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Research Article
Annual Growth and Benefit Cost Analysis of *Aquilaria malaccensis*

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Abstract

Background and Objectives: Growth performance of any tree species is a major parameter to determine the felling rotation of that species. The growth of *Aquilaria malaccensis* has not assessed so far. Thus, this study was aimed to assess and compare the annual increment of height, basal area and volume and also, evaluate the economic potentiality of this species. **Materials and Methods:** The private plantation forest of Bharse, Gulmi Nepal was selected for the study site. Stratified random sampling was carried out based on the good, medium and poor site. Total 150 plants were measured and plant's age were recorded asking with the farmers. The diameter and height were measured by using D-tape, Abney's level and simple tape. The collected data were analyzed by using descriptive statisics and cost benefit analysis as well. **Results:** The result showed that mean annual diameter increment was 0.582, 0.36 and 0.31 cm. Mean annual height increment was 0.86, 0.69 and 0.50 m. Mean annual volume increment was 0.0000456, 0.000282 and 0.000308 m^3 and mean annual carbon increment was 0.19, 0.12 and 0.13 t ha^{-1} at age 6, 9 and 12 year, respectively. All the parameters were in decreasing trend with an increasing age in very good site. If *Aquilaria* species is considered as other local species and then the selling amount would be US$1377.27, the net profit after inoculation of the plant and selling the product would be US$489345.45. Estimated benefit cost (B/C) ratio would be 21.97. **Conclusion:** The well growth and its economic potential showed, this species can be planted as commercially valuable plants. This paper will be provide useful information for scientific community and decision maker.

Key words: Agar wood, growth, inoculation, cost benefit ratio

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Aquilaria malaccensis belongs to Thymelaeaceae family known as Agar wood, Eagle wood, Aloe wood and "Woods of the God". The agar wood producing species consisting of 13 species belong to 2 genera *Aquilaria* and *Gyrinops* that distributed throughout South East Asia. Phyto-geographically, the genus of *Aquilaria* are distributed from India (Bengal and Assam) to New Guinea through Burma (Tenasserim), Indo-China (Cambodia, Annam and Cochinchina), China (Hongkong and Hainan), Malaysia, Singapore, the Philippines, Indonesia and Thailand as well. While, *Gyrinops* spp. is distributed in Ceylon, Lesser Sunda Island, Celebes, Moluccas and New Guinea[1]. This plant is large evergreen tree more than 20 m tall and 1.5-2.4 m in girth with somewhat straight and fluted bole. Leaves are alternate 0.5-10 cm by 2-5 cm, oblong, lancelets or elliptic, caudate, acuminate and glabrous with slender nerves. Venation is parallel and petiole is 0.3-0.5 cm long. It is commercially used as fragrant and drugs. The tree contains plenty of oleoresin and has irregular dark patches. The aromatic resin obtained from this tree is one of the most famous and most expensive on the planet. It is found up to 750-1000 m, mostly at the bank of the rivers and streams and on ridges with sandy soils.

The *A. malaccensis* is on the brink of extinction in the wild and is now considered. Critically Endangered (CR) on the International Union for Conservation of Nature (IUCN) Red List. Due to large-scale logging operations, many forested areas where *A. malaccensis* was once abundant have been destroyed to rising demand for agar wood, as well as shortcomings in monitoring harvests and an increasing illegal trade. Since, 1994, agar wood has been included in Appendix II CITES under species group of *Aquilaria* spp.

This precious wood and its oil have a deep spiritual history and significance and they are mentioned in the oldest spiritual texts and it has been used for medicinal purposes[2], aromatherapy[3], pharmaceutical tinctures, asthma, rheumatism and other body pain treatment[4]. Many religious groups use it as a meditation incense to calm the mind and spirit. It is also the main ingredient of perfumery as well as cosmetic industry[5,6]. In the Middle East, both agar wood smoke and oil are customarily used as perfume[2], in contemporary time it is widely used as incense, perfume and for the rapetis use. The trading value of pure agar oil[7] is $30,000-40,000 kg^{-1}. Based on resin presence, agar wood chips sell[8] from $30-$10,000 kg^{1}. The global market for agar oil and other agar wood related products was estimated in the range of $6-8 billion and the major agar oil industrial buyer expects to exceed it in 2017 up to $36 billion[9].

