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Effects of Deficit Irrigation and Mulching on Yield and Water Productivity of Furrow Irrigated Phaseolus Vulgaris in Anchar Condition, Eastern Ethiopia

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Abstract: Water saving in agriculture intends to raise water use efficiency resulting in higher economic yield on irrigated farm land with minimum usage of water. An experiment was conducted to investigate the effect of deficit furrow irrigation and mulching on yield and water productivity of Phaseolus Vulgaris, in Anchar Woreda, Eastern Ethiopia. The experiment was conducted using a randomized complete block design (RCBD) with three replications considering three irrigation level (100%ETc, 85%ETc and 70% ETc) and three mulching technique (no mulch, straw and plastic mulch). The results showed that maximum Phaseolus vulgaris yield (5.38 ton ha^{-1}) was achieved under full irrigation combined with plastic mulch, which significantly exceeded all other treatments. The application of plastic mulch under full irrigation increase yield by 28.70% compared to non-mulched conditions. However, the highest water use efficiency (0.64 kg m^{-3}) was observed under deficit irrigation at 70% ETc combined with plastic mulch. Therefore, for water scarce regions such as Anchar district the adoption of deficit furrow irrigation at 85% ETc combined with plastic mulching is recommended. In areas with sufficient water resources, full irrigation under plastic mulch is preferable.

Keywords: Deficit irrigation, mulching, common bean, yield, water productivity

1. Introduction

The rapidly growing population of Ethiopia is leading to a higher demand for food. The existing agricultural land area, the technology employed by farmers, the reliance solely on rainfall, the production conditions, and the impact of climate change are inadequate to satisfy the needs of the increasing population [1].

The government is presently concentrating on irrigation development to address this problem at its core. Nevertheless, the expected outcomes have not been realized because of insufficient focus on making effective use of these irrigations and available water resources [2].

The scarcity of water in the country is the most severe constraint for the development of agriculture in arid and semi-arid areas. Enhancing the water use efficiency of irrigated crops through field irrigation management is a vital option in water-scarce areas [3], [4] .

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Improving water productivity in moisture stressed area is a major attention through different water saving technologies like, supplementary irrigation, evaporation minimization techniques like mulching and greenhouse farming, different furrow irrigation managements and other suitable technologies [5].

Deficit irrigation has been suggested as an alternative strategy for making better use of irrigation water where the amount of irrigation water applied is less than the actual crop water requirement either during a particular period or throughout the whole growing season while minimizing adverse effects on yield [6],[7]. Reduced yield as a result of deficit irrigation, especially under water limiting situations, may be compensated by increased production from the additional irrigated area with the water saved by deficit irrigation [8], [9], [10].

Mulching has been widely used as a moisture conservation tool that improves soil moisture content and consequently increases water use efficiency [11]. Besides conserving soil moisture, polyethylene plastic mulch also increases soil temperature and moisture in early spring, reducing weed problems and certain insect pests and stimulating higher crop yields by more efficient utilization of soil moisture [10],[12].

Common bean (*Phaseolus vulgaris*) is the major crop cultivated across Ethiopia, serving both as economic commodity and essential source of food security and nutrition [13].In western Hararghe, including the Anchar district, farmers traditionally cultivate common bean alongside sorghum and maize in intercropping systems to secure yields and enhance soil fertility through nitrogen fixation. However, in recent years, delayed rainfall has increased the risks associated with growing maize and sorghum, leading farmers to replace these crops with common bean [14]. The area under common bean cultivation has therefore expanded, as its early maturity provides households with rapid cash returns to meet food and other essential needs.

Nevertheless, water scarcity during the dry season remains a major constraint and making the precise control of irrigation frequency and depth essential for optimizing the productivity to ensure food security in the region. Thus, efficient use of irrigation water is increasingly critical, requiring coordinated efforts to improve water use efficiency in agriculture. Therefore, the objective of this paper was to investigate the effects of deficit furrow irrigation and mulching practices on yield and water productivity of Common Beans (Phaseolus vulgaris).

2. Materials and Methods

2.1 Study Area

Field experiment was conducted at Anchar district located in West Hararghe zone, Eastern Ethiopia. The area is located between 8.55°-8.95° N latitude and 40.05°-40.35°E longitude at average elevation of 2300 m a.s.l.

