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Research Article

Production potential of forage crops and grasses *vis-a-vis* sheep production system in arid region of Rajasthan

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Abstract

This study evaluates the water requirements and biomass yield of five forage crops employed in sheep production systems under arid environmental conditions. For this, two forage crops, *i.e.*, pearl millet (*Pennisetum glaucum*) and cowpea (*Vigna unguiculata*), were assessed with three perennial forage grasses, *i.e.*, napier hybrid bajra (*P. purpureum*), sewan (*Lasiurus sindicus*), and Dhaman (*Cenchrus ciliaris*). These crops were evaluated in a randomized block design (RBD) with four replications during kharif 2022. The results demonstrated significant variation in growth performance and resource-use efficiency. Cowpea yielded the highest fresh biomass with the lowest water productivity. Conversely, sewan grass recorded the highest dry matter yield along with superior water productivity, highlighting its adaptability to arid conditions and efficiency of utilization of available moisture. Napier hybrid bajra and pearl millet recorded the highest plant height, measuring 200.35 and 167.20 cm, respectively, with corresponding water productivity values of 1.72 and 1.57 kg m^{-3}. To tested their effects on livestock performance, dry fodder of napier, lasiurus and cenchrus were fed with cowpea in a 50:50 ratio in the evening hours and bajra dry fodder along with concentrate in morning hours, respectively, to lambs of G_1, G_2, and G_3 groups (a total 21 lambs of 3 months age, average weight 14.4 kg) using a randomized block design. The feeding schedule continued over a five-week period. Significant differences (p <0.05) were observed in dry matter intake and water consumption per kilogram of feed. Lambs on a cenchrus-based diet (G_3) had the lowest water intake among the tested groups. The highest body weight gain (p <0.01) was recorded in this group with the least virtual water requirement per kilogram of body weight gain (4,966.94 ± 268.50 L) and was followed by diet Lasiurus (G_2) at 5,188.06 ± 190.44 L. The water requirement of the napier-based diet (G_1) at 6,724.98 ± 394.20 L was found the highest. Overall, these findings highlight that *C. ciliaris*, in particular, demonstrated high water-use efficiency and strong potential for supporting sustainable livestock farming under water-limited conditions.

Keywords: Arid climate, Kharif forage, Sheep production system, Water requirement.

Introduction

Water scarcity is emerging as a critical global challenge due to climate change, industrialization, and a growing population. India, with only 4% of the world's freshwater resources, is one of the largest water users globally. Agriculture and livestock production play a vital role in ensuring food security, and utilize over 80% of total water consumption. According to Hoekstra and Mekonnen (2012), livestock farming alone consumes more than 30% of global agricultural water demand. In India, total water demand is projected to rise from 710 BCM in 2010 to 1,180 BCM by 2050 (Bassi *et al*., 2020). This demand highlights an urgent need for optimizing water use in agriculture-based livestock systems. This challenge is especially acute in the northwestern region (NWR) of Rajasthan, where agriculture-based livestock farming heavily relies on rapidly depleting groundwater resources. In NWR of Rajasthan, sheep and goat farming has gained popularity due to the resilience of these animals to harsh climates. Sheep farming, in particular, serves multiple purposes, providing meat, milk, wool, skin, and manure. Mutton contributes 70–80% of the earnings for sheep farmers (Shinde and Mahanta, 2020). Rajasthan's total meat production reached 240.28 thousand tons in 2022–23 with an annual growth rate of 8.92%. Increasing demand for animal products, driven by population growth and economic factors, is expected to further stress water resources. Water usage in sheep farming is distributed across drinking, washing, and processing of animal products, accounting for less than 1% of total water consumption. In contrast, a significant portion, approximately 98%, is used to irrigate feed crops for livestock (Deutsch *et al.*, 2010). This underscores the importance of enhancing fodder crop water productivity to reduce the overall water footprint of livestock production.

