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STUDIES ON CANOPY ARCHITECTURE IN A MULTI-SPECIES CROPPING SYSTEM

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ABSTRACT

A method has been designed to study the architecture and development of crop canopies in a multi-species and multi-storeyed cropping systems involving thirteen different crop species. New terminologies such as apparent air space requirement (AASR), actual air space utilization (AASU), air space use efficiency (ASUE) and average exposed surface area (AESA) are introduced as useful parameters in quantifying canopies of crops and cropping systems. Coffee had the highest percentage increase in canopy diameter followed by mango while clove had the lowest increase. AASU and AESA showed considerable increase in all the mixed cropping combinations. In the case of crops such as nutmeg and clove, with initial small canopy and which grow at a slow pace to start with, it is possible to increase actual air space utilization and air space use efficiency considerably through mixed cropping.

INTRODUCTION

In recent years, cropping system approach has been assuming new dimensions embracing many disciplines of agricultural sciences. Although, quite a lot of work has been done on cropping systems involving annuals in many countries, studies on mixed cropping systems in perennial crops are of recent development. Dustane (1973) defined multi-storeyed cropping as a system aimed at maximum production per unit area of land per unit time, wherein economic yields of compatible crop species are harvested from different heights. Nair (1979) made a comprehensive review on the intensive multiple cropping with coconuts in India. Bavappa and Jacob (1981) developed mixed-cropping models involving many species of perennial crops for small farmer settlement programmes. They have highlighted the prospects of high intensity multi-species cropping in the tropics as a system to generate gainful employment and income in the rural sector.

In multi-species cropping where the component crops are occupying different storeys, the major consideration is the canopy alignment taking into consideration the air-space and root-space requirements of the crops. Bavappa (1975) showed that coconut palms occupy less than 30-40% of the air-space during major part of their life span. Dustane (1973), Nelliat, Bavappa and Nair

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(1974) have suggested that in multi-storeyed cropping, species having widely different morphological frame should be included in order to have high crop production potential. When the photo-synthetic canopy (leaves and / or green stem) of a component crop is set higher than that of another otherwise similar component, the taller canopy intercepts the greater share of light (Trenbath, 1976). Measurements of light fluxed in leaf canopies showed that the inclination of the leaves greatly influenced the amount of light which is intercepted by the canopies of taller intercrop components or shade trees (Monsi and Saeki, 1953). Recently, Lakso (1980) has developed the 'fish-eye' photography technique to evaluate canopy densities in relation to the physical light climate within the canopy. Wickramasinghe and Jacob (1982) developed a new method to map cocoa canopy during the establishment phase. The results of a study carried out on the canopy development and arhitecture in a multi-species mixed cropping system involving 13 crops of varying canopy size and shape are reported in this paper.

MATERIALS AND METHODS

The study was conducted in one hectare multi-species mixed cropping trial comprising 13 crops, established in 1978 in the mid-country region of Sri Lanka (Bavappa and Jacob, 1982). From this trial, the following 8 treatments with 4 replications each involving different crop combinations, were demarkated for the study (Fig. 1).

Observations were made on plant height, stem diameter, canopy height and canopy diameters (at widest point, top and bottom). Height between the ground level and the bottom end of the canopy was also recorded in respect of all the crops involved in each treatment once in September, 1980 and subsequently in June, 1981. Percentage increase in canopy diameter in these treatments were compared. In order to facilitate calculations in the study of canopy development, the general basic canopy shape was defined for each crop. Parameters such as Actual Air Space Use (AASU), Average Exposed Surface Area (AESA) and the Air Space Use Efficiency (ASUE) of the canopies were introduced in this study. AASU for each crop was calculated using the appropriate geometrical formulae according to the shape of the crop canopy as shown below :

