Enhancing Maize Productivity through Mulching Practices in Semi-Arid Regions: Impact on Yield, Water Use Efficiency, and Economic Viability

ABSTRACT

Plastic film mulching (PF) was extensively used to improve maize yields, but its continuous application with ridge-furrow practices led to a significant depletion of soil organic carbon (SOC) and soil water storage (SWS). A study conducted during the 2018–19 rabi season on sandy loam soils evaluated the impact of different mulching techniques—Reflective Silver Plastic Mulch (RSPM), Rice Straw Mulch (RSM), Biodegradable Mulch (BM), and control without mulching (CK)—under irrigation regimes defined by IW/CPE ratios of 0.6, 0.8, and 1.0. The highest grain yields were achieved with an IW/CPE ratio of 1.0, with Reflective Silver Plastic Mulch significantly outperforming other treatments in grain yield (7086.57 kg/ha) and water use efficiency (WUE), followed by Biodegradable Mulch and Rice Straw Mulch. Reflective Silver Plastic Mulch also enhanced all major yield attributes, particularly when combined with the highest irrigation level, while the lowest values were observed under minimal irrigation and no mulch. The study concluded that irrigation at an IW/CPE ratio of 1.0 combined with Reflective Silver Plastic Mulch optimized maize yield, water use efficiency, and economic returns under drip irrigation.

Keywords: Plastic mulch, productivity, Biodegradable mulch, irrigation regimes, yield, WUE, B: C Ratios)

1. INTRODUCTION

Maize (Zea mays) was recognized as one of the most important and adaptable cereal crops globally, contributing significantly to food security in many developing nations. Water, being essential for all biological processes, played a crucial role in enhancing crop yields. High-quality water was used for various purposes, including irrigation, industrial activities, power generation, livestock needs, and domestic consumption in both urban and rural areas. In arid and semi-arid regions, annual crop evapotranspiration (ETc) often exceeded total precipitation, with nearly half of the evapotranspiration occurring through the soil surface. Farmland irrigation primarily relied on groundwater (Chauhan et al., 2008), but its overuse often led to scarcity. The water requirement for maize, ranked as the third most important cereal crop globally, ranged between 500 and 800 mm during the growing season (Brouwer et al., 1986).

An effective irrigation schedule required proper timing and the right quantity of water application. Developing water-saving strategies was also crucial for achieving stable or increased grain yields, especially in water-limited regions. Studies highlighted the growing preference for advanced irrigation techniques, such as sprinkler, drip, and subsurface drip systems (Zeng et al., 2009). Drip irrigation, in particular, proved effective in reducing soil evaporation and irrigation frequency while increasing efficiency by up to 90% (Tiwari et al., 2003). Improved irrigation efficiency further enhanced soil moisture retention under mulch with appropriate application frequency.

Mulching techniques included flat plastic covers (Zhang et al., 2015), plastic film mulching on ridges (Wang et al., 2009, 2015, 2016), and ridge-furrow mulching (Gu et al., 2016). Since the 1970s, advancements in modern industry enabled the widespread adoption of plastic film mulching for dryland agriculture in arid and semi-arid regions (Luo, 1982; Dong et al., 2009). These practices conserved soil moisture by regulating the balance between soil evaporation and plant transpiration. Both organic and plastic mulching significantly improved crop yields by enhancing soil moisture (Li et al., 2000; Wang et al., 2009), reducing evaporation (Wang et al., 2009, 2011), preventing nutrient loss, fostering a favorable microclimate, and maintaining optimal topsoil temperatures (Wang et al., 2011; Zhou et al., 2009).

Mulch films served multiple beneficial purposes, including water retention, temperature regulation, disease prevention, insect resistance, weed suppression, and the enhancement of crop growth, yield, and economic returns. These functions highlighted the importance of proper irrigation scheduling and the use of effective mulching techniques to maximize maize productivity while maintaining soil health. Effective scheduling involved selecting appropriate irrigation methods, applying the right quantity of water, and incorporating suitable mulching materials. By addressing these factors, it was possible to not only boost crop yields but also ensure long-term soil sustainability.

