Original Research Article

Performance of wheat varieties at different sowing dates under open and *Pongamiapinnata* based agroforestry systems

Abstract

The experiment was carried out in a *Pongamiapinnata*-based agroforestry system to assess the impact of land use systems, sowing dates, and wheat varieties on wheat cultivation at the Forestry Research Farm, JNKVV, Jabalpur during the Rabi season of 2021-22 The experiment followed a three-factor double split plot design with two systems (open system and agroforestry system) as the main plot, three sowing dates (12th November, 27th November, and 12th December) as subplots, and two wheat varieties (MP-3336 and GW-322) as sub-sub plots. The results showed that the open system outperformed the agroforestry system in terms of plant population, plant height at harvest, grain yield, straw yield, biological yield, and harvest index. Early-sown wheat consistently showed better performance in most parameters compared to timely-sown and late-sown varieties. Among the wheat varieties, the MP-3336 variety exhibited higher plant population, while the GW-322 variety showed taller plants at harvest, longer spikes, higher grain yield, and better harvest index. These findings provide valuable insights into optimizing wheat cultivation in agroforestry systems and emphasize the importance of considering land use systems, sowing dates, and wheat varieties to maximize crop productivity.

Keywords- Agroforestry system, Wheat varieties, *Pongamiapinnata* and Yield.

1. INTRODUCTION

The global challenge of achieving food security while preserving environmental quality has become increasingly urgent, especially in light of projections indicating that the global population will reach 11 billion by 2050 [1]. This challenge has prompted researchers to explore sustainable agricultural practices that can mitigate the adverse effects of climate change and enhance agricultural productivity. One such practice is agroforestry, a discipline that integrates woody perennials with crops and/or animals on the same land, providing a practical approach for soil carbon sequestration and climate change mitigation [2], [3] and [4].Climate and soil conditions play a vital role in agricultural productivity, profitability, and human well-being [5], [6]. However, climate adversities, such as extreme weather events, have had detrimental effects on crop productivity, natural resources, food security, and environmental health [7], [8]. In this context, agroforestry emerges as a significant contributor to environmental services, moderating microclimates in the short term and sequestering carbon in the long term, thereby mitigating the impacts of climate change [9].Wheat (*Triticumaestivum L.*, *Poaceae*), being one of the most important and widely cultivated crops globally, plays a crucial role in meeting the protein and calorie needs of billions of people [10]. However, the production of wheat is highly vulnerable to climate change, as it increases both abiotic pressures (such as cold, drought, heat, salinity, and waterlogging) and biotic stresses (such as diseases and insect pests) [11]. Researchers have been studying global climate changes, including the rise in atmospheric carbon dioxide (CO_2) and ozone levels, and exploring measures to mitigate the adverse effects of these changes on wheat cultivation [12], [13].Amidst these challenges, the utilization of alternative crops with unique characteristics becomes crucial. *Pongamiapinnata*, commonly known as pongamia or Indian beech tree, is a non-food legume indigenous to northern Australia, Southeast Asia, and India. Pongamia possesses remarkable attributes that make it a promising candidate for various applications. It exhibits rapid growth, can symbiotically fix biological nitrogen, and thrives in agriculturally unproductive soils characterized by water scarcity, nutrient deficiency, and high salinity [14], [15].Moreover, pongamia offers medicinal properties and potential insecticidal and nematicidal activities, diversifying its usefulness [16]. Its seeds, with a significant oil content of 30-40% by volume, hold promise as a sustainable source for biodiesel and aviation fuel production, while other parts of the plant can be utilized for electricity cogeneration or fermentation processes [17], [18].Given its versatility, pongamia presents an opportunity to address the global challenge of sustainable agriculture, particularly in marginal lands, and contribute to energy and pharmaceutical sectors. This paper aims to explore the potential of pongamia as a valuable crop in addressing food security, environmental sustainability, and economic diversification, taking into account its unique characteristics and applications.

2. MATERIAL AND METHODS

2.1 Experimental Location, Topography and Climate

The experiment was conducted in *Pongamiapinnata*based 14 years old agroforestry model during *Rabi* season of 2021-22 at Forestry Research Farm, Jawaharlal Nehru KrishiVishwaVidyalaya, Jabalpur (MP), located at 23° 12’ 50” North latitude and 79° 57’ 56” East longitude. This location is part of the Kymore Plateau and Satpura hill agro-climatic zone, with a subtropical climate with hot, dry summers and cold, dry winters. In May and June, the temperature reaches 46 °C, while in December and January, it drops to 2 °C. The average annual rainfall in the area is 1350 mm, with most of it falling between June and September. The soil is reasonably black in colour, and the region is simple to softly sloppy (0-1 percent).

2.2 Experimental Details

The experiment was performed in three factor double split plot design which consist of two system viz., S1 (Open system) and S2 (Agroforestry system) as main plot, three sowing dates viz., D1 (12th November), D2 (27th November), D3 (12th December) as subplot and two wheat varieties viz., V1 (MP-3336) and V2 (GW-322) as sub-sub plot each treatments had three replications. The field was ploughed two times with cultivator and one-time rotavator and levelled by labour. The Crop was line sowed with distance of 20 cm apart at three sowing dates i.e., 12th November, 27th November and 12th December using the seed rate of 100 kg ha^{-1} following a manual hand hoeing method. The recommended doses of fertilizers Nitrogen, Phosphorus and Potassium were applied at the rate of 120:60:40 kg ha^{-1} using urea, Single Super Phosphate (SSP), and muriate of potash (MOP), respectively. All fertilizers were applied at the time of sowing as basal doses, while remaining 50% nitrogen was applied in split doses. Weeds were controlled through herbicide spray of VESTA (ClodinafopPropargyl 15%+Metsulfuron Methyl 1% WP) at 30 days after sowing. Irrigations were provided five times during the crop duration at proper interval. The

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information gathered was submitted to statistical analysis of variance, as Gomez and Gomez (1984) recommended.

