TABLE OF CONTENTS

	Page
ACKNOWLEDGEMENT	iii
ABSTRACT IN ENGLISH	v
ABSTRACT IN THAI	viii
LIST OF CONTENTS	xi
LIST OF TABLES	xvii
LIST OF ILLUSTRATIONS	xxi
ABBREVIATIONS AND SYMBOLS	xxiv
CHAPTER I: INTRODUCTION	1
1.1 Miang Production in Northern Thailand	1
1.2 Constraints of Miang Production	2
1.3 Miang in Transition	3
1.4 Rationale	3
1.5 Purposes of the Study	5
1.6 Usefulness of Study	5
CHAPTER II: REVIEW OF INDIGENOUS MIANG SYSTEMS	6
2.1 Miang Systems	6
2.1.1 Processes and Cost of Miang System	6
2.1.2 Marketing of Miang	7
2.2 Indigenous Miang-based Agroforestry Systems	8
2.3 Environment for Tea Plant	10
2.3.1 Shading Effect	10
2.3.2 Temperature Effect	11
CHAPTER III: REVIEW OF CANOPY AND ROOT	12
3.1 Canopy Structure	12
3.1.1 Measurement of Canopy Structure	12
3.1.2 Temporal Changes of Canopy Structure	12

3.2 Microclimate	13
3.2.1 Rainfall Redistribution	13
3.2.2 Light Interception	13
3.2.3 Humidity and Temperature Modification	14
3.3 Tree Characteristics	14
3.3.1 Crown Characteristics	14
3.3.2 Phenological Characteristics	15
3.3.3 Bole Characteristics	15
3.4 Root Architecture	16
3.5 Tree-crop Interaction Study	17
3.5.1 Above-ground Study	18
3.5.2 Parameters in Root Study	19
3.5.2.1 Number of Branching Point and Link	20
3.5.2.2 Total Root Length	20
3.5.2.3 Total Root Dry Weight	20
3.5.2.4 Specific Root Length	21
3.5.2.5 Horizontal Root Spread	21
3.5.3 Methodologies in Root Study	21
CHAPTER IV: MATERIALS AND METHODS	26
4.1 Farmer Interview	26
4.1.1 Location	26
4.1.2 Methods	26
4.2 Field Study	27
4.2.1 Experiment Site	27
4.2.2 Materials	28
4.2.3 Management of Experiment	28
4.2.4 Above-ground Measurement	30
4.2.4.1 Stem Measurement	31
4.2.4.2 Canopy Measurement	31
4.2.4.3 Phenological Characteristics Record	32
4.2.4.4 Canopy Structure	32

xiii

4.2.5 Root Measurement	32
4.2.5.1 Test of Fractal Model	33
4.2.5.2 Specific Root Density	34
4.2.5.3 Root Isoline or Altitude	34
4.2.5.4 Total Root Length	34
4.2.5.5 Root Dry Weight	34
4.2.5.6 Specific Root Length	34
4.2.5.7 Length of Main Axis	35
4.2.5.8 Index of Shallow Rootedness	35
4.2.6 Spatial Analysis in Miang-based Agroforestry systems	35
4.2.7 Financial Assessment	37
CHAPTER V: MIANG PRODUCTION SYSTEMS AT BAN PHADENG	39
5.1 Demographic Profile of Ban Phadeng	39
5.1.1 Migration	39
5.1.2 Age	40
5.1.3 Labour	40
5.2 Structure of Miang Production at Ban Phadeng	40
5.2.1 History	40
5.2.2 Experience in Miang Production	41
5.3 Land Ownership and Land Tenure	41
5.4 Land Use	43
5.5 Income and Cost of Miang Production	44
5.5.1 Income	44
5.5.2 Cost	45
5.6 Constraints in Miang Production	46
5.7 Miang in Transition	48
5.7.1 Future of <i>Miang</i>	48
5.7.2 Incorporation of New Crops as Land Use Strategy	49
5.8 Contribution of Miang to Village Livelihood	49
5.9 Harmonising Miang Production and Resource Conservation	50
5.10 Contributing Factors to Economic Potential of Miang	50

