CHAPTER VI

RESULTS OF FIELD STUDY

6.1 General Information of the Farm

The field study was conducted in one farmer's field. The family had two traditional *miang* orchards which provides an average annual income of only 10,000 baht (AAN, 1995). Since, it was not enough, therefore, they bought another *miang* orchard of 6.4 ha in year 1984, and developed it into an integrated land use system.

6.2 Development of Integrated Land Use

The newly bought 6.4 ha-plot in 1984 was originally planted with about 1,000 *miang* scattering over the area. Land use improvement began in late 1984. Seeds of rhetsa were broadcasted and the field was burnt. The farmers observed that burning the weed residue would promote germination of rhetsa seeds. Local maize was planted to provide seasonal income. Banana was also incorporated. New *miang* plants were transplanted in rows as hedges so that to facilitate picking when matured.

Mango and other fruit trees were established in 1985 and 1986 by arranging in alternate rows with *miang*. The annual income were derived from field crops such as maize, red kidney bean and banana. From 1988 to present, the farmer had added the other fruit trees such as pomelo, peach, santol, Japanese apricot, litchi, guava and macadamia nut to the plot.

In 1990, all of the main plants and trees such as tea plant, mango and rhetsa had provided harvestable yields. The stages of change are depicted as in Figure 6.1.

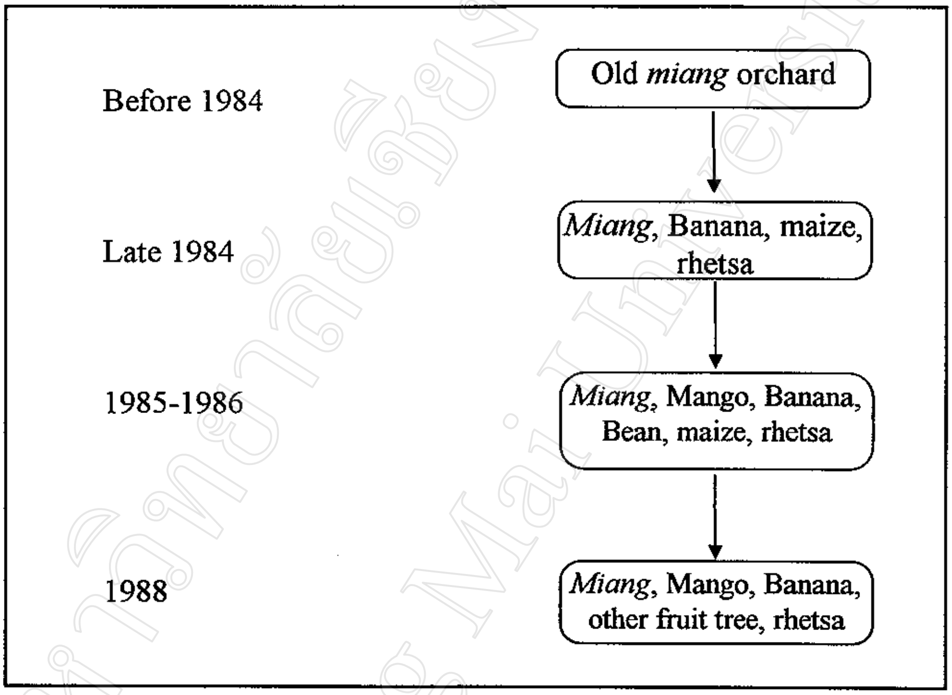


Figure 6.1 Land use changes of the farm during 1984 to 1988.

However, the change in land use happened in three distinct zones which could be identified:

(1) Rhetsa and fruit tree dominance with scattered *miang*: It was an oldest section of the field where the farmer classified it as the mature stage. The land use before 1984 was an old *miang* orchard. In 1984, rhetsa was intercropped with maize. Red kidney bean was another field crop, grown in the following year. Mango, pomelo, Japanese apricot and peach were added to the stage by planted in row with spacing of 4*4 m in the late of 1985. In 1986, new *miang* was transplanted in short row depended on the area available.

(2) Rhetsa, fruit tree, and *miang* in managed planting arrangement: In 1985, rhetsa was intercropped with maize. *Miang* was transplanted in row with spacing 4*1 m in 1986. In 1987, mango was transplanted in alternate row with *miang* with the intra-row of 8 m. Another fruit tree, litchi, was transplanted in 1994. Ginger was also planted in this plot in 1992 as cash crop. It was a middle stage.

(3) Fruit trees and *miang* dominance with juvenile rhetsa: The direction of change was opposite with the above two stages, i.e., *miang* and mango were planted in alternate row in 1986. A few rhetsa was added in 1991, but the number was increasing in 1995. It was grown in row which was different from mature stage and middle stage. It was an early stage.

6.3 Whole Farm Income

The annual gross income of the farm derived from the harvest of several commodities as listed in Table 6.1. However, income in January and February came from banana solely, which was in small proportion as compared with other months.

The annual gross income of the year 1996 had shown that rhetsa and *miang* were the leading commodities, providing equal incomes and both constituting about 86% of the total (Table 6.2). Mango provided about 2% of the total income. Since 1993, income from *miang* was stable while that of rhetsa tended to increase every year (Figure 6.2).

Table 6.1 Distribution of harvestable products throughout the year.

Month	Rhetsa	*Miang*	Mango	Pomelo	Japanese apricot	Peach	Jack fruit	Banana
January								↕
February								↕
March		↕			↕			↕
April		↕				↕		↕
May		↕	↕			↕		↕
June		↕	↕					↕
July		↕					↕	↕
August		↕						↕
September		↕		↕				↕
October	↕	↕		↕				↕
November	↕	↕						↕
December		↕						↕

Table 6.2 Gross income and proportion of the farm in 1996.

	Gross income (baht)	Percentage
Rhetsa	85,000	32.00
Miang	144,000	54.22
Green tea	23,000	8.66
Mango	5,000	1.88
Pomelo	5,000	0.38
Japanese apricot	5,000	1.88
Peach	2,000	0.75
Jack fruit	100	0.04
Banana	500	0.19
Total	265,600	100

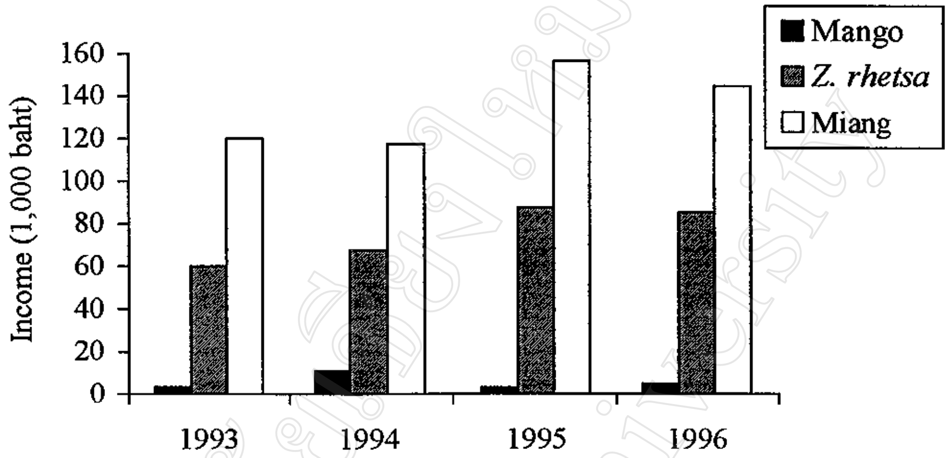


Figure 6.2 The three main sources of income of the farm during 4 years, 1993-1996.

6.3.1 *Miang* Production

The seasonal activities of *miang* production system of the farm was started in late March. *Miang* was picked three to four times a year depended upon the duration of rainfall. Preechapanya (1996) studied *miang* production in Ban Mae Ton Luang, Thep Sadet sub-district, Doi Sa Ket district, Chiang Mai, found that *miang* was picked up to four times a year. But Sangchai (1993) pointed out that there were 3 times per year for picking *miang*. In general, however, *miang* picking season could be classified as *miang huapi*, *miang klang*, *miang soi* and *miang moei.*

At the study site, *miang* was harvested four times a years (Table 6.3). *Miang huapi* constituting about 30% of the yearly production, was harvested during months of March and May. *Miang klang* was harvested from May to July and usually had good quality, producing about 30% of yearly production. *Miang soi* was harvested during the rainy season from July to September, the production was about 25%. The last type, *miang moei* was when the temperature was becoming cooler, from September to middle of December, the production was about 15%.

The price of *miang* in 1996 was 6-7 baht kam^{-1}. Nevertheless, the price of *miang* was fluctuated during the year. The price was related to the *miang* quality and future production, for instance, *miang huapi* was sold at the lowest price than others. *Miang soi* and *miang moei* were the highest price (Table a.1 in Appendix A).

Table 6.3 Distribution and seasons of *miang* production in the study site, Ban Phadeng, Pa Pae sub-district, Chiang Mai.

Type of *miang*	Picking period	Distribution (%)	Quality
Miang huapi	late March - late May	30	thick, dirty, dark green
Miang klang	late May - late July	30	thin, clean, yellow
Miang soi	late July - September	25	thin, clean, yellow
Miang moei	September- mid December	15	thin, clean, yellow

6.3.2 Mango Production

There were many varieties of mango in the study site such as *Kaeo*, *Pimsaen*, *Nang Klangwan* and *Kieo Sawui*. However, the main production came from *Kaeo* variety. The season of mango in the farm was during June and July. Mango began produce fruit in year five and fruit yield became stable after year seven (Figure 6.3). Mango in the farm showed alternate bearing, and only half of mango trees provided marketable yield each year.

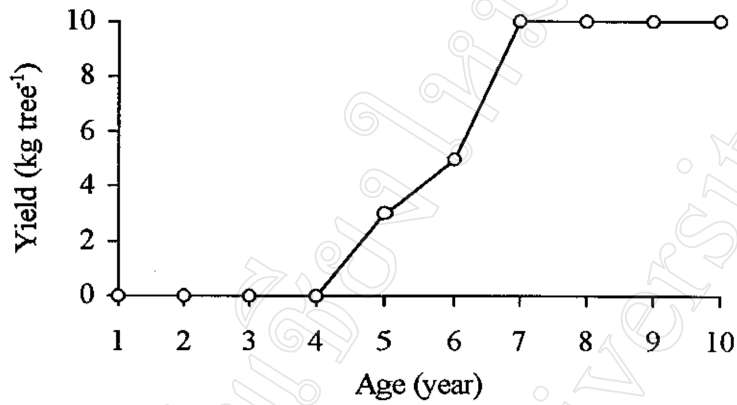


Figure 6.3 Yield of mango in the study farm, from interview with farmer.

6.3.3 Rhetsa Production

Income from rhetsa was becoming more important, in 1995 and 1996 the crop produced the income as high as 87,500 and 85,000 baht (Figure 6.2). The seasonal production of rhetsa was during late September to late October. The tree began to produce marketable seed after five years of planting and yield remain stable after year nine (Figure 6.4).

Figure 6.4 The whole farm production of rhetsa of each age.

6.4 Production and Financial Assessment of Land Use Patterns

The selected plots representing three stages of land use changes, with plot size of 3,200, 2,800 and 2,400 m^2 for mature stage, middle stage and early stage respectively. The number of each species in each plot are shown in Table 6.4.

