LIGHT INTERCEPTION AND CONVERSION IN ALLEY CROPPING IN THE DRY ZONE OF SRI LANKA

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ABSTRACT

Effect of gliricidia hedgerows on light interception and conversion was evaluated during a period of four seasons in the Dry zone of Sri Lanka in an experiment having 2 m wide alley cropping, 2 m wide sole alley and two sole crop treatments. Above ground solar radiation was measured using tube solarimeters throughout four seasons. Solarimeters were placed across the alley, one on the northern half and the other on the southern half of the alley in alley cropping and sole alley treatments. Light interception by hedgerows varied within the season from zero at the commencement of the season to 77% maximum at the end of the season thus reducing the seasonal light transmission into the alley by about 30 to 41%. Alley cropping achieved higher light interception than sole alley or sole crop treatments. Mean light conversion coefficients of the three systems varied depending on the season; sole alley recording highest conversion coefficients of 1.65 and 1.46 g MJ^{-1} in the two yala seasons and alley cropping recording 1.02 and 1.03 g MJ^{-1} in the two maha seasons. Results of the study showed that reduction of available light to the crop was mainly responsible for the reduced dry matter production in alley cropping.

KEY WORDS: Alley cropping, Light interception, Light conversion coefficient

INTRODUCTION

Shifting cultivation with 10-15 years of fallow periods has been the traditional farming system on the upper slopes of the catena in the Dry zone of Sri Lanka (Abeyrathna, 1956). These lands are presently under semi permanent rainfed cultivation and due to continuous cultivation the productivity of the land has reduced. In order to improve productivity, alley cropping, which introduces trees into annual cropping systems, has been tested and promoted over a long period (Keerthisena, 1995).

Light interception and conversion to dry matter is a useful parameter to evaluate the efficiency of cropping systems. This phenomenon has been quantified for individual components of conventional intercropping systems (Marshall and Willey, 1983; Natarajan and Willey, 1985). However, such information for complex alley cropping systems is scarce. Corlett *et al.* (1992) measured light interception and conversion in alley cropping systems with leucaena as the tree species in a semi arid situation. This study was conducted to determine the variation of light usage and its effect on productivity in the Dry zone of Sri Lanka.

MATERIALS AND METHODS

The experiment was conducted from April 1998 to February 2000 over four cropping seasons under rainfed conditions at the Field Crops Research and Development Institute, Maha Illuppallama located in the Dry zone of Sri Lanka. The *yala* season is short covering the period of mid April to mid June while *maha* season is longer and extending from October to January. The *yala* 99 was drier than *yala* 98 as denoted by the rainfall figures of 179 mm and 272 mm respectively. Rainfall values during the two *maha* seasons were comparable (580 mm and 550 mm respectively). The site was situated in the upper aspects of the mid slope of the catena having about 2% gradient and the soil type was well drained Reddish Brown Earth soils (Rhodustalfs)

The experiment included two alley cropping treatments, namely 2 m (AC-2) and 6 m wide alleys (AC-6), two similar sole alley treatments (SA-2 and SA-6) and three sole crop treatments with three rates of gliricidia mulch - zero (SC-0), equivalent to biomass yield of 2 m (SC-2) and 6 m (SC-6) wide alleys. All treatments were assigned in a Randomized Complete Block Design with 3 replicates. Plot size of AC-6 and SA-6 were 12 x 12 m to include 2 alleys in each plot while the AC-2, SC-0, SC-2 and SC-6 treatments were tested in 6 x 12 m plots.

Alleys in alley cropping and sole alley treatments were established using tree hedgerows of 3 months old gliricidia seedlings planted at a spacing of 0.5 m within rows in *yala* 97. They were oriented in an east-west direction. The hedgerows were pruned at the beginning and at the end of each season commencing from *yala* 98. The prunings were applied as mulch in the alley. Short duration cowpea (60 days old) var. MI 35, and long duration blackgram (90 days old) var. MI 1, were sown as food crops in alley cropping and sole crop treatments in *yala* and *maha* respectively. They were seeded at 50 cm inter-row spacing parallel to hedgerows, the first row being 25 cm away from hedgerow. Within row density was 2 plants/hill spaced at 15 cm. All plots were fertilized with a mixture of $16N:60P_2O_5:45K_2O$ kg ha^{-1} at seeding stage and 14 kgN ha^{-1} at flowering. Plots were regularly hand-weeded throughout the growing period. The sole crops were mulched at each hedgerow pruning with the appropriate amount of gliricidia prunings obtained from a nearby gliricidia tree stand, which was planted and managed as trees in the experiment.

