation and 75% fertigation levels.

Keywords: Mulching, deficit irrigation, water productivity, onion yield

Introduction
Water plays a crucial role in our lives, serving essential functions in agriculture and everyday household use. Furthermore, the survival of all Earth's ecosystems depends on water. Approximately 70% of the world's freshwater withdrawals are currently allocated to the agricultural sector, with developing countries expected to increase this figure to around 95% according to the FAO Water Report in 2012.
With population growth and the challenges posed by climate change, there is a growing need to boost food production while conserving water resources in agriculture. One proposed approach to achieve this is deficit irrigation, which allows for the maintenance and even enhancement of crop yields while using less water. However, it has not yet seen widespread adoption, as crops subjected to deficit irrigation experience some level of water stress during specific growth stages or throughout the growing season. Despite this, the benefits of saving water and reallocating it to other crops outweigh the potential yield reduction, making deficit irrigation an appropriate focus for this study.
In terms of irrigation methods, surface techniques are known for their low water use efficiency, whereas pressurized methods such as trickle irrigation are highly suitable for horticultural and vegetable crops, with water use efficiency ranging from 80% to 95%. This approach also has the potential to optimize water use in irrigated systems, as indicated by FAO in 1985.

Given the rising demand for water, a change in irrigation management and scheduling is necessary to enhance crop water use efficiency, ensuring that the limited water supply is conserved for agricultural purposes. This improvement in water efficiency can occur at three levels: reducing the water footprint per unit of production at the user level, efficiently allocating water at the catchment level, and engaging in smart virtual water trade at the international level.

Enhancing water efficiency in agriculture is a significant challenge for achieving sustainable crop cultivation. Water productivity, which measures the effectiveness of water use in crop evapotranspiration and its impact on crop yield, is crucial in regions with limited water resources, such as the dry Mediterranean area. Employing economically viable and scientifically supported methods is a practical way to improve water productivity. Deficit irrigation combined with mulching is an appealing strategy for addressing water scarcity and its consequences.

Materials and Methods

Field Observations

Soil Moisture

Soil samples were gathered at intervals of 30 days both prior to and following irrigation. These samples were taken at depths of 0-10 cm, 10-20 cm, 20-30 cm, and 30-40 cm from each control group. The moisture content of the soil was assessed using the gravimetric technique.

$$\text{Moisture content } \% = \frac{\text{Weight of moist soil} - \text{Weight of dry soil}}{\text{Weight of dry soil}} \times 100$$

Number of leaves

Every thirty days, the total number of green leaves per plant from each treatment was counted and an average number of leaves per plant is calculated.

Yield (tons/ha)

The harvested onion crop was weighed out from each treatment and replication and computed to give the overall yield of the crop in tons per hectare.

Canopy cover

Green Canopy Cover (CC) of the crop was observed in every 30 days after transplanting until maturity from different treatments across replications by means of Canopeo software tool

Biomass

Biomass was collected from each treatment when the crops matured, signifying the end of their growth periods. The harvested biomass was subsequently quantified to determine the yield in tons per hectare.

Soil samples were obtained at 30-day intervals before and after irrigation. These samples were extracted from various depths, including 0-10 cm, 10-20 cm, 20-30 cm, and 30-40 cm. This process was carried out for all control treatments, and the soil moisture content was assessed using the gravimetric method.

The soil moisture content was determined using the gravimetric technique.

$$\text{Moisture content } \% = \frac{\text{Weight of moist soil} - \text{Weight of dry soil}}{\text{Weight of dry soil}} \times 100 \quad (3)$$

Water productivity

Water productivity was obtained by dividing the yield by seasonal evapotranspiration using the following equation.

$$\text{Water productivity (WP)} = \frac{\text{Actual Yield,kg}}{\text{ETc m}^{-3}}$$

Cost of production

The direct cost associated with onion production per hectare under each treatment was computed by considering various inputs used to raise the produce under different treatments.

Net revenue

The monetary output per hectare was calculated from the existing market price and onion yield under each treatment.

Gross margin: The gross margin obtained per hectare was computed for each treatment by deducting the variable costs of production under specific treatment from the Net revenue of the same treatment.

