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Maximizing Crop Productivity: Investigating the Impact of Land Use, Sowing Dates, and Wheat Varieties on Chlorophyll Content and APAR under *Pongamia pinnata* based Agri-silviculture system

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ABSTRACT: This study was conducted in JNKVV, Jabalpur, India, assessed the impact of land use systems, sowing dates, and wheat varieties on chlorophyll content and absorbed photosynthetically active radiation (APAR) in a *Pongamia pinnata*-based Agri-silviculture system. This experiment was conducted over two years in three-factor double split plot design. The open system consistently exhibited higher chlorophyll content and APAR values than the agroforestry system, attributed to improved light penetration and reduced shading effects. Early sowing led to significantly higher chlorophyll content and APAR values due to favorable climatic conditions and prolonged sunlight exposure. The MP-3336 wheat variety consistently displayed superior chlorophyll content, while GW-322 exhibited higher APAR values. Integrating complex interactions between multiple species in the Agri-silviculture system and addressing environmental variability while generalizing results to diverse agro-climatic regions pose challenges. Optimizing land use practices, selecting appropriate sowing dates, and utilizing high-performing wheat varieties are crucial for enhancing chlorophyll production, improving photosynthetic efficiency, and increasing crop productivity in Agri-silviculture systems. Conducting long-term monitoring to assess the system's sustainability and productivity, and exploring climate change impacts and economic analysis for informed decision-making are promising areas of future research.

Keywords: Agroforestry systems, *Pongamia pinnata*, wheat varieties, Chlorophyll content, PAR.

INTRODUCTION

Climate change poses an urgent global challenge, with far-reaching impacts on agricultural systems and food security (IPCC, 2021). As temperatures rise and weather patterns become increasingly unpredictable, finding sustainable and resilient agricultural solutions becomes imperative. Agroforestry systems, which involve the integration of trees into agricultural landscapes, have emerged as a promising approach to mitigate climate change impacts while enhancing crop production (Montagnini, 2016; Hassan *et al.,* 2022). The integration of specific tree species, such as *Pongamia pinnata*, with associated crops like wheat varieties, has shown potential in addressing climate change impacts and promoting sustainable agriculture (Natarajan *et al.*, 2021). Understanding the correlations between chlorophyll content and photosynthetically active radiation (PAR) values within these agroforestry systems can provide valuable insights into optimizing plant growth and resource utilization (Vicente *et al.*, 2020).

Pongamia (*Pongamia pinnata*) tree is an indigenous to north Australia, south and south-east Asia including India. It is a non-food legume that grows quickly and ability to fix biological nitrogen (BNF), a process that is not present in other well-known biodiesel feedstocks such as canola, mustards, oil palm, and jatropha. It is a short-trunked, medium-sized semi-evergreen tree with a spreading crown. In India, it is commonly planted both as an ornamental tree and to provide shade (Tomar and Gupta 1985). Wheat, as a major staple crop, faces increasing challenges due to climate change-induced temperature and precipitation variations (FAO, 2020). Integrating *Pongamia pinnata* trees within agroforestry systems has shown promise in enhancing the resilience of wheat varieties and mitigating the adverse impacts of climate change (Kumar *et al.*, 2022).

Chlorophyll content serves as a critical indicator of a plant's photosynthetic activity and overall vitality, directly influencing its ability to capture and utilize light energy for photosynthesis, thus affecting growth and productivity (Oukarroum *et al.*, 2021). The fraction of solar radiation within the visible spectrum that plants may use for photosynthesis is referred to as photosynthetically active radiation (Mishra *et al.*, 2012).

Recent studies have explored the impact of agroforestry systems, including the presence of *Pongamia pinnata*, on crop performance and environmental factors. These studies have highlighted the positive influence of *Pongamia pinnata* trees on soil fertility, microclimate regulation, and water use efficiency, which can potentially benefit wheat varieties grown in proximity (Yadav *et al.*, 2022).

MATERIALS AND METHODS

A. Experimental Location, Topography and Climate

The experiment was carried out at the Forestry Research Farm of Jawaharlal Nehru Krishi Vishwa Vidyalaya in Jabalpur (MP), in a 14-year-old agroforestry model centered around *Pongamia pinnata*. The experiment was performed for 2 years during the Rabi season of 2021-22 and 2022-23. The research farm is situated in the Kymore Plateau and Satpura hill agro-climatic zone, characterized by a subtropical climate with hot, dry summers and cold, dry winters. The location's coordinates are approximately 23° 12' 50" North latitude and 79° 57' 56" East longitude. The region experiences high temperatures, reaching up to 46 °C in May and June, and low temperatures, dropping to 2 °C in December and January. The average annual rainfall is around 1350 mm, with the majority occurring between June and September. The soil in the area is predominantly black in color, and the topography is gently sloping, with a gradient of 0-1 percent. The chosen location provides a representative example of the agro-climatic conditions prevalent in the region and offers valuable insights into the interactions and performance of *Pongamia pinnata* and wheat varieties within this specific agroforestry model.

