**Performance evaluation of growth and carbon sequestration potential of Pongamia [*Pongamia pinnata* (L.) Pierre] germplasms**

**Abstract**

 Agroforestry has emerged as a powerful land management practise to address the shrinking land holdings, size and reduced productivity of the land with improved ecosystem services. In recent decades, evaluation of the germplasms, particularly in Agroforestry systems is gaining a lot of importance in tree improvement programmes. The genetic section involves the selection of desired attributes, such as stress tolerance, increased wood properties, pest & disease resistance, etc. Pongamia based agroforestry system not only helps to mitigate climate change, but it will also have a significant share in the global biofuel production. The study was conducted in the ‘M’ block of AICRP on Agroforestry unit, ZARS, UAS, GKVK, Bangalore, during January 2022 to June 2022. The objective of this study is to compare the growth parameters (tree height, stem diameter and crown width in East-West & North-South directions) and carbon sequestration potential of eight Pongamia germplasms to identify the most productive genotype. These eight germplasms are established in 5 x 5 spacing of RCBD design in three replications. The results revealed that RAK-2015-10 performed better for height growth, stem diameter and crown spread (East-West and North-South directions) compared to other germplasms. Since the tree height and stem diameter positively correlate with volume and biomass accumulation, RAK-2015-10 has recorded the maximum volume and biomass accumulation among the other germplasms. .The findings suggest that the cultivation of RAK-2015-10 can improve yield significantly and helps to mitigate climate change.

**Keywords:** Agroforestry, Biomass, Biofuel, Carbon sequestration and Germplasm.

**INTRODUCTION**

Agroforestry is frequently regarded as a viable way to mitigate climate change. Agroforestry systems retain carbon in the soils and woody biomass. The majority of agroforestry systems can store carbon, although this capacity may vary depending on the trees pecies (Prasad *et al.,* 2012) and management practices adopted in agroforestry systems. Pongamia (*Pongamia pinnata* (L.) Pierre) belongs to the family – Fabaceae and is endemic to the Indian subcontinent and South-East Asia. Pongamia is recognised as the best biofuel yielding species due to its high oil content in seed (27 to 39 percent) (Fu *et al.,* 2021). The presence of toxic and anti-nutritional substances like pongamol, karanjin and glabrin, render it inedible (Bala *et al.,* 2011).

In particular, in a tree with the desired attributes in terms of optimum growth pattern, phenology and yield component distribution, the knowledge of variation would be beneficial for genotype selection. In the current scenario, the trapping of atmospheric CO2 in long-lived carbon pools of plant biomass and soil is one of the most viable ways to deal with elevated CO2 levels in the atmosphere. The natural process by which plants absorb CO2 from the atmosphere through photosynthesis and store it for as long as the plants are alive is known as biological sequestration of carbon. More photosynthesis results in more CO2 being transformed into biomass, which reduces atmospheric carbon and sequesters it in above and below ground plant tissue, leading to the expansion of various portions of the plant (Chavan and Rasal, 2010).

Since, Pongamia is an important biofuel yielding species, it will help in the sequestration of carbon by minimizing the dependency on conventional fuels as well plays a critical role in reducing the pollution load in the atmosphere by providing biofuel (Degani *et al.,* 2022). So, the species gaining a lot of importance in the field of tree improvement over some time to develop new lines, varieties and hybrids to obtain better gains in the growth. Germplasm selection is another way of screening the germplasms to select the better genotype to obtain the high yield.

The present study aims to estimate the growth and carbon sequestration potential in eight Pongamia germplasms located at the ‘M’ block in (AICRP) on Agroforestry unit, ZARS, UAS, Banaglore.

**MATERIAL AND METHODS**

The present study was carried out at ‘M’ block, in All India Coordinated Research Project (AICRP) on Agroforestry unit, Zonal Agricultural Research Station (ZARS), Gandhi Krishi Vigyana Kendra (GKVK), University of Agricultural Sciences, Bengaluru, Karnataka during January 2022 to July 2022. The experimental plot was established in July 2017 and consists of eight Pongamia germplasms at 5X5 meters spacing. These eight Pongamia germplasms are aligned in a Randomized Complete Block Design (RCBD) with three replications and the experimental site comprised 140 trees. Details of the eight Pongamia germplasms are given in Table 1.