Agar wood plantation is exotic in Nepal some private plantation has been initiating for 25 years. There are no massive and systematic cultivation practices, but it is initiated as home garden plantation. Agar wood was introduced in Nepal by the people who returned from Assam, India and Thailand. There was no study carried out related to growth performance and cost benefit analysis after the inoculation of *Aquilaria malaccensis* in Nepal.

MATERIALS AND METHODS

Study site: Satyawati Rural Municipality ward number 8 Bharse, Gulmi district, Nepal, was selected as the study site. A Retired Indian Army person, Mr. Dhan Bahadur Pun has planted the seedling of *Aquilaria malaccensis* in 4.3 ha of land with mixed plantation in 2004, brought from Thailand. It is the only one registered planted private forest of *Aquilaria malaccensis* in Nepal. The study site lies at an altitude of 1400 m with latitude 20°07' N and longitude 83°46' E. The recorded mean temperature is 18°C and total annual rainfall is 1700 mm. The site lies in sub-tropical climatic region of Nepal[10]. *Albizia* species, *Prunus* spp. and *Toona ciliata* are the major natural tree species in this site. After the establishment of private forest, different silvicultural operations like weeding, cleaning were carried out with enrichment planting as shown in Fig. 1 and 2.

Sampling and data collection: The seedling process was done in random pattern mixed with horticulture species. The whole plantation area was divided into 3 sites namely Best, Medium and Worst, respectively based on its growth performance. Total 150 plants were measured in 2018 during field visit so, the trees were marked by using red ribbon, as gathered from the available records from DFO, Gulmi and private forest owner which includes the repetition in measurement. The diameter and height were measured. The diameter was recorded by using D-tape and heights were measured by using Abney's level and simple tape. The secondary information was plantation time, seed sources and previous measurements.

Data analysis: Collected data were analyzed by using descriptive statistics such as; mean and inferential statistics to compare the growth among the sites. Mean Annual Height Increment (MAHI), Mean Annual Basal Area Increment (MBAI), Mean Annual Volume Increment (MAVI) and Mean Annual Carbon Increment (MACI) were calculated via using following formula:

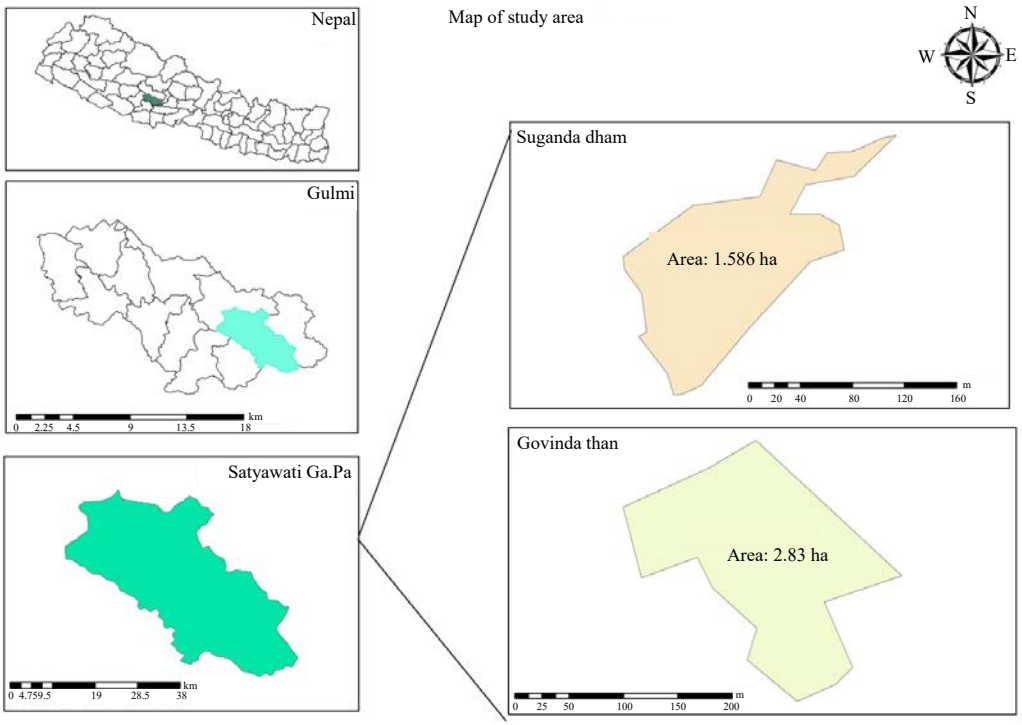

Fig. 1: Map of study area
Source: Field survey

Fig. 2(a-b): Private plantation of *Aquilaria malanccensis,* (a) *Aquilaria malanccensis* plantation at worst site and (b) 15-year plantation of *Aquilaria malanccensis*
Source: Field Observation, 2018

Basal area was calculated by using following formula:

$$\text{Basal area (BA)} = \frac{\pi d^2}{4}$$

where, D is diameter at breast height in cm.

Volume of tree was calculated by using volume calculation formula mentioned in inventory guide line, 2004:

$$\text{Volume (V)} = \frac{\frac{\pi d^2}{4} \times \text{Height} \times \text{form factor}}{10000}$$

where, volume in m^3.

Above Ground Tree Biomass (AGTB) calculation: The equation developed by experts[11] was used to calculate ground tree biomass:

$$AGTB = 0.0509 \times \rho \times d^2 \times H$$

Where:

AGTB = Above ground tree biomass (kg)
ρ = Wood density of the species (g cm^{-3})
d = Diameter (cm)
H = Tree height (m)

The carbon content was calculated by using following default factor as following[12]:

$$\text{Carbon content (C)} = 0.47 \times \text{Total biomass}$$

Besides, the cost benefit analysis was done comparing the price selling of the wood as timber and as a agar wood after inoculation.

RESULTS

Mean annual increment of *Aquilaria malaccensis* in different sites

Average height and annual height increment: The average height and mean annual height increment were varied according to site and age. The highest average height was found 5.1666±0.3333 whereas, mean average height increment was found to be 0.8611 m at 6 year age in plantation at site quality 1. So, the lowest mean average height increment was 0.5043 m at 12 years. It was around 0.6296 m at 9 years old (Table 1). There was significant difference in the height growth of *Aquilaria malaccensis* among 3 different sites: site 1, site 2 and site 3. Since, p-value was less than 0.05 and Tukey's test showed that there were significant differences in the height growth of the trees among three different sites.

Average basal area and annual basal area increment: The average basal area and mean average basal area increment were varied according to site and age. The highest average basal area was found to be 1.7097 m^2, whereas, mean basal area increment was about 10.258±3.859 m^2 at 6 year plantation age in site quality 1. The lowest mean average basal area increment was d 0.9225 m^2 ha^{-1} at 12 years and was found 0.9522 m^2 at 9 years old (Table 1).

There was significant difference in the basal area growth of *Aquilaria malaccensis* in three different sites, site 1, site 2 and site 3 at 95% confidence level ($p<0.05$). Tukey's *post hoc* test showed that the data were normal. It showed that there were significant differences in the basal area growth of trees in 3 different sites at 95% confidence.

Table 1: Growing stocks and their mean annual increment

	Site quality 1		Site quality 2		Site quality 3	
Age	AH (m)	AHI (m)	AH (m)	AHI (m)	AH (m)	AHI (m)
Average Height (AH) and Annual Height Increment (AHI)						
6	5.1666±0.3333	0.8611				
9	5.666±0.52041	0.6296				
10			6.7410±0.3653	0.6741		
12	6.0526±0.1575	0.5043	4.838±0.2669	0.4031	1.9347±0.1058	0.1612
	BA (m^2)	ABI	BA (m^2)	ABI	BA (m^2)	ABI
Average Basal Area (BA) and Basal Area Increment (BAI)						
6	10.2583±3.8596	1.7097				
9	8.5705±2.5195	0.9522				
10			5.8378±2.5612	0.5837		
12	11.6671±4.2779	0.9225	3.2314±0.3534	0.2692	3.6568±0.4506	0.3047
	Volume (m^3)	MVI	Volume (m^3)	MVI	Volume (m^3)	MVI
Average Volume and Mean Volume Increment (MVI)						
6	0.002±0.001	0.0004				
9	0.002±0.0005	0.0002				
10			0.0021±0.0003	0.0002		
12	0.0036±0.0003	0.0002	0.0009±0.0001	0.0000082	0.00042±0.000004	0.000003
	Carbon (t)	Carbon increment	Carbon (t)	Carbon increment	Carbon (t ha^{-1})	Carbon increment
Average carbon and annual carbon increment (ACI)						
6	1.1676±0.4778	0.1946				
9	0.0025±0.2468	0.1301				
10			0.1296±0.9226	0.0922		
12	1.5745±0.1302	0.1212	0.4211±0.0681	0.035	0.1820±0.03330	0.0151