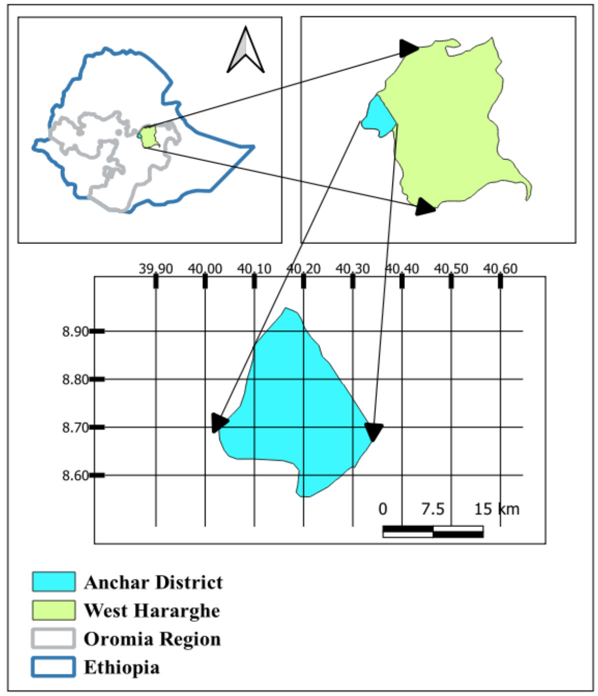

Figure 1: The study area location map.

The mean monthly maximum and minimum temperatures of Anchar district is 33°C and 10.8 °C, respectively. It is characterized by unimodal, low, and erratic rainfall patterns with average annual rainfall of 767 mm. The soil is dominated by clay loam type with 34.95% sand, 28.40% silt and 36.65% clay. The top 30 cm of the soil at the experimental site has average field capacity of 33.12%, permanent wilting point of 17.82%, and bulk density of 1.1 g cm-3. The total available water content was approximately 50.49 mm m^{-1} depth.

2.2 Experiment Design and Treatment

The effect of deficit irrigation and mulching practices on yield and water productivity of Phaseolus vulgaris was investigated. The experiment was conducted using randomized complete block design (RCBD) with three replications, considering two factors: irrigation level and mulching technique. The irrigation treatments included 100% ETc, 85% ETc, and 70% ETc, while the mulching treatments comprised no mulch (NM), teff straw mulch (SM), and white plastic mulch (PM).The detail experimental treatments were presented in Table 1.

A field experiment was conducted during the dry cropping season. The experimental area was ploughed and subdivided into 27 plots, each measuring 3m × 5m. Every plot accommodated five furrows with ridge spacing of 60 cm and furrow length of 5m. The buffer zone between plots was 1.5m, whereas the spacing between blocks was 2m.

After plot preparation, highly stress- resistant bean variety named Awash Melka was planted on prepared experimental field plots. For this experiment, 100 kg ha-1

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of Di-Ammonium Phosphate (DAP) and urea fertilizer was uniformly applied to the plots.

Uniform light irrigation was applied for ten days before treatment initiation, after which three irrigation regimes were imposed: full irrigation (100% ETc) and two deficit levels (85% ETc and 70% ETc). Mulching technique of 6 ton ha-1 was done using teff straw mulch and also plastic mulch was applied to comparable area plot.

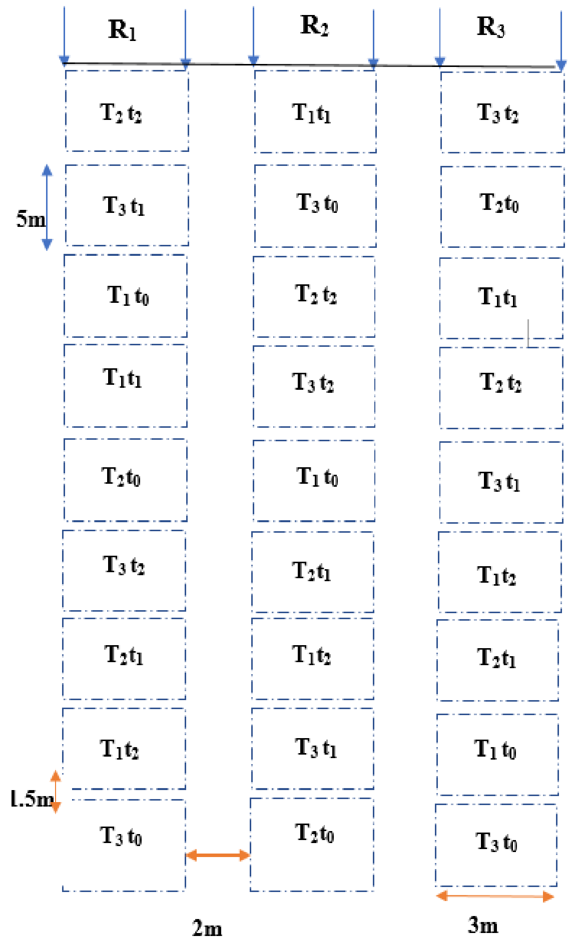

Figure 2: Experimental plot and treatment conditions where, T1 is 100%ETc, T2 is 85%ETc, and T3 is 70%ETc and t0 is No Mulch, t1 is Straw Mulch and t2 is Plastic Mulch

