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Sustainable Kharif Season Cropping System: A *Grewia optiva* based Agroforestry Approach with Optimized Tree Spacing and nutrient Management for Cereals and Pulses

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ABSTRACT: The present study was conducted to examine the impact of integrated nutrient management on yield of maize and black gram under three varying tree distances: S_1 (8m × 1m), S_2 (8m × 2m), and S_3 (8m × 3m) in mid hills of Himachal Pradesh during the years 2021-2022 and 2022- 2023. The study was conducted within an existing agroforestry system of *G. optiva* trees, which were 17 years old. The trees were arranged in rows with three different spacings: 1m, 2m, and 3m apart. The experiment utilized a split-plot design, where cereal crop maize (*Zea mays)* and pulse crop black gram, (*Vigna mungo*) were planted as intercrops during the Kharif season. During the two-year study, the crops grown under different spacings were supplemented with the application of eight different integrated nutrient doses, namely: no nutrient doses (T_1), recommended dose of inorganic fertilizers-NPK (T_2), FYM (T_3), vermicompost VC - (T_4), FYM+VC+NPK - (T_5), 75% FYM + 25% VC - (T_6), 50% FYM + 50% VC - (T_7), 50% (25% FYM + 25% VC) + 50% NPK - (T_8). The study revealed that the S_0 spacing level and T_5 fertilizer treatment, which combines organic manures with chemical fertilizers, have the highest yield for both crops. In contrast, the S_1 spacing level and T_1 treatment, where no nutrients were applied, resulted in the lowest yield. Significant differences were also observed in yield parameters over the years.

Keywords: Maize, Black gram, Integrated Nutrient Management, Tree Spacing.

INTRODUCTION

Agroforestry, a sustainable land-use system, combines tree farming with agriculture to optimize productivity, especially as land-holding sizes shrink. Owing to its productivity and economic potential, it can sustain agricultural production. Tree-based agroforestry systems act as nutrient pumps by circulating nutrients from deeper layers to the surface and adding organic matter through leaf litter, helping to maintain soil health. It offers diverse, sustainable product yields, and aids in soil conservation and ecological balance (Gold and Garret 2009). According to Dhyani *et al.* (2013), agroforestry covers 8.2 percent of India's entire geographical area, accounting for 25.32 Mha.

In the mid-hills of Himachal Pradesh, agroforestry is a common practice. In the Himalayan region, several indigenous agroforestry systems based on people's needs and site-specific characteristics have been developed over the years. One such traditional agroforestry system is *Grewia optiva*-based agroforestry system. Among the various trees used in agroforestry, *Grewia optiva* Drummond. is an important multipurpose tree. It belongs to the family Malvaceae and is one of the most essential fodder trees of the north western Himalayas. It is sparingly found in forest areas and mostly raised along agriculture fields; the tree is heavily lopped for palatable leaf fodder. It is very popular among the farmers of the western Himalayas for feeding their cattle during the winter when no other green fodder is available. It provides sustainable biomass production on a short rotation basis and enriches the soil by adding leaf litter.

Cereals and pulses are most commonly integrated with tree crops in the agroforestry systems of Himachal Pradesh. Agroforestry contributes the most to the total farm income, followed by agriculture and livestock in the low hills and mid-hills of Himachal Pradesh (Samriti, 2017). Amongagri-silviculture systems, cereals like wheat and maize were major cereal crops grown in Himachal Pradesh. Pulses are an important source of dietary protein. They have unique properties of maintaining and restoring soil fertility through biological nitrogen fixation and conserving and improving soil's physical properties through their deep root system and leaf fall. Pulse crops leave a reasonable quantity of nitrogen in the soil and add up to 40kg N/ha (Chaudhary *et al.*, 2023)

Continuous cereal-based cropping leads to a rapid decline in soil fertility. Integrated nutrient management, which combines organic and inorganic nutrient sources and incorporates grain legumes into a cereal-based cropping system, can contribute to the replenishment of soil fertility through the fixation of atmospheric nitrogen (Seifritz, 2011). These crops are grown as cash crops, bringing remunerative returns to the small and marginal hill farmers. Being a short-duration crop (4-5 months) of both the seasons and its natural occurrence up to mid-hill regions of Himachal Pradesh, it holds potential for large-scale cultivation. Cultivating cereals and pulses under *Grewia optiva* trees can improve soil fertility, crop productivity, and farmer income, promoting sustainable agriculture in the region.