3. RESULTS AND DISCUSSION

3.1.Plant population of wheat varieties influenced by sowing dates and systems

The observations presented in Table 1 and Figure 1 highlight the impact of different factors such as land use systems, sowing dates, and wheat varieties on wheat plant population under the *Pongamiapinnata*-based agri-silviculture system. The findings clearly indicate that these factors significantly influence the plant population of wheat. In terms of land use systems, the open system outperformed the agroforestry system at 20 days after sowing (DAS), with a significantly higher plant population of 217.17 compared to 204.65. Similarly, at harvest, the open system continued to exhibit a significantly higher plant population of 206.43, while the agroforestry system recorded 196.09. When considering different sowing dates, early-sown wheat displayed the highest plant population at 20 DAS, significantly surpassing both timely-sown and late-sown varieties. The early-sown wheat maintained its superiority at harvest as well, with a maximum plant population of 207.51, followed by timely-sown (199.78) and late-sown (196.49) varieties. Among the different wheat varieties, the MP-3336 variety consistently performed better in terms of plant population. It exhibited higher plant population at both 20 DAS (214.80) and harvest (205.18) compared to the GW-322 variety, which recorded 207.02 and 197.32, respectively. The presented observations on the effects of land use systems, sowing dates, and wheat varieties on wheat plant population under the *Pongamiapinnata*-based Agri-silviculture system provide valuable insights for optimizing wheat cultivation. The study reveals that the open system, early sowing, and the MP-3336 variety consistently resulted in higher plant populations. The superiority of the open system in terms of plant population at both 20 DAS and harvest can be attributed to factors such as increased sunlight availability and reduced competition for resources compared to the agroforestry system. This finding aligns with previous research indicating that open systems tend to promote better plant growth and productivity [19].Early sowing proved beneficial for achieving higher plant populations, likely due to the plants having a longer growth period, favourable climatic conditions, and reduced competition from weeds. These results are in line with studies that have highlighted the advantages of early sowing in terms of crop establishment and yield potential [20], [21]. The MP-3336 variety consistently outperforming the GW-322 variety in plant population suggests genetic differences between the two varieties. Varietal characteristics, such as early vigor, tillering capacity, and adaptability, can contribute to variations in plant population. Previous studies have also reported varietal differences in wheat plant population and growth parameters [22], [23]. Overall, these findings emphasize the importance of considering land use systems, sowing dates, and wheat varieties for optimizing wheat plant population in the *Pongamiapinnata*-based Agri-silviculture system. The open system, early sowing, and the MP-3336 variety have shown promise in achieving higher plant populations, which can contribute to improved crop productivity and yield.

3.2 Plant height (cm) of wheat varieties influenced by sowing dates and systems

The findings presented in Table 1 and Figure 1 shed light on the profound impact of different factors, such as land use systems, sowing dates, and wheat varieties, on plant height in the *Pongamiapinnata*-based Agri-silviculture system. The results unequivocally

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demonstrate that these factors play a crucial role in shaping plant height. Among the various land use systems, the agroforestry system exhibited the highest plant height (46.56 cm) at 30 days after sowing (DAS), surpassing the open system (42.72 cm) with statistical significance. However, at harvest, the open system recorded the maximum plant height (98.99 cm), which was significantly greater than the plant height in the agroforestry system (85.30 cm). Importantly, there was no statistically significant difference in plant height between the two land use systems at harvest. In terms of sowing dates, early-sown wheat showcased the tallest plant height (49.75 cm) at 30 DAS, significantly outperforming both the timely-sown (43.98 cm) and late-sown (40.18 cm) varieties. At harvest, the early-sown variety maintained its dominance by displaying the highest plant height (95.83 cm), significantly surpassing the late-sown variety (87.76 cm) while showing no statistical difference compared to the timely-sown variety (92.83 cm). Regarding the wheat varieties, the MP-3336 variety exhibited superior plant height (45.33 cm) compared to the GW-322 variety (43.93 cm) at 30 DAS. However, at harvest, the GW-322 variety took the lead with the highest plant height (95.22 cm), significantly surpassing the MP-3336 variety (89.07 cm).The observed differences in plant height between the agroforestry system and the open system indicate the influence of canopy structure and light availability. Similar findings have been reported in previous studies, where the agroforestry system resulted in taller plants due to increased light interception and reduced competition for resources [24], [25]. On the other hand, the taller plant height observed in the open system at harvest may be attributed to enhanced access to sunlight and reduced shading from surrounding vegetation [26].The influence of sowing dates on plant height is evident, with early-sown wheat displaying taller plants compared to timely and late-sown varieties. These results align with previous research highlighting the positive impact of early sowing on crop growth and development, which can lead to increased plant height [27], [28]. The superior plant height observed in the early-sown variety at harvest suggests the importance of optimizing sowing timing for maximizing crop performance. Varietal differences in plant height were also observed, with the MP-3336 variety exhibiting greater height than the GW-322 variety at 30 DAS. However, at harvest, the GW-322 variety surpassed the MP-3336 variety in terms of plant height. These findings highlight the genetic variation and phenotypic plasticity of different wheat varieties in response to environmental conditions, including nutrient availability, temperature, and moisture [29], [30].

3.3 **Yield contributing attributes of wheat varieties as influenced by sowing dates and different systems**

The presented observations in Table 2 and Figure 2 provide insights into the impact of land use systems, sowing dates, and wheat varieties on yield-contributing characteristics, including effective tillers m^{-2}, spike length (cm), grains $spike^{-1}$, and test weight (g), within the *Pongamiapinnata*-based Agri-silviculture system. The findings clearly indicate that these attributes are significantly influenced by the different factors.

3.3.1 Effective tillers m^{-2} of wheat varieties influenced by sowing dates and systems

Among the different land use systems, the open system exhibited the highest number of effective tillers (435.27 m^{-2}), which was significantly superior to the agroforestry system (320 m^{-2}). This finding suggests that the open system provides more favourable conditions for the development of tillers, leading to increased potential for grain production. Similar results have been reported in previous studies, where open systems with reduced

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competition and better light penetration promoted higher tiller numbers [31], [32]. Regarding different sowing dates, the early-sown wheat displayed the maximum number of effective tillers (397.50 m^{-2}), significantly surpassing both the timely-sown (374.58 m^{-2}) and late-sown (360.83 m^{-2}) varieties. This observation aligns with research indicating that early sowing promotes better tiller initiation and subsequent tiller development, contributing to higher tiller numbers [33], [34]. Early sowing provides a longer duration for tiller establishment and growth, resulting in increased tiller production.Among the varieties, the MP-3336 variety exhibited the highest number of effective tillers (389.67 m^{-2}), significantly surpassing the GW-322 variety (365.60 m^{-2}). These findings highlight the genetic variation in wheat varieties, with some varieties inherently possessing traits that promote higher tiller production [35], [36]. The MP-3336 variety's superior tiller production suggests its potential for higher grain yield.

3.3.2 Spike length (cm) of wheat varieties influenced by sowing dates and systems

Among the different land use systems, the open system exhibited the longest spike length (7.64 cm), which was significantly greater than the spike length in the agroforestry system (7.03 cm). This finding suggests that the open system provides more favourable conditions for spike development, leading to longer spikes. Previous studies have also reported similar results, with open systems promoting increased spike length due to better light interception and reduced competition [37], [38]. In terms of different sowing dates, the early-sown wheat displayed the maximum spike length (7.61 cm), significantly surpassing both the timely-sown (7.20 cm) and late-sown (7.19 cm) varieties. This observation aligns with research indicating that early sowing allows for longer grain filling duration and promotes spike elongation, resulting in longer spikes [39], [40]. The early-sown wheat benefits from extended growth and development periods, contributing to enhanced spike length.Regarding the wheat varieties, the GW-322 variety demonstrated superior spike length (8.02 cm), significantly surpassing the MP-3336 variety (6.65 cm). These findings indicate genetic variations between the varieties, with some varieties inherently possessing traits that promote longer spikes [41], [40]. The GW-322 variety's performance in spike length suggests its potential for enhanced grain yield due to increased floret development and potential grain production.