A critical strategy for ensuring animal food security under water-stressed conditions is prioritizing water-efficient fodder crops that provide high dry matter yields. Approaches like "more crops per drop" emphasize the need for sustainable water management practices. Drought-tolerant and climate-resilient summer-season forage crops such as Pearl millet (*Pennisetum glaucum*), Cowpea (*Vigna unguiculata*), and perennial crops like napier hybrid bajra (*P. purpureum*), sewan (*Lasiurus sindicus*) and dhaman (*Cenchrus ciliaris*) are a suitable option for arid regions (Getiso and Mijena, 2021).

These crops are well known for their high yields, nutrient content and exceptional drought tolerance and ability to maintain consistent livestock health and live weight gain, even under challenging climatic conditions Saini *et al*., 2024; Rani *et al*., 2025; and Panchta *et al*., 2025. Integrating such crops with efficient irrigation systems, such as sprinkler irrigation, can significantly improve water productivity. Several models using various assumptions and secondary data have been proposed to predict the water requirement of farm animals produced globally. However, there is limited information on quantifying water use in sheep farming under arid climatic conditions. To address this, experiments were conducted to assess water usage per kilogram of fodder produced under sprinkler irrigation and to evaluate its impact on water requirement per kg live weight in sheep production systems.

Materials and Methods

Study site: The present study was carried out at ICAR-CSWRI, Arid Region Campus (ARC), Bikaner during kharif season, 2022 (July to October) to estimate water requirement and performance of forage crops in sandy loam soil. Geographically, ARC Bikaner is situated at 28º 18′ 0″ N latitude, 73º 30′ 0″ E longitude, and 236 meters above sea level. The annual rainfall in this area ranges from 250 to 450 mm with an erratic distribution throughout the year. The temperatures during this month ranged from a maximum of 36.0°C to a minimum of 22.7°C, humidity levels ranged from a maximum of 76.0% to a minimum of 49.0%, and wind velocity was 5 km hr^{-1} with an evaporation rate of 8.5 mm.

***Treatment details and statistical analysis*:** This experiment was carried out in a Randomized Block Design (RBD) consisting of five treatments, viz., Pearl millet (*Pennisetum glaucum* L.) variety of Raj Bajra-1, Cowpea (*Vigna unguiculata* L.) variety of Kohinoor and Napier bajra hybrid (*P. glaucum x P. purpureum*), a cross between napier grass and pearl millet, Sewan (*Lasiurus sindicus*), and Dhaman grass (*Cenchrus ciliaris*), with four replications. The net plot area was kept 40 m^{-2}. Planting distances were maintained at 45 x 15 cm for cowpea, 45 x 10 cm for Pearl millet, 75 x 75 cm for Napier bajra, 50 x 50 cm for Sewan and Dhaman. Seed rates of 10 and 35 kg ha^{-1} were employed for pearl millet and cowpea, respectively. Recommended doses of fertilizers (N: P: K) were applied 60:40:40 in pearl millet, and 20:40 (N:P) in cowpea through urea, single super phosphate, and muriate of potash. Fertilizers were applied as basal dressing, with split doses of urea applied later in two stages. Irrigation scheduling was based on crop water requirements, which were determined using a reference crop evapotranspiration (ETO) approach. A total of five irrigations were applied by using sprinkler systems to ensure uniform water distribution. Standard agronomic practices were followed for weeding and pest control. Plant height, green fodder yield, dry matter yield and water productivity were recorded for each treatment at the time of harvesting. Water productivity was computed as the ratio of biomass yield (kg ha^{-1}) to the total amount of water applied (m^{-3} ha^{-1}) during the experimental period. The data generated from the field experiment were statistically analyzed using the analysis of variance (ANOVA) technique for factorial RBD and significance was tested by applying the F test (p <0.05).