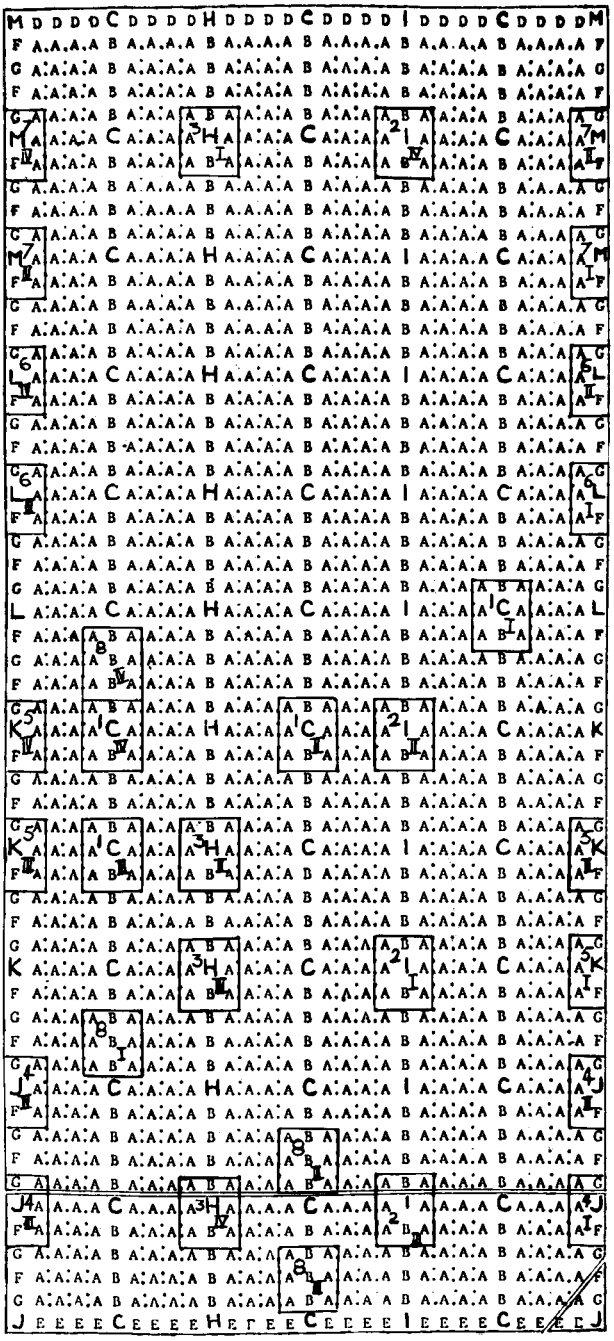
1. PEPPER : cylinder
2. COCONUT, COFFEE, MANGO, BREADFRUIT, NUTMEG AND AVOCADO : frustrum of cone
3. JACK AND CLOVE : cone

In the calculation of AASU and AESA of the canopies, the areas of bottom surfaces facing the soil were excluded. Air space use efficiency (ASUE) was calculated by the following formula:

$$ASUE = \frac{AASU}{AASR} \times 100$$

Analysis of the data was carried out using adjusted treatment means after co-variance analysis (Little and Hill, 1978) as there was fertiliser gradient in the plot.

FIG. 1. HIGH INTENSITY MULTI-SPECIES CROPPING MODEL



Code	Crop		No. of plants
A.	Pepper	–	1296
B.	Coffee (robusta)	–	220
C.	Coconut	–	36
D.	Arecanut	–	24
E.	Banana	–	24
F.	Lime	–	44
G.	Papaya	–	44
H.	Nutmeg	–	12
I.	Clove	–	12
J.	Jack	–	6
K.	Bread fruit	–	6
L.	Avocado	–	6
M.	Mango	–	6
•	Coffee San Ramon Katura		1908

Treatment plot

Plot size: 75.59 m × 136.54 m (1.03 ha)

Spacing: 1) 12.19m × 12.19m — Jack, Bread fruit, Avocado, Mango, Coconut, Nutmeg and Clove.

2) 2.44m × 2.44m — Papaya, Arecanut, Banana, Pepper, Coffee (robusta)

3) 1.22m × 2.44m — Coffee (San Ramon and Katura).

RESULTS

Data in respect of canopy height, diameter, AASU and AESA of crop combinations involving pepper are presented in Table I. It could be observed from the Table that treatment differences for height, AASU and AESA were not significant while canopy diameter of pepper has shown highly significant effect for the treatments. The highest mean canopy diameter for pepper was in treatment 4 (jack + pepper) and the lowest mean canopy diameter for the same crop was in treatment 3 (nutmeg + pepper + coffee). In the case of coffee all these parameters did not show significant effect for the treatments.

The percentage increase in the canopy diameter and height of various crops, between 24 and 33 months, after planting, is presented in Table II. Coffee had the highest percentage increase (59.5) followed by mango (51.1). The lowest increase in canopy diameter was in clove (3.0%). Coconut and jack had more than 40% increase in canopy diameter. The increase in height was comparatively lesser than the increase in diameter. The results of orthogonal comparison (Steel and Torrie, 1960) of canopy diameter of pepper in different treatments showed that treatment 3 (nutmeg + pepper + coffee) *vs* treatment 8 (coffee + pepper) was significant at 5% level while treatment 4 (jack + pepper) *vs* treatment 7 (mango + pepper) was significant at 1% level.