3.3.3 Grainsspike^{-1} of wheat varieties influenced by sowing dates and systems

Among the different land use systems, the open system demonstrated the highest number of grains spike^{-1} (50.98), which was significantly greater than the agroforestry system (45.89). This finding suggests that the open system provides more favourable conditions for grain development, resulting in a higher grain count spike^{-1}. Previous studies have also reported similar results, with open systems promoting increased grain production due to improved light interception and reduced competition [42], [43]. Regarding different sowing dates, the early-sown wheat exhibited the maximum number of grains spike^{-1}(50.19), significantly surpassing the late-sown variety (46.13) but statistically similar to the timely-sown variety (48.98). This observation aligns with research indicating that early sowing promotes better grain filling and increased grain formation, leading to a higher number of grains per spike [44], [45]. Early sowing provides a longer grain filling period, allowing for more grain development.In terms of wheat varieties, the GW-322 variety recorded the highest number of grains spike^{-1}(51.89), significantly surpassing the MP-3336 variety (44.98). These findings highlight the genetic variations among wheat varieties, with

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some varieties possessing inherent traits that promote higher grain production [46], [47]. The GW-322 variety's performance in terms of grains per spike suggests its potential for enhanced grain yield.

3.3.4Test weight (g) of wheat varieties influenced by sowing dates and systems

Among the different land use systems, the open system exhibited the highest test weight (41.55 g), which was significantly greater than the test weight in the agroforestry system (39.46 g). This finding suggests that the open system provides more favourable conditions for grain filling and development, resulting in higher test weights. Previous studies have also reported similar results, with open systems promoting improved grain quality characteristics, including higher test weights [48], [49]. Regarding different sowing dates, the early-sown wheat displayed the maximum test weight (41.23 g), significantly surpassing the late-sown variety (39.62 g) but statistically similar to the timely-sown variety (40.66 g). This observation aligns with research indicating that early sowing facilitates longer grain filling duration, allowing for improved grain filling and higher test weights [50], [51]. Early sowing provides favourable conditions for grain development, leading to better grain quality attributes.In terms of wheat varieties, the GW-322 variety demonstrated better test weight (41.01 g) compared to the MP-3336 variety (40 g). These findings highlight the genetic variations among wheat varieties, with some varieties inherently possessing traits that promote higher test weights [52], [53]. The superior test weight observed in the GW-322 variety indicates its potential for enhanced grain quality.

3.4 Yield parameters of wheat varieties influenced by sowing dates and different systems

The findings presented in Table 3 and Figure 3 highlight the significant impact of different factors, including land use systems, sowing dates, and wheat varieties, on yield parameters such as grain yield (q ha^{-1}), straw yield (q ha^{-1}), biological yield (q ha^{-1}), and harvest index (%) within the *Pongamiapinnata*-based Agri-silviculture system.The results clearly indicate that these factors play a crucial role in determining the yield potential and distribution of biomass within the system.

3.4.1 Grain yield q ha^{-1} of wheat varieties influenced by sowing dates and systems

Among the different land use systems, the open system exhibited the highest grain yield (53.47 q ha^{-1}), which was significantly greater than the grain yield in the agroforestry system (44.21 q ha^{-1}). This finding indicates that the open system provides more favourable conditions for maximizing grain production. Previous studies have also reported similar results, with open systems promoting higher crop yields due to improved light interception, reduced competition, and enhanced nutrient availability [54], [55]. Regarding different sowing dates, early-sown wheat demonstrated the maximum grain yield (51.18 q ha^{-1}), significantly surpassing both the timely-sown (49.16 q ha^{-1}) and late-sown (46.18 q ha-1) varieties. This observation aligns with research indicating that early sowing leads to better crop establishment, increased photosynthetic activity, and improved grain filling, resulting in higher grain yields [56], [32]. Early sowing allows for a longer growing period, optimizing the crop's yield potential.Among the wheat varieties, the GW-322 variety exhibited the highest grain yield (51.49 q ha^{-1}), significantly surpassing the MP-3336 variety (46.19 q ha^{-1}). These findings highlight the genetic variability among wheat varieties, with some varieties possessing traits that contribute to higher grain yields [57], [58]. The superior

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performance of the GW-322 variety indicates its potential for maximizing grain yield in the specific agri-silviculture system.

3.4.2 Straw yieldq ha^{-1}of wheat varieties influenced by sowing dates and systems

When comparing different land use systems, the open system exhibited the highest straw yield (67.64 q ha^{-1}), which was significantly greater than the straw yield in the agroforestry system (64.28 q ha^{-1}). This finding suggests that the open system provides more favourable conditions for biomass accumulation and straw production. Previous studies have also reported similar results, with open systems allowing for better light penetration and airflow, promoting higher biomass production [31], [52]. Regarding different sowing dates, early-sown wheat demonstrated the maximum straw yield (69.40 q ha^{-1}), significantly surpassing both the timely-sown (66.27 q ha^{-1}) and late-sown (62.21 q ha^{-1}) varieties. Early sowing provides the crop with a longer growth period, allowing for increased tillering and higher biomass accumulation[59], [60]. These results highlight the importance of timely sowing in optimizing straw yield in wheat cultivation.Among the wheat varieties, the GW-322 variety exhibited the highest straw yield (67.75 q ha^{-1}), significantly surpassing the MP-3336 variety (64.17 q ha^{-1}). This indicates that the genetic characteristics of the GW-322 variety contribute to higher biomass production and straw yield. Varietal differences in straw yield can be attributed to variations in canopy architecture, tillering capacity, and overall growth and development [61], [62]. The superior performance of the GW-322 variety in terms of straw yield suggests its potential for maximizing biomass production in the specific agri-silviculture system.