Table 1: Details of Pongamia germplasms

|  |  |  |
| --- | --- | --- |
| **Treatment** | **Germplasm** | **Passport data** |
| **Germplasm collection**  | **Propagation material** |
| **T1** | RAK-2015-01 | MPKV, Rahuri | Clone |
| **T2** | RAK-2015-02 | MPKV, Rahuri | Clone |
| **T3** | RAK-2015-03 | MPKV, Rahuri | Clone |
| **T4** | RAK-2015-04 | MPKV, Rahuri | Clone |
| **T5** | RAK-2015-07 | MPKV, Rahuri | Clone |
| **T6** | RAK-2015-08 | MPKV, Rahuri | Clone |
| **T7** | RAK-2015-09 | MPKV, Rahuri | Clone |
| **T8** | RAK-2015-10 | MPKV, Rahuri | Clone |

 *Growth parameters:* The tree biomass was calculated by non-destructive method by taking the measurements of stem diameter and total height of the standing trees and then volume was calculated. The total tree height was measured with the help of a measuring stick from the ground level to the tip of the tree and expressed in meter. The stem diameter at breast height (1.37 m) from the ground level was measured with the help of measuring tape and expressed in centimeter (Chaturvedi and Khanna, 1981). The crown spread of the tree was measured in East-West and North-South directions with the help of measuring tape and usually expressed in meter (Jennings *et al.*, 1999). Then the tree volume was calculated with the following formula, given by Chaturvedi and Khanna, 1981 and expressed in cubic meter.

$$V=\frac{Π \* D^{2}}{4}\* h$$

Where ‘D’ is stem diameter at breast height (m), ‘h’ is height in (m), п is 3.142

*Biomass:* The tree above ground biomass was estimated by multiplying mean volume with specific wood density and expressed in kg tree-1 (Brown and Lugo, 1982).

Above ground biomass (AGB)= Volume x Specific wood density.

V= Basal area x Height x Form Factor

Basal area= (πd2)/ 4$\frac{g2}{4\*3.142}$

Below ground biomass (BGB) of Pongamia trees was calculated by multiplying 26 percent to the above ground biomass (Ravindranath and Ostwald, 2008). Usually expressed in kg ha-1.

BGB = AGB X 0.26

Total biomass (TB) of Pongamia trees was calculated by adding above and below ground biomass. Usually total biomass is expressed in kg ha-1.

TB = AGB + BGB

*Carbon sequestration potential:* Fixed carbon content in wood was determined by multiplying the total biomass with the dry weight of wood. The dry weight of Pongamia was taken as 45%. Usually expressed in kg ha-1(Pearson *et al*., 2005).

Fixed carbon = TB X 0.45

CO2 is composed of one molecule of carbon and two molecules of oxygen. The atomic weight of carbon, oxygen and carbon dioxide is 12, 16 and 44 respectively. The ratio of atomic weight of CO2 to C is 3.6663. Therefore, to determine the weight of carbon dioxide sequestered in the tree, multiply the weight of carbon in the tree by 3.6663.Usually expressed in kg ha-1.

Carbon sequestration = Fixed carbon content in wood X 3.6663

 *Statistical Analysis:* Experimental data obtained were subjected to statistical analysis adopting Fisher’s method of ‘analysis of variance’ as out lined by Gomez and Gomez (1984). The level of significance used in ‘F’ test was given 5 per cent for agroforestry studies. Critical difference (CD) values are given in the table at 5 per cent level of significance for agroforestry studies, wherever the ‘F’ test was found significant. Effective control of variation across blocks and replications was achieved through strategic experimental design and assumption validation. This ensured the reliability of treatment comparisons and strengthened the statistical integrity of the ANOVA results.

