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Optimizing year-round fodder production for sustainable goat based integrated farming systems in the Yamuna ravines of Uttar Pradesh

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ABSTRACT

The field experiment was conducted during the *kharif* and *rabi* seasons of 2020 and 2021 at ICAR-Central Institute for Research on Goats, Makhdoom, Mathura, Uttar Pradesh to optimize year-round fodder production for 20 goats and their 30 followers using one acre of land through the development of intercropping concept with different cereals and leguminous fodder crops; along with the implementation of good agricultural practices (GAP) during rainy (*kharif)* and winter (*rabi)* seasons. The technique demonstrated the potential to yield 7,600 kg of green fodder and 760 kg of maize grain from approximately one acre area during the *kharif* season. This output was sufficient to meet the green fodder requirements of the herd for six months. Similarly, during the *rabi* season, the technique produced 19,545 kg of green fodder and 652 kg of barley grain from one acre area, providing a surplus of green fodder and replacing over 85% of the barley requirement in concentrate feed for the herd over six months. The study highlights that by integrating intercropping strategies and GAP, goat farmers can sustainably produce the required green fodder and concentrate grain for a herd of 20 goats and 30 followers for a full year on just one acre of land.

Keywords: Cereal-legume intercropping, Fodder sustainability, Good agricultural practices (GAP), Land-use efficiency, Monetary advantage

Goat farming has traditionally been an integral part of rural livelihoods, relying on community rangelands, pastures and barren lands with minimal inputs. This low-cost system has primarily supported economically disadvantaged populations, providing them with a sustainable source of income and nutrition. Recently, goat farming has gained popularity among peri-urban entrepreneurs, evolving into a model for commercial goat farming and a key component of integrated farming systems. This shift is driven by increasing demand for goat products and the potential for higher profitability in peri-urban areas. Despite this growth, challenges persist, particularly the shrinking pasturelands and limited availability of green fodder. For decades, land allocated for fodder cultivation has stagnated at around 5% of the total cropped area (Roy *et al.* 2019), creating a gap between fodder demand and supply, especially in peri-urban regions with limited agricultural land.

To bridge this gap, sustainable agricultural practices like intercropping and good agricultural practices (GAP) provide viable solutions. Intercropping cereal fodder crops with leguminous fodder crops optimizes land use, enhances fodder quality, and stabilizes agricultural systems (Tripathi 1989). Research showed that cereal-legume intercropping increases forage yield, improves land-use efficiency and ensures economic viability (Tamta *et al.* 2019, Ghosh *et al.* 2009). Additionally, precise fertilizer management and optimized seed rates are crucial for resource efficiency. Inefficient nitrogen application leads to nutrient loss through leaching and volatilization (Wang *et al.* 2015). Splitting nitrogen doses into smaller, well-timed applications improves uptake and reduces waste (Davies *et al.* 2020, Venterea and Coulter 2015). Likewise, optimal seed rates maximize resource efficiency and balance forage and grain yields (Ayub *et al.* 2002, Kharub *et al.* 2013).

Therefore, to address the year-round feed and fodder requirements of small goat herds in resource-constrained settings, this study aims to develop a sustainable fodder production plan. Using a one acre land area, the research explores different intercropping combinations and GAP for

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commonly grown fodder crops in the Yamuna ravines with an aim to develop sustainable strategies for adequate fodder supply and improve productivity in goat-based integrated farming systems.

MATERIALS AND METHODS

Experimental setup: The field experiment was conducted during the *kharif* and *rabi* seasons of 2020 and 2021 at ICAR-Central Institute for Research on Goats, Makhdoom, Mathura, Uttar Pradesh. The soil in the experimental fields were nearly neutral in *p*H, low in organic carbon and available nitrogen, and medium in available phosphorus and potassium. The study involved trials of intercropping combinations and the development of good agricultural practices (GAP) for grain maize, fodder berseem and dual-purpose barley. Hybrid Napier grass was planted along three sides of the field as a green fence to supplement fodder during lean periods (Table 1 and 2).

Cultural practices: *Kharif* season fodder crops were sown with row to row spacing of 30 cm in both sole as well as in intercropping combinations. Hybrid maize for grain production was sown at the spacing of 60 cm × 20 cm. The *rabi* season fodder crops in intercropping were sown with a row-to-row spacing of 25 cm. In the seed rate and fertilizer dose experiments, fodder berseem was sown by broadcasting, while dual-purpose barley was sown with a row-to-row spacing of 22.5 cm. All the intercultural operations like thinning and weeding were done manually. Harvesting of fodder sorghum and pearl millet was done twice, fodder oats+berseem thrice. In barley+berseem, berseem was harvested thrice and barley was harvested for grain only. In fodder berseem experiment, it was harvested in four cuttings, while in dual purpose barley experiment barley first harvested for fodder and then for grain.

