Variations in the light interception and associated physiological traits ofcowpea and fodder sorghum grown under different Agroforestry system

Abstract

Light interception is major factor for characterizing the resource capture and use efficiency of cropping systems under intercrops. Agroforestry system is land use practices that combine agricultural crops and trees in different ways and has shown to benefits agriculture and forestry. The choice crop in agroforestry depends on light availability penetrated through trees which would alter the physiological processesinturn to yield. The experiment was conducted out with cowpea followed by fodder sorghum as intercrops under four agroforestry systems viz., *Khaya senegalenesis, Melia dubia, Dalbergia sissoo and Casuarina equisetifolia* and measured the light interception, gas exchange parameters and yield traits. Light interception ratio of cowpea under *Dalbergia sissoo* were observed maximum with 76 % and minimum of 58 % in *Khaya senegalenesis* @ 60 days after sowing.In case of gas exchange parameters, photosynthetic rate and stomatal conductance of cowpea and fodder sorghum were found significantly higher under*Dalbergia sissoo* compared to other agroforestry systems. The yield traits for cowpea and fodder sorghum were recorded higher in open space followed by *Dalbergia sissoo* while lower yield was noticed in cowpea under *Khaya senegalenesis*and *Casuarina equisetifolia*in case of fodder sorghum.The yield reductions in cowpea and fodder sorghum under *Dalbergia sissoo*were 19 % and 31% compared to open conditions indicating the differential response of C_3 and C_4 crops towards intercepted light. Microclimatic variables mainly altered due to influence of canopy structure that was reflected in reduction in temperature especially under *Khaya senegalenesis.* In conclusion, cowpea was found to be better intercrop mainly under Melia dubia based on gas exchange and yield parameters.

Introduction

Exploring the nature of interactions between trees and crops is of major importance in determining approaches to improve crop management under Agroforestry system. Agroforestry system is assimilated land use practicesof agricultural crops and trees in different ways andhas shown multidimensional benefits in the field ofagriculture and forestry related resources (Hildreth, 2008). The system is a concrete wayof enhancing the capability and productivity of landin terms of crop, forage, soil fertility, biomass, fruits,medicinal as well environmental values and timberproduction (Meijer *et al.,* 2015; Nairand Toth 2016).Agroforestry is potential option not only for improving the economic status of farming community and also for mitigating the effect of global warming.

In deeply shaded understories, plant carbon gain can be improved mostly by capturing more light and efficient light harvesting is of paramount importance for plants growing in competition in dense stands under natural conditions (Valladares and Niinemets 2008). At ecosystem scale, positive relationships between canopy productivity and the amount of intercepted light have often been observed (Lagergren*et al.,* 2005) further demonstrating that light is the major driver of productivity.The incident quantum flux density declines exponentially with increasing canopy leaf area index and there are always extensive light gradients from the top to the bottom of plant canopies. The percentage of above canopy light reaching through the tree foliage to the herb and moss layer on the forest floor is often less than 1% in tropical rainforests and less than 2–5% in moderately humid temperate deciduous forests.

The crop component in agroforestry system generally performs better if it has higher shade requirements or early in agroforestry establishment as competition for light is one of the predominant yields limiting factors (Burgess *et. al.,* 2022). In case of annual intercropping, combining architectural traits can aid resource capture in agroforestry systems. This is particularly the case for root systems, whereby resource use and more complete soil exploitation can be achieved through root stratification of tree and crop roots (Bayalaand Prieto, 2020; Borden *et al.,* 2017). Light is major deciding factor for the growth and yield of intercrops when nutrients and water are not limiting. In agroforestry, tree with different canopy architecture affect the light availability to the crops grown below the trees as intercrops. Light extinction through crowns of canopy trees determines light availability at lower levels within forests.The choice intercrop is based on availability of light which depends on canopy architecture of trees and compatibility in terms of nutrient uptake, rooting depth and other associated factors. It is therefore important to select the intercrop which has potential to adopt to light intensity penetrated through different canopy architecture.