Cost-benefit analysis

Benefit cost ratio (BCR) was used to determine the benefit obtained from a unit cost of input per hectare of produce for different treatments. It was computed using the expression below in equation (3);

$$\text{Benefit cost ratio} = \frac{\text{Gross margin (Rs/ha)}}{\text{Cost of production (Rs/ha)}}$$

Results and Discussion

Soil moisture: To monitor soil moisture levels in an onion crop, measurements were taken at various depths (0-10cm, 10-20cm, and 20-30cm) every 12 days during the irrigation period. Prior to irrigation, the soil moisture at a depth of 10cm was 89.3. After 12 days, the soil moisture at this depth varied among different treatment levels, with the highest moisture content observed in T_4 (115). Similarly, at a depth of 20cm, the soil moisture was 129.1 before irrigation, and after irrigation, the moisture increased, with the maximum moisture found in T_5 (150). The pattern was repeated for the 20-30cm depth of soil samples, where the soil moisture was highest at T_4 (177.3) before irrigation and reached a maximum of 189 after irrigation. From the provided data, it is evident that an increase in the number of irrigations results in higher soil moisture levels both before and after irrigation, and this effect is more pronounced as you go deeper into the soil. Additionally, the use of mulching had a significant impact on moisture levels, with mulched treatments displaying higher moisture content compared to unmulched treatments.

Number of leaves

The number of leaves per plant, as indicated in Table 1 and Figure 1/2, ranged from 7 to 12 across all treatments. Deficit irrigation, mulching, and fertigation had no discernible effect on the quantity of leaves per plant. The treatments that received 100% ETc, 80% ETc, and 60% ETc along with straw mulching (referred to as T_4, T_5, and T_6) exhibited the highest leaf counts. Conversely, treatments with limited water and no mulching showed the lowest leaf counts. Importantly, there was no significant difference in leaf count among various fertigation percentages.

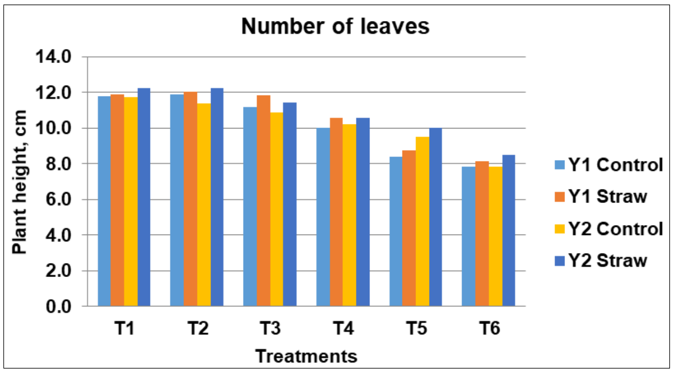

Fig 1: Mean number of leaves per plant as influenced by DI and mulching with fertigation Canopy Temperature

Canopeo, a mobile application, was employed to evaluate the temperature of the plant canopy. The assessments were made from a minimum distance of one foot from the canopy and were carried out daily for two hours, ranging from 12 to 2 PM, with a frequency of once a month. In a given net plot, temperature measurements were taken from four distinct directions, and these values were averaged and documented. The table below provides the recorded canopy temperature for an onion crop in the year 2022, with readings taken every 30 days post-transplantation.

Table 1: Pooled Effect of DI and mulching on canopy temperature (°C) of plant

Treatments	1 DAP	30 DAP	60 DAP	90 DAP
T_1	31.63	34.3	38.08	40.91
T_2	31.41	34.51	39.92	43.37
T_3	34.47	35.47	39.48	40.20
T_4	30.00	33.5	37.05	37
T_5	30.	33.5	37.05	37
T_6	32	31.54	36.06	38.20

Fertilizer use efficiency

From the above experiment it is clear that as yield of onion increase as fertigation percentage increases, from the table of onion yield treatment T_1(100% fertigation) and T_4 (100% fertigation with mulch) had the highest yield as the moisture increases bulb diameter increases and yield increases directly, At sub treatment of different fertigation level (100%, 75% and 50%) highest yield was found in 100% of fertigation level and there is no significant difference in yield at T_4 and T_5, so it I clear that more fertilizer used by plant more yield and there is no significant difference at 100% and 75% level of fertigation.

Water productivity

Water productivity was determined by calculating the yield of bulb onions per unit volume of water used (kg/m3) for various irrigation treatments. The most efficient water productivity (WP) was observed in the mulched treatment, particularly at T_5 and T_6, while the least efficient WP was seen at T_3 for both years. Notably, the water productivity values for 2023 were generally higher than those for 2022. In both years, the highest WP was consistently achieved at T_5 and T_6, while the lowest was at T_1 across all treatments. Specifically, the straw mulched treatment exhibited the greatest WP at T_4, with values of 6.00 kg/m3 in 2022 and 5.67 kg/m3 in 2023. In contrast, the control treatment demonstrated the highest WP at T_1 (5.90 kg/m3 in 2022 and 4.90 kg/m3 in 2023) and the lowest at T_5 (3.83 kg/m3 in 2022 and 3.13 kg/m3 in 2023). Refer to Tables 2 and 4.15 for further details.