The computed value of apparent air space requirement (AASR) and the

Table I. *Height, diameter, AASU and AESA of pepper under different crop combination (treatments)*

Items		Mean of treatments								Variance
		T1	T2	T3	T4	T5	T6	T7	T8	
Canopy height	Mean	8.73	7.92	6.58	10.60	9.30	8.24	8.56	8.90	0.332 NS
	Adjusted mean	8.88	8.36	5.94	11.20	9.23	9.36	8.93	9.00	0.276 NS
Canopy diameter	Mean	2.16	2.78	0.77	2.88	1.41	0.94	0.95	1.85	0.174 **
	Adjusted mean	2.06	2.22	0.22	2.79	0.89	1.71	1.73	2.10	0.160 **
AASU	Mean	2.18	3.35	1.32	5.85	4.38	3.08	2.10	2.02	0.55 NS
	Adjusted mean	2.07	3.20	1.25	5.15	2.93	6.93	7.34	3.44	0.54 NS
AESA	Mean	16.28	20.66	9.91	29.67	21.46	16.73	14.78	14.81	8.78 NS
	Adjusted mean	16.78	11.68	8.08	28.11	14.86	22.26	21.85	21.13	8.76 NS

** = Significant at 0.01

air space use efficiency (ASUE) for different crops under monocropping systems are given in Table III. The highest value for apparent air space requirement (AASR)/ha (45,000 m^3) was for jack while the highest AASU was in coconut (1278.12 m^3). Coconut had the highest ASUE at both 24 and 33 months after field planting (5.5% and 11.4% respectively). Coffee came out second in rank for ASUE scoring 3.9% and 11.5% respectively at 24 and 33 months after field planting. At 33 months, the difference in ASUE between coconut and coffee was 0.19%. However, when percentage increase of ASUE is considered, coffee had the maximum increase.

The AASU/ha for various mixed-cropping combinations and its percentage increase over monoculture are

Table II. *Percentage increase in canopy diameter and height of crops*

Crop	Diameter (m)		(%) increase	height (m)		(%) increase
	x	y		x	y	
Coconut	1.93	2.71	40.41	2.32	3.04	31.03
Clove	0.66	0.68	3.03	1.16	1.76	51.72
Nutmeg	0.37	0.41	10.81	0.55	0.59	7.27
Jack	1.89	2.65	40.21	4.50	5.09	13.11
Bread fruit	1.25	1.40	12.00	2.36	2.48	5.08
Avocado	1.43	1.89	32.17	2.43	2.78	14.40
Mango	1.39	2.10	51.08	2.84	2.49	11.16
Coffee	0.42	0.67	59.52	0.72	0.95	31.94
Pepper	0.50	0.69	38.00	2.04	2.13	4.41

x = 24 months after planting
y = 33 months after planting

Table III. *AASR, AASU and ASUE for different crops under monoculture at 24 and 33 months after planting*

Crop	AASR/ha		AASU/ha		ASUE (%)		Percentage increase of ASUE
	24 months	33 months	24 months	33 months	24 months	33 months	
	(A_1) (m^3)	(A_2) (m^3)	(U_1) (m^3)	(U_2) (m^3)	$U_1/A_1 \times 100$	$U_2/A_2 \times 100$	
Coconut	23200	30400	1278.12	3531.50	5.51	11.64	111.25
Clove	11600	17600	33.13	102.40	0.29	0.58	100.00
Nutmeg	5500	5900	9.51	11.41	0.18	0.19	5.55
Jack	45000	50900	445.83	900.69	1.00	1.77	77.00
Bread fruit	23600	24800	278.47	441.67	1.18	1.78	50.85
Avocado	24300	27800	485.94	1095.31	2.00	3.93	96.50
Mango	22400	24900	520.31	121.50	2.32	4.86	109.48
Coffee	7000	9500	272.00	1088.00	3.89	11.45	194.34
Pepper	20462	21300	736.00	1216.00	3.60	5.71	58.61

shown in Table IV. Both at 24 months and 33 months after field planting, coconut-based mixed-cropping combination (coconut + pepper + coffee) utilized maximum air space of 1342.76 m^3/ha and 3674.8m^3/ha respectively. Jack and pepper combination came out second scoring 1157.52m^3 / ha and 2112.6m^3 / ha respectively at 24 and 33 months after planting.