Table 1: Detail description of treatments

Treatment labels (%ETc x Mulching)	Treatment description
100 x NM	Full irrigation depth with no mulch
100 x SM	Full irrigation depth with straw mulch
100 x PM	Full irrigation depth with plastic mulch
85 x NM	85% of Full irrigation depth with no mulch
85 x SM	85% of Full irrigation depth with straw mulch
85 x PM	85% of Full irrigation depth with plastic mulch
70 x NM	70% of Full irrigation depth with no mulch
70 x SM	70% of Full irrigation depth with no mulch
70 x PM	70% of Full irrigation depth with plastic mulch

ETc: crop evapotranspiration, NM: no mulch, SM: straw mulch, PL: plastic mulch

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2.3 Data Collection and Analysis

Field experiment was carried out during dry cropping season from December 2023 to the end of March 2024.

Table 2: The growth stage of the crop

Stage	Days	Period
Initial	20	15 Dec 2023 → 4 Jan 2024
Development	25	5 Jan 2024 → 29 Jan 2024
Mid-season	35	30 Jan 2024 → 4 Mar 2024
Late season	25	5 Mar 2024→ 29 Mar 2024
Total	105	Harvest ≈ 29 Mar 2024

Data on grain yield was collected and recorded from three middle rows of each plot and five randomly selected plants from those rows. Crop water use efficiency was determined as the ratio of harvested yield to the total water lost through crop evapotranspiration, while irrigation water use efficiency was estimated as the ratio of harvested yield to the total volume of irrigation water applied, as expressed below.

$$CWUE = \frac{Y}{ET_c} ----------- (1)$$

$$\mathrm{IWUE} = \frac{\mathrm{Y}}{\mathrm{I_g}} ------------ (2)$$

$$1 - \frac{Y_a}{Y_m} = K_y\left(1 - \frac{ET_a}{ET_m}\right) ------ (3)$$

where CWUE is crop water use efficiency (kg $ha^{-1}mm^{-1}$), Y is yield in kg ha^{-1}, ETc is crop evapotranspiration (mm), ETa actual evapotranspiration (mm), ETm is maximum evapotranspiration (mm), IWUE is irrigation water use efficiency (kg $ha^{-1}mm^{-1}$), I_g is gross irrigation water applied (mm) that includes all losses, Ya is actual harvested yield (ton ha^{-1}), Ym is maximum harvested yield (ton ha^{-1}), Ky is yield response factor.

2.4. Statistical Analysis

The data collected were statistically analyzed using GenStat software. When the treatment effects are found significant, the least significance difference (LSD) test was used to assess the difference among treatments.

3. Results

3.1. Effects of Deficit Irrigation on Crop Yield and Water Use Efficiencies.

The study analyzed the effect of deficit irrigation on crop yield, crop water use efficiency and irrigation water use efficiency. The analysis of variance showed that deficit irrigation significantly affects crop yield (common bean) at $p<0.01$ (Table 3). Data presented in Table 3 indicates that 30% deficit water application was resulted in low total yield (4.12 ton ha^{-1}) as compared to that obtained under full irrigation (5.18 ton ha^{-1}).The maximum amount of yield obtained under full irrigation might be due to applying the right amount of water required by the crop to complete its growth period. The findings indicate that grain yield declined as the irrigation level decreased, with reductions of 7.1% and 20.5% at 85% and 70% ETc, respectively, compared to full irrigation.

Table 3: Deficit irrigation and mulching effects on common bean yield and water use efficiencies