Table 6.4 Components and plant density of each stage plot.

	Mature stage		Middle stage		Early stage	
	Number	Density (plant ha^{-1})	Number	Density (plant ha^{-1})	Number	Density (plant ha^{-1})
Rhetsa	44	137	31	111	29*	121
Miang	236	738	485	1,732	346	1,442
Mango	109	341	72	257	44	183
Pomelo	10	31	3	11	1	4
Litchi	2	6	2	7	15	63
Santol	1	3	0	0	1	4
Peach	5	16	0	0	0	0
Guava	0	0	0	0	1	4
Jack fruit	3	9	0	0	1	4

* only 2 trees could produce yield

Density of rhetsa in mature stage plot was the highest (137 trees ha^{-1}). All of rhetsa in mature stage and middle stage plots could produce the yield, but only 2 of 29 trees in early stage plot produced the yield. The density of mango was the highest in mature stage plot (341 plant ha^{-1}). *Miang* was dominated in middle stage and early stage plots and it was approximately half of them in mature stage.

Cluster yield of rhetsa was significant at 99% depended on the crown width. From the 10 sample trees, the fresh weight yield of rhetsa ranged from 8 kg tree^{-1} in smaller tree to 32 kg tree^{-1} in the bigger tree, the average yield was 21 kg tree^{-1}. The dry weight of rhetsa was 34% of fresh weight.

Cluster yield of rhetsa did not correlate with tree height, stem basal diameter, and crown depth. However, the yield could be estimated from the crown width. This was fitted to various models such as linear, logarithm and power relationship, but the best fit was logarithm relationship (Figure 6.5), the model is shown as follows:

$$\text{Yield} = 22.01 * \text{Ln (crown width)} - 120.92$$

$t = 6.23$

$R^2 = 0.83$ $n = 10$

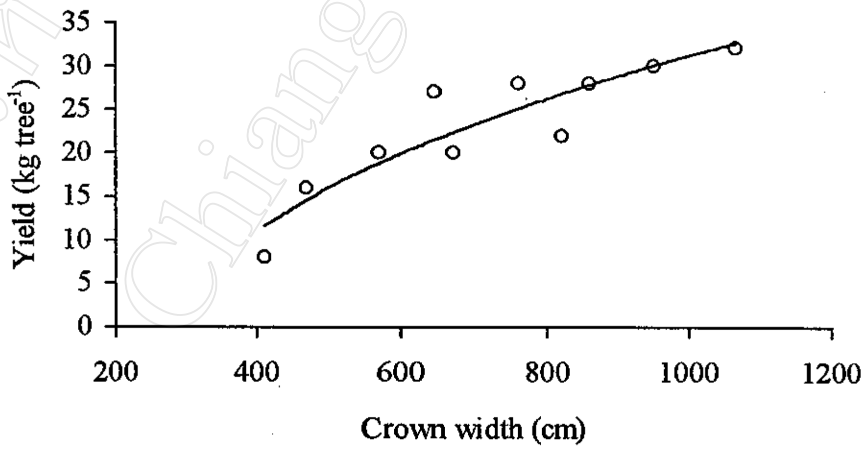


Figure 6.5 Relationship between yield of rhetsa and crown width

From farmer interview, the yield of *miang* depended on the size of the plant, viz., smaller size resulting from row-planted had lower yield than the randomly-and-wide-planted. The yield of randomly-and-wide-planted from old orchard could reach 2-3 *kams* in one picking time, while 3 *kams* were obtained from 2 plants in row-planted. Moreover, some *miang* which were randomly-and-wide-planted and unprunned could produced the yield as high as 2 kg in one picking time.

The number of *miang* in mature stage plot was 84 plants with randomly-and-wide-planted from the old orchard. The rest, 151 plants, were planted in row. There were only 12 plants of *miang* in middle stage from with spaced planting and 473 plants were planted in row. In early stage, there were 338 plants planted in row and 8 plants planted scatteringly from the old orchard.

Miang harvesting was done in rotation. During the rainy season, the rotation would take about one month to harvest the same plant. But the lag period would be longer during the late rainy season and *miang* yield was also lower. On average, one plant of *miang* could be harvested 5-6 times in one year.

Mango in the farm was alternately beared fruit. The farmer stated that only half number of mango could bear fruits. The average yield in 1996 of mango aged 8-10 year old was 5 kg per tree.

Peach was only planted in the mature stage plot. The yield was 5 kg per tree. The yield of pomelo was 3 fruits per tree. The other fruit trees such as santol, guava and jack fruit gave small yield in 1996. Litchi was in juvenile stage.

6.4.1 Income

The main sources of income of the farm came from *miang*, rhetsa and mango. Nevertheless, the population of each plant in each plot was different such as the yielding of rhetsa was dominated in the mature stage and the middle stage plots, but rhetsa in the early stage trees were too young to produce seed. Rhetsa was sold as dry product, however, the price of the dry product depended on the price of the fresh one. For instance, the price of fresh material in the early season was 50 baht kg^{-1} and the price of the dry one was 160 baht kg^{-1}. In the late season, the price of the fresh product was 60 baht kg^{-1}, that increased the price of dry one as much as 185 baht kg^{-1}.

Miang was dominated in the middle stage and the early stage plots. The amount of production, prices and seasons of each species of each stage are shown in Table a.1 in Appendix A. The selling price of *miang huapi* was 6 baht kam^{-1}, the lowest as compared to the other kinds of *miang*. Since the quality of *miang huapi* was considered to be lower by consumers. *Miang klang* considered to be high quality, could get the price of 6.5 baht kam^{-1}. The selling price of *miang soi* and *miang moei* were the highest, 7 baht kam^{-1}, because of the quality and the two last seasons.

Income estimation from each stage revealed that the mature stage was the highest hectarage return followed by the middle stage and the early stage plots (Table 6.5). The return in one hectare of the mature stage, the middle stage and the early stage plots were 167,338, 157,466 and 31,579 baht ha^{-1}, respectively. The present value of return was the highest in mature stage (Table a.2 in Appendix A). However, it was about 8,717 baht ha^{-1} higher than middle stage plot. The present return of early stage was the lowest. The present value of return of mature stage, middle stage and early stage were 152,048, 143,331 and 29,179 baht ha^{-1}, respectively.

Table 6.5 Income of each commodity of mature stage, middle stage and early stage plots

	Income (baht ha^{-1})		
	Mature stage	Middle stage	Early stage
Rhetsa	141,865.60	122,680.00	4,947.20
Miang huapi	4,471.88	7,987.55	6,634.49
Miang klang	4,844.53	8,653.17	7,187.36
Miang soi	4,347.66	7,765.67	6,450.19
Miang moei	2,608.59	4,659.40	3,870.12
Mango	5,740.00	5,060.00	2,250.00
Pomelo	1,860.00	660.00	240.00
Peach	1,600.00	0	0
Total	167,338.26	157,465.75	31,579.35

6.4.2 Cost

There were 2 times of weeding in a year, i.e., in March and in August. The cost for the whole farm of the first weeding and the second weeding were 3,000 baht and 7,800 baht, respectively.

Miang required intensive labour for picking. The hired labour and the owner operator worked on shared crop basis. For instance in 1996, *miang* price was 6-7 baht kam^{-1}, and the wage for picking *miang* was 3-3.50 baht kam^{-1}. However, the wage of *miang moei* sometimes was as high as 5 baht kam^{-1}. The material cost was for bamboo lath which tied the *miang* leaves into handful (*kam*). Bamboo lath cost was 600 baht for 10,000 pieces.

The cost also came from processing of *miang*. *Miang* processing begins with steaming, pressing and packaging. One hundred and twenty *kam*s of *miang* were placed in wooden barrel for one lot of steaming. The fuelwood used for steaming one wooden barrel of *miang* by 1 hour cost 5 baht.

Before packaging, the basket was lined with banana leaves and plastic bag inside and *miang* was pressed. Thus, the material costs here were bamboo basket and banana leaves. The bamboo basket priced at 45 baht with the capacity of 200 *kam*s of *miang*. The total banana leaf used in one year of the farm was 3,500 baht.

However, the farmer concluded that the cost for materials and fuelwood per one basket of *miang* (200 *kam*s) was 110 baht. Consequently, the total cost excluded the family labour of *miang* was 3.55-4.05 baht kam^{-1} (if the wage were 3-3.5 baht).

Rhetsa has no other input besides harvesting and drying. There was no hired labour for harvesting, only the farmer and his family. The labour wage for agricultural sector in Chiang Mai province was 138 baht day^{-1} (Min. Labour and Social Welfare, 1996). Within one day, they could harvest 5 trees. The farmer used hot air room to dry the seeds of rhetsa before marketing. The capacity of drying room was approximately 600 kg and required three days to dry it. Three pick-up trucks of fuelwood (900 baht) was enough for drying 6,000 kg of seed clusters.

To harvest mango fruit, the farmer used the family labour as well. One person could harvest 16 trees of mango as similar as harvesting peach. Another cost of fruit tree was animal manure. The farmer would applied animal manure to mango, pomelo, peach and litchi at average 1 bag to 3 trees of fruit tree after harvesting. The price of manure was 5 baht per bag. The whole farm cost of manure was 2,500 baht.

Table 6.6 Cost and time of each task

	Mature stage		Middle stage		Early stage	
	Cost (baht ha^{-1})	Month	Cost (baht ha^{-1})	Month	Cost (baht ha^{-1})	Month
Weeding 1	500.00	March	500.00	March	500.00	March
Weeding 2	1,300.00	August	1,300.00	August	1,300.00	August
Picking *miang huapi*	2,235.93	May	3,993.78	May	3,317.25	May
Picking *miang klang*	2,422.26	July	4,326.60	July	3,593.69	July
Picking *miang soi*	2,173.82	September	3,882.83	September	3,225.11	September
Picking *miang moei*	1,304.31	November	2,329.71	November	1,935.05	November
Steaming and packaging *miang huapi*	409.92	May	732.19	May	608.16	May
Steaming and packaging *miang klang*	409.92	July	610.16	July	608.16	July
Steaming and packaging *miang soi*	341.60	September	366.16	September	506.80	September
Steaming and packaging *miang moei*	204.96	November	3063.60	November	304.08	November
Harvesting rhetsa	3,781.20	November	3,063.60	November	230.00	November
Fuelwood for dry rhetsa	391.17	July	338.27	July	13.64	July
Harvesting mango, peach and pomelo	1,273.67	July	1,085.60	July	485.16	July
Manure for fruit trees	678.05	August	460.92	August	437.54	August
Total	17,426.81		23,721.94		17,064.64	

The *miang* production showed the highest cost (Table 6.6). Only picking leaf of it would cost 54%, 72% and 83% of the total cost in mature stage, middle stage and early stage plots, respectively. Moreover, additional cost came from material inputs such as fuelwood for steaming and materials for packaging. Rhetsa production required lesser cost than *miang*, there were cost incurred for harvesting and drying. Therefore, all plots had similar cost.