With this understanding, a study was conducted in 2018 at the College of Agricultural Engineering and Technology, Anand Agricultural University, Godhra, to evaluate the combined effects of various irrigation regimes and mulch conditions on maize performance. The research aimed to explore innovative strategies for enhancing productivity while optimizing resource use. Specifically, the study focused on two objectives: assessing the impact of drip irrigation regimes on maize productivity and evaluating the techno-economic feasibility of integrating drip irrigation with mulching practices. This research was novel in its approach, as it investigated the synergy between advanced irrigation techniques and mulching in improving maize yield, resource efficiency, and economic viability under semi-arid conditions, addressing critical challenges in sustainable agriculture.

2. MATERIAL AND METHODS

An experiment was conducted at the College Farm, College of Agricultural Engineering and Technology, Dholakuva, Godhra (Fig 1), to evaluate the effects of different drip irrigation levels (0.6 IW/CPE, 0.8 IW/CPE, and 1.0 IW/CPE) combined with various mulch types (silver-black plastic mulch, rice straw mulch, and biodegradable plastic mulch) and a control treatment (drip and furrow or ridge-furrow system) on the productivity of GAYMH-1 (Gujarat Anand Yellow Maize Hybrid-1). The experimental design followed a strip plot layout with twelve treatment combinations, each replicated four times.

The soil at the experimental site was sandy loam in texture, neutral in reaction, and non-saline, consisting of 61% sand, 21% silt, and 18% clay. The soil's hydraulic conductivity was 2.8 cm h^{-1}, with a moderate infiltration rate. The organic matter content was 0.42%, while the total nitrogen, available phosphorus, available potassium, and inorganic nitrogen levels were 21.43, 62.5, and 204 kg ha^{-1}, respectively, indicating a medium-fertility status for organic carbon, nitrogen, phosphorus, and potassium.

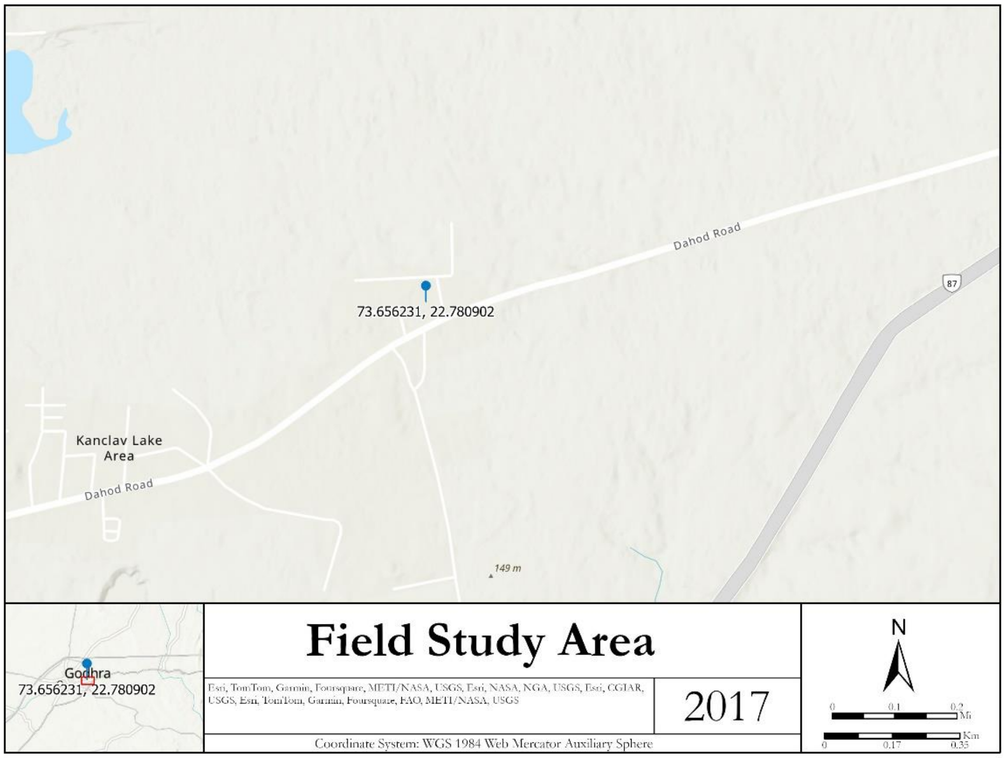


Fig 1 Base map of Study area, CAET, AAU, Godhara

Drip irrigation was applied every three days, tailored to the crop's water requirement during its growth period, while the furrow method followed a conventional schedule with 36 irrigations. The maize hybrid was planted with a spacing of 60 cm x 20 cm, and standard agronomic practices recommended by Anand Agricultural University were followed. Morphological parameters and yield attributes were monitored throughout the crop cycle to assess treatment effects on maize productivity. This study provided valuable insights into optimizing irrigation and mulching practices for improved yield and resource efficiency.