Intercropping with leguminous crops is promoted as a sustainable practice, enhancing agricultural productivity and providing nutritional food sources to rural communities. Cowpea was selected for this study since it is a legume that helps to improve soil fertility by fixing nitrogen biologically, high nutrientavailability by reducing soil pH and consequently, the improved nutrient acquisition by the plants leading to higher yield and quality (Mousavi and Eskandari, 2011).In addition to leguminous crop like cowpea, optimization of the forest related resources in order to satisfy the demand of growing livestock population would be one of the sound alternatives (Barsila*et al.*, 2013). Limited information is available on modality of silvipastoral system mainly in case of tree fodder integration (Devkota, 2000), and scientific information with respect to the physiological adaptations particularly to that for trees and associated understorey forage crops.

Despite the qualitative understanding of species and life form changes in plant canopies, physiological traits limiting the acclimation to low light in shade intolerant species in forest and herb communities are still not entirely understood (Kothari and Schweiger, 2022). Therefore, the suitability of intercrops is depending on efficiency with which the crops alter the physiological traits to adopt different light environment including gas exchange parameters.With this back ground, the study was formulated with the objective to study influence of the of different agroforestry systems on light interception, gas exchange parameter and yield traits of cowpea and fodder sorghum grown as intercrop and to understand how light energy derived from different canopy architecture is utilised in terms of altering physiological traits under changing light intensity penetrated under different agroforestry systems.

Materials and methods

The experiment was carried out during July, 2019 to August, 2021 at forest college and research institute, Mettupalayam utilizing the existing nine years old four agroforestry systems viz., *Khaya senegalenesis, Melia dubia, Dalbergia sissoo and Casuarina equisetifolia*. As intercrops, cowpea variety CO-7 followed by fodder sorghum variety CO-31 weregrown and seeds were sourced from Department of pulses and Department of forages, Tamil Nadu Agricultural University, Coimbatore respectively and management practices were followed as per recommended practice. The experiment was carried out in RBD design with three replications for each treatment and statistically analyzed (Gomez and Gomez, 1984)

Measurement of light associated traits

Light integrated meter with quantum, pyrano and photometric sensors (Model LI-1500) was used to quantify the light interception of intercrops using following formula.

$$\text{Light interception} = \frac{\text{Light intensity in the open} - \text{Average of light intensity at the middle of the canopy and ground level}}{\text{Light intensity in the open}} \times 100$$

Measurement of photosynthetic rate and stomatal conductance

Leaf gas exchange measurements were performed using portable photosynthesis system (PPS) (Model LI-6400 of LICOR inc., Lincoln, Nebraska, USA) equipped with a halogen lamp (6400-02B LED) positioned on the cuvette. Totally, three measurements were taken in the same leaf. Leaves were inserted in a 3 cm^2 leaf chamber and Photosynthetic Photon Flux Density (PPFD) and relative humidity were set at 1500 µmol of photons m^{-2} s^{-1} and 50-55 per cent respectively. CO_2 concentration maintained at 390 ppm by using 12g CO_2 cylinder. The measurements at specified growth stages were recorded in the fully expanded leaf of plants between 9.30 am to 11.00 am to avoid effects of photo-inhibition

Measurement of Yield and yield attributing traits of cowpea and fodder sorghum

At physiological maturity, plant above ground parts was picked from each replication under both control and treatments. The important components contributing to the yield were recorded at harvest for fodder sorghum and cowpea.

Results and Discussion

Variability in light associated traits under different agroforestry systems

Agroforestry includes the incorporation of trees with livestock and/or crops in different spatial arrangements. Growing crops in the interspaces of tree rows is attractive since it permits harvesting of intermediary products which fetches short-term profitability while maintaining the planted trees and enables efficient utilization of the land. Agroforestry is the important land use system which integrates trees, crops that is scientifically sound, ecologically desirable, practically feasible and socially acceptable to farmers. The choice of crops mainly depends on light availability below the canopy of trees which in turn depends leaf area, and leaf angle or the canopy architecture. The light requirement varied with crops depends on many light responsive photochemical and biochemical reactions and processes that would reflect on the growth and yield of crops. Therefore, the studly aimed to quantify the light available to crops grown under different agroforestry system to understand whether lightpenetrated per se is sufficient to meet the crop requirements in terms of maintaining photosyntheticrate, growth and yield traits. We have quantified the light availability to crops using light integrated meters equipped with three sensors for measuring photosynthetically active radiation, total radiation and photometric measurements and compared with light availability under open condition. As expected, open space showed higher light associated traits viz., photosynthetically active radiation, total radiation and photometric measurements which were measured by about 1648 µmole m^{-2} sec^{-1}, 937 Watts m^{-2} and 83838 lux respectively.