6.4.3 Net Present Value and Benefit-Cost Ratio

Net present value (NPV) of mature stage was 135,982 baht ha^{-1} which claimed to be the highest followed by middle stage and early stage. The NPV of middle stage and early stage were 121,406 and 13,344 baht ha^{-1} respectively. All stages showed benefit-cost ratio (B.C. ratio) more than 1, with mature stage having the highest B.C. ratio of 9.46 followed by middle stage of 6.54 and early stage of 1.82 (Figure 6.6).

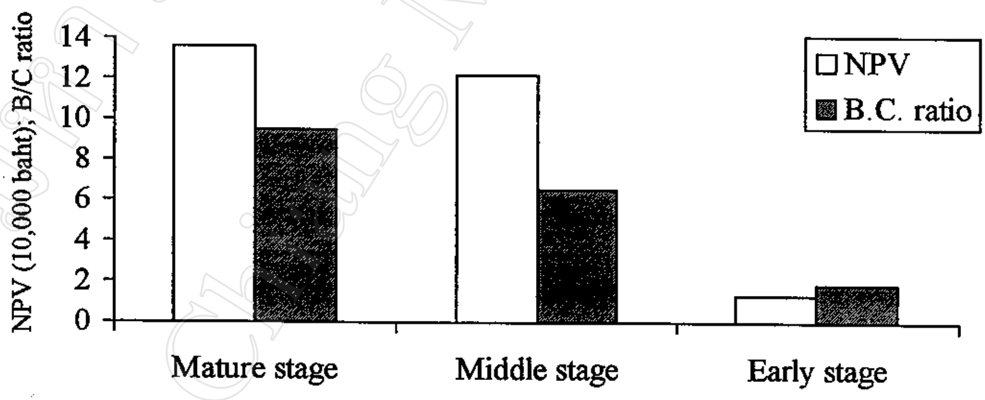


Figure 6.6 Net present value (NPV) and benefit-cost ratio (B.C. ratio) of the 3 stages.

6.5 Overview of Field Measurement

The framework for measuring tree-crop interaction on-farm is given in Figure 6.7.

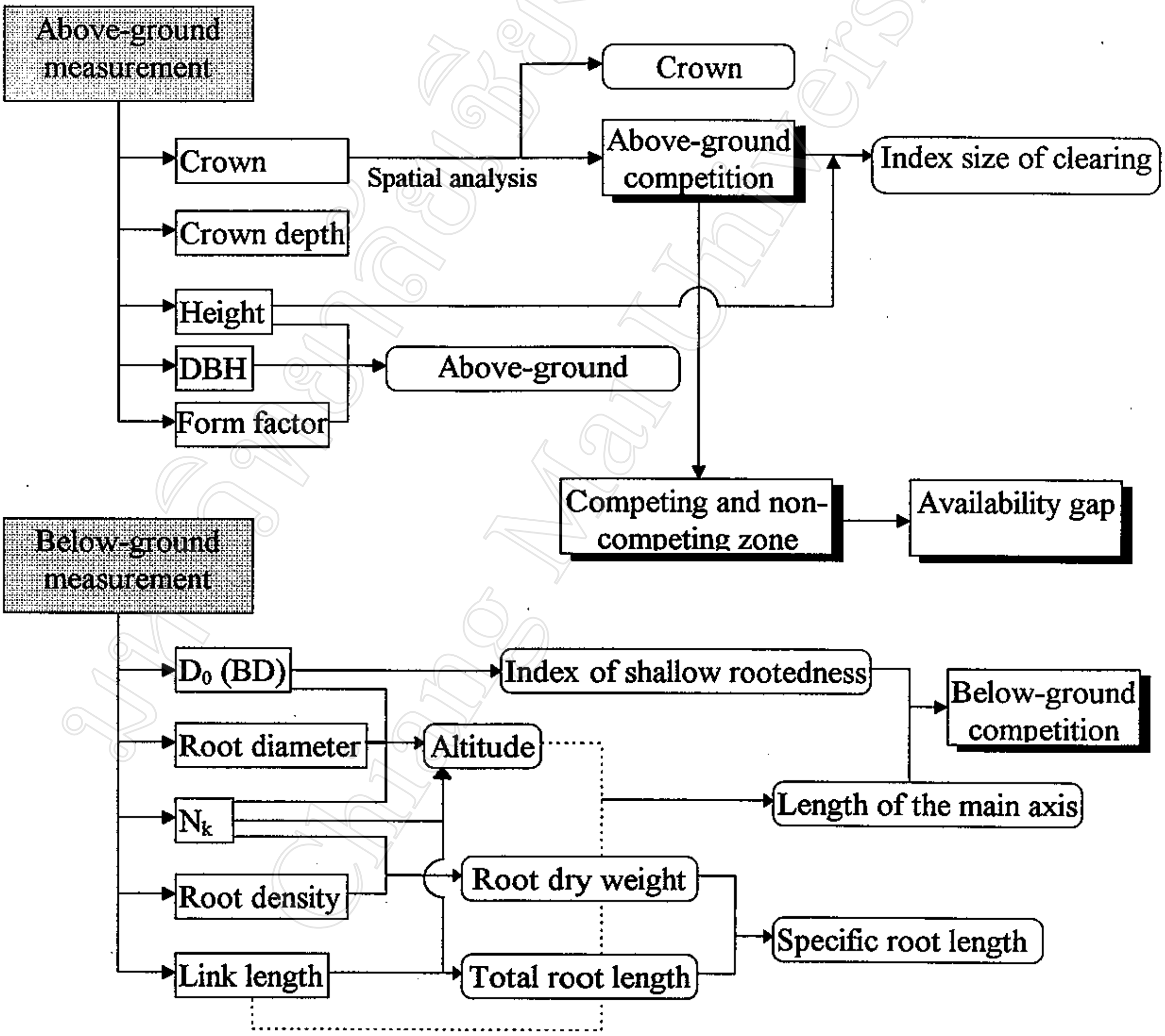


Figure 6.7 Overview of the measurement in *miang*-based agroforestry system

6.6 Above-ground Measurement

6.6.1 Trees and *Miang* Arrangement

The mature stage plot had only four trees of forest tree, i.e., three of *Dipterocarpus alatus* and one of bamboo. *Miang* was grown in two arrangements. i.e., scatteringly and in row. The scattered one was the old age *miang* which from the old orchard before the farmer bought the farm. The new planted *miang* was adjusted in row spacing which could ease weeding, pruning, harvesting and tree intercropping. The spacing of the new established *miang* was 1.0-1.2 m apart with the row distance of 4 m. *Miang* was grown in alternate row with mango. Mango spacing was 4*4 m with two propagated methods as direct seedling and marcotting. The direct seedling had the bigger either tree trunk or canopy than the marcotting. The other fruit trees such as peach, santol, jack fruit and litchi were planted in less orderly arrangement. Rhetsa was also planted in the same way as fruit trees, but it was planted before mango. The species allocation of three stages are as shown in Figure 6.8.

There were no forest tree in the middle stage plot. The tree species was less diverse. Mango was grown in spacing 8*4 m in alternate row with *miang*. The other fruit trees such as pomelo and macadamia nut were only the replacing fruit trees. Rhetsa was scattered throughout the plot.

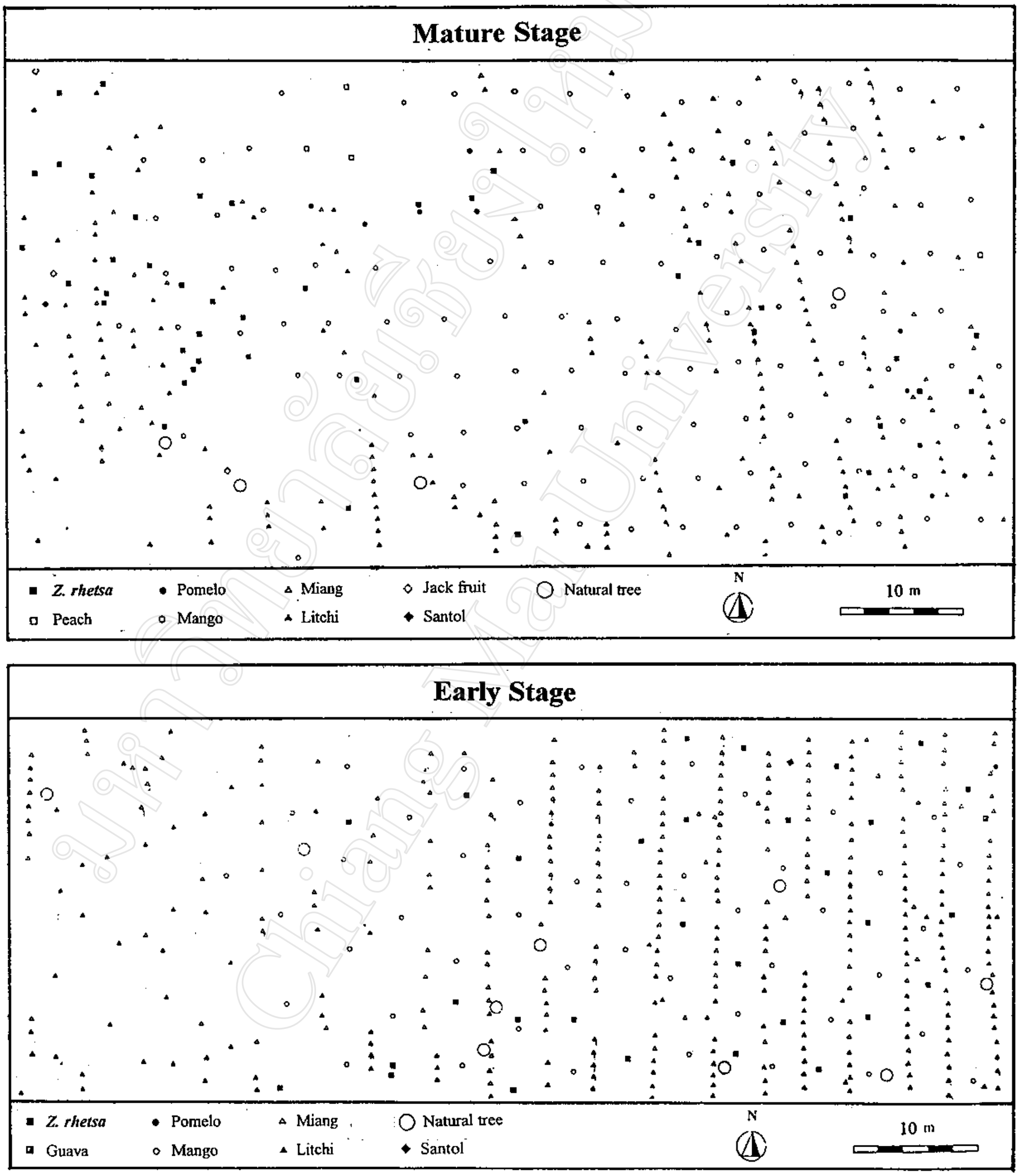


Figure 6.8 Trees and *miang* allocation in mature stage, middle stage and early stage.