3.4.3 Biological yield q ha^{-1}of wheat varieties influenced by sowing dates and systems

In terms of biological yield, the open system exhibited the highest yield of 121.11 q ha^{-1}, which was significantly superior to the agroforestry system's yield of 108.49 q ha^{-1}. This suggests that the open system was more effective in achieving a higher overall crop yield compared to the agroforestry system.Among the different sowing dates, the early sown period resulted in the highest biological yield of 120.58 q ha^{-1}. This yield was significantly higher than the timely sown yield of 115.42 q ha^{-1}and the late sown yield of 108.39 q ha^{-1}. These differences were found to be statistically significant, indicating that the choice of sowing date has a significant impact on the biological yield. Specifically, early sowing resulted in the highest yield, followed by timely sowing and then late sowing.When comparing the varieties, GW-322 demonstrated the maximum biological yield of 119.23 q ha^{-1}. This yield was significantly higher than the yield of the MP-3336 variety, which was 110.36 q ha^{-1}. This indicates that GW-322 outperformed MP-3336 in terms of achieving a higher biological yield. The results presented in the given information provide valuable insights into the impact of different factors on the biological yield in agricultural systems. The findings suggest that the open land use system outperformed the agroforestry system in terms of achieving a higher biological yield. This is consistent with previous studies that have reported higher yields in open systems compared to agroforestry systems [63], [64]. The open system allows for greater access to sunlight and reduces competition for resources, resulting in improved crop productivity [65]. Furthermore, the influence of sowing dates on biological yield was evident, with early sowing demonstrating the highest yield, followed by timely sowing and late sowing. These findings align with the general understanding that early sowing provides crops with favourable conditions for growth and development, resulting in higher yields [56]. Timely sowing ensures optimal plant establishment and

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minimizes exposure to adverse environmental conditions, contributing to a respectable yield. Late sowing, on the other hand, may lead to reduced crop performance due to suboptimal conditions during crucial growth stages [66]. Varietal selection also played a significant role in determining the biological yield. The GW-322 variety exhibited superior performance in terms of achieving a higher yield compared to the MP-3336 variety. This finding highlights the importance of selecting suitable varieties that are well-adapted to the local agroecological conditions. Selecting high-yielding and resilient varieties can significantly contribute to maximizing crop productivity [67].

3.4.4. Harvest Index (%) of wheat varieties influenced by sowing dates and systems

Among the various land use systems assessed, the open system exhibited the highest harvest index (44.10%), which was significantly superior to the harvest index observed under the agroforestry system (40.76%). This finding indicates that the open system was more effective in maximizing crop yield compared to the agroforestry system. In terms of sowing dates, the maximum harvest index was observed for late-sown crops (42.53%), followed by timely-sown crops (45.45%) and early-sown crops (42.31%). However, statistical analysis revealed that there were no significant differences in harvest index among the different sowing dates. Therefore, while slight variations in harvest index were observed, they were not statistically significant.Regarding the varieties, the GW-322 variety displayed the highest harvest index (43.08%), which was significantly superior to the harvest index of the MP-3336 variety (41.78%). This indicates that GW-322 outperformed MP-3336 in terms of maximizing crop yield.The results indicate that the open system achieved a significantly higher harvest index compared to the agroforestry system, indicating its superiority in maximizing crop yield. This is in line with previous research indicating that open systems generally exhibit higher productivity compared to agroforestry systems [63], [64]. When considering the influence of sowing dates on the harvest index, it was observed that late-sown crops achieved the highest harvest index, followed by timely-sown and early-sown crops. However, statistical analysis revealed no significant differences in the harvest index among the different sowing dates. While slight variations in the harvest index were observed, they were not statistically significant in this particular study. It is important to note that the effect of sowing dates on crop yield can vary depending on the specific crop, growing conditions, and geographical location [68]. Regarding the varieties, the GW-322 variety demonstrated a significantly higher harvest index compared to the MP-3336 variety. This indicates that GW-322 outperformed MP-3336 in terms of maximizing crop yield. The choice of high-yielding varieties is crucial for enhancing crop productivity and meeting the demands of food production [69-72].

4. CONCLUSION

In conclusion, the findings from this study highlight the importance of considering land use systems, sowing dates, and wheat varieties for optimizing wheat cultivation in the *Pongamiapinnata*-based Agri-silviculture system. The open system outperformed the agroforestry system in terms of higher plant populations, longer plant height at harvest, and improved yield-contributing characteristics. This can be attributed to increased sunlight availability and reduced competition for resources in the open system. Early sowing demonstrated significant benefits, resulting in higher plant populations, taller plant height at harvest, and improved yield-contributing characteristics. Early-sown wheat consistently outperformed the timely-sown and late-sown varieties, emphasizing the importance of

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optimizing sowing timing for maximizing crop performance. The choice of wheat varieties also played a crucial role, with the MP-3336 and GW-322 varieties exhibiting superior performance in terms of plant populations, plant height, and yield-contributing attributes. These varietal differences highlight the importance of selecting high-yielding and well-adapted varieties for maximizing crop productivity. Overall, the open system, early sowing, and the MP-3336 and GW-322 varieties consistently demonstrated promise in achieving higher plant populations, taller plant height, and improved yield-contributing characteristics. These insights can inform farmers and agronomists in making informed decisions to optimize wheat cultivation and enhance crop productivity and yield in the Pongamiapinnata-based Agri-silviculture system. By considering these factors, farmers can maximize their crop's potential and contribute to sustainable and efficient agricultural practices.

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Table 1.Plant population and plant height (cm) of wheat varieties as influenced by sowing dates and different systems.

Treatments	Plant population		plant height (cm)	
	20 DAS	At harvest	30 DAS	At harvest
Systems				
S_1- Open	217.17	206.43	42.72	98.99
S_2- Agroforestry	204.66	196.09	46.56	85.30
SEm±	**0.89**	**0.98**	**0.52**	**2.44**
CD (P = 0.05)	**5.39**	**5.96**	**3.16**	**14.82**
Date of sowing				
D_1- Nov. 12	218.55	207.51	49.75	95.83
D_2- Nov. 27	209.16	199.78	43.98	92.83
D_3- Dec. 12	205.03	196.49	40.18	87.77
SEm±	**2.07**	**2.10**	**1.13**	**1.15**
CD (P = 0.05)	**6.74**	**6.86**	**3.68**	**3.76**
Varieties				
V_1- MP-3336	214.81	205.19	45.33	89.07
V_2- GW-322	207.02	197.33	43.94	95.22
SEm±	**0.87**	**0.76**	**0.30**	**1.05**
CD (P = 0.05)	**2.68**	**2.35**	**0.93**	**3.22**

