Comparative Assessment of Water Productivity and Crop Performance of Cluster Bean, Cowpea and Pearl Millet in Arid Zones"

Abstract

Arid and semi-arid regions face mounting challenges due to water scarcity exacerbated by climate change, necessitating sustainable agricultural practices to ensure food security and economic stability. This study compares the water productivity and crop performance of Cluster Bean (*Cyamopsis tetragonoloba* L), Cowpea (*Vigna unguiculata* L.) and Pearl Millet (*Pennisetum glaucum* L.) under sprinkle irrigation in the Thar Desert, India. The experiment, conducted over two years (2022 and 2023) at ICAR – CSWRI – Arid Region Campus, Bikaner evaluated plant height, leaf number, branch development, fresh and dry biomass yields and water productivity. Pearl Millet exhibited the tallest plants (160.03 cm) and highest water productivity (1.57 kg/m³), emphasizing its drought resilience and efficient water use. Cowpea demonstrated substantial biomass production (average fresh weight of 16,348.75 kg/hac.) and moderate water productivity (1.16 kg/m³), suitable for forage and soil improvement. Cluster Bean, although less productive in biomass, showed adaptability with increased branching (from 4.65 to 7.35 branches/tiller/plant), indicative of its resilience in arid conditions. These findings underscore the importance of crop selection and management practices in maximizing agricultural productivity and resource use efficiency in water-limited environments.

Key Words: - Cluster Bean, Cowpea, Pearl Millet, Water productivity, Crop performance, Arid regions, Drought tolerance, Sustainable agriculture and Biomass yield.

1. INTRODUCTION

Arid and semi-arid regions face escalating challenges in agricultural sustainability due to increasing water scarcity exacerbated by climate change. Efficient water management and enhancing crop productivity per unit of water used (water productivity) are imperative to ensure food security and economic stability in this adverse climatic condition. Cluster bean (*Cyamopsis tetragonoloba* L.) Cowpea (*Vigna unguiculata* L.) and pearl millet (*Pennisetum glaucum* L.) are

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staple crops grown in arid regions contributing significantly to local food security and rural livelihoods depends on Agri- based livestock production system. Understanding of overall water productivity of fodder crop is crucial for calculating the virtual water requirement of livestock production as fodder contribute significant part of this requirement.

Cluster bean, Cowpea and pearl millet are selected for this study due to their importance as drought-tolerant crops and their adaptability to arid conditions. These crops exhibit varying degrees of water requirement and drought tolerance mechanisms, influencing their productivity under limited water availability. Pearl millet, characterized by its deep root system and C4 photosynthetic pathway, is known for its resilience to drought stress and efficient use of water. In contrast, cowpea and cluster bean, while also possessing drought tolerance traits, may exhibit higher sensitivity to water deficits, impacting their growth, yield and overall water productivity.

The research seeks to identify optimal water requirement strategies and agronomic practices that enhance crop yield under varying water availability. Such insights are essential for sustainable agricultural development in arid regions. The study aims to assess the comparative water productivity of cowpea, pearl millet and cluster bean under sprinkle irrigation regimes in arid environments.

2. Materials and Methods

Experimental Location

The study was conducted at ICAR – CSWRI – Arid Region Campus, Bikaner (28^0 18' 0" N latitude, $73^0$30' 0" E longitude and 236 meters above sea level) in the heart of the Thar Desert. The experimental period covered two planting cycles: July to October 2022 and 2023. The arid climate is characterized by hot, dry conditions with irregular rainfall (annual range: 260 to 440 mm). Mean max. and min. temperature ranges between 22.7 to 36.57°C. The soil type is characterized as sandy loam. Detailed climatic variables during the growing periods of 2022 and 2023 are summarized in Table 1.

Crop Species and Planting Details

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Three fodder crops were studied: cluster bean (*Cyamopsis tetragonoloba L.*) variety of RGC-936, cowpea (*Vigna unguiculata L.*) variety of Kohinoor and pearl millet (*Pennisetum glaucum L.*) variety of Raj Bajra–1. Sowing was conducted on July 5, 2022 and 2023, with seeding rates of 40 kg/ha for cluster bean, 30-40 kg/ha for cowpea and 10 kg/ha for pearl millet.

Fertilizers

At sowing, fertilizers were applied per plot: for cowpea and cluster bean, 0.31 kg urea and 1.8 kg single super phosphate (SSP) were used, while for pearl millet, 0.940 kg urea, 1.80 kg SSP and 0.480 kg Muriate of Potash (MOP) were applied per plot. Fertilizers were incorporated into the soil as basal dressing, with split doses of urea applied later in two stages. RDF dose required for Cluster bean, cow pea are 20:40 (N: P_2O_5) and for Pearl millet are 60:40:40(N:P: K).

Experimental Procedures

1. **Crop Management**: Standard agronomic practices were followed, including weeding, pest control and irrigation scheduling based on crop water requirements.
2. **Data Collection**: At harvest, biomass from each plot was collected and oven-dried at 100°C to determine dry weight using an electronic balance.