	. xiv	
	5.10.1 Price Trend	50
	5.10.2 Marketing Opportunity	52
CHAPTER VI	: RESULTS OF FIELD STUDY	53
6.1 Ger	neral Information of the Farm	53
6.2 Dev	velopment of Integrated Land Use	53
6.3 Wh	ole Farm Income	55
	6.3.1 Miang Production	57
	6.3.2 Mango Production	58
	6.3.3 Rhetsa Production	59
6.4 Pro	duction and Financial Assessment of Land Use Patterns	60
	6.4.1 Income	63
	6.4.2 Cost	64
	6.4.3 Net Present Value and Benefit-cost Ratio	67
6.5 Ove	erview of Field Measurement	68
6.6 Ab	ove-ground Measurement	69
	6.6.1 Trees and Miang Arrangement	69
	6.6.2 Above-ground Biomass	72
	6.6.3 Fruit tree Characteristics	76
	6.6.4 Relationship between Age of Mango and Canopy Structure	77
6.7 Roc	ot Measurement	80
	6.7.1 Fractal Model Testing	80
	6.7.2 Specific Root Density (δ)	82
	6.7.3 Proximal Root Diameter (D _{prox})	82
	6.7.4 Number of Branching Point Per Branch Event (N _k)	83
	6.7.5 Root Isoline or Altitude (N _p)	83
	6.7.6 Total root length (L _t)	83
•	6.7.7 Total Root Dry Weight (W _t)	85
	6.7.8 Specific Root Length	86
	6.7.9 Shallow Rootedness	87
	6.7.10 Length of the Main Axis (N _{max})	88

Root Volume Root Volume	89
6.8 Root Arrangement in Sloping Land	93
6.9 Spatial Analysis of Canopy and Root	93
6.9.1 Canopy Coverage of Rhetsa and Fruit Trees	93
6.9.2 Availability Space	97
CHAPTER VII: DISCUSSION OF FIELD STUDY	98
7.1 Sustainable land use of Miang-based AFS	98
7.2 Miang-based AFS Different Stages	100
7.2.1 Income	100
7.2.2 Cost	101
7.2.3 Financial Return	101
7.3 Above-ground Interaction in Miang-based AFS	102
7.3.1 Above-ground Biomass Affects on Microclimate	102
7.3.2 Phenological Characteristics and Interaction	103
7.3.3 Fruit tree Selection by Above-ground Criterion	104
7.4 Below-ground Interaction in Miang-based AFS	106
7.4.1 Fractal Model	106
7.4.2 Root System of Rhetsa	107
7.4.3 Roots of Mango in Different Age	109
7.4.4 Roots of Mango in Different Propagating Method	111
7.4.5 Spacing and Roots of Mango	112
7.4.6 Fruit trees Selection by Root Criterion	111
7.4.7 Root System of Ramdomly-planted and row-planted	
Miang	113
7.4.8 Root Arrangement in Different Stage	114
7.5 Root Management Effects on Root Distribution	116
7.6 Spatial Arrangement of Canopy and Root in Miang-based AFS	119
7.7 Tree-crop Interaction in Sloping Land	123
7.7.1 Competition for Light in Sloping Land	123
7.7.2 Root Interaction in Sloping Land	125

xvi

CHAPTER VIII: CONCLUSION AND RECOMMENDATION	128
8.1 Conclusion	128
8.2 Recommendations	131
8.2.1 Technological Recommendations	131
8.2.2 Research Recommendations	132
REFERENCES	134
APPENDICES	147
APPENDIX A: FIELD EXPERIMENT RESULTS	148
APPENDIX B: STATISTICAL ANALYSIS	154
APPENDIX C: IMAGES IN SPATIAL ANALYSIS	160
GLOSSARY	166
CURRICULUM VITAE	167