The dry matter production of gliricidia trees in hedgerows during each season was determined by sampling the trees at weekly intervals in *yala* and at 10 days interval in *maha*. Above ground dry matter production of the crop in alley cropping and sole crop treatments was determined by sampling plants at weekly intervals commencing from 14 days after emergence in *yala* and at 10 days interval commencing from 20 days after emergence in *maha*. Each sample comprised of plants from 16 neighbouring hills cut at the base of the stem. Dry weight was recorded after drying at 80 °C to constant weight.

Tube solarimeters (Model: Type TSL, Delta-T Devices, UK) were used to measure solar radiation below the combined hedgerow and crop canopies in AC-2 treatment and hedgerow canopy in SA-2 treatment in three replicates. Two 97 cm-long solarimeters were placed at 90°

to the crop rows/ hedgerows across the alley. Below canopy solar radiation in SC-0 and SC-2 treatments were also measured. Solarimeters were installed in the 3rd week of crop growth in *yala* 98 and in the 1st week of crop growth in three subsequent seasons, and kept throughout each season. They were periodically purged to remove condensed water and cleaned. The incident solar radiation was measured using two solarimeters oriented as for below canopy solarimeters and mounted at a height of 1 m close to the experimental area. All solarimeters were connected to a data logger (Model: Type DL2e, Delta-T Devices, UK) programmed to record readings at every 10 minutes, calculate and store the hourly means from 6 measurements.

The radiation interception by the canopy above each solarimeter was estimated by subtracting measured solar radiation by the incident solar radiation. The daily light interception was then calculated by converting intercepted radiation at any given time into hourly light interception and summing up for the day.

Weekly light interception in *yala* and 10-day light interception in *maha* for SC-0, SC-2, SA-2 and AC-2 treatments were estimated by summing up the average daily interception (s) as measured by two solarimeters in each treatment over the respective period. They were expressed as a fraction of total incident light during the respective period to calculate fractional light interception (f). Mean fractional light interception ($\bar{f}$) was estimated by dividing the seasonal light interception (S) by the total incident light during the season.

Conversion coefficient of light (e) in each treatment was estimated by dividing the dry matter production (system area basis) by light interception during the respective period. The mean conversion coefficient ($\bar{e}$) was estimated by fitting a simple linear regression to dry matter production against corresponding light interception. Slope of regression was taken as $\bar{e}$ (Monteith, 1977).

Light availability for the crop in AC-2 (AC-$2_{(crop)}$) and light interception of two components individually (hedgerow and crop) in AC-2 were estimated by using the light interception measurements made in AC-2 and SA-2. Assuming that the hedgerow growth in AC-2 was similar to that in SA-2, light interception by hedgerow component in AC-2 was estimated as similar to SA-2, and light availability for AC-$2_{(crop)}$ component was estimated subtracting light interception of SA-2 by incident light. Based on the same assumption, light interception by AC-$2_{(crop)}$ component was estimated subtracting light interception of SA-2 by that of AC-2. All interception parameters (fractional light availability, fractional light interception, conversion coefficient, mean light availability, mean light interception and mean conversion coefficient) were estimated as for the other treatments for AC-$2_{(crop)}$ component too.

RESULTS

Dry matter production of gliricidia

Dry matter production in gliricidia was higher in *yala* than in *maha* with highest production taking place between 20 - 60 days after hedgerow pruning in both seasons (Figure 1). Dry matter production in AC-2 and SA-2 systems were comparable while that of AC-6 and SA-6 treatments were not significantly different at the final harvest (Table 1). However, average dry matter production of AC-6 and SA-6 was 1/3 that of the average production of AC-2 and SA-2 treatments. Accordingly 2 m wide and 6 m wide systems produced approximately 3 and 1 t ha^{-1} dry matter per season respectively.

