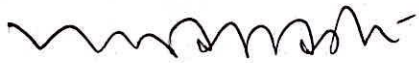


DECLARATION

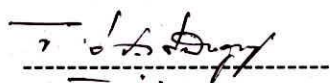
The work described in this thesis was carried out by me under the supervision of Prof. P.A.J. Yapa and Prof. R.B. Mapa, and a report on this has not been submitted to any University for another degree



R.S.K. Keerthisena



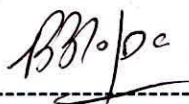
We certify that the above statement made by the candidate is true and that this thesis is suitable for submission to the University for the purpose of evaluation



Prof. P.A.J. Yapa
Professor in Botany
Department of Botany
University of Sri Jayewardenepura
Nugegoda

2002.10.01

Date



Prof. R.B. Mapa
Professor of Soil Science
Department of Soil Science
University of Peradeniya
Peradeniya

2002.10.01

Date

**Evaluation of alley cropping systems on resource utilization
in the Dry Zone of Sri Lanka**

by

Ranhotige Sisira Kumara Keerthisena

**Thesis submitted to the University of Sri Jayewardenepura
for the award of the degree of Doctor of Philosophy in Botany**

October 2002

TABLE OF CONTENTS

	page
TABLE OF CONTENTS	i
LIST OF TABLES	v
LIST OF FIGURES	vii
LIST OF PLATES	xii
ACKNOWLEDGEMENTS	xiii
ABSTRACT	xiv
CHAPTER 1 - INTRODUCTION	1
1.1 Introduction	1
1.2 Objectives	3
1.3 Organization of the thesis	4
CHAPTER 2 - LITERATURE REVIEW	6
2.1 Introduction	6
2.2 Soil water as a resource in agriculture	6
2.3 Light as a resource in agriculture	12
2.4 Dry Zone as a production area	17
2.5 Alley cropping as a production system	21
CHAPTER 3 - RESEARCH METHODOLOGY	31
3.1 Study area	31
3.2 Hypothesis	34

3.3 Methodology	35
3.3.1 Treatments	35
3.3.2 Design	36
3.3.3 Management	38
3.3.4 Observations and data collection	41
3.3.5 Data analysis	56
CHAPTER 4 - WEATHER AND SOIL AT THE EXPERIMENTAL SITE	58
4.1 Weather	58
4.2 Soil	61
4.3 Conclusions	63
CHAPTER 5 - HEDGEROW AND CROP PERFORMANCES	65
5.1 Introduction	65
5.2 Results	66
5.2.1 Shoot dry matter production of the hedgerows	66
5.2.2 Plant dry matter production of the crop	69
5.2.3 Leaf area index	72
5.2.4 Specific leaf area	75
5.2.5 Relative leaf water content	78
5.2.6 Free proline content in leaves	81
5.2.7 Crop yield	84
5.3 Discussion	87
5.4 Conclusions	93

CHAPTER 6 - SOIL CHEMICAL PROPERTIES	95
6.1 Introduction	95
6.2 Results	95
6.2.1 pH and electrical conductivity	95
6.2.2 Available P	97
6.2.3 Exchangeable K	98
6.2.4 Exchangeable Na, Ca and Mg	99
6.3 Discussion	99
6.4 Conclusions	102
CHAPTER 7 - SOIL WATER DYNAMICS	104
7.1 Introduction	104
7.2 Theory	105
7.3 Calculations	106
7.4 Results	106
7.4.1 Neutron moisture meter calibration	106
7.4.2 Variability of soil water parameters among treatments	107
7.4.3 Variability of soil water parameters within treatments	118
7.5 Discussion	132
7.6 Conclusions	138
CHAPTER 8 - LIGHT INTERCEPTION AND CONVERSION	140
8.1 Introduction	140
8.2 Theory	140

8.3 Calculations	142
8.4 Results	145
8.4.1 Incident and transmitted solar radiation	145
8.4.2 Incident light and light availability	148
8.4.3 Light interception	152
8.4.4 Light conversion	158
8.4.5 Seasonal mean light interception and conversion	159
8.5 Discussion	165
8.6 Conclusions	173
CHAPTER 9 - GENERAL DISCUSSION AND CONCLUSIONS	175
REFERENCES	179
APPENDICES	200