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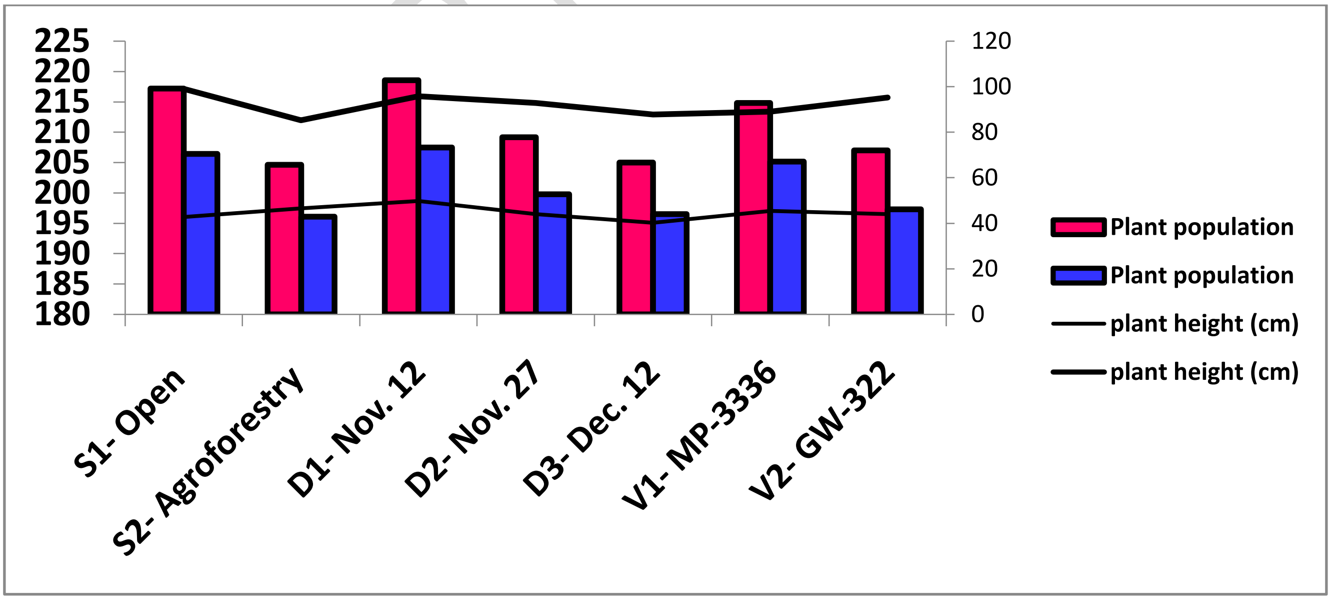

Figure.1 Plant population and plant height (cm) of wheat varieties as influenced by sowing dates and different systems.

Table 2. Yield contributing parameters of wheat varieties as influenced by sowing dates and different systems.

Treatments	Effective tillers m^{-2}	Spike length (cm)	Grains $spike^{-1}$	Test weight (g)
Systems				
S_1- Open	435.27	7.64	50.98	41.55
S_2- Agroforestry	320	7.03	45.89	39.46
SEm±	**2.53**	**0.05**	**0.55**	**0.19**
CD (P = 0.05)	**15.37**	**0.28**	**3.35**	**1.18**
Date of sowing				
D_1- Nov. 12	397.50	7.61	50.19	41.23
D_2- Nov. 27	374.58	7.20	48.98	40.66
D_3- Dec. 12	360.83	7.19	46.13	39.62
SEm±	**6.02**	**0.10**	**0.93**	**0.32**
CD (P = 0.05)	**19.62**	**0.33**	**3.03**	**1.03**
Varieties				
V_1- MP-3336	389.67	6.65	44.98	40.01
V_2- GW-322	365.60	8.02	51.89	41.00
SEm±	**2.50**	**0.10**	**0.38**	**0.26**
CD (P = 0.05)	**7.70**	**0.31**	**1.16**	**0.81**

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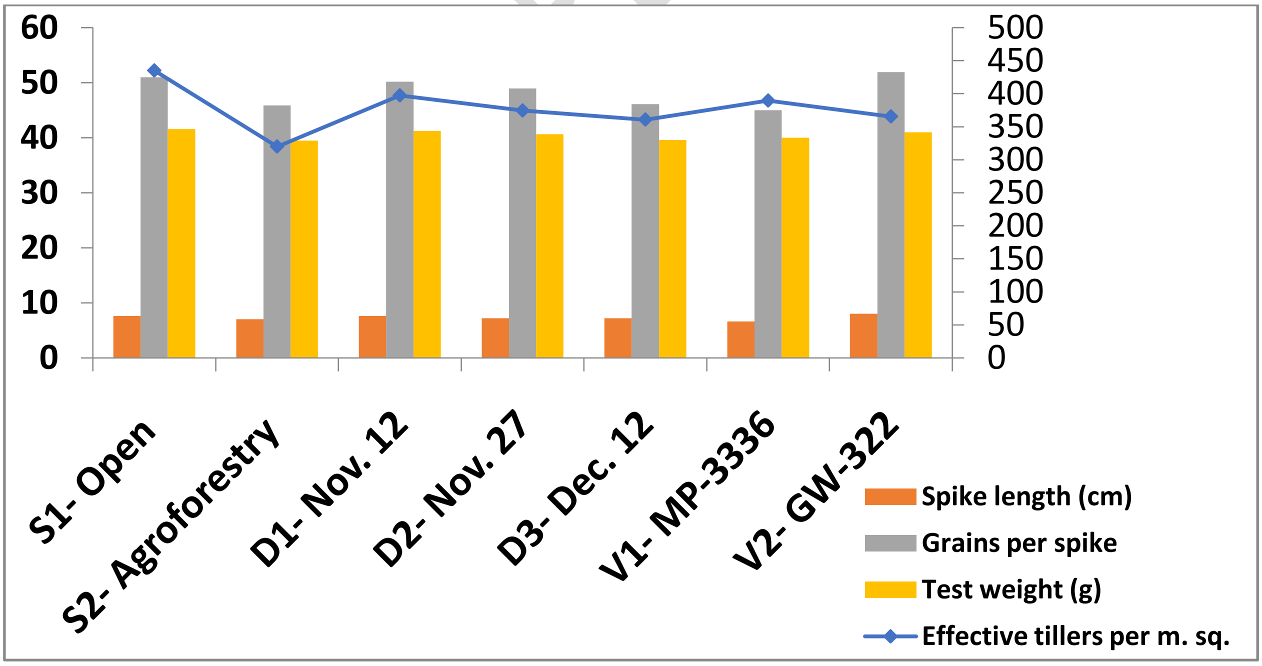

Figure2. Yield contributing parameters of wheat varieties as influenced by sowing dates anddifferent systems.

Table 3. Yield parameters of wheat varieties as influenced by sowing dates and different systems during 2021-22.