Optimizing the spatial arrangement of *Grewia optiva* and constructing a nutrient strategy that resonates with both the tree and its understory crops are essential to increasing yields. This research aims to optimize spatial composition, *viz*., Ideal spacing for *Grewia optiva* that maximizes its beneficial shade and resource utilization while ensuring optimal light penetration for optimal cereal and pulse growth, nutrient dynamics to harmonize *Grewia optiva's* nitrogen-fixing abilities and organic matter contributions with targeted fertilizer application for high-yielding of cereals and pulses and sustainable management to optimize soil health, and nutrient uptake, and minimize environmental impact within the *Grewia optiva* system.

MATERIAL AND METHODS

Location: The present investigation was carried out at the experimental farm of the Department of Silviculture and Agroforestry. Dr. Y.S. Parmar University of Horticulture and Forestry, Nauni, Solan (HP) during 2021-2023.The experimental site is located in the mid-hill zone of Himachal Pradesh, with an elevation of 1200 m above mean sea level. It lies between 30°51' N latitude and 76°11' E longitude (Survey of India Toposheet Number 53F/1). It is 15 km south-east of Solan town. The area falls in the sub-tropical, sub-humid agro-climatic zone of Himachal Pradesh, India. The area receives an average annual rainfall of approximately 1400 mm, about 75 percent of which is received from July to September. The average annual temperature is 17.4ºC. The soils in the research plots belong to the group "Inceptisol" and sub-group "Eutrochrept" according to the soil taxonomy of USDA.

Experimental details: The agroforestry system (Agri-silviculture) in this experiment comprised two components. The first component included pre-established *Grewia optiva* trees planted at various spacings, such as five trees planted one meter apart, five planted two meters apart, and five planted three meters apart in a row. Cereal (maize) and pulse (black gram) crops were grown as intercrops between such rows of *Grewia* trees in the kharif season and as a sole crop without trees. The experiment had three *G. optiva* tree spacings *viz*., S_1 (8×1 m), S_2 (8×2 m), S_3 (8×3 m), and a control treatment (S_0) i.e., open condition without a tree. In these four treatments, maize (*Zea mays*) and black gram (*Vigna mungo*) were grown, and eight nutrient sources, *viz*., T_1 (control), T_2 (Recommended Dose - NPK), T_3 (Farm yard manure - FYM), T_4 (Vermicompost -VC), T_5(FYM+VC+NPK), T_6 (75% FYM + 25% VC), T_7 (50% FYM + 50% VC), T_8 (25% FYM + 25% VC + 50% NPK) were applied to the crops under study. The split-plot experimental design was used where main plot treatments are allocated to various tree spacings and subplot treatments to nutrient doses. The study was carried for two years (2022 & 2023) and the yield data was pooled and analysed after each kharif season for both maize and black gram.

Statistical analysis: The data was statistically analysed in MS Excel and OP stat software by using the analysis of variance (ANOVA) following the procedure outlined by (Gomez and Gomez 1984).

RESULTS AND DISCUSSION

A. Effect of INM on the yield of cereal crop maize (Zea mays) under G. optiva based agrisilviculture system

Upon analysing the data presented in Table 1, it becomes evident that the yield of maize was significantly affected by tree spacing, integrated nutrient management, and the year of study. In the first year (2021-22), the highest grain yield was recorded in the open field condition (S_0) with 29.22 q/ha, displaying a significant advantage over the yield in the agroforestry system, while the lowest yield of 24.15 q/ha (quintal per hectare) was observed in S_1 (1m × 8m). Among the different fertilizer treatments, treatment T_5 achieved the maximum yield of 32.22 q/ha, and the minimum grain yield of 21.30 q/ha was registered in T_1. Similarly, in the second year, the highest grain yield of 30.15 q/ha was observed under S_0. In comparison, the minimum yield of 24.92 q/ha was recorded in S_1. But the yield in S_3 is on par with S_0, and there is no significant difference in the yield among them. In terms of fertilizer treatments, T_5 exhibited the highest grain yield of 33.21 q/ha, outperforming all other treatments significantly, and the lowest yield of 22.03 q/ha was reported in T_1. The interaction between tree spacing and fertilizer treatments was found to significantly affect the grain yield of maize in both years. Pooling the data for 2021-22 and 2022-23 showed that the maximum yield of 29.68 q/ha was achieved in S_0 (open), while the minimum yield of 24.54 q/ha was observed in S_1 (1m × 8m). Among fertilizer treatments, the highest yield of 32.72 q/ha was recorded in T_5, followed by T_8. The lowest yield of 21.67 q/ha was observed under T_1, where RDF was given, the second year (2022-23) registered a significantly higher yield of 33.21 q/ha compared to the first year (32.22 q/ha). Notably, different interactions between tree spacing, fertilizer treatments, and year were found to significantly affect the maize crop's grain yield.