Table 1. The total dry matter production of hedgerow (t ha^{-1}) by season

Treatment	*Yala* 98	*Maha* 98/99	*Yala* 99	*Maha* 99/00	Average
AC-2	2.7 a*	2.6 a	3.2 a	3.6 a	3.0 a
SA-2	3.1 a	2.9 a	2.8 a	3.3 a	3.0 a
AC-6	1.0 b	0.8 b	0.8 b	0.8 b	0.85 b
SA-6	1.2 b	1.1 b	1.0 b	1.2 b	1.13 b
LSD 5%	0.5	1.3	0.9	1.2	3.5
CV%	12.3	34.3	23.0	26.9	12.9

* Values followed by the same letter along the columns are not significantly different

Plant dry matter production

Plant dry matter production of cowpea was lower than that of blackgram (Figure 2). Average dry matter production at final harvest of cowpea in both *yala* seasons was only 47% of the dry matter production of blackgram in both *maha* seasons. Differences were also observed in the average dry matter production among seasons. Average dry matter production of cowpea at final harvest in *yala* 98 was 210% of that produced in *yala* 99 while that of blackgram produced in *maha* 98/99 was 122% of that produced in *maha* 99/00.

Plant dry matter production of cowpea (in *yala* seasons) and blackgram (in *maha* seasons) differed significantly among treatments at all sequential harvests 35 and 50 days after emergence respectively (Figure 2). The sole crop systems accumulated more dry matter than alley cropping systems. Between two sole crop systems SC-2 accumulated more dry matter than SC-0 in all seasons.

Incident light

The incident light values were 610.4, 912.8, 1209.6 and 1251.9 MJ m^{-2} with daily means of 17.4, 16.3, 13.4 and 13.9 MJ m^{-2} in *yala* 98, *yala* 99, *maha* 98/99 and *maha* 99/00 respectively.

Light availability

Light availability for the crop in AC-2 (AC-$2_{(crop)}$) varied depending on the season. Mean light availability was 60, 70, 62, and 59, per cent in *yala* 98, *yala* 99, *maha* 98/99 and *maha* 99/00 respectively.

Yet, within seasonal variation in light availability as a fraction of 7-day or 10-day incident light (fractional light availability) varied between maximum of approximately 1 at the beginning of the season and the lowest of 0.35, 0.43, 0.23 and 0.31 at the end of the respective seasons in *yala* 98, *yala* 99, *maha* 98/99 and *maha* 99/00 respectively (Figure 3).

Light interception

Fractional light interception (f) showed that there were differences among treatments (Figure 4). While SC-0, SC-2 and AC-2 treatments recorded similar f values while SA-2 recorded lower f values during most of the crop growing period during all seasons except *yala* 99. The f values for AC-$2_{(crop)}$ component reached the maximum, but were smaller than the maximum values reached in other treatments, during the middle of the season and decreased thereafter.

Light conversion

Figure 5 shows the relationship between cumulative plant dry matter production and cumulative light interception in all treatments for four seasons. The *e* values were in the order of SC-0<SC-2<AC-2 among these three treatments for any given interception in all seasons. Dry mater production within the first 200 MJ m^{-2} of light intercepted by SA-2 in any season was very much higher than the other treatments. Thereafter, it reduced to lower values than all other treatments in *maha* 98/99 and, AC-2 and SC-2 treatments in *maha* 99/00. However, the *e* values of SA-2 in the two *yala* seasons remained higher than those of all other treatments within the amount of intercepted light by SA-2. The intercrop cowpea in *yala* seasons showed lower *e* values than sole cowpea while *e* values of intercrop blackgram were higher than sole blackgram in both *maha* seasons. The *e* values for crop in all treatments decreased after flowering in all seasons.