A significant (p=0.05) difference was observed between different agroforestry systems, among which *Dalbergia sissoo* recorded maximum photosynthetically active radiation (681 µmole m^{-2} sec^{-1}), total radiation (260 watts m^{-2}) and photometric measurements (35576 lux), whereas minimum photosynthetically active radiation of 347 µmole m^{-2} sec^{-1} was observed in *Khaya* senegalenesis. In case of *Casuarina equisetifolia*, a minimum total radiation of 119 watts m^{-2} and photometric measurements of 2317 lux were also observed. The result indicated that the availability of light including PAR was higher under *Dalbergia sissoo* followed by *Melia dubia,* which is three times less than the open condition and further this has been validated with cowpea and fodder sorghum to understand whether available light is sufficient to trigger the physiological process including photosynthesis and yield components.

Measurement of gas exchange parameters and light interception of cowpea and fodder sorghum under different agroforestry systems

When annual and perennial crops are grown on the same unit of land, they will influence the growth and development of each other and affects the overall performance than when these are grown as sole crops. Understanding the interactions between different components of these agroforestry practices is necessary to increase productivity, minimize the negative interactions and develop successful agroforestry practices specific to the respective agro-climatic region. Developing suitable tree-crop combinations and assessing productivity is the major field to be considered in agroforestry (Jincy *et al.*, 2022).

One of major interactions is the light interceptions by the crops grown under tree crops. The availability of light varied from different agroforestry system depending on leaf area index and canopy architecture and therefore, light interception by the canopy of cowpea and fodder sorghum was measured to understand how intercepted light influence the gas exchange parameters and yield components. Light interception ratio of *Dalbergia sissoo* were also observed maximum with 73 % and 76 % and minimum light interception ratio of 53 % and 58 % were noted in *Khaya senegalenesis* @ 40 and 60 DAS, respectively. In addition, it was found that cowpea and fodder sorghum grown in open intercepted higher light than crops grown as intercrop. Kermah*et al.*,(2017) reported that sole legumes intercepted more PAR than intercrops whilst intercrops intercepted more PAR than sole maize as this was more evident after silking when maize leaves started senescing. As both the crops are not of senescing type, we could not observe differential response in our study.

In case of gas exchange parameters, photosynthetic rate and stomatal conductance of cowpea were found significantly higher under*Dalbergia sissoo* with 19.43 μmole CO_2 $m^{-2}sec^{-1}$ and 0.09 cm^2sec^{-1} respectively compared to agroforestry systems. It is established fact that C_3 crops requires less light than C_4 crops. In this study, both the crops responded linearly with light availability for photosynthetic rate indicating that crops have not reached the light saturation and available light may be just sufficient to drive the photosynthesis. The cowpea showed 9.21% increase in photosynthetic rate under *Dalbergia sissoo*based agroforestry system that received higher light whereas the fodder sorghum showed 14.28% increase over the *Dalbergia sissoo* indicating the light requirement for the fodder sorghum has not attained the peak may be because of fact that C_4 crops require more sunlight than C_3 crops (Li *et al.*, 2021).Singh *et al.* (2019) observed that with the advancement inheight and crown expansion of trees, the shading effects on the crop had increased, which in turnaffected the photosynthetic efficiency of the crop resulting in lower vegetative growth and lesser grainyield as compared to the sole crop.

Influence of different agroforestry systems on yield of cowpea and fodder sorghum

The different agroforestry system allows varying quantity of light intensity and impact physiological and biochemical process that would alter the yield parameters. Among different agroforestry systems, yield parameters like number of pods per plant (30.10) and yield (1150 kg/ha) were recorded higher in open space followed by *Dalbergia sissoo* with number of pods per plant by 29.33 and 923.33 kg/ha of yield. The minimum number of pods per plant (21.90) and yield (776.67 kg/ha) were noticed in *Casuarina equisetifolia*while compared to other agroforestry systems. Similarly, a different agroforestry system showed significant impact on yield of fodder sorghum. The highest yield was recorded in open space were 28.5 t/ha and 124.6 t/haand lowest yield was observed in *Khaya senegalenesis* (5.6 t/ha and 35.5 t/ha), during single cut and four cuts respectively. The yield reduction in cowpea and fodder sorghum under intercrop system compared to sole crop or open system is evident that ranges from 13 to 25 percent which was mainly due to light interception is more in early growing season (Gebru *et al.*, 2015). Similar reduction in yield was observed in cowpea which might be due to competition of crops under the tree canopy for light, water and nutrients (Ajaykumar*et al.*,2021)