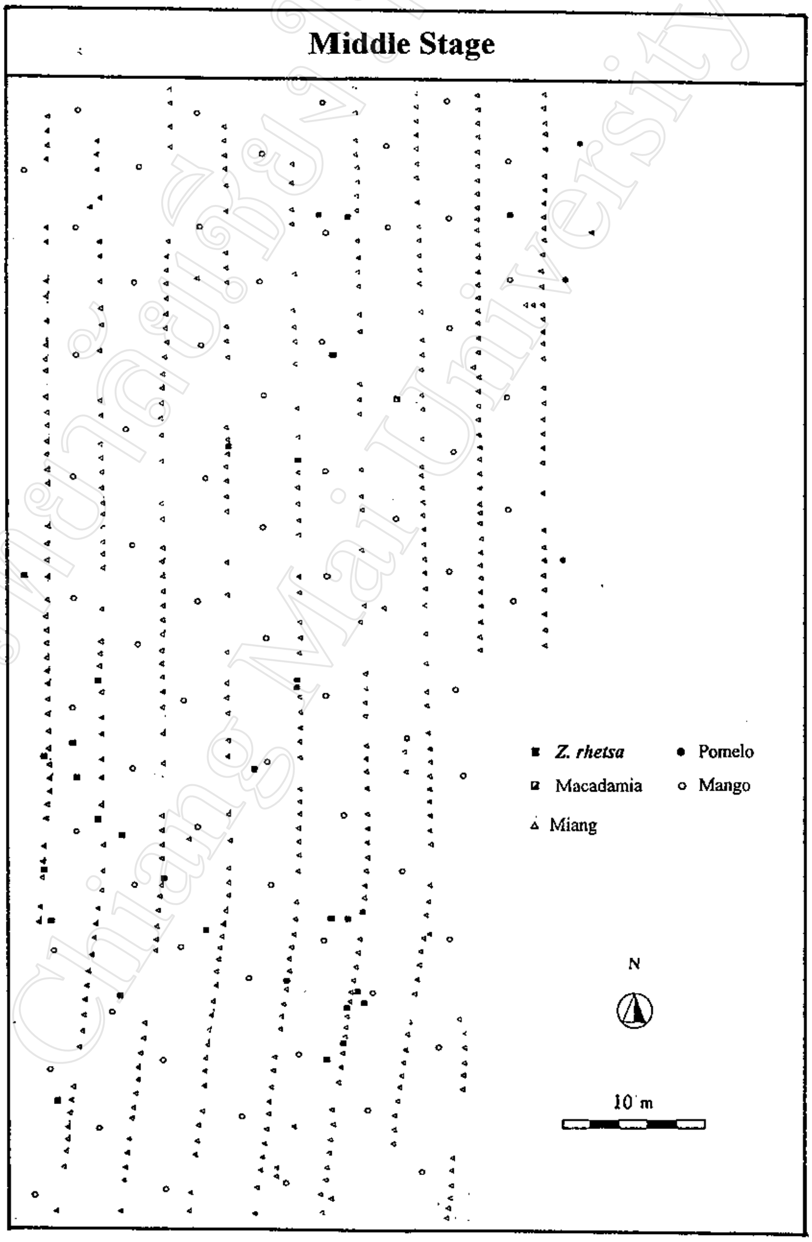


Figure 6.8 (continued)

The early stage plot had nine natural trees such as *Dipterocarpus alatus*, *Schima wallichii* and *Gemelia arborea*. Only 3% of *miang* were grown at scattering, the rest was grown in row with the same spacing as mature stage. Mango was planted in alternate row with *miang* and also with rhetsa. Therefore, mango and rhetsa were arranged in the same row with 4 m apart. However, majority of rhetsa were immature, only 2 trees producing seed.

6.6.2 Above-ground Biomass

Table 6.7 Total volume of each species in 3 different stage plots.

Species	Mature stage		Middle stage		Early stage	
	Volume (m^3 ha^{-1})	%	Volume (m^3 ha^{-1})	%	Volume (m^3 ha^{-1})	%
Rhetsa	11.23	27.01	22.20	64.59	0.54	7.99
Mango	27.64	66.49	9.79	28.49	4.80	71.01
Pomelo	0.52	1.25	0.21	0.61	0.16	2.37
Peach	0.16	0.38	-	-	-	-
Jack fruit	0.76	1.83	-	-	-	-
Litchi	0.01	0.03	-	-	0.08	1.18
Guava	-	-	-	-	0.03	0.44
Santol	-	-	-	-	0.05	0.74
Miang	1.25	3.01	2.17	6.31	1.10	16.27
Total	41.57	100	34.37	100	6.76	100

Table 6.7 shows that, mature stage had similar species to early stage and both has more species diversified than middle stage, but the numbers of species in mature stage were more than early stage. The total above-ground biomass of mature stage in term of plant volume was 42 m^3 ha^{-1}. It was more than middle stage and early stage, which were only 34 and 7 m^3 ha^{-1}, respectively. Mango produced large proportion of biomass, particularly in the mature stage and the

early stage ranging 66-71%. The volume of *miang* was 1.10 m^3 ha^{-1} in early stage, smaller than the other two stages.

The average height of rhetsa in mature stage was similar to that in middle stage and higher than early stage as well as crown width and basal diameter. Figure 6.8 showed the average height of rhetsa, there were 991 cm in mature stage and middle stage, and 151 cm in early stage. The crown width of rhetsa in middle stage was the widest followed by mature stage of 877, 728 cm and only 87 cm in early stage. The height of mango in early stage was 292 cm with the crown width of 270 cm.

Jack fruit had the deepest crown set in mature stage (Figure 6.9). It was 533 cm, meanwhile it's canopy height was only 177 cm. Crown depth of rhetsa was similar to pomelo, mango and peach, i.e., 322, 323, 233 and 228 respectively. Rhetsa was the highest which was the top storey and fruit trees as the middle storey. However, the heights of fruit trees with the exception of jack fruit did not reach the lowest crown edge of rhetsa. *Miang* in mature stage was 161 cm high which was almost contact with the lowest crown edge of mango. The average crown edge height of mango in mature stage was 201 cm.

Since, the middle stage did not have jack fruit, consequently, fruit trees were not interfered by the crown of rhetsa. *Miang* in this stage was 144 cm high which did not reach the lowest crown edge of mango, which was 185 cm.

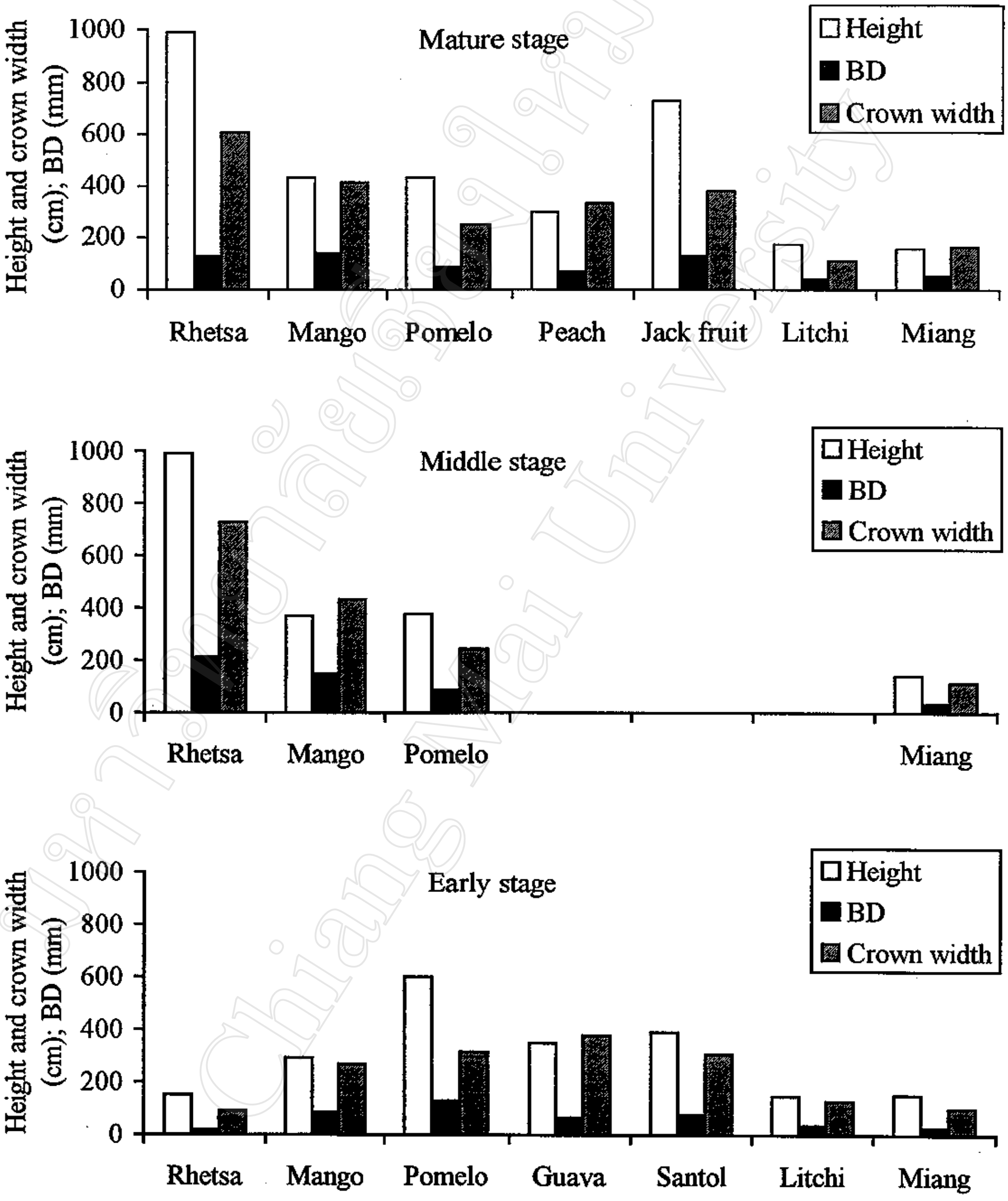


Figure 6.9 Average height, crown width and basal diameter of each main species in 3 stages.