LIST OF TABLES

Table		Page
2.1	The cost of <i>miang</i> practices at Pa Pae sub-district, Mae Taeng district, Chiang Mai	7
2.2	Components of miang orchard of Ban Kui Tuai, Pa Pae sub- district, Mae Taeng district, Chiang Mai province	9
3.1	The nature of study of the three main interactions in agroforestry systems	17
3.2	The conventional methods and new methods, type of data obtained, and disadvantages of each study method	22
4.1	Meteorological data in 1996 of Nong Hoi meteorological station, Mae Rim district, Chiang Mai	27
4.2	Characteristics of three planting patterns in miang-based system	30
5.1	List of tree species in <i>miang</i> orchard obtained from interviewing with 19 households at Ban Phadeng	43
5.2	Sources of income expressed in percentage and contributed household	45
5.3	Annual investment of miang in 1995	46
5.4	Ranking of problems of miang growers at Ban Phadeng	47
6.1	Distribution of harvestable products throughout the year	56
6.2	Gross income and proportion of the farm in 1996	56
6.3	Distribution and seasons of <i>miang</i> production in the study site, Ban Phadeng, Pa Pae sub-district, Chiang Mai	58
6.4	Components and plant density of each stage plot	60
6.5	Income of each commodity of mature stage, middle stage and early stage plots	64
6.6	Cost and time of each task	66
6.7	Total volume of each species in 3 different stage plots	72
6.8	Linear regression analysis between root diameter before branching and α, q and L _L of Rhetsa, mango, pomelo and miang	80

xviii

6.9	Root volume and above-ground ratio	90
6.10	The percentage of canopy coverage in each pattern	93
7.1	Sources of interaction, parameter and ranking of relative severity of interaction of each species in each pattern	115
a.1	Productions, prices and seasons of each species of each stage in 1996	148
a.2	Present value of income based on opportunity cost of capital 12% per year	148
a.3	Present value of cost based on opportunity cost of capital 12% per year	149
a.4	Yield of rhetsa and tree dimension	149
a.5	Average height, basal diameter (BD), crown edge height (CEH), crown depth (CD) and crown width (CW) of the species in each pattern	150
a.6	Average height, crown depth, crown edge height and crown depth of different age of mango	150
a.7	Mean and coefficient variation of α , q, L _L and β of each species	150
a.8	Specific root density of Rhetsa, mango, pomelo and miang	151
a.9	Proximal root diameter (D_{prox}), number of branching point per branch event of root (N_k), root altitude (N_p) and length of the main axis	151
a.10	Total root length (L_t) , total root dry weight (W_t) , specific root length (L_{rw}) and shallow rootedness (SR)	152
a.11	The proximal root which less and more than 45° and proximal root classified by species and direction	152
a.12	Total root length (L _t) and total root dry weight (W _t) classified by species and direction	153
a.13	Specific root length (L_{rw}) and length of the main axis (N_{max}) classified by species and direction	153
b.1	Regression analysis relationship between yield of miang, and density of forest tree and miang	154