It was observed that cowpea recorded lower *e* values than blackgram. Even between the two *yala* seasons, cowpea recorded considerably lower *e* values most of the time in *yala* 99 ranging between 0.34 g MJ^{-1} and 0.55 g MJ^{-1} than in *yala* 98. In both *maha* seasons, *e* values varied between 0.8 g MJ^{-1} and 1.0 g MJ^{-1} during most of the period.

Mean light interception and conversion

The total dry matter production, seasonal light interception (S), mean fractional light interception ($\bar{f}$) and mean conversion coefficient ($\bar{e}$) of different treatments for the four seasons are shown in Table 2. The S and $\bar{f}$ values in SC-0 were always lower than in SC-2. While $\bar{f}$ values in SA-2 were lower than in SC-0 except in *yala* 99, AC-2 recorded highest $\bar{f}$ values

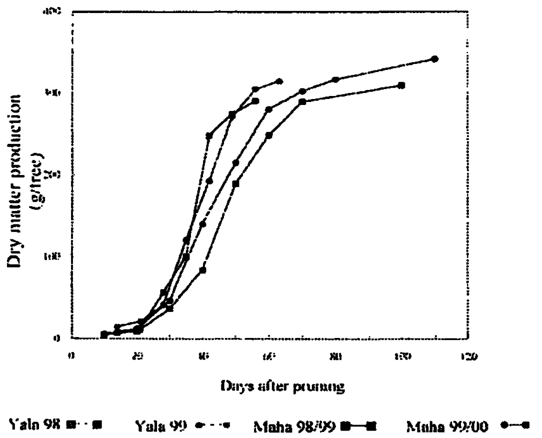

Figure 1. Dry matter production of gliricidia trees during four seasons

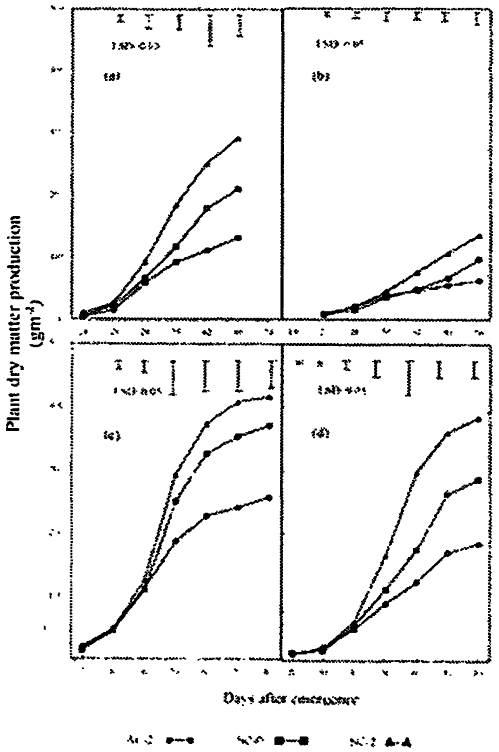

Figure 2. Plant dry matter production of cowpea in (a) *yala* 98 and (b) *yala* 99, and of blackgram in (c) *maha* 98/99 and (d) *maha* 99/00 in AC-2, SC-0 and SC-2

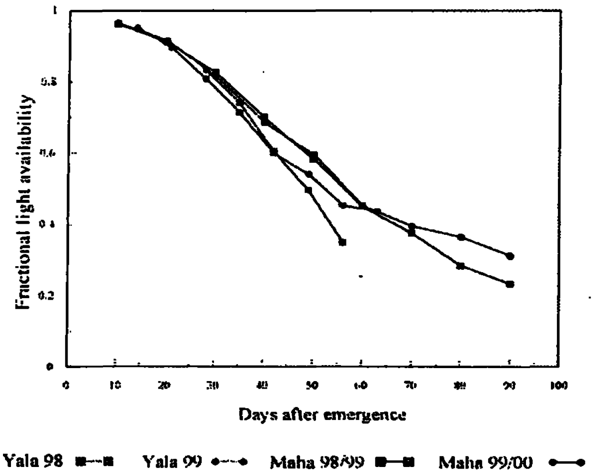

Figure 3. Light availability as a fraction of incident light during four seasons [Weekly (in *yala* seasons) or 10-day (in *maha* seasons)]