Table 2: Comparison of selling cost after inoculation of Agar wood

Details	Total in US$
Management cost	14300
Sale as timber	1377.27
Inoculation cost of agar wood	7963.64
Total selling price after inoculation	511609
Net profit after inoculation	489345.5
Benefit cost ratio (B/C)	21.97958

Source: Field data 2018

Average volume and annual volume increment: The average volume and mean annual volume increment were varied according to the site and age. The highest average volume was found 0.002±0.001 m^3, whereas, highest mean annual volume increment was found to be 0.00045 m^3 at 6 year plantation age. It was decreasing according to the age in site quality 1. The lowest mean volume increment was about 0.00020 m^3 at 12 years and around 0.0002 m^3 at 9 years old (Table 1).

There was significant difference in the volume growth of *Aquilaria malaccensis* in three different sites: site 1, site 2 and site 3. Since, the p-value is less than 0.05. The data obtained were normal. Tukey's *post hoc* test showed that there were significant differences in the volume of trees in 3 different sites.

Average carbon and mean carbon growth of *Aquilaria malaccensis* in different sites: Average carbon and mean annual carbon increment were varied according to site and age. The highest average carbon was 1.1676±0.477823 t and highest mean average carbon increment was found to be 0.1946 t at 6 year plantation age and it was decreasing according to the age in site quality 1. So, the lowest mean average carbon increment was about 0.1212 t at 12 years. It was around 0.1301 t at 9 years old (Table 1).

There was significant difference in the carbon growth of *Aquilaria malaccensis* in 3 different sites, site 1, site 2 and site 3 at 95% confidence level ($p<0.05$) and Tukey's *post hoc* test showed that there were significant differences in the carbon growth of trees in three different sites.

Cost benefit analysis: According to the district rate and local rate, the management cost was calculated. It showed that total management cost was US $14300. Where, US$ = NRs110 including the major management activities.

If *Aquilaria* species is considered as other local species mentioned above then the selling amount would be US $1377.27. Table 2 showed the total inoculation cost for the production of agar wood would be US $7963.63 per 600 tree. It also shows the sale amount after agar wood formation. A single tree would give 3 items of good viz. fresh wood, semi resinous wood and resinous wood. Assuming the single tree would produce minimum 0.2 kg of agar wood and the selling amount would be high. Price calculation is based on $1 = NRs110.

The cost of the plantation establishment and management of *Aquilaria malaccensis* may be estimated as $14300 (1US$ = NRs 110) and considering the total sealable *Aquillaria malaccensis* volume with other merchantable species of Gulmi like *Pinus roxburghii* (Salla), *Toona cilitae* (Tooni) and other species, the total gained price may be 727, 363 and $272, respectively, based on local market price.

On the other hand, if this *Aquilaria malaccensis* tree is inoculated then the cost and selling price of this species is different. The cost for the inoculation may be $13.27 per tree whereas, the selling price after the inoculation and formation of agar wood may be $511609 in total production and $852.68 per tree. The net profit after inoculation is estimated as $489345.45 and the benefit cost (B/C) ratio is $21.97.

This result gives the conclusion that *Aquilaria malaccensis* species would not be valuable unless it produce agar wood. Agar wood can be gain naturally as well as artificially. Natural process is long and unsure in production of agar wood in all tress. So, to gain profit artificial, inoculation is necessary. In this study the farmers has tress of about 12 years which were suitable for inoculation on age basis, but on DBH basis they had not gain desirable DBH. To compensate the further management cost if inoculation is done it would gain reasonable profit. This study recommended for inoculation.