***Animal experiment layout*:** For assessment of water productivity per kg live weight, selected forage of known water productivity was fed to lambs on a group basis in a semi-open shed from December to January. The feeding trial lasted 35 days. A total of 21 healthy lambs age ranging from 3 months from a sheep herd maintained, both male and female, were randomly assigned to three experimental groups, each group comprising G_1, G_2 and $G_{3,}$ each comprising 7 lambs, following a randomized block design (RBD) with similar initial average body weights (average weight 14.4 kg). Housing space was provided according to BIS specifications. Records of daily minimum and maximum temperatures and humidity were maintained. The feeding schedule continued over a five-week period, included dry fodder of grasses viz., napier, lasiurus and cenchrus with cowpea in a 50:50 ratio in evening hours and bajra dry fodder along with concentrate in morning hours for G_1, G_2 and G_3 groups, respectively. Each lamb was provided with two liters of

Table 1. Plant height (PH), green fodder yield (GFY), dry matter yield (DMY) and water productivity (WP) of different forages crops in arid zone

Treatments	PH (cm)	GFY (tons ha^{-1})	DMY (tons ha^{-1})	WP (kg m^{-3})
T_1 Cowpea (*Vigna unguiculata* L.)	87.88	16.80	4.20	1.15
T_2 /Pearl millet (*Pennisetum glaucum* L.)	167.20	13.16	5.76	1.57
T_3 /Bajra Napier hybrid (*P. glaucum* x *P. purpureum*)	201.56	14.23	6.29	1.72
T_4 Sewan (*Lasiurus sindicus*)	55.23	11.03	7.60	1.99
T_5 (Dhaman) (*Cenchrus ciliaris*)	38.52	7.93	5.29	1.45
CD (P<0.05)	13.44	1.69	0.90	0.24
SEM	4.31	0.54	0.29	0.07

water per day in the morning and evening hours; leftover water was measured to determine water consumption. Likewise, leftover roughage was weighed, and feed consumption was calculated by difference. The lambs' body weights were measured weekly before feeding and watering and average daily weight gain (g/day) was calculated by difference. Records of daily feed and water intake, as well as weekly body weights, were maintained.

Results and Discussion

The vegetative growth parameters of plant height, green fodder yield (GFY), dry matter yield (DMY) and water productivity showed significant variability among the treatments, highlighting the differential impact of plant species on growth performance and resource utilization efficiency.

***Plant height*:** T_3 (bajra napier hybrid) recorded the highest plant height (201.56 cm), which could be attributed to its superior ability to promote vertical growth, its genetic potential and adaptability to the prevailing growing conditions. Napier grass is well-known for its vigorous growth habit and adaptability across various agro-climatic zones and is preferred for fodder production (Singh *et al*., 2018).

The findings of the present study also align with the observations of Patel and Sharma (2021), who reported that Napier grass excels in biomass production under favorable conditions due to its rapid growth rate and efficient photosynthetic mechanisms. In contrast, T_5 (Dhaman, *Cenchrus ciliaris*) showed the lowest plant height (38.53 cm) among the fodder crops tested. The lower growth performance of Dhaman could be attributed to its relatively slower growth rate and limited resource utilization capacity compared to other species. According to Kumawat *et al.* (2016), Dhaman tends to exhibit moderate growth under water-scarce or nutrient-deficient conditions, which might have contributed to its comparatively lower plant height.

***Green fodder yield*:** The highest green fodder yield was recorded in T_1 (16.80 tons ha^{-1}) (Table 1). This showed its potential for producing lush, high-moisture biomass. Cowpea, being a leguminous crop, has the ability to fix atmospheric nitrogen, promoting rapid vegetative growth and enhancing biomass production. The findings align with previous studies that emphasize the superior performance of legumes like cowpea in generating fresh biomass due to their nitrogen-fixing ability and efficient use of available resources (Adewale and Nnamani, 2022). T_3 (Napier, *Pennisetum purpureum*) and T_2 (Pearl millet, *P. glaucum* L.) showed statistically at par GFY 14.23 and 13.16 tons ha^{-1}, respectively (Table 1). The results indicated that both crops were effective in producing substantial biomass under similar agronomic conditions. Similarly, Pearl millets demonstrated their adaptability and effectiveness in generating significant biomass in diverse environments. The lowest GFY (7.93 tons ha^{-1}) was recorded in T_5 (Dhaman) (Table 1), which reflected its limited growth vigor and biomass accumulation capacity compared to other treatments. The lower GFY attained in Cenchrus was consistent with its known growth characteristics, particularly in arid and semi-arid regions where water and nutrient availability are constrained. However, Meena (2018) reported higher average GFY potentials of pearl millet ranged from 35 to 45 tons ha^{-1}, Cenchrus 9 to 10 tons ha^{-1}, and cowpea 35 to 40 tons ha^{-1}. The variations could be attributed to differences in environmental conditions, soil fertility, and management practices across studies.