b.2	Regression analysis relationship between yield of rhetsa and crown width	154
b.3	One way analysis of variance for height, crown depth, crown edge height and crown width across fruit tree species in mature stage	154
b.4	Regression analysis relationship between height and age of mango	155
b.5	Regression analysis relationship between crown depth and age of mango	155
b .6	Regression analysis relationship between crown edge and age of mango	155
b.7	Regression analysis relationship between crown width and age of mango	156
b.8	One way analysis of variance for proximal root diameter (D_{prox}), specific root length (L_{rw}) and length of the main axis (N_{max}) for 4, 8 and 10 year old mango	156
b.9	One way analysis of variance for proximal root diameter (D_{prox}) , specific root length (L_{rw}) and length of the main axis (N_{max}) for direct seedling mango, marcotting mango and pomelo, planted spacing $4*4$ m	156
b.10	One way analysis of variance for proximal root diameter (D_{prox}), specific root length (L_{rw}) and length of the main axis (N_{max}) for 10 year old of marcotting mango planted spacing 4*4 and 4*8 m	157
b.11	One way analysis of variance for proximal root diameter (D_{prox}), specific root length (L_{rw}) and length of the main axis (N_{max}) for miang which row-planted and randomly-planted	157
b.12	One way analysis of variance for total root length (L _t), total root dry weight (W _t), and shallow rootedness (SR) for 4, 8, 10 year old mango	157
b.13	One way analysis of variance for total root length (L _t), total root dry weight (W _t), and shallow rootedness (SR) for 10 year old of direct seedling mango, marcotting mango and pomelo, planted	
	spacing 4*4 m	157

b.14	One way analysis of variance for total root length (L _t), total root dry weight (W _t), and shallow rootedness (SR) for 10 year old of marcotting mango planted spacing 4*4 and 4*8 m	158
b.15	One way analysis of variance for total root length (L_t) , total root dry weight (W_t) , and shallow rootedness (SR) of miang which row-planted and randomly-planted	158
b.16	Regression analysis between root volume and tree volume across the species	158
b.17	Linear regression analysis between root volume and tree volume of mango	159
b.18	Linear regression analysis between root volume and tree volume of miang	159
b.19	One way analysis of variance of 4 directions of proximal root lesser and more than 45° across species, L _t , and W _t , i.e., Rhetsa, mango 1, mango 2, mango 3, mango 5, miang 1 and miang 2.	159
b.20	One way analysis of variance of 4 directions L_{rw} , M_{max} , D_{max} , i.e., rhetsa, mango 1, mango 2, mango 3, mango 5, miang 1 and miang 2.	159

LIST OF ILLUSTRATIONS

Figure		Page
2.1	Market prices of miang during 1985-1989	7
4.1	A cartographic model for determines the area under canopy cover of rhetsa and fruit trees	36
4.2	A cartographic model for classifying the canopy	36
4.3	A cartographic model for classifying the availability space for adding new plants	37
5.1	Percentage of <i>miang</i> and non- <i>miang</i> household at Ban Phadeng, Pa Pae sub-district, Mae Taeng district, Chiang Mai province	39
5.2	Percentage of household with land holding size at Ban Phadeng	42
5.3	The relationship between yield of <i>miang</i> and density of natural tree and <i>miang</i>	44
5.4	Sources of fuelwood for miang production at Ban Phadeng	47
5.5	Price of miang at Ban Phadeng, Pa Pae sub-district from 1983 to 1997	51
6.1	Land use changes of the farm during 1984 to 1988	54
6.2	The three main sources of income of the farm during 4 years, 1993-1996	57
6.3	Yield of mango in the study farm from interview with farmer	59
6.4	The whole farm production of rhetsa of each age	59
6.5	Relationship between yield of rhetsa and crown width	61
6.6	Net present value (NPV) and benefit-cost ratio (B.C. ratio) of the 3 patterns	67
6.7	Overview of the measurement in <i>miang</i> -based agroforestry system	68
6.8	Trees and miang allocation in mature stage, middle stage and early stage	70
6.9	Average height, crown width and basal diameter of each main species in 3 stages	74