Green fodder and concentrate requirement: The green fodder and concentrate requirement of 20 adult goats and its 30 followers for six months were calculated using the following formula:

Green fodder requirement: (20 adult × 1 kg × 180 days) + (30 followers' × 0.70 kg × 180 days) = 3600 + 3780 = 7380 kg

Concentrate requirement: (20 adult × 300 g × 180 days) + (30 followers × 200 g × 180 days) = 1080 + 1080 = 2160 kg;

Maize/barley grain requirement in concentrate: 35% parts (2160 kg × 0.35) = 756 kg.

Table 1 The details of the experiments conducted during *kharif* season 2020

Intercropping of cereal + Leguminous fodder crops		
Maize + Cowpea	Sorghum + Cowpea	Pearl millet + Cluster bean
Sole Maize	Sole Sorghum	Sole Pearl millet
Sole Cowpea	Sole Cowpea	Sole Cluster bean
Maize + Cowpea (1:1)	Sorghum + Cowpea (1:1)	Pearl millet + Cluster bean (1:1)
Maize + Cowpea (2:1)	Sorghum + Cowpea (2:1)	Pearl millet + Cluster bean (2:1)
Maize + Cowpea (1:2)	Sorghum + Cowpea (1:2)	Pearl millet + Cluster bean (1:2)
Maize + Cowpea (2:2)	Sorghum + Cowpea (2:2)	Pearl millet + Cluster bean (2:2)
Maize + Cowpea (3:1)	Sorghum + Cowpea (3:1)	Pearl millet + Cluster bean (3:1)
Maize + Cowpea (1:3)	Sorghum + Cowpea (1:3)	Pearl millet + Cluster bean (1:3)
Maize + Cowpea (3:3)	Sorghum + Cowpea (3:3)	Pearl millet + Cluster bean (3:3)
Treatment, 9; Replication, 3; Design, RBD		
Good Agricultural Practices (GAP) for Maize grain production Dose of N application: 75% RDN, 100% RDN and 125% RDN Time of application: 2 split, 3 split and 4 split applications Treatments , 9; Replications, 5; Design, Split plot		Fencing of area with hybrid Napier for lean period fodder supply

Table 2 The details of the experiments conducted during *rabi* season 2020–21

Intercropping		Good Agricultural Practices (GAP)	
Oat + Berseem Intercropping	Barley + Berseem Intercropping	Fodder Berseem	Dual Purpose Barley
Sole Oat	Sole Barley	Seed rate	Seed rate
Sole Berseem	Sole Berseem	20 kg/ha	75 kg/ha
Oat + Berseem (1:1)	Barley + Berseem (1:1)	25 kg/ha	100 kg/ha
Oat + Berseem (2:1)	Barley + Berseem (2:1)	30 kg/ha	125 kg/ha
Oat + Berseem (1:2)	Barley + Berseem (1:2)	P fertilizer	N fertilizer
Oat + Berseem (2:2)	Barley + Berseem (2:2)	40 kg P_2O_5/ha	30 kg N/ha
Oat + Berseem (3:1)	Barley + Berseem (3:1)	60 kg P_2O_5/ha	45 kg N/ha
Oat + Berseem (1:3)	Barley + Berseem (1:3)	80 kg P_2O_5/ha	60 kg N/ha
Oat + Berseem (3:3)	Barley + Berseem (3:3)	100 kg P_2O_5/ha	75 kg N/ha
		120 kg P_2O_5/ha	90 kg N/ha
Treatment, 9; Replication, 3, Design, RBD		Treatment, 15; Replication, 3; Design-factorial RBD	

Efficiency and cost effectiveness: The efficiency of different intercropping experiments was calculated by using the following formulas:

$$\text{Land equivalent ratios (LER)} = La + Lb,\ La = \frac{Yab}{Yaa},\ Lb = \frac{Yba}{Ybb}$$

Monetary advantage index (MAI) = Net returns from combined produce (₹/ha) × LER–1/LR

where L_a and L_b, Land equivalent ratio of cereal and legume crops, respectively; Y_{aa} and Y_{bb}, Yields as sole crop of a (cereal) and b (legume); Y_{ab} and Y_{ba}, Yields as intercrops of cereal and legume, respectively; Z_{ab}, Proportion of intercrop area allocated to cereal; Z_{ba}, Proportion of intercrop area allocated to legume. Further, to find out the cost effectiveness of the treatments, economics of different treatments was worked out as B:C ratio:

B:C ratio = Gross return (₹/ha)/Cost of cultivation (₹/ha)

All the data were subjected to statistical analysis by adopting appropriate method of analysis of variance as described by Gomez and Gomez (1984).

