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Optimizing land use efficiency and soil health improvement through Rajmah (*Phaseolus vulgaris* L.) intercropping in rainfed uplands of Assam

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Abstract

Agricultural crops are recognized as one of the sectors most vulnerable to climate change, a growing concern in recent decades, exacerbated by increasing population and food security challenges. Intercropping is seen as a potential strategy to enhance crop resilience in the face of these climate challenges. To explore this, an experiment was conducted by Krishi Vigyan Kendra, Nagaon, during the rabi season of 2022-2023 in farmers' fields in the Nagaon district of Assam. The experiment included seven different treatments with three replications to assess the effect of various intercropping combinations with Rajmah. The study revealed that intercropping Rajmah with Toria in a 2:1 additive series resulted in greater plant height (42.33 cm and 69.21 cm), a higher number of branches per plant (3.21 and 3.92), more pods per plant (7.57 and 84.07), and more seeds per plant (3.42 and 13.60) for Rajmah and Toria, respectively. Additionally, the seed yield (6.70 q/ha for Rajmah and 5.97 q/ha for Toria) and stover yield (10.52 q/ha for Rajmah and 14.94 q/ha for Toria) were significantly higher in this system. The intercropping system also achieved a higher equivalent Rajmah yield of 13.47 q/ha and better economic returns, with a benefit-cost ratio (BCR) of 2.24, closely followed by the 1:1 additive series of Rajmah and Toria. From this experiment, it can be concluded that intercropping Rajmah with Toria in a 2:1 additive series offers better yield, higher economic returns, and greater sustainability.

Keywords: Intercropping, Rajmah, toria, linseed, climate change

Introduction

Rajmah (*Phaseolus vulgaris* L.), or kidney bean, is a highly nutritious pulse crop widely cultivated in India. It is an important dietary staple, rich in protein, dietary fiber, vitamins, and minerals, making it a significant contributor to nutritional security. Rajmah grows best in regions with temperate to subtropical climates, thriving in well-drained loamy soils with a pH range of 6.0 to 7.5. The crop is predominantly grown in states like Himachal Pradesh, Uttarakhand, Jammu and Kashmir, and parts of the north-eastern states in India.

Rajmah plays a critical role in improving soil fertility through its symbiotic relationship with Rhizobium bacteria. These bacteria form nodules on the plant roots and fix atmospheric nitrogen, converting it into forms that plants can absorb. This reduces the dependence on chemical fertilizers and enhances soil fertility for succeeding crops. Additionally, rajmah plants release root exudates that stimulate beneficial soil microbes, improving microbial diversity and suppressing harmful pathogens. Incorporating rajmah residues into the soil further enhances organic matter, soil structure, and water retention capacity.

Rajmah is also a nutritional powerhouse, rich in protein, fiber, and essential micronutrients like iron, potassium, and magnesium. It is particularly beneficial for vegetarians and vegans as a primary protein source. Its high dietary fiber content supports digestive health and regulates blood sugar levels, making it suitable for individuals with diabetes. Furthermore, rajmah is packed with antioxidants such as flavonoids and phenolic compounds, which reduce oxidative stress and lower the risk of chronic diseases like cardiovascular conditions and certain cancers. Its ability to contribute to both soil health and human nutrition underscores its importance in sustainable agricultural systems. For example, intercropping rajmah with crops like linseed and

maize has been shown to increase land use efficiency and overall productivity (Singh *et al.*, 2022). Intercropping rajmah with other crops like linseed and toria can enhance resource use efficiency and overall productivity. Studies have shown that the rajmah + linseed (2:1) intercropping system is particularly advantageous. This system achieved a land equivalent ratio (LER) of 1.10, indicating efficient land utilization, and recorded significant economic benefits with a net return of Rs. 50,367 per hectare and a benefit-cost ratio of 2.55. The inclusion of linseed with rajmah ensures better use of available resources such as sunlight, nutrients, and water, making it a sustainable agricultural practice under rainfed conditions.

In contrast, the rajmah + toria intercropping system was less efficient. The 2:1 row ratio of this combination yielded a lower LER of 0.67, reflecting poor land use efficiency compared to sole cropping. Economically, it produced the lowest net return of Rs. 10,259 per hectare and a benefit-cost ratio of 1.31. Despite these challenges, intercropping rajmah with compatible crops can improve overall farm productivity, optimize resource use, and ensure crop diversification. The choice of crops and planting ratios plays a critical role in determining the success of such systems, highlighting the potential of strategic intercropping practices in sustainable agriculture.