Table -1 Treatment combination for irrigation regimes and mulching

Treatments	**Irrigation Regimes, (I) (IW/CPE)**	**Mulch Type, (A)**	**Treatments Combinations**
1.	0.6	No Mulch (A_0)	I_1A_0

		Reflective Silver Plastic Mulch (A_1)	I_1A_1
		Straw Mulch (A_2)	I_1A_2
		Biodegradable Plastic Mulch (A_3)	I_1A3
2.	0.8	No Mulch (A_0)	I_2A_0
		Reflective Silver Plastic Mulch (A_1)	I_2A_1
		Straw Mulch (A_2)	I_2 A_2
		Biodegradable Plastic Mulch (A_3)	I_2A3
3.	1.0	No Mulch (A_0)	I_3A_0
		Reflective Silver Plastic Mulch (A_1)	I_3A_1
		Straw Mulch (A_2)	I_3 A_2
		Biodegradable Plastic Mulch (A_3)	I_3A3

Silver-black plastic mulch made of 25-micron LDPE with a 1.2 m width and biodegradable plastic mulch of 20 microns were chosen based on the row-to-row spacing of the maize crop. Round holes with a 5 cm diameter were punched at the center of the mulch film, and both ends of the film were anchored 3 inches into the soil. The mulching films were manually laid out. The configuration of the mulch and drip irrigation system is illustrated in Fig. 2.

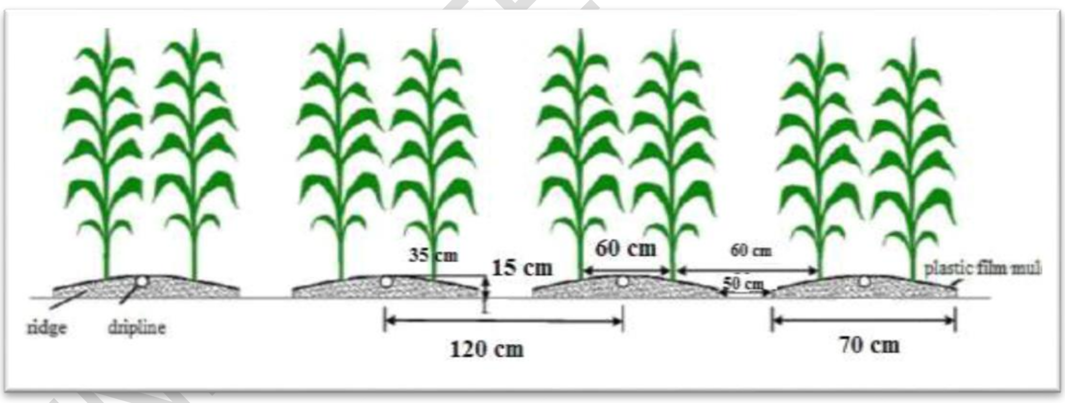


Fig: 2 Schematic diagram for maize crop pattern with drip line and mulching

For the rice straw mulch treatment, air-dried rice straw collected from the previous rice crop was applied uniformly at the rate of 6 t/ha (600 g/m²) immediately after sowing. This rate created a 3 cm thick straw layer on the soil surface, providing effective coverage.

To monitor growth, plants from a 1.2 m² area within each net plot were selected and labeled for accurate identification. Observations included plant height, the number of leaves, the number of cobs per plant, grains per plant, grain weight per plant, and the number of grain rows per cob. These measurements provided a comprehensive assessment of the effects of the treatments on the maize crop's growth and productivity.

3. RESULTS AND DISCUSSION

3.1 Yield attributes

Incorporating mulch with drip irrigation significantly improved seed maize yield compared to treatments without mulch. Data on grain yield, as influenced by different irrigation schedules and mulching treatments (Fig. 3), revealed that both factors had a significant impact. Maize grain yield increased consistently with crop maturity, irrespective of the treatment combinations. The highest grain yield (8164.06 kg/ha) was recorded in the treatment combining a 1.0 IW/CPE ratio with reflective plastic mulch (I_3A_1), outperforming all other combinations. Treatments I_2A_1 and I_1A_1 produced yields comparable to I_3A_1. In contrast, the lowest yield (3812.84 kg/ha) was observed in the treatment with a 0.6 IW/CPE ratio and no mulch (I_1A_0).