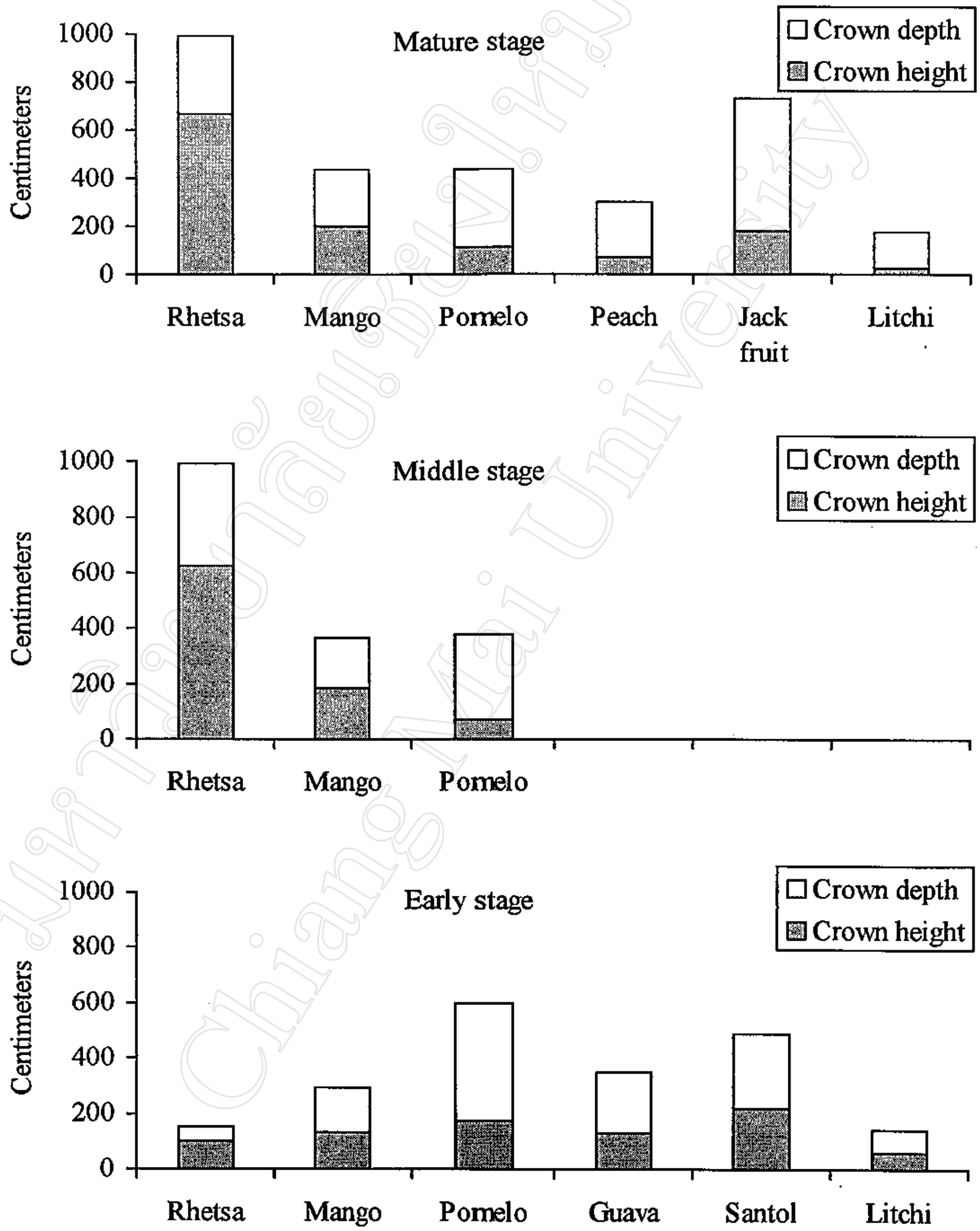


Figure 6.10 Crown depth and crown height ratio of main species in different 3 stages.

Unlike the two previous stages, rhetsa in early stage was the lowest storey by average. Since there were 2 trees which were higher than the fruit trees, 7 trees had similar height as fruit trees and the rest was the new establishment. The crown edge height of mango was very low, only 133 cm which was lower than the height of *miang*. *Miang* height in early stage was 152 cm.

6.6.3 Fruit Tree Characteristics

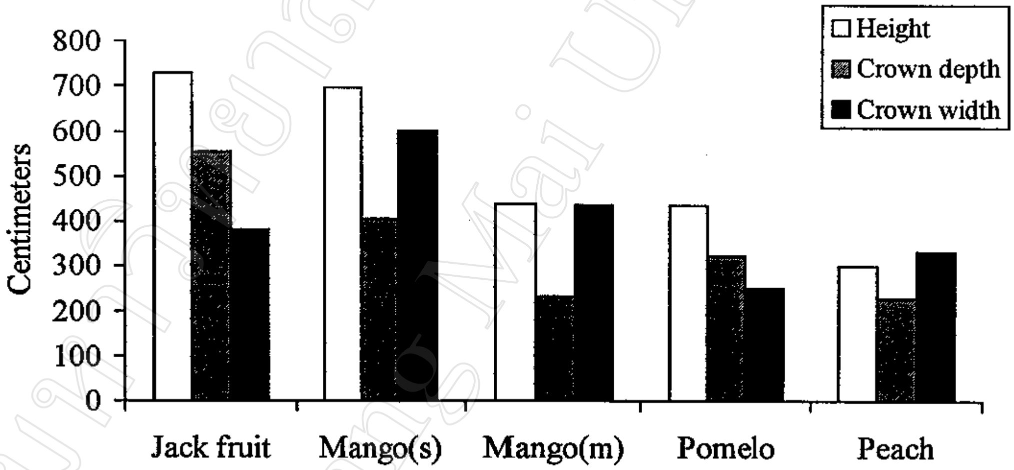


Figure 6.11 Canopy structure of 10 years old trees of jack fruit, mango, pomelo and peach.

There were 2 main fruit trees in the three stages, viz., mango and pomelo. The other two minor fruit trees were peach and jack fruit. The mature stage had all of these fruit trees which they were integrated with spacing 4 m apart. The age of them was 10 years at the year of measurement. At the same age, jack fruit was the tallest tree, peach was the shortest tree, and pomelo had the similar height with marcotting mango, i.e., 434 and 438 cm respectively as well as seedling mango had similar height with jack fruit, i.e., 696 and 730 cm respectively. The height of peach was lower than the other significantly by one way analysis of variance (Table b.3 in Appendix B). There were significantly different in crown depth and crown width among fruit tree species (Figure 6.11).

Not only the tree species but also the method of propagation affected the canopy characteristics, i.e., mango grown by seedling [mango (s)] was taller, and had deeper and wider crown than the marcotting [mango (m)]. Nevertheless, mango from seedling had wider crown width than other fruit trees, i.e., 602 cm significantly. Mango from marcotting, jack fruit and peach had similar crown width. Pomelo had the smallest crown width. Meanwhile the crown width of jack fruit, pomelo and peach were 380, 251 and 331 cm individually. Jack fruit had the deepest crown depth followed by mango from seedling, pomelo, mango from marcotting and peach, i.e., 553, 406, 323, 230 and 228 cm respectively. The crown edge height of peach was the lowest (69 cm) which was significantly different from pomelo, jack fruit, and marcotting mango. The crown edge height of mango from seedling was significantly taller than the others.

6.6.4 Relationship Between Age of Mango and Canopy Structure

There were two intra-row spacing of only one inter-row spacing (4 m) of mango in the farm, i.e., 8 and 4 m. Since there were three different stages of farm development, thus, the mango age in the farm was different, i.e., 2, 4, 8 and 10 years. The youngest mango trees was the re-transplanting. The regression analysis of the same spacing of 8*4 m of mango showed the highly significant relationship between age and height. The projection of age and crown width was as follow:

$$\text{Height} = 85.03*(\text{age})^{0.67}$$
$$t = 19.91$$
$$R^2 = 0.78 \qquad n = 113$$

The average height of mango aged 2, 4, 8, 10 years were 120, 256, 399 and 375 cm respectively. The deviations of height of each age are shown in Figure 6.12a.

The crown depth was another factor which used to evaluate the tree species along with tree's height. The regression analysis between age and crown depth was highly significant (Figure 6.12b). The relationship was explained by,

$$\text{Crown depth} = 30.93*(\text{age})^{0.82}$$
$$t = 13.22$$
$$R^2 = 0.61 \qquad n = 113$$

The regression analysis between age and crown edge height was the highly significant (Figure 6.12c). The relationship was explained by,

$$\text{Crown edge height} = 48.87*(\text{age})^{0.58}$$
$$t = 15.71$$
$$R^2 = 0.69 \qquad n = 113$$

The crown width plays an important role in light penetration to the ground. The average crown width of mango's age 2, 4, 8 and 10 years were 94, 248, 365 and 439 cm respectively. The regression analysis between age and crown width was shown to be highly significant. The relationship was explained by,

$$\text{Crown width} = 54.71*(\text{age})^{0.91}$$

$$t = 25.19$$

$$R^2 = 0.78 \qquad n = 113$$

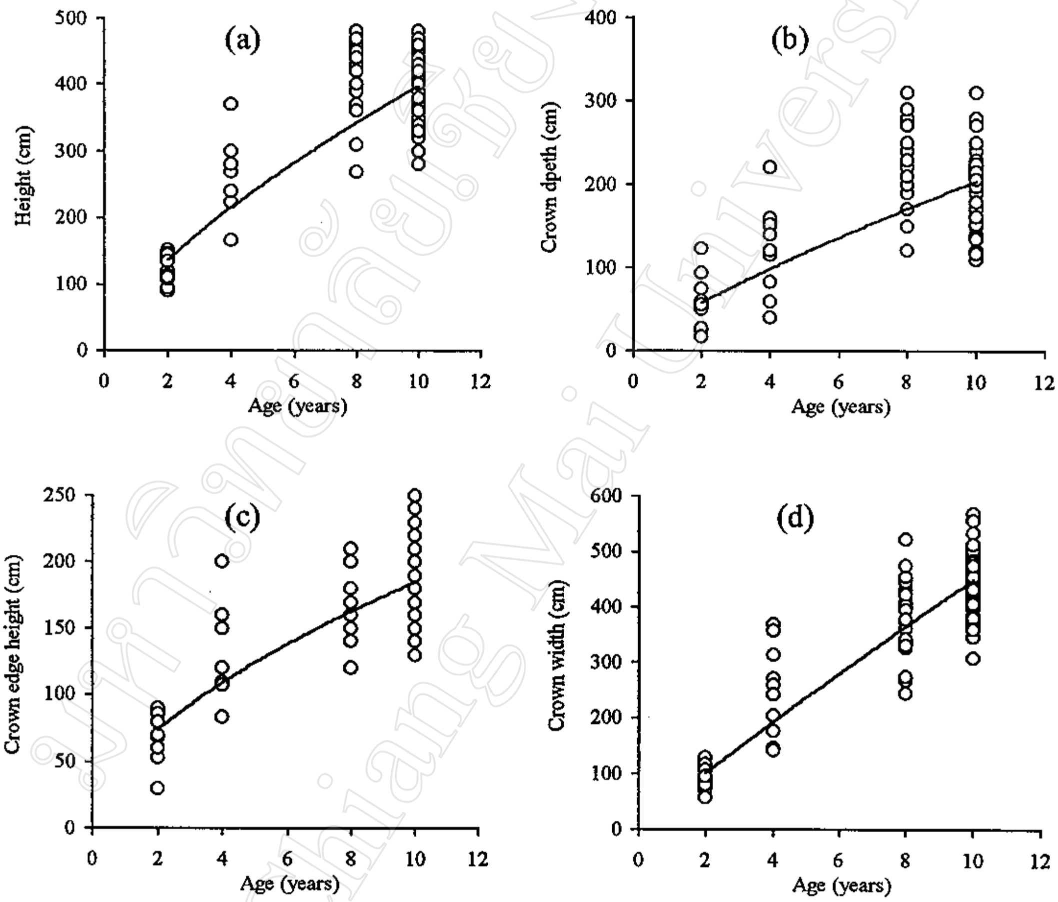


Figure 6.12 Relationship between height, crown depth, crown edge height and crown width, and age of mango.

Figure 6.12d showed the crown of mango trees with 4 m planting distance would reach each other at year nine. The projection of crown width of 9 year old mango was 404 m.