**RESULTS AND DISCUSSION**

The tree growth parameters like tree height, tree diameter at breast height, and crown spread (East-West direction and North-South direction) were computed and the data is presented in the Tables 2 and 3.The results present in Table 2 shows a significant variation in tree height among the eight different Pongamia germplasms over a period of six months: the total height of five year old plants was found to be maximum in **RAK-2015-10** (4.15 m) followed by **RAK-2015-07** (3.83 m) and **RAK-2015-01** (3.81 m). Minimum performance was recorded in **RAK-2015-02** (3.10 m). Data presented in the Table 2, indicate the variation in the diameter at breast height (DBH) over a period of six months**.** Among the eight different Pongamia germplasms**,** the diameter of five year age plants was found maximum in **RAK-2015-10** (8.37 cm) followed by **RAK-2015-07** (7.67 cm) and **RAK-2015-01** (7.62 cm). The lower diameter at breast height was observed in **RAK-2015-02** (6.54 cm). Better performance of growth characteristics like height and stem diameter in **RAK-2015-10** may be due to the genotypic response and environmental factors of the germplasms. As a consequence of variation in the germplasm which could contribute to increased biomass production can be exploited for enhancing land productivity. This was also in accordance with the Whittet *et al*. (2016).

Table 2: Tree height (m) and stem Diameter at Breast Height (DBH) (cm) of Pongamia germplasms

|  |  |  |
| --- | --- | --- |
| **Germplasm** | **Tree height(m)** | **DBH (cm)** |
| **January, 2022** | **June, 2022** | **January, 2022** | **June, 2022** |
| RAK-2015-01 | 3.46 | 3.81 | 6.73 | 7.62 |
| RAK-2015-02 | 2.87 | 3.10 | 5.96 | 6.54 |
| RAK-2015-03 | 2.82 | 3.18 | 5.56 | 6.57 |
| RAK-2015-04 | 3.16 | 3.59 | 6.83 | 7.53 |
| RAK-2015-07 | 3.15 | 3.83 | 7.00 | 7.67 |
| RAK-2015-08 | 3.08 | 3.32 | 6.74 | 7.41 |
| RAK-2015-09 | 2.94 | 3.19 | 6.24 | 6.90 |
| RAK-2015-10 | 3.65 | 4.15 | 7.74 | 8.37 |
| **S.Em ±** | **0.15** | **0.22** | **0.42** | **0.51** |
| **CD (p=0.05)** | **0.47** | **0.68** | **NS** | **NS** |
| **C.V (%)** | **8.67** | **11.16** | **10.93** | **12.17** |

\*Significant at 5% level of significance NS- non significant

The data presented in the Table 3, reveals the variation in the crown spread of east-west direction in an interval of six months. Among the eight different Pongamiagermplasms**,** the crown spread of east-west direction was found maximum in **RAK-2015-10** (3.92m) followed by **RAK-2015-07** (3.51m) and **RAK-2015-01 (**3.44m**)**. The minimum crown spread was recorded in **RAK-2015-02** (3.06m). Among the eight different Pongamiagermplasms**,** the significant variations were observed in crown spread (north- south) over a period of six months. After five years of planting the crown spread were found to be maximum in **RAK-2015-10** (4.15m) followed by **RAK-2015-07** (3.97m) and **RAK-2015-01 (**3.75m**)**. The minimum crown spread was recorded in **RAK-2015-02** (3.10m). The higher crown spread in **RAK-2015-10** might be due genomic response of the respective germplasm, easy availability of nutrients from the decomposition of litter and also from the mineralization.

Table 3: Canopy spread (m) ofPongamia germplasms

|  |  |  |
| --- | --- | --- |
| **Germplasm** | East – West direction (m) | North – South direction (m) |
| **January, 2022** | **June, 2022** | **January, 2022** | **June, 2022** |
| RAK-2015-01 | 2.95 | 3.44 | 3.25 | 3.75 |
| RAK-2015-02 | 2.75 | 3.06 | 2.85 | 3.10 |
| RAK-2015-03 | 2.47 | 3.11 | 2.77 | 3.19 |
| RAK-2015-04 | 2.74 | 3.18 | 2.83 | 3.53 |
| RAK-2015-07 | 3.02 | 3.51 | 2.87 | 3.97 |
| RAK-2015-08 | 2.59 | 3.16 | 2.67 | 3.32 |
| RAK-2015-09 | 2.75 | 3.11 | 2.48 | 3.19 |
| RAK-2015-10 | 3.07 | 3.92 | 3.26 | 4.15 |
| **S.Em ±** | **0.19** | **0.27** | **0.15** | **0.23** |
| **CD (p=0.05)** | **NS** | **NS** | **0.46** | **0.69** |
| **C.V (%)** | **11.78** | **13.87** | **9.13** | **11.10** |