LIST OF TABLES

	page
3.1 Summary description of treatments	36
3.2 Details of management	40
4.1 Monthly rainfalls, mean maximum and minimum temperatures (T) at Mahailuppallama during the study period	59
4.2 Important soil characteristics in different soil horizons of the experimental site	64
5.1 Shoot dry matter production of hedgerows ($t\ ha^{-1}$) of different treatments during the study period	67
5.2 Dry matter addition ($t\ ha^{-1}$) during the study period for sole crop treatments	67
5.3 Leaf area index of the crop for different treatments on different occasions during the study period	73
5.4 Specific leaf area ($cm^2\ g^{-1}$ of leaf dry weight) for different treatments on different occasions during the study period	76
5.5 Relative leaf water content (%) of different treatments on different occasions in two seasons	79
5.6 Free proline content in leaves ($\mu\ mol\ g^{-1}$) of different treatments on different days in four seasons	82
5.7 Crop yield ($kg\ ha^{-1}$) of different treatments in four seasons	85
6.1 Electrical Conductivity ($mS\ m^{-1}$) in different soil layers of different treatments in 1998 and 2000	96
6.2 Available P ($\mu g\ g^{-1}$) content in different soil layers of different treatments in 1998 and 2000	97

6.3	Exchangeable K ($\mu\text{g g}^{-1}$) content in different soil layers of different treatments in 1998 and 2000	98
6.4	Exchangeable K ($\mu\text{g g}^{-1}$) content in different soil layers at the hedgerow (h) and centre (c) of AC-2 and AC-6 treatments in 1998 and 2000	99
7.1	Neutron moisture meter calibration equations for each soil horizon and the correlation coefficients (r^2 values)	107
7.2	Profile water storage (mm) and depletion (mm) with standard deviations in different treatments during the two drying periods	119
7.3	Profile water storage (mm) and depletion (mm) with standard deviations at various distances from the hedgerow in each treatment during two drying periods	133
8.1	Seasonal incident light, mean daily incident light, seasonal available light and mean daily available light during four seasons	148
8.2	Total dry matter production (g m^{-2}), seasonal mean fractional light interception (\bar{f}), seasonal light interception (S) (MJ m^{-2}), and seasonal mean conversion coefficient (\bar{e}) (g MJ^{-1}) of different treatments for four seasons	164
8.3	Total dry matter production (W) (g m^{-2}), seasonal mean fractional light interception (\bar{f}), total light interception (S) (MJ m^{-2}), and seasonal mean conversion coefficient (\bar{e}) (g MJ^{-1}) of crop component in northern and southern parts of AC-2 system during four seasons	166

LIST OF FIGURES

	page
2.1 Three major climatic zones in Sri Lanka	18
2.2 Schematic presentation of an alley field	22
3.1 Agro-ecological map of Sri Lanka showing the DL ₁ region and location of Mahailuppallama	32
3.2 Mean monthly rainfall, mean monthly maximum temperature and mean monthly minimum temperature during 1978 - 1997 at Mahailuppallama	33
3.3 Experimental field lay out	37
3.4 Schematic presentation of a cross section of (a) AC-2 alley and (b) AC-6 alley showing the numbering system of crop rows, the distance to each crop row, and the identification system of hedgerows and alley area relative to the hedgerow	42
3.5 Lay-out of different plots and access tube positions in each plot	51
3.6 Solarimeter positioning and identification in AC-2 treatment	53
4.1 The daily rainfall during four crop growing periods	60
5.1 Shoot dry matter accumulation of gliricidia trees during each cropping season	68
5.2 Plant dry matter production of cowpea with time in (a) <i>yala</i> 98 (b) <i>yala</i> 99, and of blackgram in (c) <i>maha</i> 98/99 and (d) <i>maha</i> 99/00	70
5.3 Plant dry matter production of different crop rows identified relative to the distance from northern hedgerow of the alley in (a) AC-2 and (b) AC-6 in relation to plant dry matter production in (c) sole crop treatments on four days in four seasons	71

5.4	Leaf area index of different crop rows identified relative to the distance from northern hedgerow of the alley in (a) AC-2 and (b) AC-6 in relation to leaf area index in (c) sole crop treatments on four days in four seasons	74
5.5	Specific leaf area of different crop rows identified relative to the distance from northern hedgerow of the alley in (a) AC-2 and (b) AC-6 in relation to specific leaf area in (c) sole crop treatments on four days in four seasons	77
5.6	Relative leaf water content in leaves as measured at 11 a.m. on different crop rows identified relative to the distance from northern hedgerow of the alley in (a) AC-2 and (b) AC-6 in relation to relative leaf water content in (c) sole crop treatments in two seasons	80
5.7	Free proline content in leaves on different crop rows identified relative to the distance from northern hedgerow of the alley in (a) AC-2 and (b) AC-6 in relation to free proline content in (c) sole crop treatments on four days in four seasons	83
5.8	Crop yield of different crop rows identified relative to the distance from northern hedgerow of the alley in (a) AC-2 and (b) AC-6 in relation to crop yield in (c) sole crop treatments in four seasons	86
7.1	Change of average soil water content in 0-15 cm, 15-60 cm, 60-105 cm, 105-150 cm and 150-200 cm layers in relation to daily rainfall distribution in sole crop treatments	109
7.2	Change of soil water content at different layers in relation to SC treatment in SG-2 and SG-6 treatments	112