6.7 Root Measurement

6.7.1 Fractal Model Testing

To test the independent rules root diameter, parts of root system were exposed by tracing root from stem base. For each branching point where both precious and subsequent links had exposed, diameter before and after the branching point and link length were recorded and α and q parameters calculated. The fractal model were tested in main species in the farm such as rhetsa, mango, pomelo and *miang*.

Table 6.8 Linear regression analysis between root diameter before branching and α, q and L_l of rhetsa, mango, pomelo and *miang*.

	Parameter	n	T ratio	R^2	Probability
Rhetsa	α	14	-0.17	0	0.86 ns
	q	14	-1.22	0.10	0.24 ns
	L_l	14	0.11	0	0.92 ns
Mango	α	85	0.42	0	0.67 ns
	q	85	-0.56	0	0.57 ns
	L_l	85	0.23	0	0.82 ns
Pomelo	α	14	0.29	0.01	0.78 ns
	q	14	-1.97	0.23	0.07 ns
	L_l	14	0.61	0.03	0.56 ns
Miang	α	24	-0.69	0.19	0.50 ns
	q	24	-0.79	0.03	0.44 ns
	L_l	24	0.26	0	0.80 ns

None of the species tested showed a significant linear regression and non-linear regression of α or q or link length on diameter before branching for roots. The results of linear regression analysis are shown in Table 6.8. Figure 6.13 showed that the α of rhetsa mostly in 0.42-1.86 range, while the average was 1.08 with standard deviation of 0.42. The average α of mango, pomelo, and *miang* were 1.24, 1.35 and 1.15 with the standard deviation of 0.22, 0.39 and 0.23 respectively.

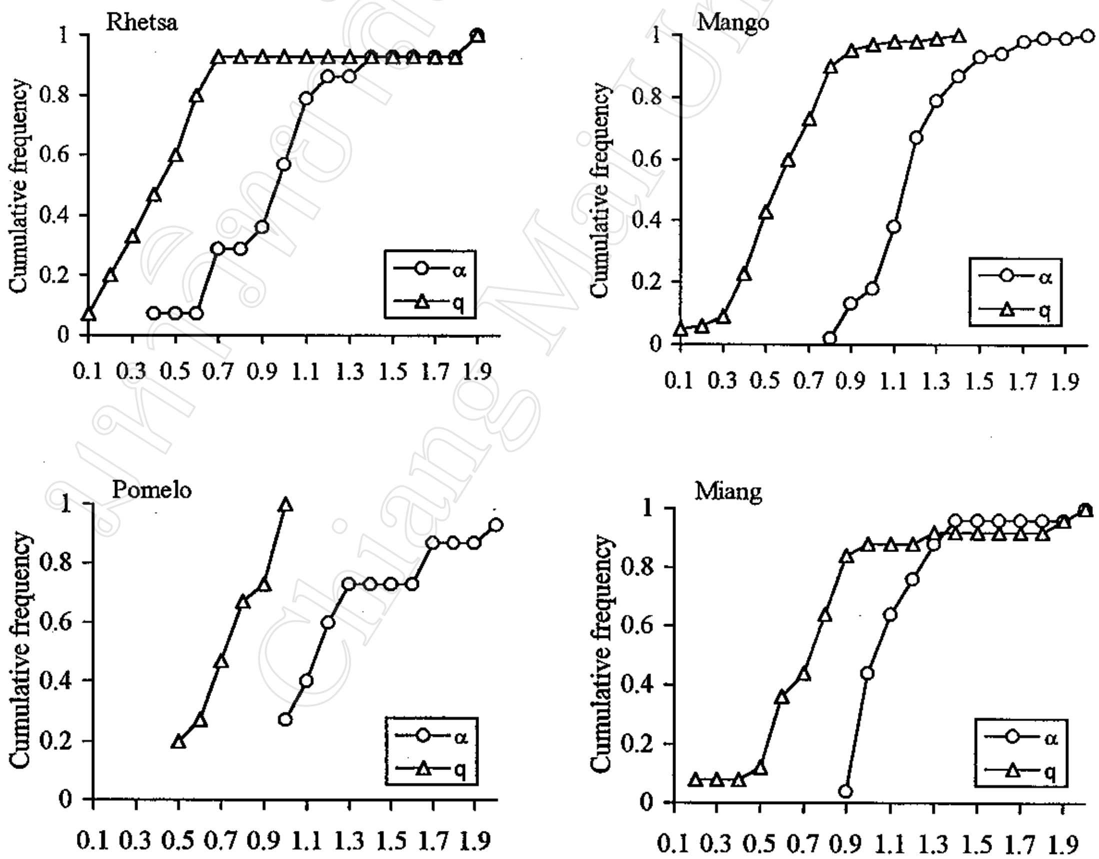


Figure 6.13 Cumulative frequency of the α and q parameter of roots for rhetsa, mango, pomelo and *miang*.

The allocation parameter q of rhetsa had mean of 0.81 with a standard deviation of 0.34, with an even spread over 0.43-1.86. There were 0.71, 0.77 and 0.82 in mango, pomelo and rhetsa with the standard deviation of 0.24, 0.18 and 0.41 respectively (Figure 6.13).

The length of internode (L_l) one was longer in rhetsa than other species. There were 31, 16, 13 and 15 cm in rhetsa, mango, pomelo and *miang* as individual. However, the variation was high especially in rhetsa (Table a.7 in Appendix A). It was as high as 69%. The coefficient of variation of mango, pomelo and *miang* were 38%, 19% and 33% respectively.

The β was similar in all species, i.e., 63° in rhetsa and *miang*, 60° in mango and 64° in pomelo. The values of all species exhibited low coefficient of variation of 14-22%.

6.7.2 Specific Root Density (δ)

The specific root density of mango, pomelo and *miang* were similar, ranging 0.43-0.44. The root of rhetsa was heavier than those species. The specific root density of it was 0.53 (Table a.8 in Appendix A).

6.7.3 Proximal Root Diameter (D_{prox})

The proximal root diameter was highly significant depended on the species. The proximal root diameter of rhetsa was the biggest, 8.94 cm with standard deviation of 3.78 cm. The proximal root diameter of mangoes ranged from 2.64 to 5.23 cm, which significantly depended on the propagated method and age, i.e., seedling mango had bigger proximal root diameter than marcotting mango and 10 year old mango had bigger proximal root diameter than 4 year old mango.

The different spacing did not affect the proximal root diameter. The proximal root diameter of pomelo was similar to marcotting mango under the same environment (age, propagated method and spacing). The radomly-and-wide-planted *miang* had significantly bigger proximal root than row-planted *miang* which both of them differed from mango's group. However, there were high variation of proximal root diameter with the coefficient of variation as high as 18-44%.

6.7.4 Number of Branching Point Per Branch Event (N_k)

The number of branching point per branch event ranged from 2-3 in all species. The average were around 2-2.07 with the very small coefficient of variation of 0-22%.

6.7.5 Root Isoline or Altitude (N_p)

Rhetsa had more root altitude than the other species. The altitudes of almost species ranged from 5 to 7 with the coefficient of variation of 15-35%, excepted rhetsa was 10 with the coefficient of variation of 11%.

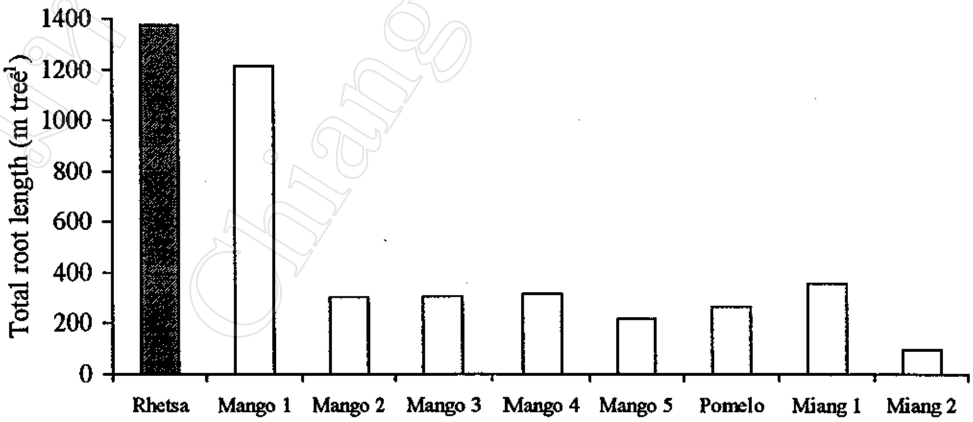
6.7.6 Total Root length (L_t)

Figure 6.13 shows the total root length per tree by proximal root geometry and fractal model method. Rhetsa had the longest, 13,736 m with the coefficient of variation of 91% which was significantly differed from the others.

The total root length was similar among various ages of mango as well as between two spacing. For instance, in mango 3, mango 4, and mango 5 which aged 10, 8 and 4 years grown in spacing 8*4 m, had total root length of 305, 316 and 219 m were the non significant difference.

Mango 2 which was 10 year old with spacing 4*4 m had the total root length of 304 m which was not different from mango 3 (305 m) which had the same age but planted in 4*8 m spacing.

There were highly significant different between the seedling mango and marcotting mango although they were the same age and planted at the same spacing (mango 1 and mango 2). The total root length of seedling mango was 1,214 m which was higher than marcotting mango and the critical value for comparison was 377 m.



Remark: the length is 10 meter in rhetsa, others are in meter

Figure 6.14 Total root length (L_t) per tree of each species.

Pomelo's total root length was 266 m with the coefficient of variation of 35.26%. However, with the same condition (marcotting, same age and spacing 4*4), total root length of mango and pomelo was not different.

The total root length of *miangs* were 356 and 96 m in randomly-and wide-planted (*miang* 1) and the row-planted *miang* (*miang* 2). The definition of each mango and *miang* such as mango 1, mango 2, mango 3, mango 4, mango 5, *miang* 1 and *miang* 2 are explained in Table 6.9.

6.7.7 Total Root Dry Weight (W_t)

Total root dry weight was highest in rhetsa which was 82 kg meanwhile the lowest was found in row-planted *miang* at about 1 kg.

In mango, the direct seedling mango (29 kg) had significantly higher total root dry weight than marcotting (6 kg) with the same age and spacing (Figure 6.15). The 10 year old pomelo had total root dry weight of 6 kg which was not significantly different form 10 years old mango.

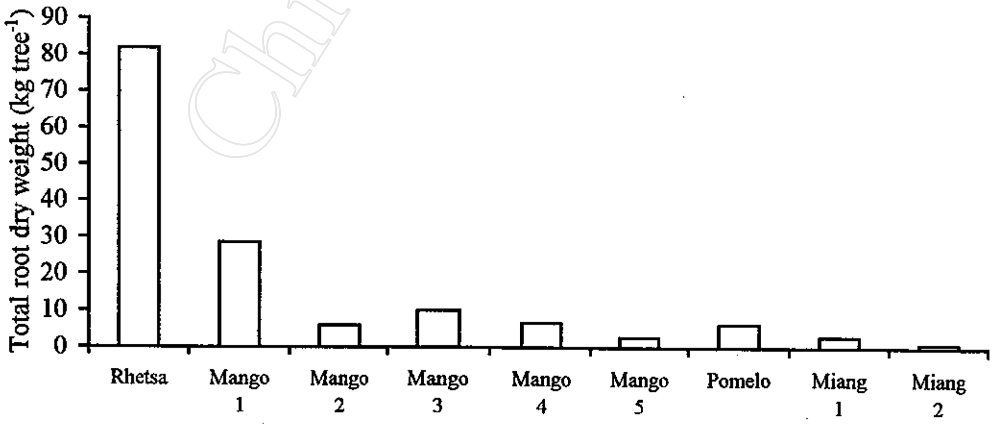


Figure 6.15 Total root dry weight (W_t) per tree of each species

Within the same spacing of mango, it was found that mango of 4, 8 and 10 years old had different root dry weight. The total root dry weight of mango aged 10, 8 and 4 year old were 10, 7 and 3 kg, respectively.