The data analysis showed that the levels of photosynthetic active radiation (PAR) significantly influenced growth by directly impacting photosynthetic capacity, dry matter accumulation, and yield (Kumar *et al.,* 2013). The reduction in photosynthetic active radiation (PAR) below the *Grewia* canopy in S_1 likely contributed to the decrease in maize grain yield. Moreover, integrating organic manures with inorganic fertilizers resulted in a significant increase in maize grain yield by 77.74% compared to using RDF (recommended dose) alone. This substantial increase can be attributed to the role of organic fertilizer in enhancing soil biological activity, leading to improved nutrient mobilization from both organic and chemical sources (Rana *et al.*, 2023; Ghazanfer *et al.*, 2024; Vijay *et al.*, 2024). Similar conclusions were drawn in studies by Yadav *et al.* (2023), Jhonsonraju *et al.* (2023); Das *et al.* (2017), supporting the positive impact of combining organic and inorganic fertilizers on maize yield.

Maize is an important cereal crop, in Himachal Pradesh and its straw serves as a source of fodder. Yet, its sustainability is threatened by the emission of greenhouse gases due to excessive use of inorganic fertilizers. These emissions can be reduced, and the health of the soil and water efficiency can be enhanced through sustainable agricultural methods, especially Integrated Nutrient Management (Khalfi *et al.*, 2024).

B. Effect of INM on the yield of pulse crop black gram (Vigna mungo) under G. optiva based agrisilviculture system

A quick analysis of the data presented in Table 2 reveals that the grain yield of black gram was significantly influenced by tree spacing, integrated nutrient management, and year. In the first year (2021-22), the maximum grain yield was observed in S_0 (7.99 q ha^{-1}), which was significantly higher than the yield in the agroforestry system, and the minimum yield (7.20 q ha^{-1}) was recorded in S_1 (1m × 8m). Among the fertilizer treatments, the highest yield (9.69 q ha^{-1}) was recorded in T_5, which was statistically similar to T_8, while the lowest grain yield (5.01 q ha^{-1}) was observed in T_1.

Table 1: Effect of tree spacing (S) and INM (T) on grain yield (q ha-^{1}) of maize under *Grewia optiva* based agroforestry systems during the years 2021 and 2022.

Nutrient sources (T)	Year (2021-2022)				Mean	Year (2022-2023)				Mean	Pooled for the years 2021-2022 and 2022-2023				Mean
	Tree spacing			Control		Tree spacing			Control		Tree spacing			Control	
	S_1	S_2	S_3	S_0		S_1	S_2	S_3	S_0		S_1	S_2	S_3	S_0	
T_1	16.09	20.84	23.55	24.71	**21.30**	16.65	21.56	24.35	25.56	**22.03**	16.37	21.20	23.95	25.14	**21.67**
T_2	19.21	21.56	23.66	24.41	**22.21**	20.02	22.47	24.67	25.44	**23.15**	19.61	22.02	24.16	24.92	**22.68**
T_3	23.17	25.94	28.35	28.74	**26.55**	23.74	26.59	29.05	29.46	**27.21**	23.46	26.26	28.70	29.10	**26.88**
T_4	22.27	23.17	25.90	25.98	**24.33**	22.99	23.92	26.73	26.81	**25.11**	22.63	23.54	26.31	26.39	**24.72**
T_5	30.05	30.92	33.59	34.32	**32.22**	30.98	31.87	34.62	35.37	**33.21**	30.51	31.40	34.10	34.84	**32.72**
T_6	27.64	29.79	31.15	32.14	**30.18**	28.41	30.62	32.02	33.03	**31.02**	28.03	30.21	31.58	32.58	**30.60**
T_7	26.94	28.03	29.08	29.71	**28.44**	27.99	29.12	30.22	30.87	**29.55**	27.46	28.57	29.65	30.29	**29.00**
T_8	27.86	30.53	33.18	33.75	**31.33**	28.58	31.32	34.04	34.62	**32.14**	28.22	30.92	33.61	34.18	**31.74**
Mean	**24.15**	**26.35**	**28.56**	**29.22**	**27.07**	**24.92**	**27.18**	**29.46**	**30.15**	**27.93**	**24.54**	**26.77**	**29.01**	**29.68**	**27.50**
$CD_{0.05}$	**S**	**=**	**0.34**			**S**	**=**	**0.35**			**Y**	**=**	**0.05**	**Y×S =**	**NS**
	T	**=**	**0.16**			**T**	**=**	**0.16**			**S**	**=**	**0.24**	**Y×T =**	**0.15**
	S×T	**=**	**0.32**			**S×T**	**=**	**0.47**			**T**	**=**	**0.15**	**T×S =**	**0.31**
														Y×S×T =	**0.30**