7.3	Change of soil water content at different layers in relation to SC treatment in AC-2 and AC-6 treatments	113
7.4	Soil profile water storage in (a) sole gliricidia and (b) alley cropping treatments in relation to SC treatment during the study period	114
7.5	Change of average soil water content with depth in relation to field capacity in (a) SC, (b) SG-2, (c) SG-6, (d) AC-2 and AC-6 treatments in <i>yala</i> 98	116
7.6	Change of average soil water content with depth in relation to field capacity in (a) SC, (b) SG-2, (c) SG-6, (d) SC-2 and AC-6 treatments in <i>yala</i> 99	117
7.7	Change of soil water content at different layers in relation to SC treatment at the hedgerow and the centre of alley in SG-2 treatment	120
7.8	Change of soil water content at different layers in relation to SC treatment at the hedgerow and the centre of alley in SG-6 treatment	121
7.9	Change of soil water content at different layers in relation to SC treatment at the hedgerow and the centre of alley in AC-2 treatment	122
7.10	Change of soil water content at different layers in relation to SC treatment at the hedgerow and the centre of alley in AC-6 treatment	123
7.11	Soil profile water storage at the hedgerow (0 cm) and centre of alley (100 cm or 300 cm) in (a) SG-2 and (b) SG-6 treatments in relation to SC treatment during the study period	125
7.12	Soil profile water storage at the hedgerow (0 cm) and centre of alley (100 cm or 300 cm) in (a) AC-2 and (b) AC-6 treatments in relation to SC treatment during the study period	126

7.13	Change of average soil water content with depth in relation to field capacity at (1) 0 cm, (2) 100 cm and (3) 300 cm away from hedgerow in (a) SG-2 and (b) SG-6 treatments in comparison with (c) SC treatment in <i>yala</i> 98	128
7.14	Change of soil water content with depth in relation to field capacity at (1) 0 cm, (2) 100 cm and (3) 300 cm away from hedgerow in (a) AC-2 and (b) AC-6 treatments in comparison with (c) SC treatment in <i>yala</i> 98	129
7.15	Change of soil water content with depth in relation to field capacity at (1) 0 cm, (2) 100 cm and (3) 300 cm away from hedgerow in (a) SG-2 and (b) SG-6 treatments in comparison with (c) SC treatment in <i>yala</i> 99	130
7.16	Change of soil water content with depth in relation to field capacity at (1) 0 cm, (2) 100 cm and (3) 300 cm away from hedgerow in (a) AC-2 and (b) AC-6 treatments in comparison with (c) SC treatment in <i>yala</i> 99	131
8.1	Diurnal variation of incident solar radiation and transmitted solar radiation on different days in four seasons	146
8.2	Diurnal variation of transmitted solar radiation in northern and southern parts of the alley on different days in four seasons	147
8.3	Weekly (in <i>yala</i> seasons) or 10-day (in <i>maha</i> seasons) mean light availability as a fraction of incident light in four seasons	150

8.4	Weekly (in <i>yala</i> seasons) or 10-day (in <i>maha</i> seasons) mean light availability for AC-2 _(crop) in different parts of AC-2 treatment as a fraction of incident light in four seasons	151
8.5	Seven day means of fractional light interception by different treatments in (a) <i>yala</i> 98 and (b) <i>yala</i> 99	154
8.6	Ten day means of fractional light interception by different treatments in <i>maha</i> (a) 98/99 and (b) <i>maha</i> 99/00	155
8.7	Seven day means of fractional light interception by southern and northern parts of different treatments in (a) <i>yala</i> 98 and (b) <i>yala</i> 99	156
8.8	Ten-day means of fractional light interception by southern and northern parts of different treatments in (a) <i>maha</i> 98/99 and (b) <i>maha</i> 99/00	157
8.9	Relation between cumulative dry matter production and cumulative light interception of SC-0, SC-2, AC-2, SG-2 and AC-2 _(crop) in (a) <i>yala</i> 98 and (b) <i>yala</i> 99	160
8.10	Relation between cumulative dry matter production and cumulative light interception of SC-0, SC-2, AC-2, SG-2 and AC-2 _(crop) in (a) <i>maha</i> 98/99 and (b) <i>maha</i> 99/00	161
8.11	Relation between cumulative dry matter production and cumulative light interception of southern and northern parts of AC-2 _(crop) in (a) <i>yala</i> 98 and (b) <i>yala</i> 99	162
8.12	Relation between cumulative dry matter production and cumulative light interception of southern and northern parts of AC-2 _(crop) in (a) <i>maha</i> 98/99 and (b) <i>maha</i> 99/00	163