Mango, which had the same age and same propagating method (marcotting) but with different spacing, showed difference in total root dry weight. The wider spacing (4*8 m) had the higher total root dry weight than the narrower spacing (4*4 m).

The total root dry weight of *miang*s were 3 and 1 kg of *miang* from the old orchard which randomly-and-wide-planted and row-planted, respectively. They were significantly different.

6.7.8 Specific Root Length (L_{rw})

Among the species cultivated by the farmer, rhetsa had the highest specific root length (14.97 cm g^{-1}), followed by *miang* (11.12 to 12.11 cm g^{-1}) (Figure 6.16).

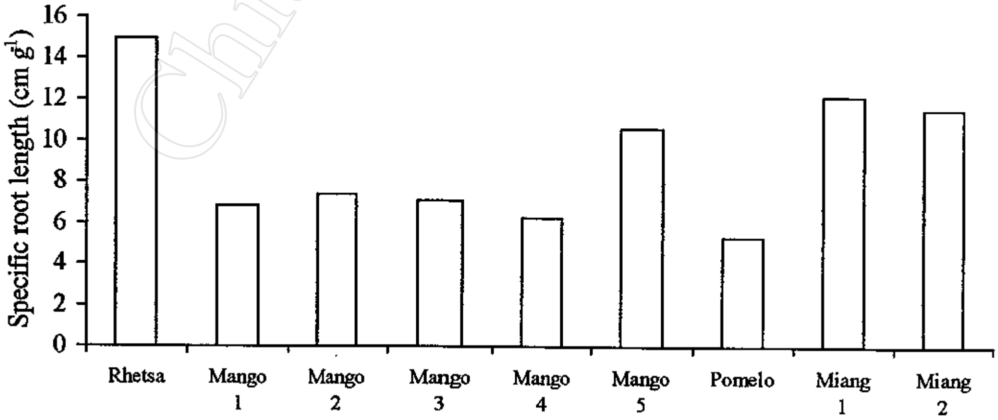


Figure 6.16 Specific root length (L_{rw}) of each species

The mango which aged between 8 to 10 years old had the specific root length ranged from 6.25 to 7.37 cm g^{-1}. However, the 4 years old marcotting mango had the highest specific root length of 10.56 cm g^{-1} which was significantly different from the others.

Pomelo had the specific root length of 5.60 cm g^{-1}.

6.7.9 Shallow rootedness (SR)

The SR of rhetsa was 0.44 which indicated that approximately 56% of proximal root was more than 45° from the horizontal plane.

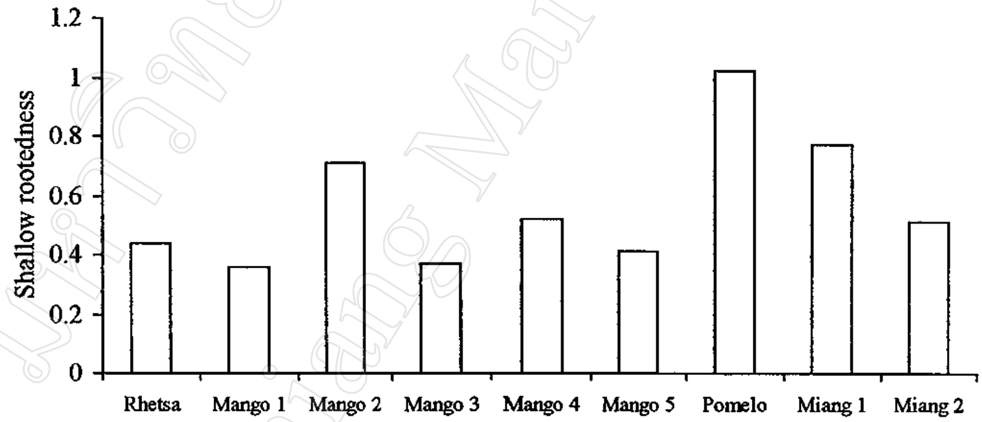


Figure 6.17 Shallow rootedness (SR) of each species across three stages

The shallowest root system was pomelo, which had the index of shallow rootedness of 1.03. It was significantly different from marcotting mango. The direct seedling mango had the deeper root system than marcotting mango significantly, that SR were 0.36 and 0.71, respectively.

The mango with spacing 4*4 m had significant shallower root system than mango planted in 4*8 m spacing, shallow rootedness of 0.71 and 0.38, respectively.

There seemed to be no apparent relationships between age of mango and shallow rootedness, as the shallow rootedness were not significantly different, average 0.41, 0.52 and 0.38 of mango aged 4, 8 and 10 years old, respectively.

Miang also had the rather shallow root system, i.e., the SR of *miang* from old orchard and row-planted *miang* were 0.77 and 0.51 respectively. However, they were not different.

6.7.10 Length of the Main Axis (N_{max})

Rhetsa had the longest N_{max} (307 cm) followed by direct seedling mango. The mango with two propagated methods showed the significant difference in N_{max}, i.e., 172 cm in direct seedling and 83 cm in marcotting mango. However, N_{max} of pomelo (76 cm) and marcotting mango did not show the difference.

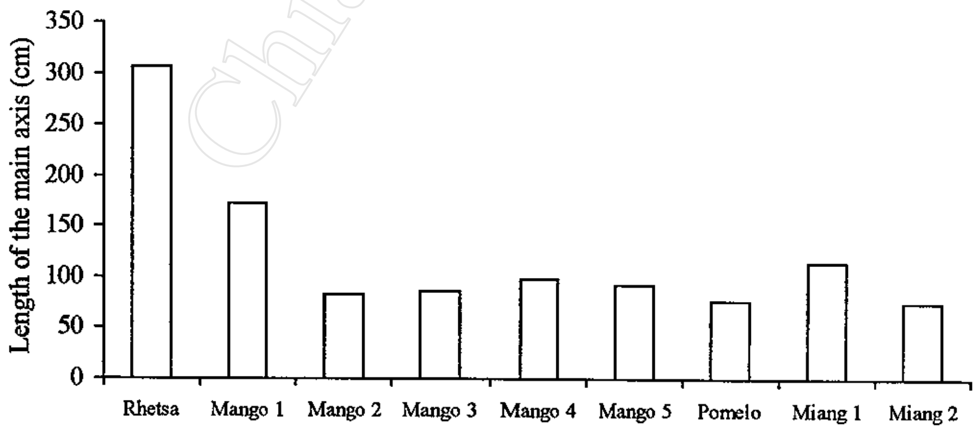


Figure 6.18 Length of the main axis (N_{max}) of each species.

N_{max} were found to be non-significant difference among the 4, 8 and 10 year old mango as well as between spacing 4*4 and 4*8 m.

Miang space-planted had longer N_{max} than *miang* row-planted, averaging 114 and 74 cm, respectively.

6.7.11 Relationship between Above-ground Volume and Root Volume

SPSS linear regression was a tool used to analyse the relationship between the tree volume and root volume. The across species linear regression of root volume as dependent variable and above-ground volume as independent variable showed the highly significant probability of 0.036. However, the R^2 was as low as 0.13 with t-ratio of 2.19. The power model of regression gave better with R^2 of 0.51 and highly significant with the t-ratio of 5.86 (Table b.16 in Appendix B).

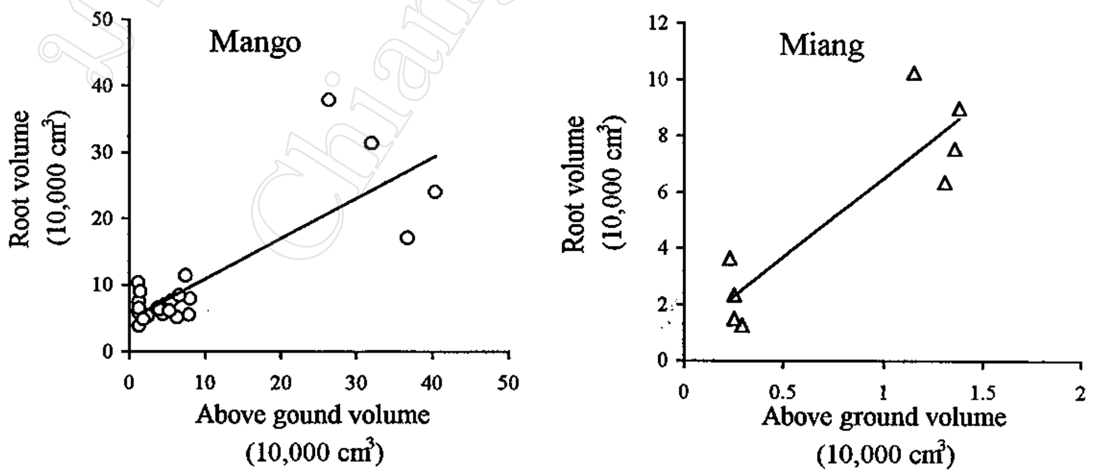


Figure 6.19 Relationship between root volume and tree volume of mango and *miang*.

The linear regression of each species shown the highly significant relationship between root volume and above-ground volume in mango and *miang* (Figure 6.19) and non significant in rhetsa and pomelo. However, there were only 3 and 4 samples of rhetsa and pomelo.

There was highly significant relationship of root volume and above-ground volume of mango, and could be explained by the following equation:

$$\text{Root volume of mango} = 1.09*(\text{above-ground volume}) - 10758.68$$

$$t = 6.47$$

$$R^2 = 0.70 \qquad n = 20$$

The average ratios of root volume and above-ground volume of mangoes were 0.87, 1.48, 1.07, 1.25 and 3.04 in mango 1, mango 2, mango 3, mango 4 and mango 5 respectively (Table 6.9). However, the majority of root and above-ground volume ratio of mango fell over the 1:1 line (Figure 6.20).