Materials and Methods

The experiment was carried out during the rabi season of 2023 in a farmer's field located in the Raha and Bajiagaon blocks of Nagaon, Assam, as part of on-farm trial programs conducted by the Krishi Vigyan Kendra, Nagaon. A total of five farmers participated in the demonstration across a 2.5-hectare area. The site lies in the Central Brahmaputra Valley Zone of Assam, characterized by extensive rivers, valleys, and hills. Geographically, the area is situated at 26°21'1.332" N latitude and 92°41'32.1108" E longitude, with an altitude of 60.6 meters above mean sea level. In 2023, the region received 1539 mm of precipitation, with the highest rainfall recorded in July at 479 mm, while November experienced minimal rainfall. The experimental field had a sandy loam soil texture, a bulk density of 1.26 g cm⁻³, a pH of 5.38, and an electrical conductivity (EC) of 0.27 dS m⁻¹. The soil was low in organic carbon (0.48%), low in available nitrogen (186 kg ha⁻¹), medium in available phosphorus (14.2 kg ha⁻¹), and contained a moderate amount of available potassium (244 kg ha⁻¹). The experiment followed a randomized block design with three replications.

The experiment comprised of nine combinations of organic and inorganic fertilizers such as T₁: Rajmah + Linseed (1:1), T₂: Rajmah + Linseed (2:1), T₃: Rajmah + Toria (1:1), T₄: Rajmah + Toria (2:1), T₅: Sole Rajmah, T₆: Sole Linseed, T₇: Sole Toria. The trial followed a randomized block design with three replications, and the plot size was 3 x 2 meters. The crop seed rate was set at 125 kg/ha for *Phaseolus vulgaris* (L.), Linseed seed rate 30 kg/ha and toria 10 kg/ha. The variety selected for rajmah was 'Uday', TS-38 for toria, Shekhar for linseed. The crop was sown on October 27th, 2023. Urea, SSP, and MOP served as sources of nitrogen, phosphorus, and potassium, respectively. The basal dose of fertilizer was applied to the respective plots according to treatment allocation, with unifurrows opened to a depth of about 5 cm. Standard agronomic practices were uniformly carried out throughout the crop growth period. The plants were monitored and data were recorded at 30, 45, and 60 days after sowing (DAS). Final harvesting of the crop was done on 12th of March, 2024. The recommended cultivation practices were followed throughout the duration of the study to grow the crop. The net plot area of

all plots were manually harvested for yield assessment. The resulting yield was then converted into q/ha. Grain and straw samples were processed for nutrient analyses. First, samples were oven dried (70 °C) until a constant weight was achieved followed by grinding using a Willey mill with stainless steel blades.

The total value of the output was quantified in monetary terms, and determined using the following formulas:

Gross returns (Rs/ha) = Value of the dry pod (Rs/ha)

Net returns (Rs/ha) = Gross returns (Rs/ha) – Total costs (Rs/ha)

B: C ratio = Net returns (Rs/ha) /Total cost (Rs/ha)

The data obtained from four separate replicates for each treatment were subjected to analysis using the general linear model procedures within the Statistical Analysis System 9.3 software package (SAS Institute, Cary, NC). The significance of 'F' value was determined based on analysis of variance (ANOVA) for randomized block design. For conducting multiple comparisons of treatment means, the Least Significant Difference (LSD) test was employed at a significance level of 5% probability.

LSD= S.Ed. × t value at error degree of freedom

Where, S.Ed.= Standard error of difference; t = value of percentage point of 't' distribution for error degrees of freedom at 5% level of significance

Results and Discussion

Plant Height and Number of Branches

The spatial configuration and crop choices significantly influenced the vegetative growth of both the main crop (Rajmah) and its companion intercrops (Linseed and Toria). The data indicates that the plant height and number of primary branches for the intercrops were consistently at their maximum under sole treatments compared to intercropped systems. For instance, Sole Toria reached a peak plant height of 81.64 cm and 5.33 branches per plant, which significantly decreased to 68.29 cm and 3.80 branches when grown in a Rajmah + Toria (1:1) system.

This behavior aligns directly with the findings of Rongpharpi *et al.* (2022) ^[4], who evaluated Rajmah-based intercropping under rainfed conditions in Assam and reported that plant height and the number of primary branches were consistently recorded at their maximum in sole stands irrespective of the companion crop. This vegetative suppression in intercropping setups is caused by immediate inter-specific competition for localized resources such as spatial availability, solar radiation, soil nutrients, and moisture (Paudel, 2016) ^[3].

Conversely, Rajmah exhibited high vegetative resilience, maintaining a relatively stable plant height (41.81 cm to 42.33 cm) across all intercropped variations relative to Sole Rajmah (43.17 cm). This demonstrates that while the legume component faces some resource pressure from oilseed companion crops, its growth baseline remains stable due to distinct root stratification and canopy architecture differences.