LIST OF PLATES

	Page
3.1 A 2 m wide alley in AC-2 treatment with 4 crop rows	43
3.2 A 2 m wide alley in AC-2 treatment with 12 crop rows	43
3.3 The positioning of solarimeter in SC treatments	54
3.4 The positioning of solarimeters in AC-2 treatments	54
4.1 The soil profile of the experimental site	62

ACKNOWLEDGEMENTS

I would like to thank my supervisors Prof. P.A.J. Yapa, Professor in Botany, Department of Botany, University of Sri Jayewardenepura, Nugegoda and Prof. R.B. Mapa, Professor of Soil Science, Department of Soil Science, University of Peradeniya, Peradeniya for their supervision, guidance, encouragement and help given in other numerous ways during the study period.

I express my sincere thanks to Mr. G.Gunawardana, Research Assistant and Mr. R.D. Dayarathna of Field Crops Research and Development Institute, Department of Agriculture, Mahailuppallama who were with me throughout the study helping me in all the activities to conduct the fieldwork.

I would also like to thank the staff, especially Director, Deputy Directors and staff of soil chemistry laboratory of the Field Crops Research and Development Institute, Department of Agriculture, Mahailuppallama for helping me in various ways to complete this study.

I specially thank Dr. L.P. Vidana Arachchi, Coconut Research Institute, Lunuwila, and Mr. Sunil Govinnage, District Training Centre, Ambepussa for their assistance given in laboratory analysis.

Finally, I would like to thank the staff of Natural Resources Management Centre of Department of Agriculture, Peradeniya for assisting me in various ways during the write up of this thesis.

Evaluation of alley cropping systems on resource utilization in the Dry Zone of Sri Lanka

R. S. K. Keerthisena

ABSTRACT

Continuous cultivation of annual crops in uplands, under rainfed conditions in the Dry Zone of Sri Lanka has led to productivity decline as a result of loss of fertility and soil erosion. Alley cropping, which incorporates tree hedgerows into annual cropping, has been recommended as a sustainable land management system for the rainfed uplands. However, the effect of hedgerows on the use of limited resource base could result in various consequences, and therefore this investigation was conducted in order to study the effect of hedgerow component on the food crop component and the utilization of agricultural resources under alley cropping. Two alley cropping systems, namely 2 m wide alleys and 6 m wide alleys were compared with similar sole gliricidia alley systems, and sole crop systems. Hedgerows were established using 3 - months old gliricidia seedlings with 0.5 m within row spacing in *yala* 1997 in alley cropping and sole gliricidia systems. Cowpea in the two *yala* seasons (1998 and 1999) and blackgram in the two *maha* seasons (1998/1999 and 1999/2000) were grown as associated food crops in alley cropping systems. The food crops were also grown as sole crops with no-mulch, mulch equal to the hedgerow biomass yield of 2 m wide, and 6 m wide alley systems. The hedgerows were pruned at the beginning and end of each season.

High hedgerow biomass production (13.5 t ha⁻¹ over a two year period) was observed irrespective of alley width and cropping. However, the increase of alley width from 2 m to 6 m reduced the hedgerow biomass by $\frac{2}{3}$ from 20.0 t ha⁻¹ to 7.05 t ha⁻¹ over the study period. The total biomass yields (hedgerow and crop) of alley cropping systems were higher than sole gliricidia or sole crop systems.

Growth parameters of the crop were measured in order to study the effect of hedgerows in alley cropping. Both 2 m wide and 6 m wide alley cropping recorded lower crop dry matter production, leaf area index, free proline content and crop yield than all sole crops. Specific leaf area in both alley cropping systems was higher than that of sole crop systems. However, relative leaf water content of the crop in 2 m wide and 6 m wide alley cropping was lower than that in respective sole crops. Between two alley cropping systems, crop dry matter production, leaf area index and crop yield were lower in 2 m wide alley than that of 6 m wide alley system. Specific leaf area in 2 m wide alley system was higher than that in 6 m wide alley system. Relative leaf water content in *yala*, and the leaf proline content in *yala* and *maha* in 2 m wide alley cropping system were lower than that in 6 m wide alley cropping system. While increasing mulch rate increased the dry matter production, leaf area index, relative leaf water content and crop yield, it reduced the specific leaf area and free proline content in sole crop systems.