The interaction between irrigation levels and mulching significantly influenced maize yield. The superior performance of the I_3A_1 combination was attributed to enhanced soil moisture availability, facilitated by reduced evaporation and better moisture conservation under the reflective mulch. Additionally, mulching regulated soil temperature, further contributing to improved growth and yield components. Enhanced soil moisture in the upper 30 cm layer under drip irrigation increased plant water status, as indicated by higher relative water content and reduced leaf water potential, aligning with findings by Viswanatha et al. (2002). These results corroborate the findings of Khurshid et al. (2006), who reported that maize yields responded positively to higher soil water content in mulched plots due to minimized evaporation losses.

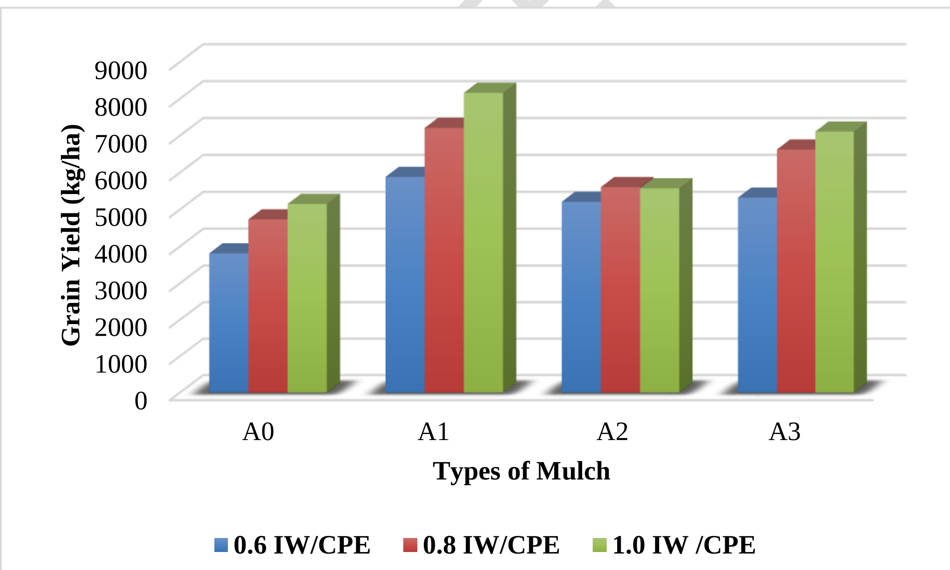
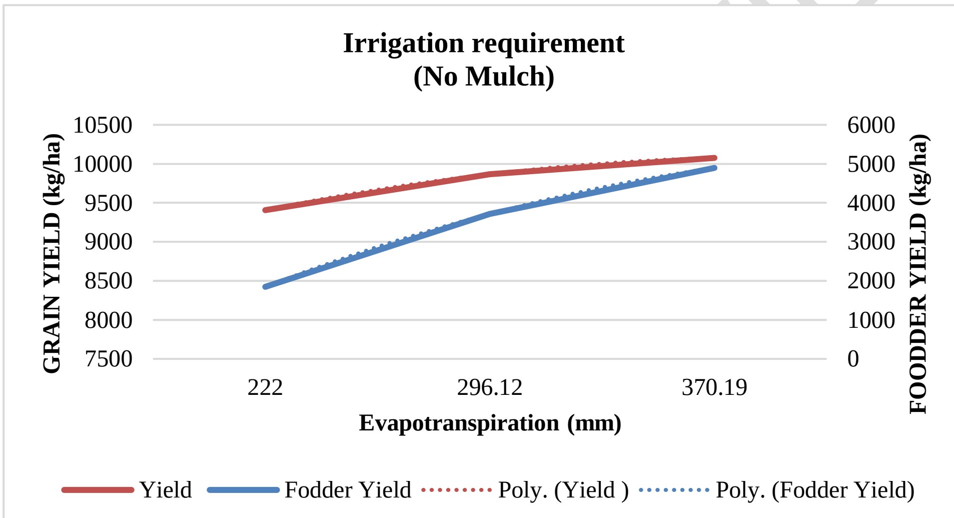