***Dry matter yield*:** The highest DMY (7.60 tons ha^{-1}) was achieved in T_4 (Sewan, *Lasiurus sindicus*) (Table 1). The result highlighted the high dry matter yield capacity of Sewan's adaptability in arid environments due to its effective moisture utilization under challenging conditions. The resilience of Lasiurus in dry regions could be due to its dense, fibrous structure contributing to higher dry matter accumulation. This quality makes it an ideal fodder crop for arid and semi-arid regions where maximizing dry matter yield is crucial for sustaining livestock productivity. On the other hand, T_1 (Cowpea, *Vigna unguiculata* L.) recorded the lowest DMY (4.20 tons ha^{-1}) (Table 1). The lower DMY could be attributed to cowpea's higher moisture content and its relatively lower proportion of structural biomass compared to perennial grasses. Our results were consistent with the findings of Meena (2018), who reported average dry matter yields ranging from 4.50 to 5.0 tons ha^{-1} for cowpea under similar conditions.

***Water productivity (WP)*:** The highest water productivity (1.99 kg m^{-3}) was found in T_4 (Sewan, *Lasiurus sindicus*) in comparison to other treatments (Table 1). Sewan's ability to efficiently convert water into biomass could be attributed to its deep-rooting system and resilience to drought. Such characteristics make sewan highly suitable for cultivation in arid and semi-arid regions, where water scarcity is a major concern. In contrast, T_1 exhibited the lowest WP (1.15 kg m^{-3}) (Table 1). This lower efficiency could be due to cowpea's higher water demand and its relatively lower dry matter output per unit of water consumed. Among other fodder crops, Lasiurus showed superior water-use efficiency due to their deep rooting system and natural adaptation to drought-prone areas. These observations aligned with prior research executed by Smith and Brown (2022), Johnson and Davis (2021) and Meena *et al*. (2018).

***Feed and water intake, and efficiency*:** The study evaluated the estimation of water consumption for the production of a unit of product, considering both direct (drinking) and indirect (through feed) water used, as well as the water required for the production of livestock feed in a sheep production system. During the study period (December and January), the ambient temperatures varied between 20.08 and 27.48°C, with an overall average temperature of 23.57 ± 1.07°C. The Temperature-Humidity Index (THI) ranged from 68.49 to 76.56 during the study period. These climatic data suggest that the animals experienced mild cold stress during the experimental period, particularly in January. However, sheep are known for their adaptability to diverse climatic conditions. They can still be affected by cold temperatures, especially when conditions fall outside their thermal comfort zone. According to Mishra (2009), the optimal comfort zone for sheep and goats in India ranges between 13°C and 27°C. Dry matter intake (DMI) in kg day^{-1} (0.487 ± 0.01) was recorded significantly higher ($p < 0.05$) in lambs of the G_3 group, which were fed the Cenchrus-based diet (Table 2). Similar values were observed in the G2 group, which was fed the Lasiurus-based diet (0.482 ± 0.09), while the lowest DMI was recorded in G_1 group, fed the Napier-based diet (0.453 ± 0.02) (Table 1). However, DMI as a percentage of body weight remained consistent across all groups, ranging from 2.91 to 3.03%, aligning with the reported values of DMI in sheep by Mathur and Siyak (2005). Interestingly, despite having the highest DMI, lambs in G_3 group consumed significantly ($p < 0.05$) less water (2.16 ± 0.05 L day^{-1}) compared to G_2 (2.27 ± 0.05 L day^{-1}) and G_1 (2.34 ± 0.03 L day^{-1}).