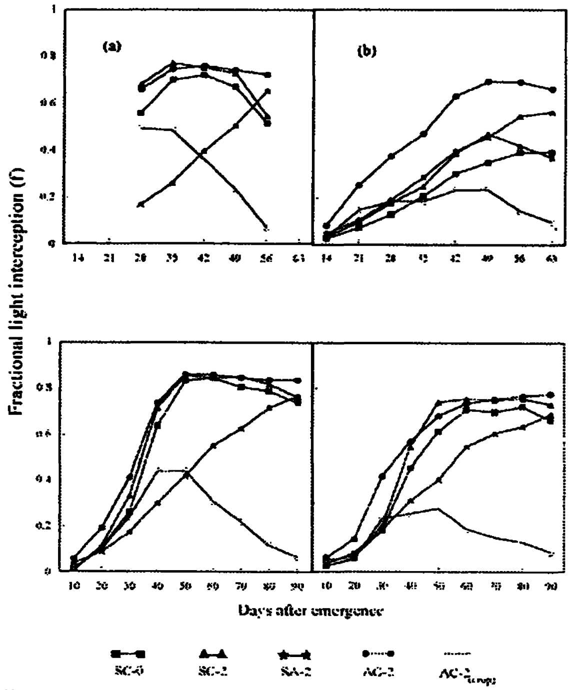

Figure 4. Fractional light interception by SC-0, SC-2, SA-2, AC-2 and AC-2$_{(crop)}$ in (a) *yala* 98, (b) *yala* 99, (c) *maha* 98/99 and *maha* 99/00

and so were S values among all treatments. AC-$2_{(crop)}$ component had intercepted less than half the light intercepted by SC-0 in three seasons except in *yala* 99, where it was only 27% lower. Seasonal light interception also followed the same trend as $\bar{f}$.

The $\bar{e}$ values in SC-0 were always lowest in all seasons except in *yala* 99 when it was only higher than the AC-$2_{(crop)}$ component. The $\bar{e}$ values in SC-2 were always higher than in SC-0. SA-2 and AC-2 treatments recorded higher $\bar{e}$ values in *yala* seasons than in *maha* seasons. Although SA-2 recorded highest of 1.55 g MJ^{-1} of $\bar{e}$ value in *yala* seasons over all treatments it was only 0.93 g MJ^{-1} which was lower than AC-2 and AC-$2_{(crop)}$ component in *maha* seasons. However, AC-$2_{(crop)}$ component in *yala* seasons recorded lower $\bar{e}$ values than in *maha* seasons.

Table 2. Total dry matter production (g m^{-2}), seasonal light interception (S) (MJ m^{-2}), mean fractional light interception ($\bar{f}$), and mean conversion coefficient ($\bar{e}$) (g MJ^{-1}) of different treatments for four seasons

	Total dry matter production				
Season	**Hedgerow**	**Crop**	**S**	$\bar{f}$	$\bar{e}$
yala 98					
SC-0	-	187.1	389.8	0.64	0.62
SC-2	-	265.0	427.4	0.70	0.79
SA-2	279.1	-	241.7	0.40	1.65
AC-2	279.1	116.1	444.5	0.73	1.10
AC-$2_{(crop)}$	-	116.1	202.8	0.33	0.63
yala 99					
SC-0	-	307.3	632.3	0.52	0.75
SC-2	-	415.5	670.2	0.55	0.80
SA-2	309.5	-	453.7	0.38	0.95
AC-2	309.5	256.6	716.5	0.59	1.00
AC-$2_{(crop)}$	-	256.6	262.7	0.22	1.02
maha 98/99					
SC-0	-	307.3	632.3	0.52	0.75
SC-2	-	415.5	670.2	0.55	0.80
SA-2	309.5	-	453.7	0.38	0.95
AC-2	309.5	256.6	716.5	0.59	1.00
AC-$2_{(crop)}$	-	256.6	262.7	0.22	1.02
maha 99/00					
SC-0	-	286.8	595.7	0.48	0.64
SC-2	-	383.3	654.8	0.52	0.81
SA-2	342.7	-	508.9	0.41	0.91
AC-2	342.7	184.8	703.3	0.56	0.98
AC-$2_{(crop)}$	-	184.8	194.3	0.16	1.03