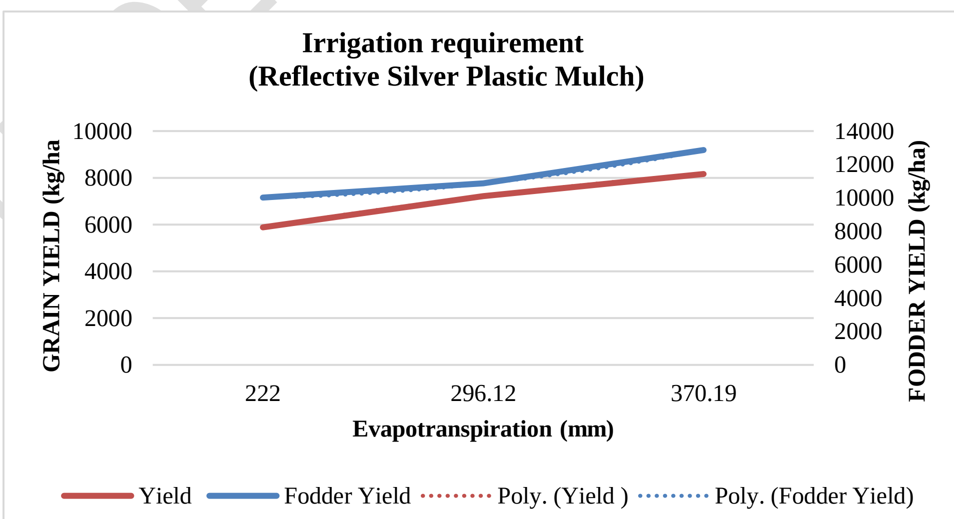
Fig. 3 Irrigation Regimes and Mulching Effect on Grain Yield of Maize

3.2 Irrigation water

A total of 36 irrigations were administered to maize across all treatments during the growing season, with the amount of irrigation water applied ranging from 222 mm to 370.19 mm. Seasonal crop water use values varied between 176.17 mm and 370.19 mm, with the highest usage observed in the full irrigation treatment due to an adequate soil water supply and the lowest in the non-irrigated treatment (Fig.4). These variations were influenced by climatic conditions and irrigation scheduling. Comparatively, seasonal crop water use of maize has been reported as 474.2–605.8 mm in the Cukurova region (Kanber et al., 1990), 353–586 mm in the Thrace region (Istanbulluoglu and Kocaman, 1996), and 357–587 mm by Tolk et al. (1998). Other studies have reported ranges from 494–644 mm (Katerji et al., 1996) to 169–547 mm (Dagdelen et al., 2006) and 385.4–537.1 mm (Igbadun et al., 2006). Moosavi (2012) noted that reductions in irrigation volumes affected ear diameter and length within thresholds of 0–400 mm. A positive linear relationship between crop water use and maize yield has been consistently observed (Payero et al., 2006; Dagdelen et al., 2006).



(A)



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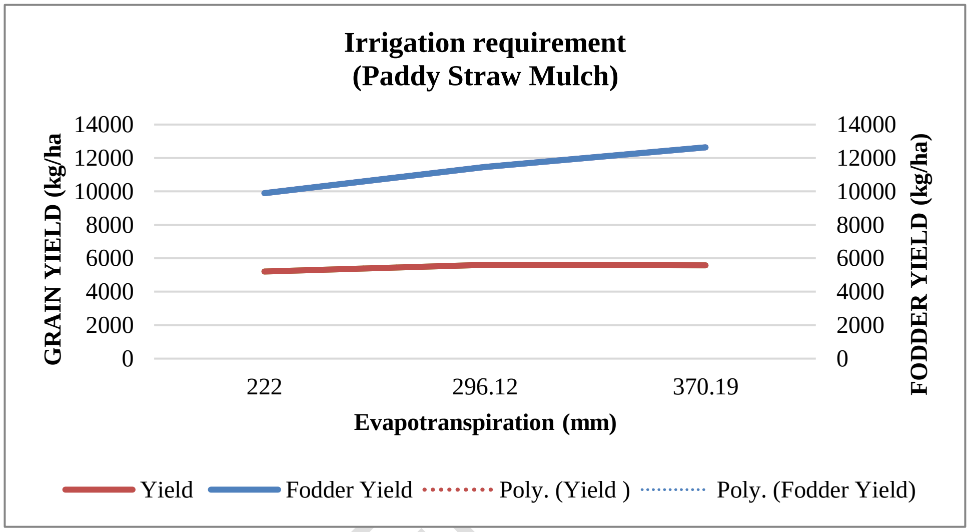