B. Experimental Details

The experiment was conducted using a three-factor double split plot design. The main plot consisted of two systems: S1, an open system, and S2, an agroforestry system. The subplot factor included three sowing dates: D1 (12th November), D2 (27th November), and D3 (12th December). Within each subplot, the sub-subplot factor comprised two wheat varieties: V1 (MP-3336) and V2 (GW-322). Each treatment was replicated three times. The field preparation involved two rounds of ploughing using a cultivator and one round of rotavator. Subsequently, the field was leveled manually by labor. The crop was sown in lines with a spacing of 20 cm at the three specified sowing dates: 12th November, 27th November, and 12th December. The seed rate used was 100 kg ha^{-1}, and the sowing was performed manually using a hand hoeing method. To meet the nutrient requirements of the crop, the recommended doses of fertilizers were applied. This included Nitrogen, Phosphorus, and Potassium at rates of 120:60:40 kg ha^{-1}, respectively. Urea, Single Super Phosphate (SSP), and muriate of potash (MOP) were used as the respective sources of these fertilizers. The basal doses of fertilizers were applied at the time of sowing, while 50% of the nitrogen was applied in split doses. Weed control was achieved by spraying the herbicide VESTA (Clodinafop Propargyl 15% + Metsulfuron Methyl 1% WP) 30 days after sowing. Irrigations were provided at appropriate intervals, totaling five times during the crop's duration. The data collected from the experiment were subjected to statistical analysis of variance, following the recommended method by Gomez and Gomez (1984).

C. Computation of chlorophyll content and PAR values

The measurement of chlorophyll content in plants was conducted at two time viz., 15 days and 30 days after sowing (DAS). A handheld chlorophyll meter (Apogee, MC 100 model) was utilized to record five readings from randomly selected plants, with one reading taken from a leaf of each plant. The average chlorophyll content was determined and recorded as the chlorophyll content index (CCI), expressed in µg cm^{-2}. To evaluate the potential energy accumulated by the plant canopy, specifically the absorbed photosynthetically active radiation (APAR) within the 400-700 nm wavebands, measurements were obtained using a line quantum sensor. The photosynthetic photon flux density (PPFD) readings of the photosynthetically active radiation (PAR) were acquired by placing the sensor at different positions. These positions included 100 cm above the crop canopy, inverted above the canopy, inside the canopy (25 cm above the soil), and inverted under the canopy. The PAR readings were then employed in the following equation to calculate APAR:

$$APAR = (PAR_o + RPAR_S) - (TPAR + RPAR_C)$$

Here, PAR_o represents the portion of incident PAR transmitted through the canopy, TPAR signifies the portion transmitted to the soil surface, $RPAR_S$ denotes the portion reflected by the soil back into the canopy, and $RPAR_C$ represents the inverted transmitted PAR under the canopy. This calculation enables the estimation of the absorbed energy by the plant canopy, which is vital for the process of photosynthesis and overall plant growth. The unit of measurement for APAR is µ mol m^{-2} s^{-1}. The aforementioned equation and methodology have been adapted from the research conducted by Gallo and Daughtry (1986).