*Where: T= Nutrient Sources, T_1 = Control (no nutrient dose), T_2 = Recommended dose of inorganic fertilizers (NPK), T_3 = Farmyard manure (FYM), T_4 = Vermicompost (VC), T_5 = RDF (FYM+VC+NPK), T_6 = 75% FYM + 25% VC, T_7 = 50% FYM + 50% VC, T_8 = 50% (25% FYM + 25% VC) + 50% NPK, S = Tree spacing, S_1: 1m × 8m spacing, S_2: 2m x 8m spacing, S_3: 3m × 8m spacing, S_0: control plots (no trees were present).

Similarly, in the second year, the maximum grain yield (8.53 q ha^{-1}) was registered under S_0. In contrast, the minimum grain yield (7.69 q ha^{-1}) was recorded in S_1. But the yield in S_3 is on par with S_0 and there is no significant difference in the yield between S_3 and S_0. Among the fertilizer treatments, Treatment T_5 had a higher grain yield (10.11 q ha^{-1}), significantly higher than all other treatments except T_8, and the minimum grain yield (5.56 q ha^{-1}) was reported in T_1. Notably, the interaction between tree spacing and fertilizer treatments had a significant effect on the grain yield of the black gram crop in both years.

Upon examining the pooled data from 2021-22 and 2022-23, the highest yield of 8.26 quintals per hectare was observed in the open condition (S_0), whereas the lowest yield of 7.45 quintals per hectare was noted in the 1m × 8m setting (S_1). Among the fertilizer treatments, the maximum yield was observed in T_5 (9.90 q ha^{-1}), and the minimum yield (5.29 q ha^{-1}) was recorded under T_1. Furthermore, interaction effects between tree spacing, fertilizer treatments, and year were found to be significant in the grain yield of the black gram crop. Research by Singh (2002) indicated that higher numbers of grains per pod were observed under open conditions due to high photo synthetically active radiation (PAR) compared to crops under the tree canopy. Islam *et al.* (2008) also reported a higher grain yield in open conditions compared to reduced light conditions. Tanni *et al.* (2010) supported these findings, showing that soybean plants outside the tree canopy had more seeds per pod and a higher grain yield. Mohammed (2012) reported higher numbers of grains per pod in various pulse crops under controlled conditions (without trees) than under trees planted at different spacings, suggesting competition for nutrients, moisture, and light. Similarly, Kaur and Puri (2013) reported that the number of grains per plant was higher in crops grown without trees than those grown under trees. Organic manures assist in root nodule formation and nitrogen fixation in legumes like black gram (Dahal & Ghosh Bag 2023). They stimulate nodule formation by releasing flavonoids that attract rhizobia, the nitrogen-fixing bacteria. The bacteria convert atmospheric nitrogen into ammonia, which is used by the plant to create amino acids and nucleotides. Therefore, the integration of organic manures with inorganic nutrients enhances soil fertility, contributing to higher yields.

Table 2: Effect of tree spacing (S) and INM (T) on grain yield (q ha-[1]) of black gram under *Grewia optiva* based agroforestry system during the years 2021 and 2022.