Several studies indicate a higher water use from the tree layer compared to monocropping systems thus future provision of water or susceptibility to drought stress must be considered prior to promoting tree species diversity (Yang *et al.*, 2021; Zhang *et al.*, 2016). For example, conversion of forest land to silvipasture through tree thinning will be affected differently than the conversion of monoculture to multiple cropping. Coble *et al.* (2020) found that conversion of forest to silvopasture in north-eastern USA led to a 35% reduction in transpiration rates, which accounted for a greater overall water saving despite an increase in soil evaporation.

Conclusion

Identification suitable intercrop in agroforestry depends on available light under the canopy of trees grown and efficacy of intercrop to utilize the available light. In the aspect, present study has led to few findings which can be used to understand the physiological process altered due to intercepted light under agroforestry system. Cowpea and fodder sorghum showed higher light associated traits under *Dalbergia sissoo* system including photosyntheticallyactive radiation, total Radiation, photometric measurements followed by *Melia dubia* and cowpea is the found to be suitable intercrop under different agroforestry system mainly under *Dalbergia sissoo* and *Melia dubia as* evidenced from gas exchange and yield parameters.The lowest yield in cowpea was recorded in casuarina in spite of receiving higher radiation compared to Khaya which could be attributed to allelopathic effect of casuarina species. Further studies on nutrient status and microbiome of soil due to cowpea followed by fodder sorghum would strengthen the concept and the information on available light under different agroforestry system can be used to identify the crops suitable for intercrop. Although yield reduction was observed compared to pure crop, it would be profitable avenue considering soil health and additional revenue from the intercrop.

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Agroforestry systems	Parameters		
	Photosynthetically Active Radiation (µmole m^{-2} sec^{-1})	Total Radiation (Watts m^{-2})	Photometric measurements (Lux)
T_1 - Open space	1648±40.36	937±22.95	83838±2053.6
T_2 - *Khaya senegalenesis*	347±8.49	150±3.67	19705±482.6
T_3 - *Melia dubia*	560±13.71	220±5.38	31898±781.3
T_4 - *Dalbergia sissoo*	681±16.68	260±6.36	35576±871.4
T_5 - *Casuarina equisetifolia*	439±10.75	119±2.91	2317±56.75
Mean	735.2	337.6	38839.1
SEd	12.2	5.04	977.82
CD (P=0.05)	25.9	10.6	2072.9

Table 1. Light associated traits under different agroforestry system

Table 2: Gas exchange parameters and light interception of cowpea under different agroforestry system

Agroforestry systems	Light Interception ratio @ 40 DAS (%)	Light Interception ratio @ 60 DAS (%)	Photosynthetic rate (µ mole CO_2 m^{-2} sec^{-1})	Stomatal conductance (cm^2 sec^{-1})
T_1 - Open space	76.6±1.87	79.5±1.94	21.22±0.52	0.12±0.0029
T_2 - *Khaya senegalenesis*	53.2±1.30	58.8±1.44	16.56±0.40	0.05±0.0012

T_3 - *Melia dubia*	71.6±1.75	73.5±1.80	17.63±0.43	0.07±0.0017
T_4 - *Dalbergia sissoo*	73.4±1.79	76.5±1.87	19.43±0.47	0.09±0.0022
T_5 - *Casuarina equisetifolia*	66.2±1.62	68.5±1.67	16.03±0.39	0.05±0.0012
Mean	65.75	68.75	17.41	0.07
SEd	0.25	0.22	0.20	0.36
CD (P=0.05)	1.56	1.87	0.50	0.89

Table 3: Gas exchange parameters and light interception of fodder sorghum under different agroforestry system