\*Significant at 5% level of significance NS- non significant

***Biomass:*** The biomass is assessed based on the data of growth performance of *Pongamia pinnata viz.,* height (m), stem diameter or diameter at breast height (cm), volume (m3), above ground biomass (kg ha-1), below ground biomass (kg ha-1) and total biomass (kg ha-1). The tree growth increment parameters like volume (m3 tree-1 & m3 ha-1), above ground biomass (kg ha-1), below ground biomass (kg ha-1) and total biomass (kg ha-1) are presented in the Tables 4 and 5. All the germplasms showed significant difference for volume per tree and volume per hectare in five years old plantation. Among the eight different Pongamia germplasms, the volume per tree and volume per hectare were found to be maximum in **RAK-2015-10** (0.0082 m3 tree-1 and 3.272 m3 ha-1) followed by **RAK-2015-07** (0.0051m3 tree-1 and 2.041 m3 ha-1) and **RAK-2015-01** (0.0050 m3 tree-1and 1.994 m3 ha-1). The lowest volume per tree was recorded in **RAK-2015-02** (0.0031m3 tree-1 and 1.249 m3 ha-1) (Table 4). Tree volume is the most important for estimation of biomass to estimate the degree of carbon sequestration by the trees. Volume to biomass is considered as the better estimation method of forest tree biomass. Similar results were also reported by Brown, 1997 and Bohre *et al*. (2014).

Different germplasms showed the significant influence on the above ground biomass, below ground biomass and total biomass (Table 5). Significantly maximum above ground biomass, below ground biomass and total biomass was recorded in **RAK-2015-10** (1992 kg ha-1, 518 kg ha-1 and 2510 kg ha-1) followed by **RAK-2015-07** (1243 kg ha-1, 323 kg ha-1 and 1566 kg ha-1**)** and **RAK-2015-01** (1214 kg ha-1, 315 kg ha-1 and 1530 kg ha-1) respectively. The lower above ground biomass observed in **RAK-2015-02** (761kg ha-1, 197 kg ha-1 and 958 kg ha-1) (Table 5). Among the different germplasms **RAK-2015-10** found to have higher accumulation of above ground biomass, below ground biomass and total biomass, might be due to environmental factors and genotypic response of the germplasm. So, this variation in the germplasm in terms of above ground accumulation, below ground biomass and total biomass can be exploited for enhancing the land productivity. This was also in accordance with the findings of Bohre *et al*. (2014) and Singh and Pokhrial, 2000.

Table 4: Tree volume (m3 tree-1 &m3 ha-1) of Pongamia germplasms

|  |  |  |
| --- | --- | --- |
| **Germplasm** | **Tree volume** (m3 tree-1) | **Tree volume** (m3 ha-1) |
| **January, 2022** | **June, 2022** | **January, 2022** | **June, 2022** |
| RAK-2015-01 | 0.0039 | 0.0050 | 1.547 | 1.994 |
| RAK-2015-02 | 0.0023 | 0.0031 | 0.933 | 1.249 |
| RAK-2015-03 | 0.0023 | 0.0031 | 1.055 | 1.371 |
| RAK-2015-04 | 0.0038 | 0.0049 | 1.511 | 1.951 |
| RAK-2015-07 | 0.0039 | 0.0051 | 1.551 | 2.041 |
| RAK-2015-08 | 0.0034 | 0.0046 | 1.353 | 1.840 |
| RAK-2015-09 | 0.0034 | 0.0045 | 1.374 | 1.813 |
| RAK-2015-10 | 0.0068 | 0.0082 | 2.725 | 3.272 |
| **S.Em ±** | **0.0004** | **0.0005** | **0.148** | **0.205** |
| **CD (p=0.05)** | **0.0011** | **0.0016** | **0.449** | **0.623** |
| **C.V (%)** | **17.03** | **18.31** | **17.03** | **18.31** |

\*Significant at 5% level of significance.