Table 2: Effect of deficit irrigation and mulching on yield and water saving (%)

2022						
Treatments	T_1	T_2	T_3	T_4	T_5	T_6
100%	5.90	5.97	4.98	6.00	5.98	4.84
75%	5.73	5.70	4.70	5.98	5.97	4.30
50%	3.83	4.23	3.73	4.40	4.37	4.47
2023						
100%	4.90	4.89	3.60	5.67	5.72	4.00
75%	4.00	4.00	3.62	5.00	4.99	4.00
50%	3.13	3.40	3.03	4.87	4.87	4.79
Pooled						
100%	4.94	4.90	3.88	5.00	5.60	4.32
75%	4.43	4.32	4.11	5.21	4.10	3.99
50%	3.00	3.00	2.99	4.00	4.51	4.36

Table 3: Effect of deficit irrigation Fertigation and mulching on yield and water saving (%)

Treatments	Available water (mm)	Bulb yield (ton/ha)	Water saved (mm)	Yield reduction (%)
T_1	574	18.5	0	0.00
T_2	523	18.4	51	0.54
T_3	470	16.4	104	11.35
T_4	574	18.9	0	+2.11
T_5	523	18.4	51	+0.54
T_6	470	16.8	104	+9.20
(+) positive sign indicate increase in yield				

Economics of Deficit Irrigation and Mulching

In general, resources for agricultural production are usually scarce compared to a wide variety of available alternative investment choices. An evaluation of physical, financial and labour resources must be carried out to choose the most feasible and profitable alternative technology among many choices before committing the scarcely available resources. In light of the foregoing, it is necessary to compute the production cost involved, total net revenue and the gross margin before making any recommendation for adoption on a commercial scale. In the current study, the mentioned parameters for various treatments were calculated on per hectare basis and presented in Tables 4 and 5.

Table 4: Economic analysis of Deficit irrigation for Control Treatments

Treatment	Cost of production (Rs/ha)			Net revenue (Rs/ha)	Gross margin (Rs/ha)	Benefit cost ratio
	Onion cultivation cost	Drip installation cost	Total cost			
T_1	46800	35027	81827	226800	144973	1.56
T_2	46800	35027	81827	212400	130573	1.54
T_3	46800	35027	81827	186800	114973	1.27

Table 5: Economic analysis of Deficit irrigation with straw mulch treatments

Treatment	Cost of production (Rs/ha)			Net revenue (Rs/ha)	Gross margin (Rs/ha)	Benefit cost ratio
	Onion cultivation cost	Drip installation cost	Total cost			
T_4	48200	35027	83227	222200	138973	1.67
T_5	48200	35027	83227	217400	134173	1.61
T_6	48200	35027	83227	172000	113573	1.19

Necessarily suggest that the crop under a particular treatment produced higher yields. It simply means that the rupee value generated per unit cost of rupee invested was high.

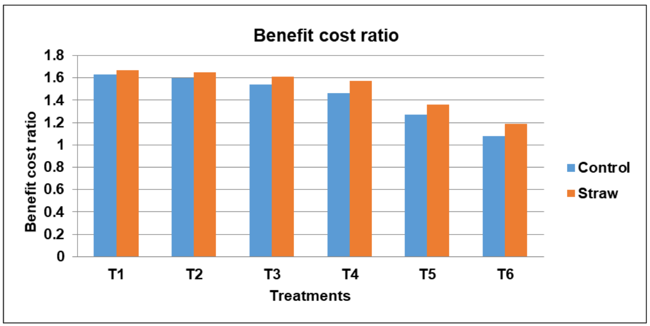

Fig 2: Benefit cost ratio of onion production under different treatments

Conclusion

1. It was found that T_5 (80% Etc. with mulch) gave maximum production of 18.1 Ton/ha as compare to treatment T_1 (100ETc without mulch). This shows very significant effect of mulching on water saving.
2. 20% Deficit irrigation, 25% deficit Fertilizer use application and paddy straw mulching gave maximum yield of onion 18.1 tons/ha as compare to 100% ETc., 100% Fertilizer use with no mulch.
3. Maximum water productivity was calculated to be 5.60kg/m3 at 75% level of fertigation.
4. The BC ratio for all the paddy straw mulch treatment was varying in the range of 1.19-1.67, while BC ratio for all the no mulch treatment was found to vary from 1.27-1.56. The effect in BC ratio due to cost of paddy straw mulching may be non-significant as it is available to farmers as free of cost.

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