Agroforestry systems	**Light Interception ratio @ 30 DAS (%)**	**Light Interception ratio @ 60 DAS (%)**	**Photosynthetic rate (µ mole CO_2 m^{-2} sec^{-1})**	**Stomatal conductance (cm^2 sec^{-1})**
T_1 - Open space	74.2±1.81	76.3±1.86	40.25±0.98	2.12±0.051
T_2 - *Khaya senegalenesis*	49.5±1.21	49.5±1.21	29.35±0.71	0.96±0.023
T_3 - *Melia dubia*	67.5±1.65	67.5±1.65	33.15±0.81	1.52±0.037
T_4 - *Dalbergia sissoo*	71.2±1.74	72.6±1.77	35.22±0.86	1.65±0.040
T_5 - *Casuarina equisetifolia*	59.2±1.45	59.4±1.45	30.45±0.74	1.11±0.027
Mean	61.50	61.50	32.04	1.31
SEd	1.22	1.22	0.42	0.22
CD (P=0.05)	2.56	2.56	0.85	0.51

Table 4: Yield and yield contributing traits of cowpea and fodder sorghum

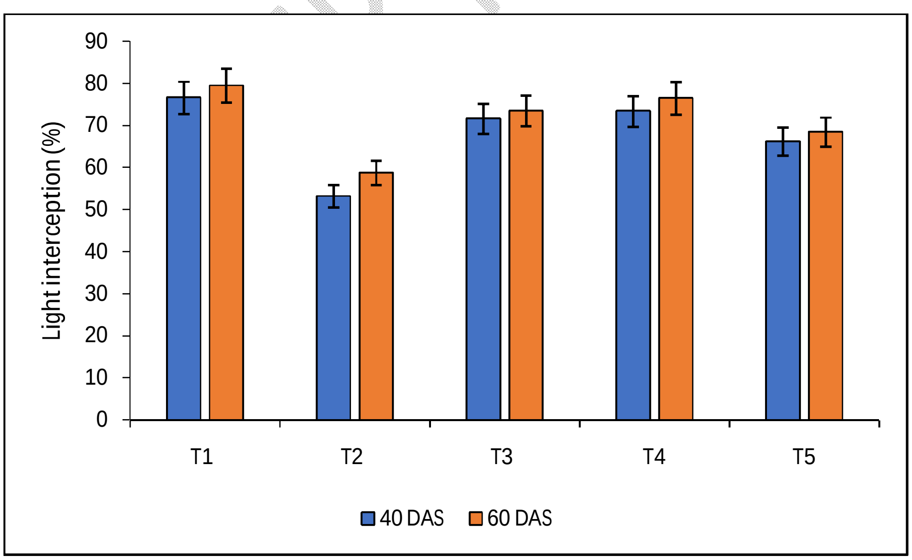
Agroforestry systems	**Cowpea**		**Fodder sorghum**	
	No. of pods per plant	**Yield (kg/ha)**	**Yield (t/ha) (Single cut)**	**Yield (t/ha) (4 cuts)**
T_1 - Open space	30.1±0.73	1150.0±28.16	28.5±0.69	124.6±3.052
T_2 - *Khaya senegalenesis*	23.0±0.56	823.3±20.16	5.6±0.14	35.5±0.86
T_3 - *Melia dubia*	26.67±0.65	865.0±21.18	17.5±0.43	75.8±1.85
T_4 - *Dalbergia sissoo*	29.33±0.71	923.3±22.61	19.6±0.48	84.5±2.07

T_5 - *Casuarina equisetifolia*	21.9±0.54	776.6±19.02	16.2±0.39	67.7±1.66
Mean	26.20	907.67	17.48	77.62
SEd	0.23	5.22	0.86	3.84
CD (P=0.05)	0.85	11.51	1.56	7.76

Table 5. Microclimatic variables of Cowpea and fodder sorghum under different agroforestry systems