DISCUSSION

The growth rates of trees that have sufficient space to grow rapidly and at the same time do not develop excessive limberness provide a practical standard for estimating potential growth. Some study showed that *A. malaccensis* is fast growing during early growth age at five years old stands with mean annual increment diameter and height of 2.8 cm and 2.0 m, respectively[13]. This growth increment results was also found to be similar in other exotic species of *A. crassna* and *A. sinensis*. Another expert stated that they are fast growing trees, hardy and in areas with adequate moisture can achieve 10 cm DBH within 4-6 years[3].

This study found that mean annual height increment (m) and DBH (cm) of *A. malaccensis* was fast earlier stages, but it decreased gradually with age. Mean annual height increment was highest for the 12 years old plantations of best sites height increased was 0.5 m per year. Height increment was also 0.86, 0.62 and 0.50 m in 6, 9 and 12 years old plantation at best sites, respectively. It was observed that the highest mean

annual DBH increment (0.58 cm per year) was in 6 years old plantations at best sites. The lowest mean annual DBH increment (0.167 cm) was for the 12 years old plantation at poor sites.

This study showed that the mean annual diameter increment of good site for 6, 9 and 12 years was 0.58, 0.36 and 0.31 cm, respectively as well as mean annual height increment of good site 6,9 and 12 years was 0.86, 0.62 and 0.5 m, respectively. The mean annual height increment and diameter increment of the tree was found to be in decreasing trend with an increasing age. This result was in agreement with Hossen and Hossain[14], who stated that "there is decreasing trend in mean annual height and diameter increment with the increase in tree age". Likewise, the basal area of the tree was also found in decreasing with the age.

Another study[3] showed that the annual growth rates of DBH ranged from 0-1.95 cm/yr at Pasoh Forest Reserve, Malaysia. It reported that the distribution of growth rates of DBH was strongly skewed with a mean value of 0.33 cm/yr and a median value of 0.22 cm/yr. The growth rates achieved by the 12 fastest growing trees (90% percentile) exceeded 0.80 cm annually[3].

The growth of *Aquilaria malaccensis* was rather low at 0.33 cm per year in native forests. Nevertheless, tree growth can reach upto 0.8-1 cm/1 yr in Peninsular, Malaysia[3].

In the same way, the entire study showed that, the average height, average, diameter and average, volume along with average annual height increment, average annual diameter increment and average annual volume increment of 4 (6, 9, 10 and 12) different years. Similarly, annual height increment, annual diameter increment, annual volume increment and basal area increment have found to be ranged from 0.8-0.16, 0.5-0.16 cm and 0.00046-0.000035 m^3 and 1.70-0.26 m^2, respectively.

Aquilaria malaccensis tree would be benefitted only after the agar wood production. For economic benefit inoculation is necessary in the Bharse, Gulmi. The benefit cost (B/C) ratio is 21.97. It showed after inoculation benefit would be gained. This supported by the research of Bangladesh[15], Depending on BCR analysis, it was clearly seen that agar wood production is highly profitable which could change the economic condition of the agar wood growers by 9.31 per tree.

CONCLUSION

The overall growth performance of *A. malaccensis* with respect to height, diameter, volume and basal area was significantly different. The growth response of *A. malaccensis* of Bharse Gulmi has not shown good performance. This study had given picture that to gain benefit from the plantation inoculation process had been started soon. Along with it has created new horizon of research in this species in Nepal for further extensive plantation. As it is new species to new Nepal proper research and study deemed necessary for the deterrence of huge economic loss of the farmer. This study had given picture that the inoculation process is deemed necessary to gain profit from the plantation. If inoculation is done then benefit cost (B/C) ratio would be increased by 20 folds. Detail study should be carried out to find the growth performance of this species which were planted in Terai region to compare within it. The *A. malaccensis* would be valuable only after it produce agar wood so for that various research and pilot project for inoculation should be done.

SIGNIFICANCE STATEMENT

The *Aquilaria malaccensis* is first time introduced in Gulmi, Nepal. Local people and even academician have very limited knowledge about this species in Nepal. This research paper will be a mild stone for those who are interested to commercialize the forestry plants. In addition, study will provide the base line information to know the growth of this species as well as the economic value. These are major significance of this study.

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