Water consumption per kg of feed and as a percentage of body weight varied significantly across groups, with G_3 consuming significantly less ($p < 0.05$) water than G_2 and G_1. However, Sawal *et al.* (2009) observed a trend where sheep consumed more water when fed Cenchrus compared to Lasiurus hay with sole feeding. In general, the water requirement of sheep ranges between 10-20% of live weight under normal conditions. In this study, water intake as a percentage of body weight was recorded as 13.49 ± 0.26 in G_3, 14.58 ± 0.35 in G_2, and 15.11 ± 0.23% in G_1. Feed efficiency was recorded the highest in lambs fed the Cenchrus -based diet (G_3), followed by those on the Lasiurus -based diet (G_2), and lowest in those fed the Napier-based diet (G_1) (Table 2). The lower efficiency observed in G_1 was due to the higher feed intake per kg of weight gain in the Napier-based diet.

Body weight gain: The experiment revealed a significant difference ($p < 0.01$) in body weight gain and average daily gain (ADG) among the treatment groups. The initial body weights of lambs in G_1, G_2, and G_3 were 14.50 ± 0.90 kg, 14.29 ± 0.77 kg, and 14.48 ± 0.80 kg, respectively. The final body weights recorded were 16.29 ± 0.87 kg in G_1, 16.57 ± 0.78 kg in G_2, and 17.11 ± 0.81 kg in G_3. Total body weight gain (kg) was significantly higher ($p < 0.01$) in the G_3 group (Cenchrus-based diet), 2.62 ± 0.04 kg, followed by G_2 at 2.28 ± 0.08 and G_1 at 1.71 ± 0.12 kg (Table 3). Similarly, ADG was significantly higher in the

Table 2. Intake of feed and water and their efficiency on different feeding regime by lambs

Particulars	G1	G2	G3
DMI (kg day-1 lamb-1)	0.453 ± 0.02	0.482 ± 0.09	0.487 ± 0.14
DMI (% Body weight)	2.91 ± 0.11	3.09 ± 0.06	3.03 ± 0.03
Feed efficiency (feed consumed kg-1 gain)	8.69 ± 0.36	6.99 ± 0.30	6.20 ± 0.48
Water intake (L day-1lamb-1)	2.34 ± 0.03	2.27 ± 0.07	2.16 ± 0.05
Water intake (% Body weight)	15.17 ± 0.23	14.58 ± 0.35	13.49 ± 0.26
Water consumption (L kg-1 feed)	5.62 ± 0.29	5.03 ± 0.09	4.73 ± 0.06
Water efficiency (L kg-1 gain)	49.15 ± 4.25	35.24 ± 1.99	29.40 ± 2.32

G1: Napier based diet; G2: Lasiurus based diet; G3: Cenchrus based diet

Table 3. Group-wise (n= 7) average estimated virtual water requirement for per kg live weight on different feeding regimes

Particulars	G1	G2	G3
Total feed intake (kg)*	3.17 ± 0.16	3.38 ± 0.12	3.41 ± 0.09
Total water intake (L)*	16.39 ± 0.22	15.90 ± 0.50	15.17 ± 0.37
Body weight changes			
Initial body weight (kg)	14.5 ± 0.90	14.29 ± 0.77	14.48 ± 0.80
Final body weight (kg)	16.29 ± 0.87	16.57 ± 0.78	17.11 ± 0.81
Total body weight gain(kg)*	1.71 ± 0.12a	2.28 ± 0.08b	2.62 ± 0.04c
Average daily gain (g day-1) *	49.06 ± 3.65a	65.18 ± 2.36b	74.97 ± 1.31c
Average weekly basis estimated virtual water requirement for per kg live weight			
Water intake through drinking (L)*	114.70 ± 1.58	111.30 ± 3.50	106.20 ± 2.65
Water intake through feed consumed (L)	15891.40 ± 877.14	16392.20 ± 640.98	18024.00 ± 594.85
Virtual water requirement per kg live weight (L)*	6724.98 ± 394.20c	5188.06 ± 190.44b	4966.94 ± 268.50a