Deficit Irrigation (%ETc)	Ya (ton/ha)	CWUE (kgha^{-1}mm^{-1})	IWUE (kgha^{-1}mm^{-1})
100	5.18a	0.60c	0.46c
85	4.81b	0.62b	0.58b
70	4.12c	0.64a	0.73a
CV (%)	6.00	2.60	5.20
LSD(0.01)	0.39	0.01	0.04
Mulching			
No Mulch	4.02c	0.60c	0.56b
Straw Mulch	4.71b	0.62b	0.59a
Plastic Mulch	5.38a	0.64a	0.60a
CV (%)	6.00	2.60	5.20
LSD(0.01)	0.39	0.01	0.04
Interaction Effect (% ETc x Mulching)			
100 x NM	4.30cb	0.49e	0.44d
100 x SM	5.20ab	0.45e	0.48c
100 x PM	6.03a	0.49e	0.46dc
85 x NM	4.07cb	0.67c	0.55c
85 x SM	4.70b	0.64c	0.63ba
85 x PM	5.63a	0.61cd	0.55c
70 x NM	3.67cb	0.76ba	0.69a
70 x SM	4.23cb	0.77a	0.75a
70 x PM	4.47b	0.81a	0.76a
CV (%)	6.00	2.60	5.20
LSD(0.01)	0.67	0.04	0.07

SM-straw mulch PM-plastic mulch, NM-no mulch, CV-coefficient of variation, LSD-Least significance difference. The superscripts (a, b, c, d, e, ab, ba, cb, dc) in the paper indicate the statistical significance of the differences between the mean values presented in the table. This is based on the LSD (Least Significant Difference) test, which was performed on the data. When comparing mean values within the same column, if two values have different letters (for example, 'a' versus 'b', or 'a' versus 'c'), it means the difference between them is highly significant. On the other hand, if two values in the same column share the same letter (for example, if both results are marked with 'b'), it means that any difference between them is not statistically significant.

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The effect of deficit irrigation on crop and irrigation water use efficiencies was also highly significant at p<0.01. At the 30% deficit irrigation level, the maximum crop and irrigation water use efficiencies were observed, with values of 0.64 and 0.73 kg m^{-3}, respectively. In contrast, the minimum mean values, 0.60 and 0.46 kg m^{-3} for crop and irrigation water use efficiency, respectively, were recorded under full irrigation (100% ETc). Both crop water use efficiency (CWUE) and irrigation water use efficiency (IWUE) improved under deficit irrigation. CWUE increased by 3.3% at 85% ETc and by 6.7% at 70% ETc, while IWUE showed even greater improvements of 26.1% and 58.7% at the same irrigation levels. These results demonstrate that deficit irrigation leads to a measurable reduction in yield and considerably enhances water use efficiency.

3.2. Effect of Mulching Practices on Crop Yield and Water Use Efficiencies

The analysis of variance at (p<0.01) indicates that straw and plastic mulching had significant influence on crop yield and crop and irrigation water use efficiencies (Table 3). Plastic mulch produced a significantly higher crop yield (5.38 ton ha^{-1}) as compared to no mulch treatment (4.02 ton ha^{-1}). Similarly, plastic mulch treatment resulted in higher crop water use efficiency (0.64 kg m^{-3}) and irrigation water use efficiency (0.60 kg m^{-3}). This might be attributed to the capacity of mulch to reduce soil evaporation, improving availability of moisture in the root zone, and suppress weeds. However, no mulch treatment has resulted in low crop water use efficiency (0.60 kg m^{-3}) and irrigation water use efficiency (0.56 kg m^{-3}). The comparative analysis of crop yield under different mulching practices revealed a progressive increase in yield, following the order: no mulch < straw mulch < plastic mulch.

3.3. Interaction Effects of Deficit Irrigation and Mulching.

The interaction effects of various deficit irrigation levels and mulching practices were found to be highly significant at 1% level of significance. This means both deficit irrigation and mulching practices have significant effect on the yield of common bean, and crop and irrigation water use efficiencies. The maximum yield (6.03 ton ha^{-1}) was obtained under the combined application of full irrigation and plastic mulching, representing a 28.7% increase compared to full irrigation without mulch. In contrast, the lowest yield was recorded under the interaction of 30% deficit irrigation with no mulching.

3.4. Yield Reduction

The results reveal that the yield response factor (KY) declined as irrigation decreased from 85% ETc to 70% ETc. At 85% ETc, the highest KY (3.04) values were recorded without mulch, followed by teff straw mulch and plastic mulch, as illustrated in Figure 3. A higher crop reduction factor reflects greater yield loss under water stress; however, a 15% deficit irrigation regime combined with plastic mulch resulted in the lowest reduction factor (0.81). Plastic mulch consistently had the lowest KY under both irrigation levels, demonstrating its superior capacity to conserve soil moisture and reduce yield sensitivity to water deficits. The finding also indicated that KY is not only influenced by irrigation level but also by mulching practices, with plastic mulch offering a significant advantage in reducing the impact of water stress on crop yield.