Treatments	Grain yield q ha^{-1}	Straw yield q ha^{-1}	Biological yield q ha^{-1}	Harvest Index (%)
Systems				
S_1- Open	53.47	67.64	121.11	44.10
S_2- Agroforestry	44.21	64.28	108.49	40.76
SEm±	**0.02**	**0.64**	**0.64**	**0.22**
CD (P = 0.05)	**0.09**	**3.86**	**3.88**	**1.36**
Date of sowing				
D_1- Nov. 12	51.18	69.40	120.58	42.31
D_2- Nov. 27	49.16	66.27	115.42	42.45
D_3- Dec. 12	46.18	62.21	108.39	42.53
SEm±	**0.20**	**0.31**	**0.35**	**0.15**
CD (P = 0.05)	**0.65**	**1.00**	**1.15**	**0.50**
Varieties				
V_1- MP-3336	46.19	64.17	110.36	41.78
V_2- GW-322	51.48	67.75	119.23	43.08
SEm±	**0.20**	**0.27**	**0.39**	**0.10**
CD (P = 0.05)	**0.60**	**0.84**	**1.21**	**0.32**

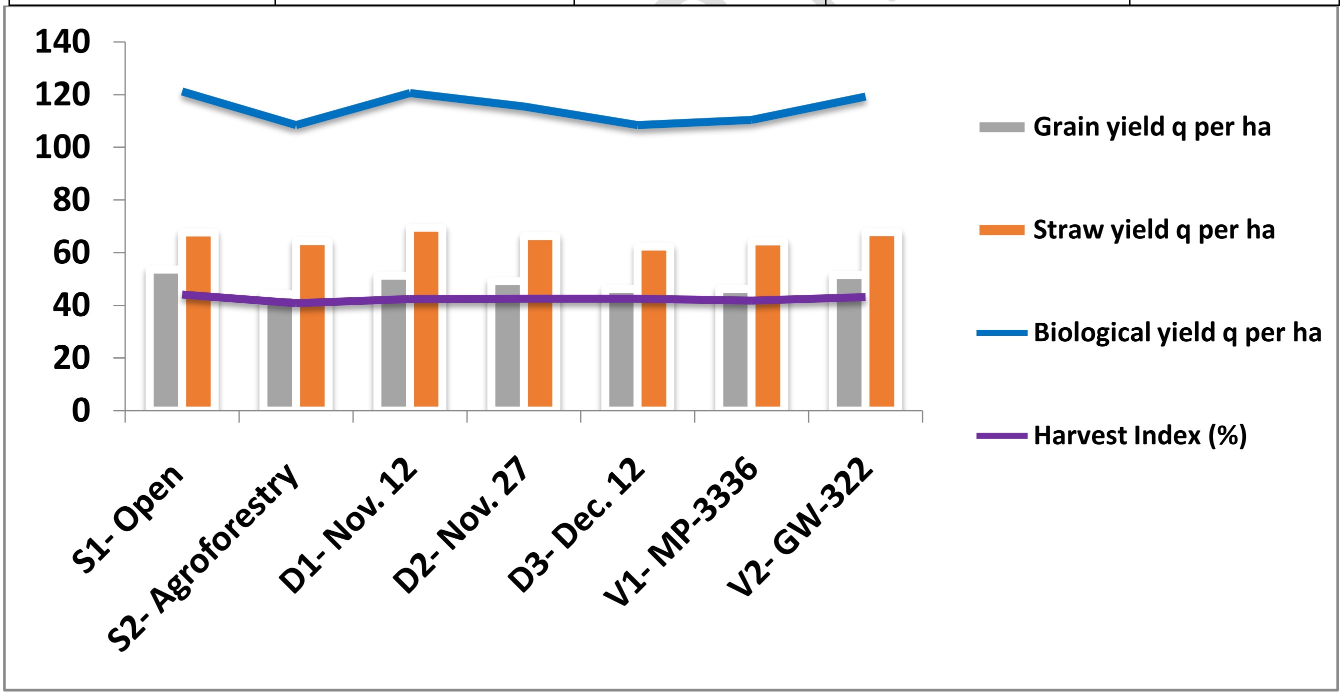

Figure 3. Yield parameters of wheat varieties as influenced by sowing dates and different systems during 2021-22.

References

1. Adam R. Population Projections 2021-2100. United Nations, Department of Economic and Social Affairs, Population Division. 2021.
2. Babu C, et al. Agroforestry: A Sustainable Land Use Option for Food Security and Environmental Quality. Journal of Environmental Science and Management. 2022a; 25(1): 1-16.
3. IPCC. Special Report on Land Use, Land-Use Change, and Forestry. Cambridge University Press. 2000;
4. Nair PKR. The Coming of Age of Agroforestry. Journal of the Science of Food and Agriculture. 2007; 87(9): 1613-1619.
5. Babu, C., et al. Climate and Soil: Major Determinants of Agricultural Productivity, Profitability, and Human Well-Being. Environmental Science and Pollution Research. 2022b; 29(7): 9253-9268.
6. Yadav A, et al. Climate Change and Agriculture: Implications for Productivity, Profitability, and Human Well-Being. Current Science. 2021a. 120(9): 1465-1474.
7. Dordevic I, et al. Climate Change and Agriculture: An Economic Analysis of Global Impacts, Adaptation, and Distributional Effects. Journal of International Agricultural Trade and Development. 2018; 67(1): 87-110.
8. Das R, et al. Climate Change, Agriculture, and Food Security: Challenges and Solutions. Frontiers in Environmental Science. 2022; 10, 768215.
9. Jain S and Mehta D. Agroforestry: An Approach for Mitigating Climate Change. Indian Journal of Ecology. 2020; 47(1): 1-4.
10. Dong B, et al. Global Wheat Production in the Face of Climate Change: Adapting to Meet the Challenges. Journal of Integrative Agriculture. 2020; 19(10): 2415-2425.
11. David B and Sharon A. Climate Change Effects on Wheat Phenology in the Southeastern European Union According to AR4 Climate Change Scenarios. Journal of Agricultural Science. 2012; 150(2): 155-168.
12. Wang G, et al. Late Sowing Increases the Effects of High Temperature on Wheat Grain Yield. Journal of Agronomy and Crop Science. 2012; 198(1): 38-49.
13. Xiao G, et al. Delaying Sowing Date Increased the Accumulation of Dry Matter and Grain Yield of Winter Wheat *(Triticumaestivum L.)* in the Cold Region of China. Field Crops Research. 2014; 156, 14-22.
14. Daniel JN. *Pongamiapinnata*: A nitrogen fixing tree for oilseed. NFT Highlights, Nitrogen Fixing Tree Association (NFTA). FACT Net Winrock International. 1997; 97-103.
15. Tomar OS and Gupta DN. Studies on Germination of *PongamiaPinnata*: A Woody Legume. Indian Journal of Forestry. 1985; 8(2): 133-135.
16. Baral D, Thapa S and Koshariya AK. First report of Pestalotiopsismacadamiae causing leaf blight on Pongamiapinnata in India. New Disease Reports. 2023; pp. 47.
17. Konwar BK and Banerjee GC. Deoiledkaranja cake (*Pongamiaglabra* Vent.) a new feed ingredient in cattle ration. Indian Veterinary Journal. 1987; 64:500-504.
18. Ramana DBV, Singh S, Solanki KR and Negi AS. Nutritive evaluation of some nitrogen and non-nitrogen fixing multipurpose tree species. Animal Feed Science and Technology 2000; 88:103-111.
19. Acharya CL, Pramanick KK, Chandra A. Productivity of Wheat *(Triticumaestivum L.)* under Different Land Use Systems in Sub-Himalayan West Bengal, India. Journal of Crop Improvement. 2018; 32, 474-486.