RESULTS AND DISCUSSION

Green fodder and concentrate production: The study evaluated the effects of intercropping and good agricultural practices (GAP) during the *kharif* and *rabi* seasons to optimize feed-fodder production techniques for small goat herds. The findings revealed that intercropping combinations and GAP significantly influenced both green fodder and grain yields. During the *kharif* season, the intercropping of maize + cowpea, sorghum + cowpea, and pearl millet + cluster bean, in a 2:1 row ratio, yielded the highest total green fodder yield compared to other intercropping ratios and sole cropping systems. The improved yield in intercropping systems might be attributed to more efficient utilization of available resources such as space, light, and nutrients. Differences in yield across intercropping combinations were likely due to the varying proportions of component crops within each combination. Similar observations were reported in earlier studies. Islam *et al.* (2018) noted that total green forage yield was significantly influenced by the crop mixtures and configurations, with millet and cowpea in a 2:1 ratio producing the highest yields. Tamta *et al.* (2019) also demonstrated superior green fodder yields in maize + cowpea intercropping with a 2:1 row ratio, while Ramanakumar and Bhanumurthy (2001) confirmed the effectiveness of this ratio for higher fodder yields in maize and cowpea intercropping systems. Moreover, sorghum intercropped with cowpea showed increased green forage and dry matter yields compared to pure sorghum stands (Gill and Verma 1993). Regarding GAP, the grain yield of maize was significantly influenced by fertilizer application rates and timing. Applying 100% of the recommended nitrogen dose (RDN) in three split doses resulted in optimal grain yields. This could be due to the improved nutrient availability and reduced losses associated with split applications. Mosisa *et al.* (2022) emphasized that precise timing enhances agronomic efficiency, minimizes nutrient losses, and reduces environmental risks. The *kharif* season results demonstrated that intercropping of maize + cowpea, sorghum + cowpea and pearl millet + cluster bean in a 2:1 ratio produced 7,600 kg of total green fodder from an 1815 m² area. Additionally, maize grown with 100% RDN applied in three splits yielded 765 kg of grain from a 1700 m² area. Furthermore, hybrid napier grass planted along the boundary of a one-acre field served as an additional fodder source during lean periods. Hence, by adopting this technique goat farmer can produce 7600 kg green fodder and 765 kg maize grain from a 3515 m^2 (approximately one acre) cultivated area during the *kharif* season. This yield is more than sufficient to meet the nutritional requirements of 20 goats and its 30 followers for six months (Table 3).

Similarly, during the *rabi* season, intercropping oats + berseem and barley + berseem in a 2:1 row ratio produced the highest green fodder yield compared to other intercropping patterns and sole cropping. This increase is attributed to reduced inter-species competition and more efficient utilization of resources such as nutrients, light, and water (Tripathi *et al.* 1997, Obuo *et al.* 1998, Pandita *et al.* 1998). Similar results were reported by Ganvit *et al.* (2018), who observed that oats + lucerne intercropping in a 2:1 row ratio outperformed sole cropping in total green fodder yield. The performance of berseem and dual-purpose barley was significantly affected by seed rates and rate of fertilizer application. Berseem sown with 25 kg seed and 100 kg P_2O_5/ha yielded optimal results in terms of green fodder. Similarly, dual-purpose barley grown with 125 kg seed and 75 kg N/ha produced the higher fodder and grain

Table 3 Best treatment combination with optimal area distribution during *kharif* season for sustaining goat fodder requirements

Best crop combination	Area cultivated	Green Fodder Produced (kg)		
		Non-leguminous	Leguminous	Total
Maize + Cowpea (2:1)	605 m^2	1770±110	520±38	2290±130
Sorghum + Cowpea (2:1)	605 m^2	2170±66	500±26	2670±52
Pearl millet + Cluster bean (2:1)	605 m^2	2200±55	440±51	2640±70
Maize grain production (100% RDN in 3 splits)	1700 m^2	Total grain production: 765±44		
Total	3515 m^2	Total green fodder production - 7600 kg Total maize grain production - 765 kg		