Water Productivity Calculation

Water productivity was assessed as the ratio of crop yield to the total amount of water supplied (irrigation plus rainfall).

Experimental Layout and Treatments

The experimental area was divided into plots using a Randomized Block Design (RBD) with three treatments and four replications. Each plot measured 4 x 10 meters, totaling 40 square meters per plot. Planting distances were maintained at 45 x 15 cm for cowpea, 45 x 10 cm for pearl millet and 45 x 15-20 cm for cluster bean to optimize plant growth and spacing.

Irrigation and Water Management

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Irrigation scheduling was based on crop water requirements, which were determined using a reference crop evapotranspiration (ETo) approach. The total number of irrigations applied was five. Irrigation was carried out using sprinkler systems to ensure uniform water distribution across the plots. The total water used, including both irrigation and rainfall, was 3,655 m³ in 2022 and 3,478 m³ in 2023, reflecting the varying climatic conditions and crop water demands during the experimental periods.

Harvesting and Biomass Measurement

At maturity, crops from each plot were harvested, separately by crop species and oven-dried at 100°C to a constant weight. Fresh and dry weights were weighed.

Water Productivity Calculation

Water productivity was calculated as the ratio of biomass yield (kg/hac) to the total amount of water applied (m3/hac), providing a quantitative measure of crop performance under irrigation regimes and arid climatic conditions.

Data Analysis

Statistical analysis was performed using Analysis of Variance (ANOVA) to compare treatment effects on crop biomass and water productivity. Data were analyzed using statistical software to generate meaningful insights.

Table: -1. Meteorological data of the experimental area during study period in 2022 and 2023 Summer season.

Years	**Months**	**Mean Max. temp.**	**Mean Min. Temp**	**Mean RH (%)**		**Mean Wind velocity (km/hr)**	**Mean sunshine (HRS)**	**Total Rain (mm)**	**Total evaporation (mm)**
				I	II				
2022	July	35.3	25.5	86.1	64.4	6.2	6.7	244.9	7.7
	Aug.	35.1	24.6	84.0	58.8	6.7	7.1	33.2	8.3
	Sept.	37.6	23.5	74.4	43.7	6.1	8.8	9.4	9.5
	Oct.	36	17.2	68.6	31.8	4.4	9.6	0.0	7.7
	Mean	**36**	**22.7**	**78.27**	**49.67**	**5.85**	**8.05**	**71.87**	**8.3**

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2023	July	37.3	25.5	81.3	55.2	6.6	6.0	256.2	8.1
	Aug.	36.1	25.4	76.7	47.3	10.2	0.0	0.0	11.1
	Sept.	37.6	24.9	74.3	46.4	5.9	7.5	61.8	8.8
	Oct.	35.3	18.8	68.5	35.4	5.1	7.0	0.0	8.9
	Mean	**36.57**	**23.65**	**75.2**	**46.75**	**6.95**	**5.12**	**79.5**	**9.22**

Result and Discussion

Plant Height

The study revealed significant differences in plant height among Cluster bean, Cow pea and Pearl millet over two years. Pearl millet had the highest average plant height of 160.03 cm, with a slight decrease from 167.20 cm in 2022 to 152.85 cm in 2023. This confirms previous studies that highlight Pearl millet's robust growth and adaptability to various soil and climatic conditions (Singh *et al*., 2021; Yadav & Kumar, 2021). Cow pea also showed considerable height, averaging 88.96 cm, with a slight increase from 87.89 cm in 2022 to 90.04 cm in 2023, indicating stable growth under the study conditions. Cluster bean, however, had the lowest average height of 47.26 cm, reflecting its typical growth pattern under similar conditions (Kumar et al., 2019).

Number of leaves per plant

The number of leaves per plant varied significantly among the treatments. Cow pea had the highest average number of leaves at 65.30, despite a decrease from 68.15 in 2022 to 62.45 in 2023. This aligns with Adewale *et al*. (2020), who noted Cow pea's leafy nature and its benefits for soil cover and organic matter. Pearl millet averaged 27.98 leaves per plant, with a slight increase from 26.10 in 2022 to 29.85 in 2023, consistent with its efficient use of available resources (Sharma *et al*., 2021). Cluster bean had the fewest leaves, averaging 24.03, with a notable decrease from 32.05 in 2022 to 16.00 in 2023, suggesting a possible sensitivity to yearly climatic variations (Patel *et al*., 2022).

Number of branches per tiller per plant

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The number of branches per tiller per plant showed notable differences, with Cluster bean displaying significant adaptability. The number of branches increased from 4.65 in 2022 to 7.35 in 2023, averaging 6.00, indicating its potential for greater productivity under favorable conditions (Kumar *et al*., 2019). Cow pea showed an increase from 2.95 in 2022 to 5.55 in 2023, averaging 4.25 branches, which is beneficial for biomass production and ground cover (Olayinka *et al*., 2019). Pearl millet had a moderate increase from 3.65 in 2022 to 4.45 in 2023, averaging 4.05 branches, aligning with its growth characteristics and efficiency in resource use (Singh *et al*., 2021).