The crop rows closer to the hedgerow recorded lower crop dry matter production, free proline content and crop yield, and higher specific leaf area and relative leaf water content than the crop rows at the centre in both alley cropping systems. Between two crop rows to the north and south of a hedgerow, difference in

above parameters varied with season. The crop row immediate to the north of hedgerow recorded a higher crop dry matter production, leaf area index, free proline content and crop yield than the one to the south in *yala*. An opposite trend was observed in *maha*. But, specific leaf area behaved *vice versa*.

The analysis of soil chemical properties revealed that electrical conductivity, available P and exchangeable K increased considerably in 0-30 cm soil layer while pH and exchangeable Na, Ca and Mg did not change significantly in all systems during the study period. In addition, both 2 m wide alley cropping and sole crop with mulch equal to 2 m wide alley system recorded higher electrical conductivity in 0-5 cm layer and higher exchangeable K in 0-30 cm soil layer respectively than 6 m wide alley cropping and sole crop with mulch equal to 6 m wide alley cropping system. Sole crop without mulch always recorded lowest values.

The water contents in 0-15 cm soil layer of all the systems were highly variable with frequent recharging after every rain. Recharge of deeper layers occurred frequently in *maha* while it happened only once in *yala*. Soil water contents in other layers fluctuated in relation to rainfall with less variability. Soil water content did not differ among three sole crop systems and so the soil water consumption. Higher soil water consumption was observed in 2 m wide alley cropping followed respectively by 2 m sole gliricidia, 6 m wide alley cropping and sole crops. The lowest soil water consumption was recorded in 6 m wide sole gliricidia alleys. The sole crops extracted most of the water from shallow depth up to 150 cm, while gliricidia hedgerows extracted water from deeper soil layers also. Soil water content across the alley was uniform in all the soil layers of the 200 cm

deep soil profile in 2 m wide alleys. However, soil water contents of all the soil layers increased towards the centre of alley in 6 m wide sole gliricidia system and of layers below 105 cm depth in alley cropping system. The soil water extraction patterns showed that the hedgerows did not extract soil water at the centre of 6 m wide alleys.

The higher interception of light by hedgerows reduced the seasonal mean available light on the associated food crop by 34.8% and 39.1% in *yala* and *maha* respectively with a within seasonal variation of 0 - 77%. The shading by hedgerows was higher to the north of the hedgerow in *maha* season and to the south of the hedgerow in *yala* season. Two meter wide alley cropping system achieved 0.73, 0.46, 0.59 and 0.56 of mean fractional light interceptions respectively in *yala* 1998, *yala* 1999, *maha* 1998/1999 and *maha* 1999/2000 with mean light conversion coefficients of 1.1, 1.08, 1.08 and 0.98 g MJ⁻¹ respectively. The mean fractional light interceptions of 2 m wide sole gliricidia system in respective seasons were 0.4, 0.3, 0.38 and 0.41, where mean seasonal conversion coefficients were 1.65, 1.46, 0.95 and 0.91 g MJ⁻¹. The sole crop treatments recorded mean fractional light interceptions higher than that of 2 m wide sole gliricidia except in *yala* 1999 and lower than 2 m wide alley cropping in all the seasons. Seasonal mean conversion coefficients of all the sole crop systems in all seasons were lower than that of 2 m wide sole gliricidia and 2 m wide alley cropping. However, the fractional light interception and conversion coefficient in sole crop systems increased with increasing mulch rate.

The results prove that effect of mulch and hedgerows are important in determining the performance of the crop that results through the change of resource use in alley cropping. While mulching affects largely on soil nutrients and light use, hedgerow effect is more prominent on use of soil water and light. Nevertheless, the crop performance in alley cropping is mainly determined by the availability of light as affected by the hedgerows. The effect of hedgerows is extended to a distance of 150 cm and 50 cm on either side of the hedgerow where incident light is changed. The results suggest that alley cropping can successfully be used to increase soil water and light resource use and efficiency for the Dry Zone of Sri Lanka. Thus, alley cropping increases the overall productivity and higher crop yields can be achieved by adopting proper pruning to minimize the competition for these resources.