Hybrid Napier as green fencing of the area provides additional green fodder for lean period.

yields. Narwal and Sardana (2002) reported similar findings for berseem, where higher seed rates resulted in improved green fodder yields. Satpal *et al.* (2020) demonstrated that applying 100 kg P_2O_5/ha across four cuts significantly enhanced berseem yields. For dual-purpose barley, Kharub *et al.* (2013) reported that increasing seed rates and nitrogen fertilizer doses by 25% above the recommended doses significantly boosted green fodder and grain yields. In this study, the intercropping of oats + berseem and barley + berseem in a 2:1 row ratio, combined with good agricultural practices, produced a total of 19545 kg of green fodder and 652 kg of barley grain from a 4000 m² area during the *rabi* season. Additionally, hybrid Napier grass, planted along the field boundary, provided supplementary fodder during lean periods. The total green fodder production far exceeded the required 7400 kg, allowing surplus fodder to be sold or processed into hay for future use, thereby generating additional income. Moreover, over 85% of the barley required for concentrate feed could be replaced with farm-produced grain. Farmers could also meet 100% of their barley needs for concentrate feed by allocating more land to barley cultivation rather than fodder berseem, as the green fodder yield already exceeds the necessary amount. Hence, by adopting this approach, goat farmers can efficiently meet the green fodder and barley grain requirements for 20 goats and their 30 followers for six months, using one acre of cultivated land during the *rabi* season (Supplementary Table 1).

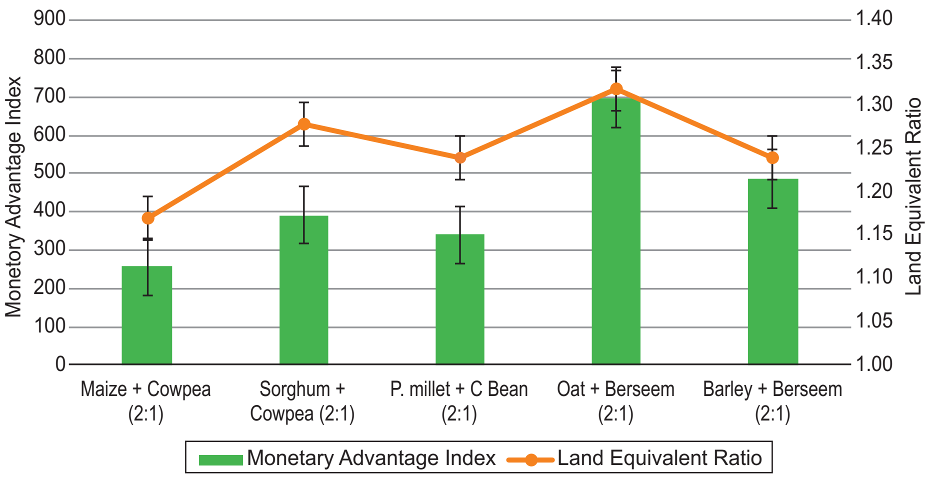

Fig. 1 Identified best crop combination in term of land area and monetary advantage

Efficiency: The intercropping treatments of various *kharif* and *rabi* season fodder crops exhibited differences in their competitive performance (Fig. 1). All intercropping combinations achieved a Land Equivalent Ratio (LER) value greater than 1, indicating a clear yield advantage of intercropping compared to sole cropping systems. The highest LER values for different intercropping systems were recorded as 1.17, 1.28, 1.24, 1.32 and 1.24 for maize + cowpea, sorghum + cowpea, pearl millet + cluster bean, oat + berseem and barley + berseem in a 2:1 row ratio, respectively. These values suggested that 17%, 28%, 24%, 32% and 24% more land would be required to grow the respective sole crops to achieve the same fodder yield as the intercropping systems. The higher LER values observed in these intercropping combinations might be attributed to better resource utilization and the complementary interaction between component crops, which enhances overall productivity. These results align closely with findings reported by Dwivedi *et al.* (2015) and Dhonde *et al.* (2016), who also observed a significant yield advantage in intercropping systems due to efficient resource sharing. In addition to LER, the monetary advantage index (MAI) was found to be highest in the 2:1 row ratio across all intercropping combinations. The positive and greater-than-one values of MAI indicate that intercropping systems are economically more viable than sole cropping. These results are consistent with the findings of Khonde *et al.* (2018), who demonstrated the economic feasibility and profitability of intercropping systems.