G_1: Napier based diet; G_2: Lasiurus based diet; G_3: Cenchrus based diet; *(p <0.05)

G_3 group (74.97 ± 1.31 g day^{-1}) due to higher feed intake and better feed efficiency compared to the G_2 (65.18 ± 2.36 g day^{-1}) and G_1 (49.06 ± 3.65 g day^{-1}) (Table 3). The trend in body weight gain indicated the cenchrus-based diet (G_3) was the most efficient in terms of feed and water utilization, supporting improved livestock water productivity. The findings were supported by Sawal *et al*. (2009), who indicated that Cenchrus had significantly higher total digestible nutrients than Lasiurus.

Virtual water requirement for weight gain**:** The present study assessed water productivity in sheep production systems by considering direct water consumption (drinking water) and indirect water use through feed and fodder production. According to Singh *et al*. (2014), livestock species such as sheep, goats, and camels require minimal water for drinking and other services like washing (<1%), while the majority of water consumption is attributed to feed production, significantly influencing overall water productivity. Noya *et al*. (2018) further emphasized that feed and fodder production account for approximately 99% of the water footprint in milk production, highlighting the critical role of indirect water use in livestock systems. In the experimental groups G_1, G_2, and G_3, direct water intake through drinking was significantly different (p <0.05), with average values of 114.70 ± 1.58, 111.30 ± 3.5, and 106.20 ± 2.6 L, respectively (Table 3). Similarly, indirect water intake through feed consumption varied significantly across groups, recorded as 15,891.40 ± 877.14 L for G_1, 16,392.20 ± 640.98 L for G_2, and 18,024.00 ± 594.85 L for G_3 (Table 3). These differences underline the impact of dietary composition on overall water consumption in sheep production. Virtual water productivity, defined as the amount of water required to produce 1 kg of live weight, varied significantly (P<0.05) among the groups.

The lowest virtual water requirement was observed in G_3 (Cenchrus-based diet) at 4,966.94 ± 268.50 L kg^{-1} live weight, followed by G_2 (Lasiurus-based diet) at 5,188.06 ± 190.44 L kg^{-1} live weight, while the highest value was recorded for G_1 (Napier-based diet) at 6,724.98 ± 394.20 L kg^{-1} live weight (Table 3). These findings indicated that diet composition significantly affects both feed and water intake efficiencies, reinforcing the importance of selecting suitable forage species for enhancing water productivity. Comparable studies have reported variations in water requirements for livestock production. Ran *et al.* (2016) highlighted that feed quality, digestibility, and feed conversion efficiency directly influence livestock water productivity. Similarly, Palhares *et al.* (2017) emphasized the role of diet formulation in improving water-use efficiency in animal products.

The values obtained in this study are lower than the estimates by Singh *et al*. (2014), who reported a higher virtual water requirement of 8,215 L/kg for sheep meat production. Additionally, Barthelemy *et al*. (1993) estimated water use of approximately 13,500 L kg-1 for livestock meat, depending on species, rearing systems, and feed sources. Okai *et al*. (2003) also noted that water productivity for meat production typically ranged from 0.04 to 0.07 kg m^{-3} of water, with an estimated requirement of 6,143 L/kg of sheep meat in developed countries. Ibidhi and Salem (2019) reported that the water footprint of sheep meat varied from 8,654 to 13,056 L kg-1 live weight, depending on the production system, with the highest values in extensive agro-pastoral systems and the lowest in agro-silvipastoral systems.

Conclusion

The superior water productivity observed in G_3, which incorporated dhaman dry fodder alongside cowpea and bajra, suggests that this diet enhances growth performance while optimizing water use efficiency. The significantly lower water requirement per kilogram of live weight and higher body weight gain in G_3 highlight the potential of dhaman-based diets for sustainable sheep farming in arid and semi-arid regions. These findings emphasize the need for strategic feed selection to improve water-use efficiency, ensuring sustainable livestock production while conserving limited water resources. By implementing optimized feeding strategies, agricultural and livestock systems can contribute to food security and improved rural livelihoods in water-scarce environments.

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