RESULT AND DISCUSSION

A. Chlorophyll content

The study aimed to investigate the effect of different land use systems, sowing dates, and wheat varieties on chlorophyll content at 15 days after sowing (DAS) and 30 DAS in a *Pongamia pinnata*-based Agri-silviculture system. The results presented in Table 1 and Fig. 1 demonstrates significant effects of these factors on chlorophyll content in both individual years of experimentation and the pooled analysis. Among the different land use systems, the open system consistently exhibited the highest chlorophyll content at both 15 DAS and 30 DAS. The open system recorded chlorophyll content of 13.55%, 14.17% and 13.86% at 15 DAS, and 28.15%, 14.17% and 27.29% at 30 DAS in both years and pooled, respectively. In contrast, the agroforestry system displayed significantly lower chlorophyll content of 12.43%, 12.54% and 12.49% at 15 DAS and 19.82%, 12.54% and 19.94% at 30 DAS in both years and pooled, respectively. These findings suggest that the open system promotes better light penetration, reduces shading effects, and enhances nutrient availability, leading to higher chlorophyll production compared to the agroforestry system (Li *et al.,* 2019; Liu *et al.,* 2020; Lu *et al.,* 2021; Wang *et al.,* 2022). The analysis of different sowing dates revealed that the early sown date consistently resulted in the highest chlorophyll content at both 15 DAS and 30 DAS. The chlorophyll content recorded for the early sown date were 13.45%, 14.27% and 13.86% at 15 DAS and 25.39%, 14.27% and 24.98% at 30 DAS in both years and pooled, respectively. These values were significantly higher compared to the timely sown, which exhibited chlorophyll content of 12.88%, 13.09% and 12.98% at 15 DAS and 24.07%, 13.09% and 23.42% at 30 DAS in both years and pooled, respectively. Additionally, the late sown date showed even lower chlorophyll content of 12.65%, 12.71% and 12.68% at 15 DAS and 22.49%, 12.71% and 22.43% at 30 DAS in both years and pooled, respectively. These results indicate that early sowing provides favorable climatic conditions for optimal photosynthetic activity, longer exposure to sunlight, and efficient chlorophyll production, while late sowing negatively affects chlorophyll synthesis due to reduced light availability and suboptimal growth conditions (Chen *et al.,* 2019; Xu *et al.,* 2020; Zhang *et al.,* 2018; Singh *et al.,* 2020; Yang *et al.,* 2021; Huang *et al.,* 2022).In terms of wheat varieties, MP-3336 consistently exhibited superior performance in terms of chlorophyll content at both 15 DAS and 30 DAS. MP-3336 displayed chlorophyll content of 13.12%, 13.51% and 13.31% at 15 DAS and 24.60%, 13.51% and 24.28% at 30 DAS in both years and pooled, respectively. In contrast, GW-322 showed lower chlorophyll content of 12.86%, 13.20% and 13.03% at 15 DAS and 23.37%, 13.12% and 22.95% at 30 DAS in both years and pooled, respectively. These variations among wheat varieties can be attributed to genetic differences and varietal characteristics influencing chlorophyll biosynthesis enzymes and regulatory proteins (Jiang *et al.,* 2018; Zhao *et al.,* 2019; Guo *et al., 2021;* Chen *et al.,* 2021). The findings of this study highlight the significant influence of land use systems, sowing dates, and wheat varieties on chlorophyll percentage in the *Pongamia pinnata*-based Agri-silviculture system. The open system, early sowing, and MP-3336 variety consistently demonstrated superior performance in terms of higher chlorophyll content. Optimizing land use practices, selecting appropriate sowing dates, and utilizing high-performing wheat varieties can contribute to enhanced chlorophyll production, improved photosynthetic efficiency, and increased crop productivity in such Agri-silviculture systems.