Fresh weight per plot

The fresh weight per hac. was significantly higher for Cow pea, averaging 16,348.75 kg, with a slight decrease from 16,797.50 kg in 2022 to 15,900.00 kg in 2023. This high biomass yield supports its use in forage and soil improvement practices (Adewale and Nnamani 2022). Pearl millet had a substantial fresh weight, averaging 12,645.00 kg, with a decrease from 13,163.13 kg in 2022 to 12,126.88 kg in 2023, emphasizing its efficiency in converting available resources into biomass (Rajput & Singh, 2018). Cluster bean had the lowest fresh weight, averaging 6,427.50 kg, reflecting its lower overall biomass production compared to the other crops studied (Kumar *et al*., 2019).

Dry weight per plot

Cow pea also led in dry weight per hac. averaging 4,149.31 kg, with a slight decrease from 4,201.88 kg in 2022 to 4,096.00 kg in 2023. This highlights its potential for producing significant dry matter, beneficial for livestock feed and organic matter input to the soil (Adewale and Nnamani 2022). Pearl millet's dry weight averaged 5,591.19 kg, with a decrease from 5,755.00 kg in 2022 to 5,427.00 kg in 2023, showcasing its efficient biomass production under various conditions (Singh *et al*., 2020). Cluster bean had the lowest dry weight, averaging 2,379.31 kg, aligning with its lower fresh weight and overall productivity (Kumar *et al*., 2019).

Water Productivity

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Water productivity was highest in Pearl millet, maintaining a consistent 1.57 kg/m³ across both years. This underscores its exceptional water use efficiency and suitability for arid and semi-arid regions (Serba *et al*., 2020). Cow pea's water productivity averaged 1.16 kg/m³, with a slight increase from 1.15 kg/m³ in 2022 to 1.18 kg/m³ in 2023, indicating good water use efficiency, albeit lower than Pearl millet (Adewale and Nnamani 2022). Cluster bean had the lowest water productivity, averaging 0.67 kg/m³, with a slight decrease from 0.69 kg/m³ in 2022 to 0.65 kg/m³ in 2023, reflecting its relatively lower efficiency in converting water into biomass (Patel *et al*., 2022).

Table 2. Comparative Assessment on Plant height, No. of leaves / plant and No. of branches / tiller /plant of Cluster bean, Cowpea and Pearl millet and in Arid Zones

Treatment	**Plant height**			**No. of leaves / plant**			**No. of branches / tiller /plant**		
	2022	**2023**	**pooled**	**2022**	**2023**	**pooled**	**2022**	**2023**	**pooled**
T1 Cluster Bean	50.87	43.65	47.26	32.05	16.00	24.03	4.65	7.35	6.00
T2 Cow Pea	87.89	90.04	88.96	68.15	62.45	65.30	2.95	5.55	4.25
T3 Pearl millet	167.20	152.85	160.03	26.10	29.85	27.98	3.65	4.45	4.05
SEM	3.78	4.22	4.04	2.11	2.80	2.45	0.35	0.46	0.405
CD 5%	13.09*	14.60*	13.84*	7.29*	9.68*	8.48*	1.22*	1.59*	1.40*

Level of significance p <0.05

Table 3. Comparative Assessment on Fresh weight /hac. (kg), Dry weight / hac. (kg) and Water productivity(kg/m3) of Cluster bean, Cowpea and Pearl millet and in Arid Zones

Treatment	**Fresh weight (kg/hac)**			**Dry weight (kg/hac)**			**Water productivity (kg/m³)**		
	2022	**2023**	**pooled**	**2022**	**2023**	**pooled**	**2022**	**2023**	**pooled**
T1 (Cluster Bean)	6815.00	6040.00	6427.50	2523.00	2235.00	2379.31	0.69	0.65	0.67
T2 (Cow	16797.50	15900.00	16348.75	4201.88	4096.00	4149.31	1.15	1.18	1.16

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Pea)									
T3 (Pearl millet)	13163.13	12126.88	12645.00	5755	5427.00	5591.19	1.57	1.56	1.57
SEM	395.73	497.98	446.85	167.77	214.95	191.36	0.05	0.06	0.055
CD 5%	1369.42*	1723.25*	1546.33*	580.57*	743.84*	662.20*	0.16*	0.22*	0.19*

Level of significance $p<0.05$

Conclusion

The study's findings indicate that Pearl Millet is highly efficient in water use and biomass production, making it ideal for water-scarce regions. Cow Pea offers high biomass yield and soil fertility benefits, suitable for forage and green manure. Cluster Bean, while showing lower overall productivity, demonstrates adaptability and resilience, which could be advantageous under specific agronomic conditions. These insights are critical for optimizing crop selection to enhance productivity, resource use efficiency and sustainability in agricultural systems.

Future Thrust

Future research should build on the findings of this study by focusing on genetic improvement, sustainable practices and technological integration to enhance crop productivity, water use efficiency and resilience to climate change. These efforts will be critical in ensuring food security and sustainable agriculture in the face of growing environmental challenges.

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