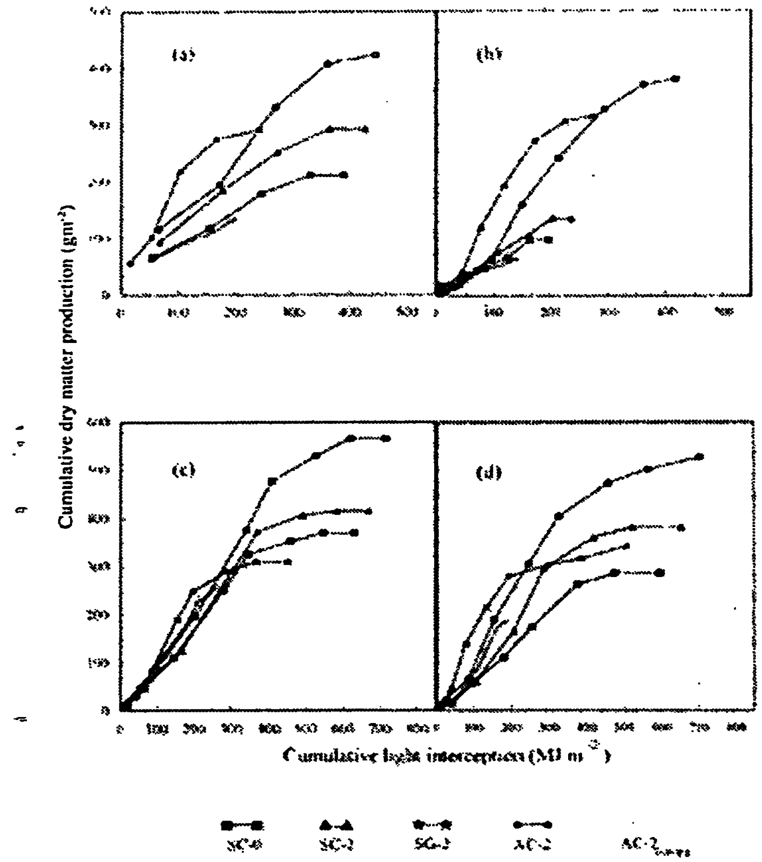

Figure 5. Relation between cumulative dry matter production and cumulative light interception of SC-0, SC-2, SA-2, AC-2 and AC-2 $_{(crop)}$ in (a) *yala* 98, (b) *yala* 99, (c) *maha* 98/99 and (d) *maha* 99/00

DISCUSSION

The degree of shading by hedgerows in terms of fractional light interception varied depending on the season and its phases. Shading varied from 0 at seeding to 77% at harvesting of the crop (Figure 3) being the maximum is lower in *yala* than in the *maha*. Since clear pruning was practiced no shading occurred at the beginning of the season as against the 30% shading observed by Singh *et al.* (1989). However, the higher seasonal shading of 30-41% reported by Lawson and Kang (1990) is not only because the hedgerows were closer and not pruned during the season but also because the short stature legumes were more likely to be shaded than the taller cereals (Duguma *et al.* 1988).

Values of *f.* were lowest in SA-2 treatment except in *yala* 99 because the hedgerows were too far apart for the canopy to close in a short period. The *f* values of SC-0, SC-2 and AC-2 in *yala* 99 were lower than in *yala* 98 because of the poor crop growth due to unfavorable climatic conditions. Alley cropping records higher light interception than sole crops or sole alley throughout the growing seasons due to the fact that combined canopy effect of both components in early stages and later on prominent interception by hedgerow canopy at the expense of component crop. The SC-2 intercepted more light than SC-0 because of the better growth achieved due to mulching with gliricidia.