B. Photosynthetically Active Radiation (PAR)

The study demonstrated the effect of different land use systems, sowing dates, and wheat varieties on absorbed photosynthetically active radiation (APAR) at 15 days after sowing (DAS) and 30 DAS in *a Pongamia pinnata*-based Agri-silviculture system. The results depicted in Table 2 and Fig. 2 demonstrates significant effects of these factors on APAR in both individual years of experimentation and the pooled analysis. Among the different land use systems, the open system consistently exhibited the highest APAR values at both 15 DAS and 30 DAS. The open system recorded APAR values of 169.28, 355.56 and 262.42 at 15 DAS and 1028.78, 1142.28 and 1085.53 at 30 DAS in both years and pooled, respectively. In contrast, the agroforestry system displayed significantly lower APAR values of 91.67, 101.06 and 96.36 at 15 DAS and 164.94, 194.83 and 179.89 at 30 DAS in both years and pooled, respectively. These findings indicate that the open system promotes better light interception and higher availability of photosynthetically active radiation compared to the agroforestry system. This could be attributed to reduced shading effects and improved light penetration in the open system, leading to increased APAR values (Li *et al.,* 2019; Liu *et al.,* 2020; Lu *et al.,* 2021; Wang *et al.,* 2022). In terms of sowing dates, the early sown date consistently resulted in the highest APAR values at both 15 DAS and 30 DAS in the first year. The APAR values for the early sown date were 155.50 and 726.42 at 15 DAS and 561.67 and 713.75 at 30 DAS in the first and second years, respectively. These values were significantly higher compared to the timely sown date, which exhibited APAR values of 89.50 and 590.67 at 15 DAS and 515.17 at 30 DAS in the first year. However, at 30 DAS in the first year, the late sown date (713.75) showed significantly higher APAR compared to the early sown (561.67) and timely sown (515.17). In the pooled analysis, the late sown date (200.71 and 701.17) exhibited significantly higher APAR compared to the early sown (184.96 and 644.04) and timely sown (152.50 and 552.92) at 15 DAS and 30 DAS, respectively. Additionally, in the second year, the late sown date (255.00) showed higher APAR compared to the timely sown (215.50) and early sown (214.42), although the differences were not statistically significant. These results indicate that early sowing promotes higher APAR values, which can be attributed to longer exposure to sunlight and favorable climatic conditions that enhance light capture and photosynthetic activity (Chen *et al.,* 2019; Xu *et al.,* 2020; Zhang *et al.,* 2018; Singh *et al.,* 2020; Yang *et al.,* 2021; Huang *et al.,* 2022). Further wheat varieties, GW-322 exhibited higher APAR values at 15 DAS in both years and pooled analysis compared to MP-3336. GW-322 recorded APAR values of 133.44, 235.56 and 184.50, while MP-3336 had APAR values of 127.50, 221.06 and 174.28 in both years and pooled, respectively. In the second year, the APAR values of the two varieties were significantly different, but in the first year and pooled analysis, the differences were not significant. At 30 DAS, GW-322 had a slightly higher APAR value (598.61) compared to MP-3336 (595.11) in the first year, but in the second year and pooled analysis, MP-3336 (677.28 and 636.19) exhibited slightly higher APAR values compared to GW-322 (659.83 and 629.22), although the differences were not statistically significant. These variations among wheat varieties could be attributed to genetic differences, varietal characteristics, and their specific responses to light interception and utilization for photosynthesis (Jiang *et al.,* 2018; Zhao *et al.,* 2019; Guo *et al.,* 2021; Chen *et al.,* 2021).The findings of this study highlight the significant influence of land use systems, sowing dates, and wheat varieties on absorbed photosynthetically active radiation in the *Pongamia pinnata*-based Agri-silviculture system. The open system, early sowing, and GW-322 variety consistently demonstrated superior performance in terms of higher APAR values. These results emphasize the importance of optimizing land use practices, selecting appropriate sowing dates, and choosing high-performing wheat varieties to maximize light interception, enhance photosynthetic efficiency, and ultimately improve crop productivity in Agri-silviculture systems.

Table 1: Chlorophyll % at 15 and 30 DAS of wheat varieties as influenced by sowing dates and different systems of both years.

Treatments	Chlorophyll % at 15 DAS			Chlorophyll % 30 DAS		
	1st year	2nd year	Pooled	1st year	2nd year	Pooled
Systems						
S_1- Open	13.55	14.17	13.86	28.15	14.17	27.29
S_2- Agroforestry	12.43	12.54	12.49	19.82	12.54	19.94
SEm±	0.05	0.09	0.07	0.16	0.09	0.11
CD (P = 0.05)	0.33	0.53	0.43	0.95	0.53	0.65
Date of sowing						
D_1- Nov. 12	13.45	14.27	13.86	25.39	14.27	24.98
D_2- Nov. 27	12.88	13.09	12.98	24.07	13.09	23.42
D_3- Dec. 12	12.65	12.71	12.68	22.49	12.71	22.43
SEm±	0.07	0.07	0.05	0.27	0.07	0.29
CD (P = 0.05)	0.24	0.21	0.17	0.89	0.21	0.94
Varieties						
V_1- MP-3336	13.12	13.51	13.31	24.60	13.51	24.28
V_2- GW-322	12.86	13.20	13.03	23.37	13.12	22.95
SEm±	0.07	0.07	0.05	0.17	0.07	0.12
CD (P = 0.05)	0.21	0.21	0.15	0.52	0.21	0.37

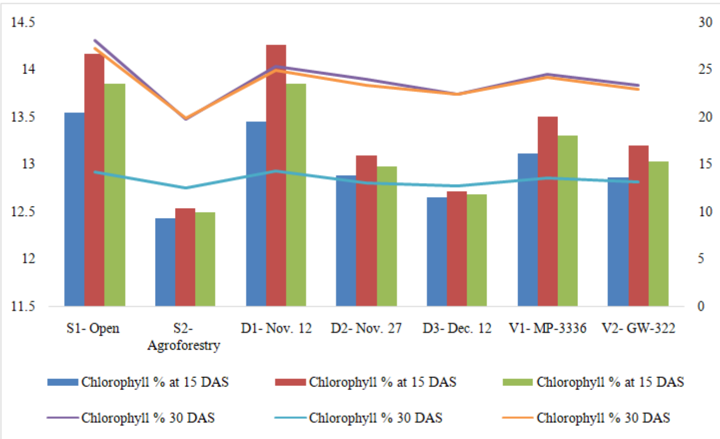

Fig. 1. Chlorophyll % at 15 and 30 DAS of wheat varieties as influenced by sowing dates and different systems of both years.