UNDER PEER REVIEW

20. Li X, Wang, J, Zhang Y, Liu J, Li X, Effects of different sowing dates on yield, quality, and water use efficiency of winter wheat in the North China Plain. Field Crops Research 2019; 240, 15–24. doi: 10.1016/j.fcr.2019.04.014
21. Duan W, Chen X, Ye X, Zhu M, Li X, Zhang Y, Guo Y. Effects of sowing date and planting density on grain yield and plant development of winter wheat in the North China Plain. Field Crops Research 2020; 250, 107763. doi: 10.1016/j.fcr.2020.107763
22. Khalid S, Shahzad A, Nawaz MA, Farooq M, Ahmad R, Nawa A. Response of different wheat varieties to nitrogen levels under agro-climatic conditions of Faisalabad, Pakistan. Archives of Agronomy and Soil Science. 2019; 65, 970–982. doi: 10.1080/03650340.2018.1542649
23. Zhang J, Yang W, Liu L, Ma Y, Xie Y, Variety-dependent variation in dry matter accumulation and partitioning among high-yield wheat cultivars in China. Field Crops Research. 2020; 255, 107886. doi: 10.1016/j.fc
24. Singh R, Singh G, Lal G, et al. Evaluation of different alley cropping systems on growth and productivity of component crops. International Journal of Current Microbiology and Applied Sciences. 2017; 6(7): 755-764.
25. Saikia S, Handique GK, Rajkhowa DJ, et al. Productivity, nutrient uptake, and economics of wheat *(Triticumaestivum L.)* under agri-silviculture systems in Assam, India. Agroforestry Systems. 2019; 93(5): 1839-1850.
26. Saxena AK, Bhandari AL, Upadhyaya SK, et al. Effect of planting geometry and establishment methods on yield and yield attributes of wheat under different farming systems. Indian Journal of Agronomy. 2018; 63(1): 42-46.
27. Choudhary N, Joshi AK, Patil BS, et al. Effect of sowing dates and varieties on growth, yield and quality of durum wheat *(Triticum durum Desf.)* under late sown conditions of North Western Plains Zone of India. Journal of Applied and Natural Science. 2020; 12(4): 162-170.
28. Kaur G, Brar KS, Thind SS, et al. Influence of sowing dates on the growth, yield, and water productivity of wheat under semi-arid conditions. Journal of Crop Improvement. 2021; 35(1): 76-92.
29. El-Hendawy SE, Al-Suhaibani NA, Alotaibi M, et al. Assessment of wheat *(Triticumaestivum L.)* genotypes for adaptation to high temperature stress during grain filling using membrane thermostability and other physiological traits. Journal of Agronomy and Crop Science. 2019; 205(3): 292-302.
30. Gill RA, Islam F, Ali B, et al. Genome-wide transcriptional profiling to elucidate key candidates involved in wheat heat stress response. International Journal of Molecular Sciences. 2020; 21(7): 2341.
31. Kumar D, Verma P, Bhardwaj SC, et al. Effect of different row spacings and sowing methods on the performance of wheat varieties. Journal of Pharmacognosy and Phytochemistry. 2018; 7(6): 1630-1633.
32. Yadav S, Singh A, Singh SP, et al. Influence of sowing dates and seed rates on growth, yield, and economics of wheat *(Triticumaestivum L.)* in Eastern Uttar Pradesh. Journal of Pharmacognosy and Phytochemistry. 2022;11(1): 1775-1779.
33. Kumar A, Gupta RK, Kumar P, et al. Productivity and profitability of rainfedpigeonpea-wheat cropping system in different agroforestry systems in Central India. Indian Journal of Agronomy. 2019; 64(2): 238-242.
34. Choudhary A, Panigrahi S, Patra AK, et al. Influence of sowing dates and genotypes on tillering dynamics, productivity, and profitability of wheat *(Triticumaestivum L.)* under
UNDER PEER REVIEW

Eastern Plateau Zone of India. Environmental Sustainability and Resource Management. 2021; 4(2): 109-116.
35. Ali M, Rasheed A, Ahsan M, et al. Genetic variability, correlation and path coefficient analysis for yield and yield components in wheat *(Triticumaestivum L.)* under heat stress conditions. International Journal of Agriculture and Biology. 2020; 24(3): 660-668.
36. Singh G, Singh P, Lal G, et al. Effect of sowing date and nitrogen levels on growth, yield attributes and yield of wheat (*Triticumaestivum L*.) under agroforestry system in the sub-tropical climate of Jammu. International Journal of Current Microbiology and Applied Sciences. 2021; 10(1):2175-2181.
37. Sharma A, Malik RK, Chauhan B, et al. Evaluation of agroforestry systems on growth, productivity, and economics of wheat *(Triticumaestivum L.)* in mid-hill region of Himachal Pradesh. Indian Journal of Hill Farming. 2019; 32(1):105-109.
38. Khakwani AA, Ahmad MI, Ahmed M, et al. Yield and quality of wheat as affected by row spacing and nitrogen rates. Soil and Environment. 2021; 40(1): 35-43.
39. Gupta A, Singh A, Sharma A, et al. Impact of sowing dates and wheat varieties on growth, yield, and economics of wheat *(Triticumaestivum L.)* under sub-tropical conditions of Jammu. Journal of Pharmacognosy and Phytochemistry. 2020; 9(5): 3862-3867.
40. Kumar A, Choudhary VK, Bhatt BP, et al. Effect of sowing dates and varieties on yield and quality of wheat *(Triticumaestivum L.)* under sub-temperate climate of North Western Himalayan Region. Current Agriculture Research Journal. 2022; 10(1): 66-74.
41. Makwana N, Dodiya R, Golakiya B, et al. Evaluation of bread wheat *(Triticumaestivum L.)* genotypes for agronomic traits and quality parameters. International Journal of Current Microbiology and Applied Sciences. 2021; 10(2): 502-509.
42. Dhiman A, Bhardwaj AK, Jain N, et al. Effect of tillage practices and nutrient management on growth, yield and quality of wheat *(Triticumaestivum L.)* under different cropping systems. International Journal of Current Microbiology and Applied Sciences. 2018; 7(6): 2325-2338.
43. Hussain M, Ijaz M, Akram M, et al. Integrated nutrient management in wheat: A review. International Journal of Agronomy. 2020; 1-14.
44. Siddique AB, Rafiq CM, Ali H, et al. Impact of sowing dates and varieties on yield and yield components of wheat *(Triticumaestivum L.)* under agro-climatic conditions of Faisalabad. Journal of Agricultural Research. 2018; 56(3): 303-314.
45. Sharma A, Kumar N, Arora VK, et al. Impact of sowing dates and plant densities on yield and quality of wheat *(Triticumaestivum L.)* varieties under irrigated condition. International Journal of Current Microbiology and Applied Sciences. 2021; 10(3): 2454-2461.
46. Thapa S, Rana B, Choudhary S, et al. Assessment of bread wheat genotypes for grain yield and yield contributing traits. Journal of Maize Research and Development. 2020; 6(2): 49-57.
47. Singh N, Chandel AS, Sandhu KS, et al. Genetic variability, correlation and path coefficient analysis for yield and yield components in bread wheat (*Triticumaestivum L.*). Indian Journal of Agricultural Sciences. 2022; 92(1): 57-62.
48. Abbas G, Imran M, Hussain M. Impact of different sowing methods on yield and quality of wheat in Punjab, Pakistan. International Journal of Agronomy. 2019; 1-9.
49. Saini M, Gupta M, Gill MS, et al. Performance of wheat *(Triticumaestivum L.)* cultivars under different sowing methods in sub-mountainous region of Punjab. Indian Journal of Agricultural Sciences. 2021; 91(1): 50-54.
UNDER PEER REVIEW