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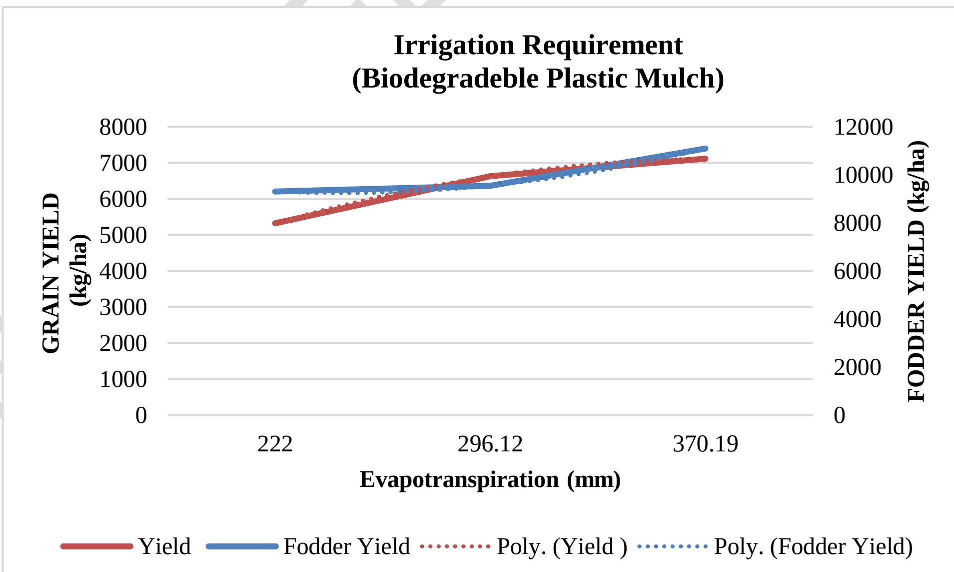

(D)

Fig. 4 (A), (B), (C) and (D) Irrigation water requirement for different mulches treatment

3.3 Water Use Efficiency

The mean water use efficiency (WUE) for various treatments is presented in Fig. 5. Due to the high water-holding capacity of mulches, soil moisture was better retained in the surface layers. A graphical summary of WUE data as influenced by irrigation regimes and mulching shows that the highest water productivity was observed in the I_2A_1 treatment, while the lowest was recorded in I_3A_0. Treatments such as I_1A_0, I_2A_0, I_3A_0, and I_3A_2 demonstrated statistically similar WUE values. Across all irrigation schedules, the use of plastic mulch consistently resulted in higher WUE compared to their respective schedules without mulch.

In treatments with mulches, WUE decreased as the IW/CPE ratio increased. Among all mulches, reflective silver plastic mulch exhibited superior WUE performance compared to other materials. These findings align with previous studies: Musick and Dusek (1980) reported an IWUE for maize ranging from 2.44 to 2.70 kg/m³, Howell et al. (1995) found values between 1.51 and 2.48 kg/m³, and Caldwell et al. (1994) determined a range of 2.07 to 2.76 kg/m³. Variations in IWUE are influenced by factors such as irrigation frequency and method, plant density, and microclimate conditions, as highlighted by Domínguez et al. (2012) and Grassini et al. (2013).