Table 2: APAR (μ mol m^{-2} s^{-1}) at 15 DAS and 30 DAS of wheat varieties as influenced by sowing dates and different systems of both years.

Treatments	APAR (μ mol m^{-2} s^{-1}) at 15 DAS			APAR (μ mol m^{-2} s^{-1}) at 30 DAS		
	1st year	2nd year	Pooled	1st year	2nd year	Pooled
Systems						
S_1- Open	169.28	355.56	262.42	1028.78	1142.28	1085.53
S_2- Agroforestry	91.67	101.06	96.36	164.94	194.83	179.89
SEm±	4.42	17.66	7.36	3.43	13.63	7.20
CD (P = 0.05)	26.89	107.45	44.76	20.90	82.95	43.82
Date of sowing						
D_1- Nov. 12	155.50	214.42	184.96	561.67	726.42	644.04
D_2- Nov. 27	89.50	215.50	152.50	515.17	590.67	552.92
D_3- Dec. 12	146.42	255.00	200.71	713.75	688.58	701.17
SEm±	6.83	19.10	8.67	7.28	13.32	6.46
CD (P = 0.05)	22.27	62.30	28.26	23.73	43.43	21.07

Varieties						
V_1- MP-3336	127.50	221.06	174.28	595.11	677.28	636.19
V_2- GW-322	133.44	235.56	184.50	598.61	659.83	629.22
SEm±	3.88	11.13	4.63	4.59	7.06	4.23
CD (P = 0.05)	11.95	34.30	14.27	14.15	21.75	13.03

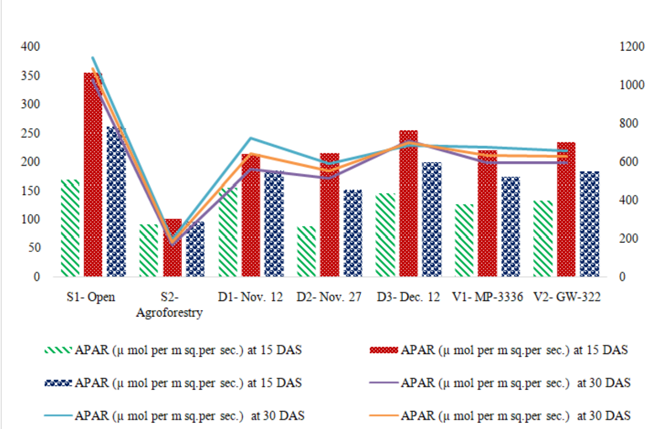

Fig. 2. APAR (μ mol m^{-2} s^{-1}) at 15 DAS and 30 DAS of wheat varieties as influenced by sowing dates and different systems of both years.

CONCLUSIONS

In conclusion, this study highlights the significant impact of land use systems, sowing dates, and wheat varieties on chlorophyll content and absorbed photosynthetically active radiation (APAR) in a *Pongamia pinnata*-based Agri-silviculture system. The open system consistently demonstrated higher chlorophyll content and APAR values compared to the agroforestry system, indicating its superiority in promoting light penetration and nutrient availability. Early sowing exhibited higher chlorophyll content and APAR values compared to timely and late sowing, emphasizing the importance of favorable climatic conditions and longer exposure to sunlight for optimal photosynthetic activity. Among the wheat varieties, MP-3336 consistently exhibited superior performance in terms of chlorophyll content, while GW-322 showed higher APAR values at 15 DAS. These findings suggest genetic and varietal differences in chlorophyll biosynthesis and light interception. Overall, optimizing land use systems, selecting appropriate sowing dates, and utilizing high-performing wheat varieties are crucial strategies to enhance chlorophyll production, improve photosynthetic efficiency, and increase crop productivity in Agri-silviculture systems.

FUTURE SCOPE

The study opens up potential future research directions in Agri-silviculture systems and crop productivity. These include optimizing land use systems, exploring interactions between sowing dates and crop varieties, investigating synergies between Agri-silviculture systems and climate change mitigation/adaptation, conducting long-term studies, exploring the integration of different crops within Agri-silviculture systems, evaluating management practices, and assessing the economic viability and benefits of these systems. These research areas will contribute to a deeper understanding of Agri-silviculture systems and the development of sustainable agricultural practices.

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Conflict of Interest. None.

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