Cost effectiveness: The benefit-cost (B:C) ratio analysis demonstrated the cost-effectiveness of intercropping technology during both *kharif* and *rabi* seasons. Among

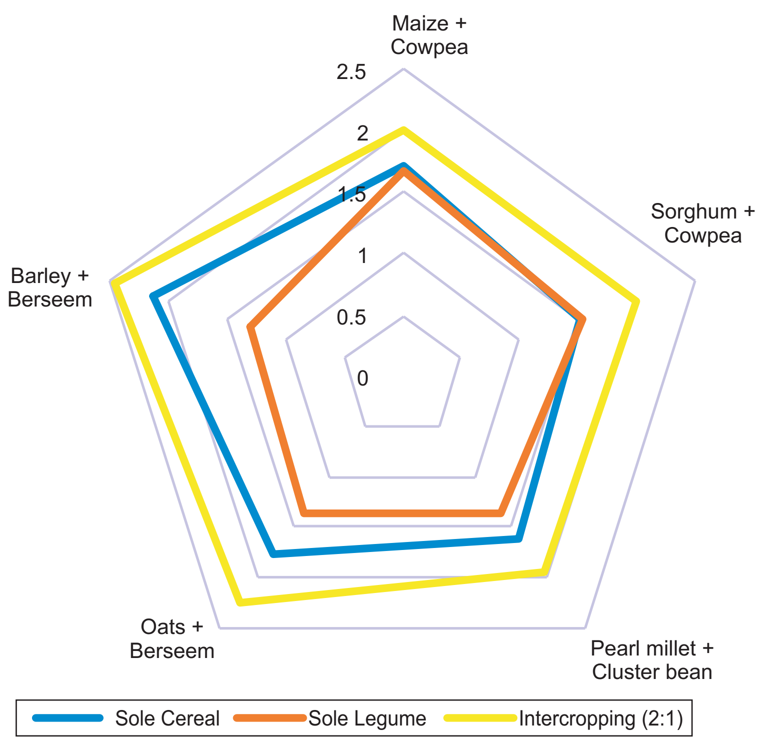

Fig. 2 Comparative evaluation of benefit cost ratio in sole cropping and intercropping combination.

the different intercropping combinations, the 2:1 row ratio consistently achieved a significantly higher B:C ratio compared to sole cropping of either cereal or legume crops (Fig. 2). The intercropping combination of 2:1, recorded 16.3, 30.3, 21.1, 27.1 and 15.1% higher B:C ratio as compared to sole cereal crop and 19.8, 28.6, 43.4, 66.7 and 87.7% higher B:C ratio as compared to sole legume crop in maize + cowpea, sorghum + cowpea, pearl millet + cluster bean, oat + berseem and barley + berseem intercropping systems, respectively. The intercropping combination of 2:1, resulted in B:C ratio increases of 16.3%, 30.3%, 21.1%, 27.1%, and 15.1% compared to sole cereal crops, and 19.8%, 28.6%, 43.4%, 66.7%, and 87.7% compared to sole legume crops in maize + cowpea, sorghum + cowpea, pearl millet + cluster bean, oat + berseem, and barley + berseem systems, respectively. The higher B:C ratio observed in the 2:1 intercropping systems might be attributed to the greater total green fodder yield achieved with relatively minimal additional investment. This improved efficiency makes the 2:1 intercropping system more economically advantageous compared to other intercropping patterns or sole cropping. These findings are in agreement with the results of Tamta *et al.* (2019) and Ginwal *et al.* (2019), who reported that maize + cowpea intercropping in a 2:1 row ratio achieved the highest B:C ratio. Similarly, Langat *et al.* (2006) and Sharma *et al.* (2008) observed that the monetary returns and B:C ratio in forage crops were significantly influenced by intercropping row arrangements.

This study developed a sustainable fodder production system for 20 goats and 30 followers through intercropping and good agricultural practices (GAP) during *kharif* and *rabi* seasons. The system produced 7,600 kg of green fodder and 760 kg of maize grain in *kharif* and 19545 kg of green fodder and 652 kg of barley grain in *rabi*, meeting the small goat herd's nutritional needs. It optimizes land use, enhances forage quality, and reduces reliance on external feed. This model offers significant potential for small-scale farmers looking to adopt integrated farming systems with limited land and resources, especially in peri-urban areas.

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