*Carbon Sequestration***:** The carbon sequestration is assessed based on the data of growth performance of *Pongamia pinnata viz.,* height (m), girth (m) or diameter at breast height (cm), volume (m3) and biomass (kg ha-1). The total carbon content (kg ha-1) and carbon sequestration potential (kg ha-1) are presented in Table 6. The data presented in the Table 6 reveals significant variation in the accumulated carbon content and carbon sequestration potential of Pongamia. **RAK-2015-10** was found to have accumulated higher carbon content and carbon sequestration potential (1129 kg ha-1 and 4142 kg ha-1) among the eight different Pongamia germplasms. Results also revealed that the lower carbon content and carbon sequestration potential was observed in **RAK-2015-02** (431 kg ha-1 and 1582kg ha-1). Assessment and adaptation of genotypic variation can play vital role in improving biomass production of agroforestry trees. It is also established that geography and ecosystem contribute to the species genetic constitution that results in the production of biomass variation within the same species (FAO, 1985).

Table 5: Above ground biomass (kg ha-1), below ground biomass (kg ha-1) and total biomass (kg ha-1) of Pongamia germplasms.

|  |  |  |  |
| --- | --- | --- | --- |
| **Germplasm** | AGB **(kg ha-1)** | BGB **(kg ha-1)** | **TB (kg ha-1)** |
| **January, 2022** | **June, 2022** | **January, 2022** | **June, 2022** | **January, 2022** | **June, 2022** |
| RAK-2015-01 | 942 | 1214 | 245 | 315 | 1187 | 1530 |
| RAK-2015-02 | 568 | 761 | 147 | 197 | 716 | 958 |
| RAK-2015-03 | 642 | 835 | 167 | 217 | 809 | 1052 |
| RAK-2015-04 | 920 | 1188 | 239 | 309 | 1159 | 1497 |
| RAK-2015-07 | 944 | 1243 | 245 | 323 | 1190 | 1566 |
| RAK-2015-08 | 824 | 1121 | 214 | 291 | 1038 | 1412 |
| RAK-2015-09 | 837 | 1104 | 217 | 287 | 1054 | 1391 |
| RAK-2015-10 | 1660 | 1992 | 431 | 518 | 2091 | 2510 |
| **S.Em ±** | **90** | **125** | **23** | **32** | **113** | **157** |
| **C. D (p=0.05)** | **273** | **379** | **71** | **98** | **345** | **478** |
| **C.V (%)** | **17** | **18** | **17** | **18** | **17** | **18** |

\*Significant at 5% level of significance

AGB-Above ground biomass BGB- Below ground biomass TB- Total biomass

Table 6: Total carbon content (kg ha-1) and carbon sequestration potential (kg ha-1) of Pongamia germplasms

|  |  |  |
| --- | --- | --- |
| **Germplasm** | **Total carbon content** **(kg ha-1)** | **Carbon sequestration potential** **(kg ha-1)** |
| **January** | **June** | **January** | **June** |
| RAK-2015-01 | 534 | 688 | 1959 | 2525 |
| RAK-2015-02 | 322 | 431 | 1182 | 1582 |
| RAK-2015-03 | 364 | 473 | 1336 | 1736 |
| RAK-2015-04 | 521 | 673 | 1913 | 2470 |
| RAK-2015-07 | 535 | 705 | 1964 | 2585 |
| RAK-2015-08 | 467 | 635 | 1712 | 2330 |
| RAK-2015-09 | 474 | 626 | 1740 | 2296 |
| RAK-2015-10 | 941 | 1129 | 3450 | 4142 |
| **S.Em ±** | **51** | **70** | **187** | **260** |
| **C. D (p=0.05)** | **155** | **215** | **569** | **788** |
| **C.V (%)** | **17** | **18** | **17** | **18** |

\*Significant at 5% level of significance.

**CONCLUSION:**

The study was conducted to assess the growth and carbon sequestration potential of eight Pongamia germplasms over six months after five years of planting. Study reveals that the height, stem diameter and crown spread in East-West and North-South directions were recorded maximum in germplasms RAK-2015-10. Since, the stem diameter and tree height growths are directly proportional to the volume increment and biomass accumulation, RAK-2015-10 has recorded the highest volume increment and biomass accumulation. The carbon sequestration potential was found to be maximum in RAK-2015-10, when compared to other germplasms. Hence, expanding the planting of RAK-2015-10 can improve the yield significantly. In addition to this, managing more and more plantations of RAK-2015-10 helps to mitigate the climate change.