Nutrient sources (T)	Year (2021-2022)				Mean	Year (2022-2023)				Mean	Pooled for the years 2021-2022 and 2022-2023				Mean
	Tree spacing			Control		Tree spacing			Control		Tree spacing			Control	
	S_1	S_2	S_3	S_0		S_1	S_2	S_3	S_0		S_1	S_2	S_3	S_0	
T_1	4.78	4.98	5.11	5.17	**5.01**	5.30	5.53	5.67	5.74	**5.56**	5.04	5.25	5.39	5.46	**5.29**
T_2	5.69	6.12	5.92	6.39	**6.03**	6.34	6.82	6.59	7.12	**6.72**	6.02	6.47	6.25	6.76	**6.38**
T_3	6.89	7.54	7.75	7.91	**7.52**	7.33	8.03	8.25	8.43	**8.01**	7.11	7.79	8.00	8.17	**7.77**
T_4	6.45	7.17	7.25	7.45	**7.08**	6.86	7.62	7.71	7.93	**7.53**	6.66	7.39	7.48	7.69	**7.31**
T_5	9.38	9.62	9.82	9.94	**9.69**	9.79	10.04	10.24	10.38	**10.11**	9.58	9.83	10.03	10.16	**9.90**
T_6	8.20	8.65	8.91	9.11	**8.72**	8.49	8.96	9.23	9.44	**9.03**	8.35	8.81	9.07	9.27	**8.88**
T_7	7.69	8.22	8.47	8.86	**8.31**	8.16	8.73	8.99	9.40	**8.82**	7.92	8.48	8.73	9.13	**8.57**
T_8	8.54	8.75	9.01	9.06	**8.84**	9.24	9.48	9.75	9.81	**9.57**	8.89	9.11	9.38	9.43	**9.21**
Mean	**7.20**	**7.63**	**7.78**	**7.99**	**7.65**	**7.69**	**8.15**	**8.30**	**8.53**	**8.17**	**7.45**	**7.89**	**8.04**	**8.26**	**7.91**
$CD_{0.05}$	**S**	**=**	**0.52**			**S**	**=**	**0.66**			**Y =**	**0.09**		**Y×S =**	**0.17**
	T	**=**	**1.21**			**T**	**=**	**1.36**			**S =**	**0.17**		**Y×T =**	**0.25**
	S×T	**=**	**1.62**			**S×T**	**=**	**1.72**			**T =**	**0.21**		**T×S =**	**0.04**
														Y×S×T =	**0.49**

*Where: T= Nutrient Sources, T_1 = Control (no nutrient dose), T_2 = Recommended dose of inorganic fertilizers (NPK), T_3 = Farmyard manure (FYM), T_4 = Vermicompost (VC), T_5 = RDF (FYM+VC+NPK), T_6 = 75% FYM + 25% VC, T_7 = 50% FYM + 50% VC, T_8 = 50% (25% FYM + 25% VC) + 50% NPK, S = Tree spacing, S_1 : 1m x 8m spacing, S_2 : 2m x 8m spacing, S_3 : 3m x 8m spacing, S_0 : control plots (no trees were present)

A B C

Fig. 1. A. Layout of the experimental plot **B.** Maize and black gram under *Grewia optiva* **C.** Harvesting and weighing of maize.

CONCLUSIONS

Based on the findings of this study, it can be concluded that the growth of maize and black gram crops was better in open conditions compared to the agroforestry system. However, it is important to note that the yield of maize and black gram in S_3 is on par S_0 (open condition) and there is no significant difference between them. In these situations, intercropping cereal and pulse crops under *G. optiva* trees can improve soil fertility and sustain yield in the long term, as compared to growing single crops in open conditions. The highest yield for both crops was observed in the S_0 (open condition) spacing level and T_5 (FYM+VC+NPK) fertilizer treatment, which combines organic manures with chemical fertilizers. On the other hand, the S_1 (8m × 1m) spacing level and T_1 treatment, where no nutrients were applied, resulted in the lowest yield. Additionally, the second year of the study had a significantly higher yield (10.11 q ha^{-1}) compared to the first year (9.69 q ha^{-1}).

FUTURE SCOPE

This study helps in understanding how cropping systems can be sustained in this era of climate change. Future studies could explore the long-term sustainability of these practices, the impact on different crops and soil types, and the economic viability of farmers. Additionally, the research could investigate optimizing nutrient doses from various other sources.

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