Pods per Plant and Seeds per Pod

The yield-attributing characters of the component crops showed high sensitivity to both row ratios and companion crop species. For the intercrops, Toria consistently produced a vastly superior

number of pods per plant compared to Linseed across all corresponding treatments. The highest number of pods for Toria was recorded in its sole stand (126.90), which fell to 112.67 in the Rajmah + Toria (1:1) system and further declined to 84.07 in the 2:1 system. This indicates that an increased row proportion or population density of Rajmah exerts aggressive competitive pressure on Toria, suppressing its secondary reproductive branches and subsequent pod development.

For the main pulse crop (Rajmah), the number of pods per plant and seeds per pod were significantly higher in the sole treatment (8.71 pods/plant and 3.83 seeds/pod) than in any of the intercropping treatments. Among the intercropping options, Rajmah paired with Toria in a 2:1 ratio performed optimally (7.57 pods/plant and 3.42 seeds/pod), while the Rajmah + Linseed (1:1) combination yielded the lowest values (6.50 pods/plant and 3.00 seeds/pod). The critical values (CD at $p=0.05$) for Rajmah pods (0.25) and seeds per pod (0.17) mathematically validate these variations.

This performance drop in mixed configurations matches historical agronomic trends where alterations in spatial geometry directly disrupt the source-to-sink relationship during reproductive phases (Ahmad *et al.*, 2013) ^[1]. Legumes are highly sensitive to shading and resource crowding during flowering; a reduction in individual plant space limits net photosynthetic accumulation, leading to the abortion of flowers and a lower overall pod count.

Stover and seed Yield of Intercrops

The economic seed yield and biological stover yield of both Linseed and Toria maximized under their respective sole crop treatments. Sole Linseed produced a seed yield of 7.12 q/ha and a stover yield of 21.34 q/ha, while Sole Toria generated a seed yield of 9.63 q/ha and a stover yield of 22.71 q/ha.

When introduced into the intercropping matrix, the absolute yields of these companion crops dropped because their row populations per unit area were scaled down. Under the Rajmah + Linseed system, changing the row ratio from 1:1 to 2:1 increased the Linseed seed yield from 4.21 q/ha to 5.47 q/ha and its stover yield from 12.22 q/ha to 13.77 q/ha. A parallel positive trend was observed in the Rajmah + Toria system, where moving from a 1:1 to a 2:1 ratio boosted Toria seed yield from 5.28 q/ha to 5.97 q/ha and stover yield from 14.15 q/ha to 14.94 q/ha.

This response indicates that spatial configuration and population management can successfully mitigate individual yield losses of the secondary crop. As documented by Willey (1990) ^[6], adjusting row arrangements helps manipulate spatial geometry, thereby optimizing light interception and minimizing individual yield declines of secondary canopy components.

Seed and Stover Yield of Rajmah

Rajmah's yield dynamics directly reflect the spatial configuration and the competitive nature of its companion crops. Sole Rajmah produced a seed yield of 8.12 q/ha and a stover yield of 13.34 q/ha. In intercropped treatments, the seed yield of Rajmah was lower than the sole stand but showed substantial improvements when transitioning from a 1:1 ratio to a 2:1 ratio. Specifically, in the Linseed system, Rajmah seed yield increased from 6.19 q/ha (1:1) to 6.55 q/ha (2:1). Similarly, in the Toria system, it rose from 5.57 q/ha (1:1) to 6.70 q/ha (2:1). The stover yield followed an identical trajectory, peaking among

intercrops at 10.52 q/ha in the Rajmah + Toria (2:1) treatment. The statistical analysis (with a strict SED $\pm$ of 0.02 and CD of 0.06 for seed yield) mathematically confirms that the 2:1 row ratio provides a significant yield advantage for the main crop compared to the 1:1 layout.

This pattern occurs because wider row ratios reduce immediate root-zone overlaps and improve light penetration into the lower canopy of the main pulse crop (Giri *et al.*, 2017) ^[2]. This allows the plant to maintain its carbohydrate synthesis levels even when grown alongside oilseed crops.

Equivalent Rajmah Yield

The Equivalent Rajmah Yield (REY) serves as the definitive benchmark parameter to evaluate the overall bio-economic efficiency and land-use advantages of an intercropping system. The data clearly demonstrates that all four intercropping treatments significantly outproduced the sole crop stands of Linseed (4.26 q/ha), Toria (8.06 q/ha), and Rajmah (8.12 q/ha) in terms of total system productivity.