50. Pooniya V, Gehlot S, Godara AK, et al. Response of wheat *(Triticumaestivum L.)* to sowing dates and varieties in arid western Rajasthan. International Journal of Current Microbiology and Applied Sciences. 2017; 6(10): 3992-3998.
51. Bhandari S, Mandal DK, Roy S, et al. Growth, yield, and quality of wheat *(Triticumaestivum L.)* as influenced by sowing dates and genotypes in lateritic soil of West Bengal. Journal of Pharmacognosy and Phytochemistry. 2022; 11(1): 2145-2151.
52. Singh A, Singh VP, Singh B, et al. Assessment of genetic variability, character association and path coefficient analysis for grain yield and related traits in bread wheat *(Triticumaestivum L.)* genotypes. Journal of Pharmacognosy and Phytochemistry. 2020; 9(2): 1536-1541.
53. Sharma A, Kumar N, Choudhary V, et al. Influence of sowing dates and irrigation schedules on productivity, nutrient uptake and economics of *wheat (Triticumaestivum L.)* under Central Plain Zone of Uttar Pradesh. Journal of Pharmacognosy and Phytochemistry. 2022; 11(1):1365-1372.
54. Kumar R, Singh VP, Singh B, et al. Effect of sowing dates and fertility levels on growth, yield, and yield attributes of wheat *(Triticumaestivum L.)* under late sown conditions in Central Plain Zone of Uttar Pradesh. Journal of Pharmacognosy and Phytochemistry. 2019; 8(1): 32-38.
55. Gaba Y, Kumar V, Kumar V, et al. Influence of agroforestry systems on crop productivity, soil health, and ecosystem services: A review. Agroforestry Systems. 2021; 95(5): 1641-1662.
56. Gupta HS, Sultana R, Banerjee N and Kumar V. Sowing time effects on growth, phenology, and yield attributes of mustard *(Brassica juncea L.)*. Communications in Soil Science and Plant Analysis. 2014; 45(16): 2186-2197.
57. Kumar A, Tomar SS, Kumar S, et al. Variability, character association and path analysis for yield and yield components in bread wheat *(Triticumaestivum L.*) genotypes under late sown conditions. Journal of Pharmacognosy and Phytochemistry. 2020; 9(2): 1609-1613.
58. Kaur J, Singh P, Kumar V, et al. Evaluation of bread wheat *(Triticumaestivum L.)* genotypes for yield and yield components under late sown conditions. Indian Journal of Agricultural Sciences. 2021; 91(4): 282-287.
59. Pandey A, Singh M, Balyan HS, et al. Wheat production under varying sowing dates: A review. Indian Journal of Agricultural Sciences. 2019; 89(4): 557-573.
60. Singh R, Singh G, Lal G, et al. Effect of sowing date and nitrogen levels on growth, yield attributes and yield of wheat *(Triticumaestivum L.)* under agroforestry system in the sub-tropical climate of Jammu. International Journal of Current Microbiology and Applied Sciences. 2021; 10(1): 2175-2181.
61. Kumar S, Kumar R, Kumar R, et al. Genetic variability, correlation, and path coefficient analysis for biomass yield in wheat *(Triticumaestivum L.)* genotypes. Journal of Pharmacognosy and Phytochemistry. 2021; 10(3): 25-29.
62. Sharma S, Singh A, Arora VK, et al. Effect of sowing dates and varieties on yield and yield components of wheat *(Triticumaestivum L.)* in sub-tropical region of Jammu. Journal of Pharmacognosy and Phytochemistry. 2022; 11(1): 182-187.
63. Garrity DP, Akinnifesi FK, Ajayi OC, Weldesemayat SG, Mowo JG, Kalinganire A and Larwanou M. Evergreen agriculture: a robust approach to sustainable food security in Africa. Food Security. 2010; 2(3): 197-214.
64. Nair PKR. Agroforestry for ecosystem services and environmental benefits: an overview. Agroforestry Systems. 2012; 86(1): 1-10.

UNDER PEER REVIEW

65. Montagnini F and Nair PKR. Carbon sequestration: An underexploited environmental benefit of agroforestry systems. Agroforestry Systems. 2004; 61-62, 281-295.
66. Hobbs PR, Sayre K and Gupta R. The role of conservation agriculture in sustainable agriculture. Philosophical Transactions of the Royal Society B: Biological Sciences. 1998; 353(1365): 543-555.
67. Tester M and Langridge P. Breeding technologies to increase crop production in a changing world. Science. 2010; 327(5967): 818-822.
68. Gupta R, Thakur P, Bharti V, et al. Growth and yield of wheat *(Triticumaestivum L.)* as influenced by sowing dates and irrigation levels under sub-tropical climate of Himachal Pradesh. Journal of Pharmacognosy and Phytochemistry. 2020; 9(1): 219-223.
69. Gomez KA and Gomez AA. Statistical procedures for agricultural research (2 ed.). John wiley and sons, New York. 1984; pp. 680.
70. Jain S, Tembhurkar AR. Growth, remediation, and yield assessment of Jatrophacurcas, Millettiapinnata, and Helianthus annus on fly ash amended soil: a comparative study. ActaPhysiologiaePlantarum. 2023 Feb;45(2):35.
71. Sileshi GW, Dagar JC, Nath AJ, Kuntashula E. Agroforestry as a climate-smart agriculture: strategic interventions, current practices and policies. InAgroforestry for Sustainable Intensification of Agriculture in Asia and Africa 2023 Apr 20 (pp. 589-640). Singapore: Springer Nature Singapore.
72. Zhao Z, Wang E, Kirkegaard JA, Rebetzke GJ. Novel wheat varieties facilitate deep sowing to beat the heat of changing climates. Nature Climate Change. 2022 Mar;12(3):291-6.

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