The average exposed surface area (AESA/ha) of the canopy is presented in Table V. For all the crops with the exception of pepper, AESA/ha was high under mixed-cropping than that under monoculture. Percentage increase of AESA/ha under mixed-cropping was highest (5148m^2) in the nutmeg based mixed-cropping (nutmeg + pepper + coffee) than that under nutmeg monoculture followed by clove mixed-cropping (1374m^2). The lowest percentage increase in AESA/ha under mixed-cropping system was in coffee + pepper combination.

Table IV. *Actual air space utilization (AASU) / ha under mixed cropping and its percentage increase over the computed AASU/ha under monoculture*

Crop combination	AASU 24 months after planting	% increase over monoculture	AASU 33 months after planting	% increase over monoculture
Coconut+pepper+coffee	1342.76	5.06	3674.48	4.04
Clove+pepper+coffee	666.56	1911.95	1206.32	1078.04
Nutmeg+pepper+coffee	659.84	6838.38	1177.76	10222.00
Jack+pepper	1157.52	159.63	2112.60	134.56
Breadfruit+pepper	955.08	242.97	1157.36	162.04
Avocado+pepper	879.48	80.98	1611.96	47.17
Mango+pepper	897.97	72.58	1674.96	38.14
Coffee+pepper	670.42	146.47	1229.84	17.42

DISCUSSION

It is assumed that the air space available for exploitation by crops is unlimited (infinite). On this unlimited natural resource, a restriction is imposed by virtue of the growth habits and canopy architecture of different crop species. In order to express this parameter, the term apparent air space requirement (AASR) is used. AASR is a relative term which varies with the crops and also with age of the respective crops (Table III). For all Practical purposes, it can be taken that AASR will follow the pattern of sigmoid curve, However, it is AASU which determines the ASUE (air space use efficiency). This term indicates the extent to which a crop or cropping system utilizes the apparent air space 'earmarked' for that crop or cropping system.

Another new parameter introduced in this study is AESA (average exposed surface area). This term indicates the average value of the canopy surface area of crops or cropping systems per hectare. This parameter will give some idea as to the potential for 'harvesting the sun' by the respective crop or cropping system. In general, higher the AESA, larger will be the 'harvest'.

Table V. *Average exposed canopy surface area (AESA)/ha for both monoculture and mixed cropping* (m^2) *33 months after planting*

Crop	AESA/ha monocrop	Crop combination	Plot size (m^2)	AESA/ha mixed cropping	% increase(+) or decrease (—) in AESA over monocrop
Coconut	4355.52	Coconut+Pepper+Coffee	53 54	11072.58	+ 154
Clove	421.30	Clove+Pepper+Coffee	53.54	6210.54	+1374
Nutmeg	114.15	Nutmeg+Pepper+Coffee	53.54	5991.06	+5148
Jack	1776.75	Jack+Pepper	23.04	16258.73	+ 842
Breadfruit	822.48	Breadfruit+Pepper	23.04	10856.51	+ 112
Avocado	2622.36	Avocado+Pepper	23.04	12978.77	+ 395
Mango	2132.18	Mango+Pepper	23.04	11594.31	+ 444
Coffee	4336.00	Coffee+Pepper	53.54	6383.52	+ 47
Pepper	6969.60	Coffee+Pepper	53.54	6383.52	— 8

Considerable variation was observed in the percentage increase in canopy diameter of the different crops. Canopy diameter along with canopy height determines the volume of the crop canopy and ASUE. From the point of view of production, it is advantageous to increase both AASU and AESA from the early growth phase of the crops in the system so that production is maximised from the beginning. Results from this study showed that there is considerable increase in the AASU and AESA in all the mixed cropping combinations. In the case of crops such as nutmeg and clove with initial small canopy which grows at a slow pace to start with, it is possible to increase these two parameters considerably through mixed-cropping.

Nair (1979) in his review has shown that growing of annual crops in mixtures and sequences have made it possible to increase the cropping density from 1.0 upto 4.0 under the most optimal conditions when sunlight, nutrients and moisture are not limiting factors and where the application of these imputs can be regulated. However, under such optimal condition, 'sky is the limit' for mixed-cropping systems of perennial crops. The present study has revealed the vast potential existing in the humid tropics for increasing the canopy volume and especially the surface area and thus possibly the dry matter production per hectare under such systems.

In multi-species cropping systems, where the components crops occupy different tiers or storeys, crop production should be viewed not in a narrow sense

to include only the immediately harvestable products, but the production of useful biomass as a whole. The study reported here opens up a new vista in this direction.

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