The $\bar{e}$ values of cowpea (0.47 - 0.79 g MJ^{-1}) and blackgram (0.64 - 1.03 g MJ^{-1}) are within the lower range of previously reported values for pulse crops (Littleton *et al.* 1979; Muchow, 1985; Muchow *et al.* 1993; Craufurd and Wheeler, 1999). However, values for sole alley (sole gliricidia) are higher especially in *yala* seasons (1.65 and 1.46 g MJ^{-1}). Since giliricidia was already established at the beginning of the rainy season with a well-developed root system it may have been able to produce more dry matter than the crop, which would have invested much of accumulation for root growth that was not accounted for the determination of dry matter. Although calculated $\bar{e}$ values for gliricidia hedgerows are scarce in literature, Corlett *et al.* (1992) estimated $\bar{e}$ for leucaena hedgerows in a leucaena/millet alley cropping system in a semi arid environment and found that $\bar{e}$ were 0.77 and 0.82 g MJ^{-1} during two rainy seasons. The values are very low compared to the values obtained in this study probably due to the differences in climatic conditions in which the two studies were conducted.

Alley cropping shows the highest light conversion efficiency. Ong and Leakey (1999) argued that conversion efficiencies of the intercepted light in agroforestry systems would generally be lower than that reported for crops since the photosynthetic system of the hedgerows was invariably C3 and thus, less efficient than that of C4 crop plants. But in cropping systems where C3 crops are involved this is not true, in fact very high efficiency of gliricidia hedgerows contributes for higher efficiency of the system.

Delaying pruning reduces the light conversion efficiency of both sole gliricidia and alley cropping. Therefore higher $\bar{e}$ values were obtained in *yala* than in *maha*. The e of hedgerows was seriously reduced after the interception of 200 MJ m^{-2} (Figure 5). The mutual shading that took place when hedgerow canopy became large would have contributed to this. The 200 MJ m^{-2} interception was achieved when canopy was 60 days old and therefore pruning the hedgerows 60 days after first pruning would be important in order to keep the conversion efficiency at a higher level. This could be also an ideal pruning frequency for highest dry matter production because if hedgerows are pruned more frequently than this, long term dry matter production is affected (Duguma *et al.* 1988).

Dry conditions reduce the light interception and conversion efficiencies of crops (Craufurd and Wheeler, 1999). Thus, lower light interception and conversion efficiencies were observed in *yala* 99 than in *yala* 98. However, the reduction of conversion efficiency of cowpea in AC-2 between *yala* 98 and *yala* 99 was larger than that of sole crops possibly because soil water status may have fallen faster in alley systems than in sole systems under severe dry weather conditions affecting the conversion efficiency of the crop in AC-2 more. The conversion efficiency of blackgram in AC-2 is higher than that of sole crops possibly because alley cropping creates favorable conditions under wet weather conditions (no soil water limitation) in *maha* seasons. Therefore the limited light falling on the crop canopy was fully used to give higher efficiency even when the shading was more severe in *maha* than in *yala*. It also points to the fact that blackgram is a suitable crop for alley cropping. Because of the higher conversion efficiency achieved by blackgram, AC-2 recorded higher light conversion efficiency in *maha* season whereas contribution from hedgerow component was important in achieving higher conversion efficiency in *yala* seasons.

CONCLUSIONS

The study indicates that hedgerows reduce the transmitted solar radiation to the alley crop to a level that affects dry matter production as determined by limiting available light and changing light conversion efficiency. Though mulching helps to achieve higher conversion efficiency in sole crops, its effect under alley cropping is altered by the effect of shading mainly as a result of hedgerows. While blackgram achieves higher conversion efficiency in *maha* seasons, cowpea records lower conversion efficiency under alley cropping than respective sole crops in *yala* seasons. Accordingly under the given conditions, it can be concluded that blackgram in *maha* season is more fitting for alley cropping than cowpea in *yala* season.

Due to increased light interception, alley cropping produces more dry matter than sole crop or sole gliricidia alleys in *yala* seasons. However, increased light conversion efficiency is also helpful in achieving higher dry matter production in *maha* seasons. Therefore, alley cropping system is more productive than sole gliricidia or sole crop system.

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