Among the systems tested, the Rajmah + Toria (2:1) row configuration achieved the highest Equivalent Rajmah Yield at 13.86 q/ha, followed closely by Rajmah + Toria (1:1) at 12.31 q/ha. The Linseed combinations provided lower equivalent yields (9.56 q/ha for 1:1 and 10.93 q/ha for 2:1) but were still highly advantageous over sole cropping. Given the CD ($p=0.05$) value of 0.27, the superiority of the Rajmah + Toria (2:1) system is statistically profound.

This trend of achieving superior system productivity via structured row geometries is thoroughly corroborated by Rongpharpi *et al.* (2022) ^[4], who observed that evaluating relative crowding coefficients ($RCC > 1$) in Rajmah + pulse/oilseed row configurations mathematically indicates a profound system yield advantage. This yield advantage matches classic polyculture findings, which demonstrate that combining a nitrogen-fixing legume with a deep-rooted or fast-growing non-legume maximizes total resource-use efficiency (Paudel, 2016; Willey, 1990) ^[3, 6]. Because the component crops utilize different soil depths and have staggered peak nutrient demand periods, they minimize negative competitive interactions and increase total economic yield returns per unit area.

Economics of rajmah linseed cropping system

The benefit-cost ratio acts as the ultimate yardstick for economic feasibility, reflecting the net economic return obtained per rupee invested. Sole Linseed and Sole Rajmah returned poor efficiency coefficients of 1.15 and 1.23, respectively, indicating a low return on capital.

In contrast, all intercropping configurations recorded highly viable B:C ratios (>1.50). The Rajmah + Toria (2:1) row design registered the maximum economic efficiency with a B:C ratio of 2.24, outperforming its 1:1 counterpart (2.12). A similar upward economic trend was visible in the Linseed pairings, where shifting from a 1:1 to a 2:1 spatial arrangement pushed the B:C ratio from 1.65 to 1.79.

These values establish that a 2:1 intercropping configuration using a highly compatible companion oilseed like Toria creates a highly productive crop matrix. This setup drastically lowers resource waste and maximizes financial returns relative to input costs (Giri *et al.*, 2017) ^[2].

Table 1: Impact of intercropping on plant growth, yield attributing characters, yield, and Equivalent Rajmah yield

Treatment	Intercrop						Rajmah						Equivalent Rajmah yield (q/ha)
	Plant height (cm)	No. of Branches/Plant	No. of Pods/Plant	No. of Seeds/pod	Seed Yield (q/ha)	Stover yield (q/ha)	Plant height (cm)	No. of Branches/Plant	No. of Pods/Plant	No. of Seeds/pod	Seed Yield (q/ha)	Stover yield (q/ha)	
Rajmah + Linseed (1:1)	46.03	2.98	23.87	8.93	4.21	12.22	41.83	3.11	6.50	3.00	6.19	9.58	9.56
Rajmah + Linseed (2:1)	47.57	2.28	22.98	8.53	5.47	13.77	41.81	3.20	6.57	3.04	6.55	9.70	10.93
Rajmah + Toria (1:1)	68.29	3.80	112.67	14.58	5.28	14.15	42.32	3.21	7.21	3.13	5.97	9.12	12.31
Rajmah + Toria (2:1)	69.21	3.92	84.07	13.60	5.97	14.94	42.33	3.21	7.57	3.42	6.70	10.52	13.86
Sole Linseed	46.17	3.22	24.30	8.98	7.12	21.34	-	-	-	-	-	-	4.26
Sole Toria	81.64	5.33	126.90	12.68	9.63	22.71	-	-	-	-	-	-	8.06
Sole Rajmah	-	-	-	-	-	-	43.17	3.98	8.71	3.83	8.12	13.34	8.12
SEd ±	-	-	-	-	-	-	0.27	0.06	0.07	0.03	0.02	2.20	0.13
CD (p=0.05)	-	-	-	-	-	-	0.58	0.09	0.25	0.17	0.06	5.02	0.27

Table 2: Impact of intercropping economic value of the intercropping system

Treatments	Cost of cultivation (Rs./ha)	Gross return (Rs/ha)	Net income (Rs./ha)	Cost: benefit ratio
Rajmah + Linseed (1:1)	29000	47800	18800	1.65
Rajmah + Linseed (2:1)	30500	54650	24150	1.79
Rajmah + Toria (1:1)	29000	61530	32530	2.12
Rajmah + Toria (2:1)	31000	69320	38320	2.24
Sole Linseed	18500	21286	2786	1.15
Sole Toria	24000	40306	16306	1.68
Sole Rajmah	33000	40600	7600	1.23

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