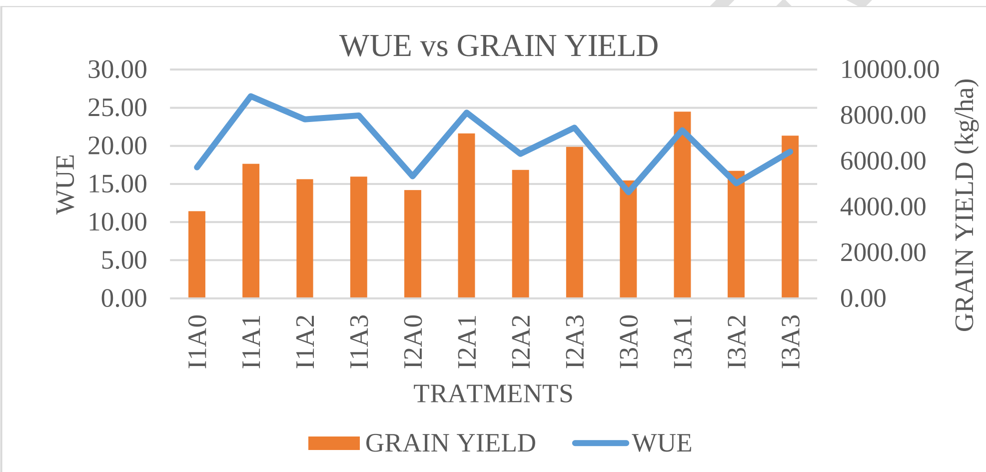

Fig.5 Effect of Grain Yield and WUE on difference treatments of Irrigation regimes and mulches for maize

3.4 Economics

The economics of drip irrigation combined with silver-black plastic mulch, rice straw mulch, drip without mulch, and furrow irrigation under varying irrigation regimes were estimated for one hectare based on the prevailing rates of 2019. The higher crop value resulted from even a marginal increase in yield, which significantly boosted the value of the crop output. According to Dhawan (2000), this increase in value was also attributed to the improved market price realization, stemming from better quality crops and earlier market arrival of drip-irrigated produce. The highest and lowest benefit-cost ratios (BCR) were 2.3 and 1.035 for the I_3A_1 and I_1A_3 treatments, respectively. Paddy straw mulch yielded a BCR of 1.68, mainly due to the lower market price of paddy straw. However, reflective silver plastic mulch resulted in significantly higher grain yields compared to biodegradable plastic mulch and other treatments.

Table -2 Techno Economic Analysis Maize with Mulching and Drip Irrigation

Treatment	Seed Yield (kg/ha)	Fodder Yield (kg/ha)	Variable Cost (Rs/ha)	Fixed Cost (Rs./ha)	TCC (Rs./ha)	Gross Income (Rs./ha)	NR (Rs./ha)	BCR
I_1A_0	3812.85	8423.61	18490	39204.37	57694.37	101528	43833.41	1.76
I_1A_1	5883.16	10017.36	80740	39204.37	119944.37	147715	27770.91	1.23
I_1A_2	5209.72	9895.83	56290	39204.37	95494.37	133882	38387.57	1.40
I_1A_3	5323.26	9305.56	95890	39204.37	135094.37	138958	3863.63	1.03
I_2A_0	4733.85	9357.64	18490	39204.37	57694.37	122750	65055.63	2.13
I_2A_1	7212.50	10868.06	80740	39204.37	119944.37	176854	56909.80	1.47
I_2A_2	5608.68	11467.01	56290	39204.37	95494.37	146575	51080.28	1.53
I_2A_3	6626.74	9548.61	95890	39204.37	135094.37	161181	26086.19	1.19
I_3A_0	5152.08	9947.92	18490	39204.37	57694.37	132885	75191.05	2.30
I_3A_1	8164.06	12864.58	80740	39204.37	119944.37	201875	81930.63	1.68
I_3A_2	5576.39	12637.15	56290	39204.37	95494.37	149439	53944.87	1.56
I_3A_3	7113.54	11093.75	95890	39204.37	135094.37	175552	40457.71	1.30

4. CONCLUSION

Drip irrigation combined with silver-black plastic mulch scheduled at 0.8 ETc showed superior performance in terms of morphological variables, yield attributes, and water use efficiency (WUE) compared to rice straw mulch, drip without mulch, and furrow irrigation systems. The benefit-cost ratio (BCR) of maize was calculated as the ratio of net seasonal return to the cost of cultivation, with the highest BCR of 2.3 observed for the I_3A_1 treatment and the lowest of 1.035 for I_1A_3. Paddy straw mulch yielded a BCR of 1.68, mainly due to its lower market value. Reflective silver plastic mulch outperformed biodegradable plastic mulch in terms of grain yield. Furthermore, the combination of mulch and drip irrigation resulted in a 60% water saving over furrow irrigation. The highest BCR of 3.2 and an internal rate of return (IRR) of 94.83% were observed for the silver-black plastic mulch scheduled at 0.8 ETc, making it the most economically viable and water-efficient option.

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