**Disclaimer (Artificial intelligence)**

Option 1:

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

**References**

BALA, M., NAG, T. N., KUMAR, S., VYAS, M., KUMAR, A. AND BHOGAL, T. N., 2011. Proximate Composition and Fatty Acid Profile of Pongamia pinnata, a Potential Biodiesel Crop. J Am Oil Chem Soc (2011) 88:559–562

Bohre, P., Chaubey, O.P. and Singhal, P. K. (2014). Biomass Production and Carbon Sequestration by *Pongamia pinnata* (Linn) Pierre in Tropical Environment, *International Journal of Bio-Sciences and Bio-Technology.,***6**(2):129-140.

Brown, S. and Lugo, A. E. (1982). The storage and production of organic matterin tropical forests and their role in the global carbon cycle. *Biotropica.*, **14**(3):161-187.

Brown, S. (1997). Estimating biomass and biomass change of tropical forests. Apremier FAO forestry paper, FAO, Rome: 134.

Chaturvedi,A. N. and Khanna, L. S. (1981). Forest Mensuration. International book distributors, Dehradun.

Chavan, B. L. and Rasal, G. B. (2010). Sequestered standing carbon stock inselective tree species grown in University campus at Aurangabad, Maharashtra, India*. International Journal of Engineering Science and Technol.,***2**(7): 3003-3007.

DEGANI, E., PRASAD, M.V.R., PARADKAR, A., PENA, R., SOLTANGHEISI, A., ULLAH, I., WARR, B. AND TIBBETT, M., 2022. A critical review of Pongamia pinnata multiple applications: From land remediation and carbon sequestration to socioeconomic benefits. *Journal of Environmental Management.* 324: 905-917

FAO (1985) A guide of forest seed handling: with special reference to tropics. *FAOFor. Pap.,*379.

Gomez, K. A. and Gomez, A. A. (1984). Statistical procedures for agricultural research, an international Rice Research Institute book, Wiley-Inter science Publication, John Wiley and Sons, New York.

FU, J., SUMMERS, S., MORGAN, T. J., TURN, S. Q. AND KUSCH, W., 2021. Fuel Properties of Pongamia (Milletia pinnata) Seeds and Pods Grown in Hawaii, ACS Omega 2021 6 (13), 9222-9233.

Jennings, S. B., Brown, N. D. and Sheil, D. (1999). Assessing forest canopies and understory illumination: Canopy closure, canopy cover and other measures. *Forestry*, **72**(1): 59–74.

Pearson, T., Walker, S. andBrown, S. (2005). Source book for Land -Use, Land Use Change and Forestry Projects. Winrock International and the Biocarbon fund of the World Bank Arlington, USA: 19-35.

Prasad,J.V.N.S.,Srinivas,K.,Srinivasarao,C.,Ramesh,C.,Venkatravamma, K. and Venkateswarlu, B. (2012).Biomass productivity and carbon stocks of farm forestry and agroforestry systems of *Leucaena* and *Eucalyptus* in Andhra Pradesh, India. *Current Science.,***103**(5):536-540.

Ravindranath, N. H. and Ostwald, M. (2008). Methods for estimating above ground biomass, In: Ravindranath, N. H. and Ostwald, M. (Editors) Carbon Inventory Methods: Handbook for Greenhouse Gas Inventory, Carbon Mitigation and Roundwood Production Projects (Advances in Global Change Research 29). Springer, Dordrecht, Netherlands, 113-147.

Singhand Sharma. (2012). *Sesbenia grandiflora*: Forage yield and nutritive value of intensive silvopasture systems. *Agroforestry Systems*., **43**(4): 84-102.

Singh, N. and Pokhriyal, T. C. (2000). Biomass distribution pattern in relation to seed source variation in *Dalbergia sissoo* seedlings. *Annals of Forestry,* **8**(2000):238-249.

Whittet,R.,Stephen,C.,Joan,C.andRichard,E. (2016). Seedsourcing for woodland creation in an area of uncertainty: analysis of the options for Great Britain. *For*., **90**: 163-173.