	xxii	
6.10	Crown depth and crown height ratio of main species in different 3 patterns	75
6.11	Canopy structure of 10 years old trees of jack fruit, mango, pomelo and peach	76
6.12	Relationship between height, crown depth, crown edge height and crown width, and age of mango	79
6.13	Cumulative frequency of the α and q parameter of roots for rhetsa, mango, pomelo and <i>miang</i>	81
6.14	Total root length (L _t) per tree of species	84
6.15	Total root dry weight (Wt) per tree of each species	85
6.16	Specific root length (L _{rw}) per tree of each species	86
6.17	Shallow rootedness (SR) of each species across three stages	87
6.18	Length of main axis (N _{max}) of each species across three stages	88
6.19	Relationship between root volume and tree volume of mango and miang	89
6.20	1:1 plot between root volume and tree volume of rhetsa, mango, pomelo and <i>miang</i>	91
6.21	Canopy cover of fruit trees overlaid with rhetsa in mature stage, middle stage and early stage	95
7.1	Total root length (L_t) , total root dry weight (W_t) , length of the main axis (N_{max}) , specific root length (L_{rw}) , proximal root diameter (D_{prox}) and shallow rootedness (SR) of 4, 8 and 10 year old of mango	110
7.2	Total root length (L_t) , total root dry weight (W_t) , length of the main axis (N_{max}) , specific root length (L_{rw}) , proximal root diameter (D_{prox}) and shallow rootedness (SR) of 10 year old mango with 2 different propagated methods	111
7.3	Total root length (L_t) , total root dry weight (W_t) , length of the main axis (N_{max}) , specific root length (L_{rw}) , proximal root diameter (D_{prox}) and shallow rootedness (SR) of mange spacing	
	of 4*4 m and 4*8 m	112

xxiii

7.4	Total root length (L_t) , total root dry weight (W_t) , length of the main axis (N_{max}) , specific root length (L_{rw}) , proximal root diameter (D_{prox}) and shallow rootedness (SR) of pomelo and mango	113
7.5	Total root length (L_t) , total root dry weight (W_t) , length of the main axis (N_{max}) , specific root length (L_{rw}) , proximal root diameter (D_{prox}) and shallow rootedness (SR) of randomly-planted miang and row-planted miang	114
7.6	Effect of crown density on penetration of solar energy into conifers plantation	119
7.7	Availability space (open space) of early stage, middle stage and mature stage plots	121
7.8	The spatial arrangement of hedgerow of fruit tree in flat land and slope land	124
7.9	Model of canopy and root interaction in sloping land with terracing practice and non-terracing	126
c.1	Canopy cover of fruit trees in mature stage, middle stage and early stage	160
c.2	Canopy cover of rhetsa in mature stage, middle stage and early stage	162
c.3	Canopy cover of miang in mature stage, middle stage and early stage	164

ABBREVIATIONS AND SYMBOLS

 $\alpha = D_{\text{before}}^2 / \sum D_{\text{after}}^2$

 δ = Specific root density

 β = Angle between subsequent link

AFS = Agroforestry system

BAAC = Bank of agriculture and agricultural co-operative

B.C ratio = Benefit cost ratio

 B_t = Benefit at t-month

C = Carbon

CD = Crown depth

CEH = Crown edge height

CSA_{BD} = Basal cross sectional area

 C_t = Cost at t-month

CW = Crown width

D = Diameter of canopy gap

 D_0 = Proximal root diameter

D_{after} = Diameter of root after branching

DB = Basal diameter

 D_{before} = Diameter of root before branching

DBH = Diameter at breast height

 D_{hor} = Diameter of root which root angle < 45°

 D_{jk} = Diameter at k^{th} branch roots after j^{th} branching event

 D_m = Diameter of root tip

 D_{vert} = Diameter of root which root angle > 45°

F = Form factor

H = Height of tree

ICF = Imaginary canopy flat

ISC = Index of size clearing

 L_1 = Length of internode

 L_{rw} = Specific root length

 L_t = Total root length

N_k = Number of root branch per branch event

 N_{max} = Length of main axis

 N_p = Root isoline or altitude

NPV = Net present value

OOC = Opportunity cost of capital

PAR = Photosynthetically active radiation

 $q = \max D_{after}^2 / \sum D_{after}^2$

SR = Shallow rootedness

V = Above-ground woody volume

 W_t = Root dry weight