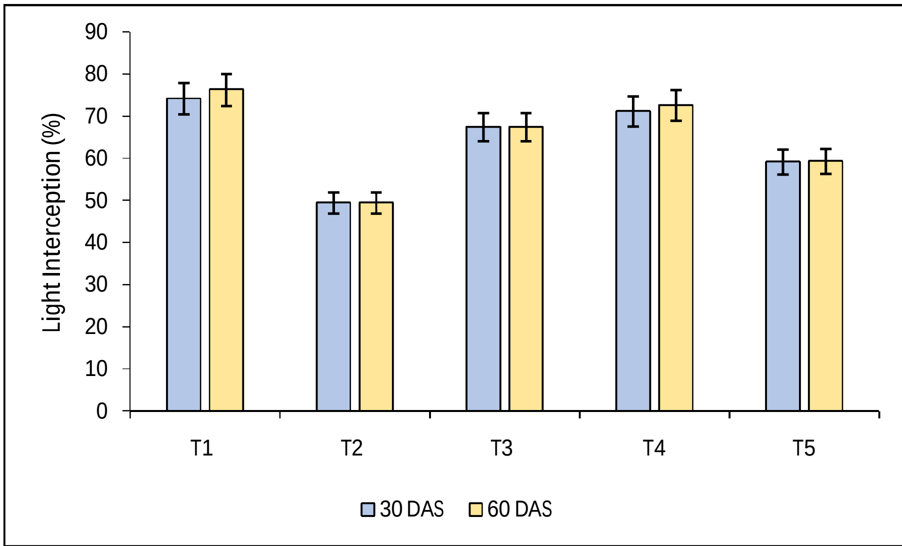
S.No.	**Agroforestry systems**	**Tempe rature**	**Relative Humidity**	**Temperat ure**	**Relative Humidity**
		Cowpea		**Fodder sorghum**	
1.	T1- Open space	34.6	76	33.1	72
2.	T2- *Khaya senegalenesis*	32.8	79	31.2	73
3.	T3- *Melia dubia*	33.1	78	31.6	73
4.	T4- *Dalbergia sissoo*	33.3	77	31.8	72
5.	T5- *Casuarina equisetifolia*	33.8	76	32.8	72
S.Ed		0.15	0.24	0.12	0.21
CD		0.11	0.31	0.23	0.41

Figure 1: Light interception of *Vigna ungiculata* under different agroforestry systems



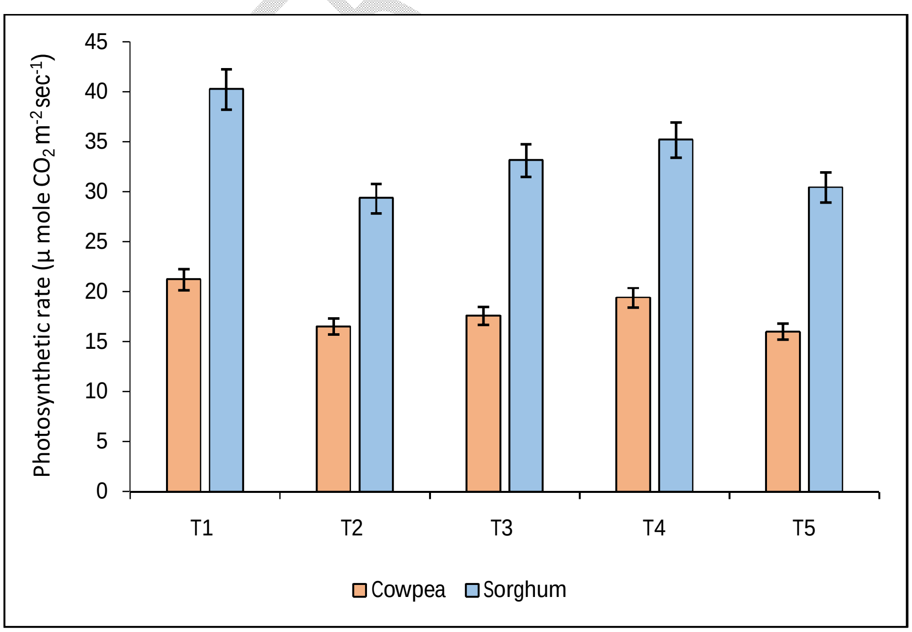
T_1 - Open space; T_2 - *Khaya senegalenesis;* T_3 - *Melia dubia;* T_4 - *Dalbergia sissoo* T_5 - *Casuarina equisetifolia*

Figure 2: Light interception of *Sorghum bicolor* under different agroforestry systems



T_1 - Open space; T_2 - *Khaya senegalenesis;* T_3 - *Melia dubia;* T_4 - *Dalbergia sissoo* T_5 - *Casuarina equisetifolia*

Figure 3: Effect of light interception on Gas exchange parameters in *Vigna ungiculata* and *Sorghum bicolor* under different agroforestry systems



T_1 - Open space; T_2 - *Khaya senegalenesis;* T_3 - *Melia dubia;* T_4 - *Dalbergia sissoo* T_5 - *Casuarina equisetifolia*