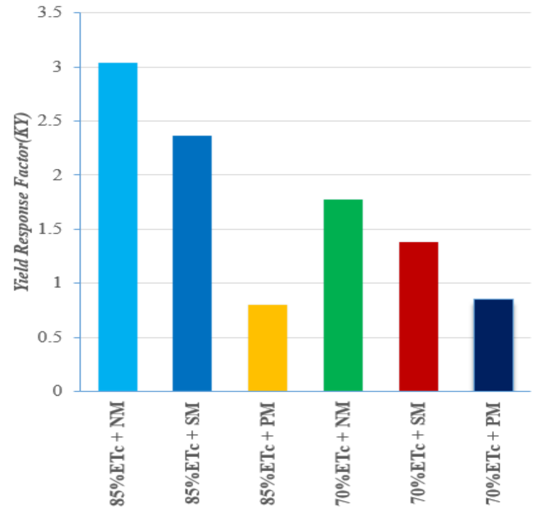

Figure 3: Yield factor response for different treatments

4. Discussion

In the present study, the maximum yield of common bean (5.18 ton ha^{-1}) was obtained under 100% ETc, while the minimum yield (4.12 ton ha^{-1}) was recorded under 70% ETc. This trend is consistent with the findings of reference [15], who reported a maximum grain yield of 4.52 ton ha^{-1} for maize under 100% ETc and a minimum yield of 3.67 ton ha^{-1} under 50% ETc. This finding implies that crop yield is directly associated with soil moisture availability. Similarly, [16] reported a decrement in yield with reduced irrigation water application. Both crop and irrigation water use efficiencies were found to be relatively high under a 70% ETc deficit irrigation level. Thus, the water conserved at this level could potentially be utilized to expand the irrigated area without causing significant adverse effects on yield.

Mulching serves as important irrigation water management practice that improves water productivity, particularly under water-limited conditions. Among the treatments, plastic mulch resulted in significantly higher crop yield (5.38 ton ha^{-1}) compared with the no mulch condition. A research finding by [17] revealed that mulching significantly improves soil water conservation and regulates seasonal crop water use in irrigated tomato production. Furthermore, [18] reported that white polythene mulch outperformed black polythene, paddy straw, and forest leaf mulch in terms of grain yield and

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water use efficiency. This was attributed to its ability to reflect solar radiation, thereby avoiding excessive root zone heating compared to black polythene mulch.

To enhance water conservation and agricultural productivity, the combined application of deficit irrigation and mulching is highly important. Findings from the present study indicate that applying 15% and 30% deficit irrigation in conjunction with plastic mulch resulted in relatively higher crop yield and improved irrigation water use efficiency. The finding by reference [19] suggested that crop and irrigation water use efficiencies were highest at the 75% irrigation water deficit, and imposing irrigation deficit levels beyond 50% is not advisable. The study by reference [7] demonstrated that mulching materials, drip deficit irrigation and mulch layer thickness had significant effect on yield of beans . Similarly,[20] indicated that irrigation and mulch rates had significant effect on grain yield of maize crop. The study of reference [21]reported that the lowest irrigation level in field-grown beans resulted in the highest crop and irrigation water use efficiencies, demonstrating the potential benefits of deficit irrigation in improving water productivity.

The observed yield response factor declined with reduced irrigation water application, consistent with the findings of study [22], which reported that the yield response factor is highly sensitive to water stress. Crop response factors below unity under 15% and 30% deficit irrigation with plastic mulch suggested that these levels of water reduction can be acceptable management options, and 85% ETc with plastic mulch is the best combination.

5. Conclusions

Deficit irrigation combined with mulching had a statistically significant effect on both crop yield and water productivity. The interaction between irrigation levels and mulching practices was highly significant ($p < 0.01$) during the experiment.

To maximize crop yield, the combination of full irrigation (100% ETc) and plastic mulch proved to be the most effective treatment, resulting in the highest yield of 6.03 ton ha^{-1}. This reflects a 28.7% increase compared with full irrigation without mulch. Therefore, in regions with adequate water availability, farmers can use full irrigation with plastic mulch to achieve high production potential.

However, in water-scarce regions, deficit irrigation is a highly effective strategy for optimizing water use. This study also showed that as irrigation levels decreased water use efficiency increased. The highest crop water use efficiency 0.64 kg m^{-3} was recorded at 70% ETc deficit level especially when combined with plastic mulch. According to this finding, it is recommended that farmers adopt 85% ETc in combination with plastic mulch for common bean production in regions with limited irrigation water availability to keep minimum yield response factor or yield loss. This leads to an option for expanding of irrigated area by the water saved through deficit irrigation without imposing significant adverse

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