Table 6.9 Root volume and above-ground volume ratio

	Root volume:Above-ground volume	
	Average	CV.
Rhetsa	15.83	98.16
Mango 1 (10 years, direct seedling, spacing 4*4 m)	0.87	50.27
Mango 2 (10 years, marcotting, spacing 4*4 m)	1.48	12.40
Mango 3 (10 years, marcotting, spacing 8*4 m)	1.07	36.38
Mango 4 (8 years, marcotting, spacing 8*4 m)	1.25	19.68
Mango 5 (4 years, marcotting, spacing 8*4 m)	3.04	32.02
Pomelo	1.35	56.13
Miang 1 (randomly-and-wide-planted)	6.48	27.43
Miang 2 (row-planted)	8.74	56.93

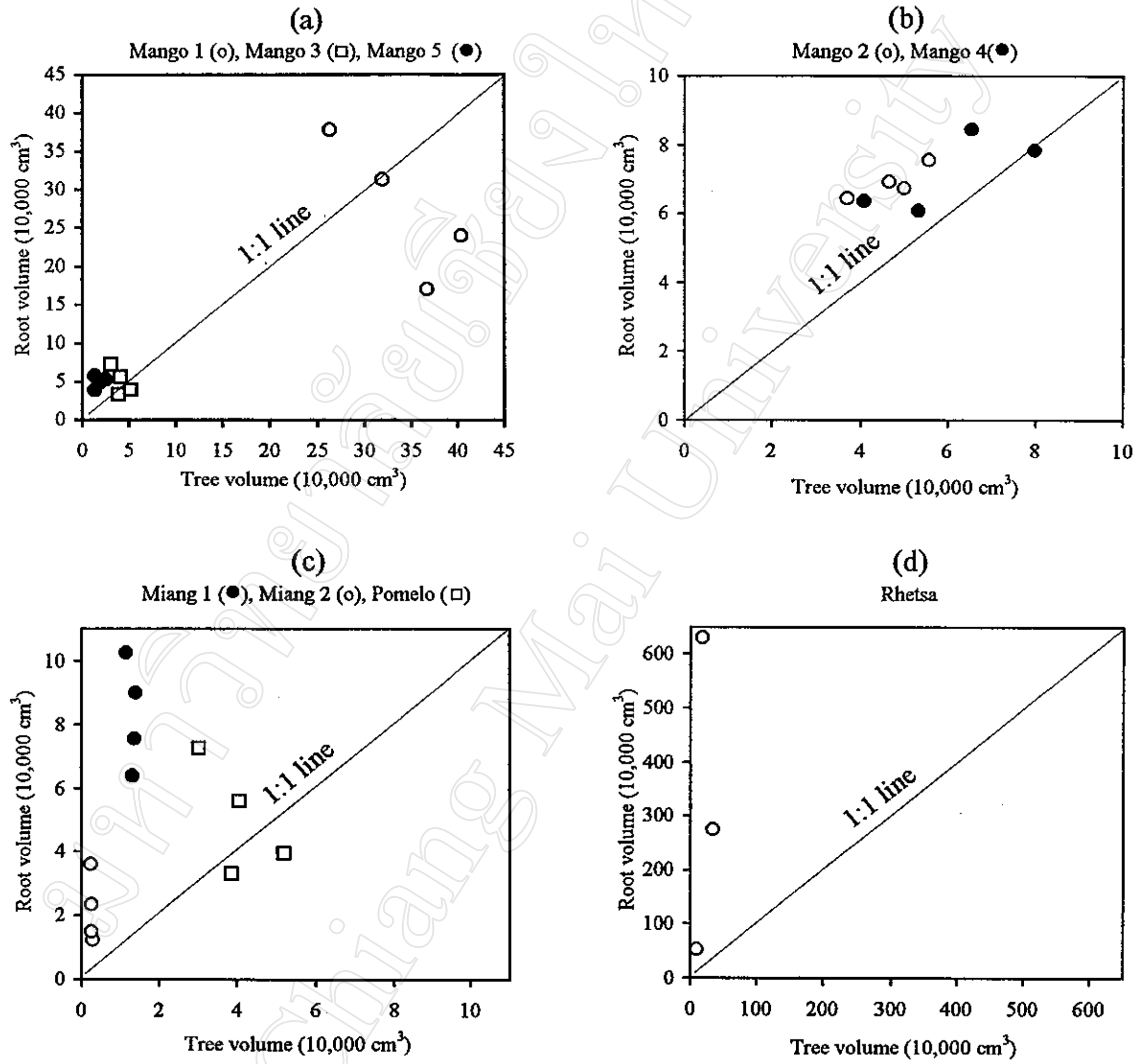


Figure 6.20 1:1 plot between root volume and tree volume of rhetsa, mango, pomelo and *miang*.

As mention earlier, the relationship of root volume and tree volume was also highly significant with the 0.89 of R^2 in *miang*. The linear relationship could be described by:

$$\text{Root volume} = 0.14*(\text{above-ground volume}) + 334.12$$

$$t = 4.89$$

$$R^2 = 0.80 \qquad n = 8$$

Comparing to mango, root volume and tree volume ratio of *miang* was about 6-9 times greater, which were 6.48 and 8.74 in the old planted and new planted *miang* (Table 6.9). The root volumes of *miang* were approximately 6 times greater than the tree volume. Therefore, the scatter plot of root volume and tree volume was over the 1:1 line (Figure 6.20).

The ratio of root volume and tree volume in pomelo was similar to mango which was 1.35.

Regarding to Table 6.9, the comparison between trees mango of the same age as well as same spacing but different in propagating method showed that the root volume and above-ground volume ratio was greater in marcotting (1.48) than direct seedling (0.87). However, the difference was not significant.

It was found that among the mango trees with different ages, the ratio was higher when mango was younger, for instance, the ratio of 4 year old mango was significantly different from 8 and 10 year old mango (Table b.17 in Appendix B).

The ratio of root volume and tree volume of rhetsa was the highest, averaging 15.83.

6.8 Root Arrangement in Sloping Land

For root measurement, the root was excavated in four direction, i.e., east, west, north and south where east and west directions were upslope and downslope. The one way analysis of variance was used to analyse the L_t, W_t, L_{rw}, N_{max}, diameter of proximal root diameter, and number of proximal root more than 45° and less than 45°.

The analysis across the species showed the non significant results in all parameters among the 4 directions (Table b.19 and Table b.20 in Appendix B).

6.9 Spatial Analysis of Canopy and Root

6.9.1 Canopy Coverage of Rhetsa and Fruit Trees

The canopy cover by crown of rhetsa and mango of mature stage was the highest compared to the other two stages, having coverage percentage or crown closer of 66% of the total area. The coverage percentage of middle stage and early stage were 57% and 19% respectively.

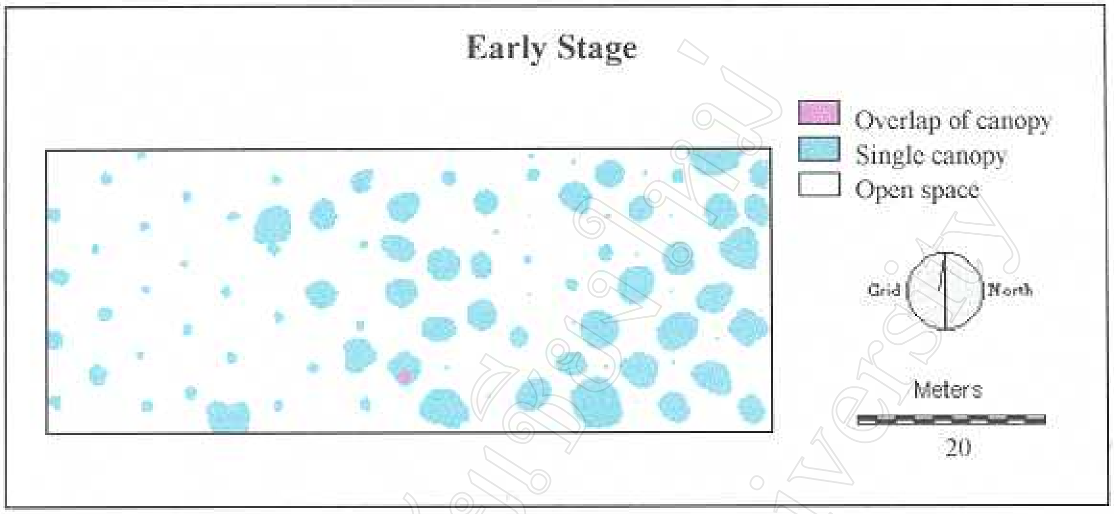
Table 6.10 The percentage of canopy coverage of each stage.

	Mature stage		Middle stage		Early stage	
	Area (m^2)	%	Area (m^2)	%	Area (m^2)	%
Total area of the plot	3,200	-	2,800	-	2,400	-
Covered by canopy of rhetsa	955	29.84	828	29.57	75	3.12
Covered by canopy of fruit tree	1,656	51.75	1,136	40.57	383	15.96
Covered by single canopy	1,591	49.72	1,241	44.32	455	18.96
Covered by overlap of canopies	510	15.94	362	12.93	2	0.08

Canopy of fruit tree in mature stage, mainly mango, could covered 52% of the total area which was larger than middle stage (41%). It was only 16% in early stage. Rhetsa provided about 30% of crown closer in mature stage and middle stage (Table 6.10).

The two layers of canopy overlaid in mature stage were the highest with 16% of the total area, meanwhile in middle stage and early stage were 13% and less than 1%, respectively (Figure 6.21).

Since the sampling size of each stage was different, therefore, the gap size was converted to 1 ha basis. The gaps were irregular shape, however, the circular in shape was a model to estimate the radius of gap. The index size of canopy gap of three stages were 11.52, 14.91 and 33.30 respectively.



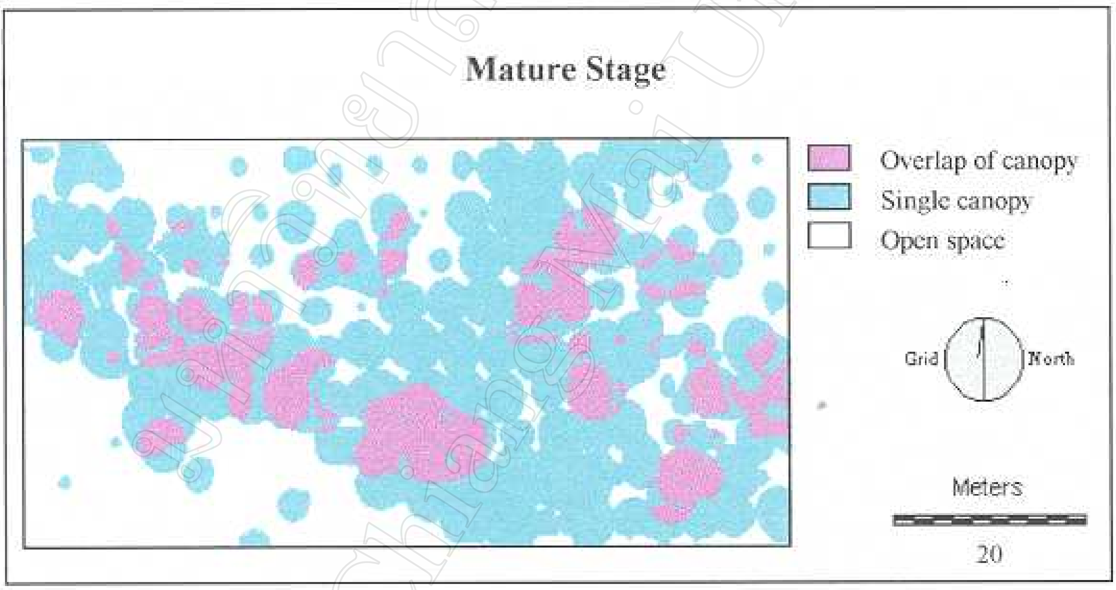


Figure 6.21 Canopy cover of fruit trees overlaid with rhetsa in mature stage, middle stage and early stage

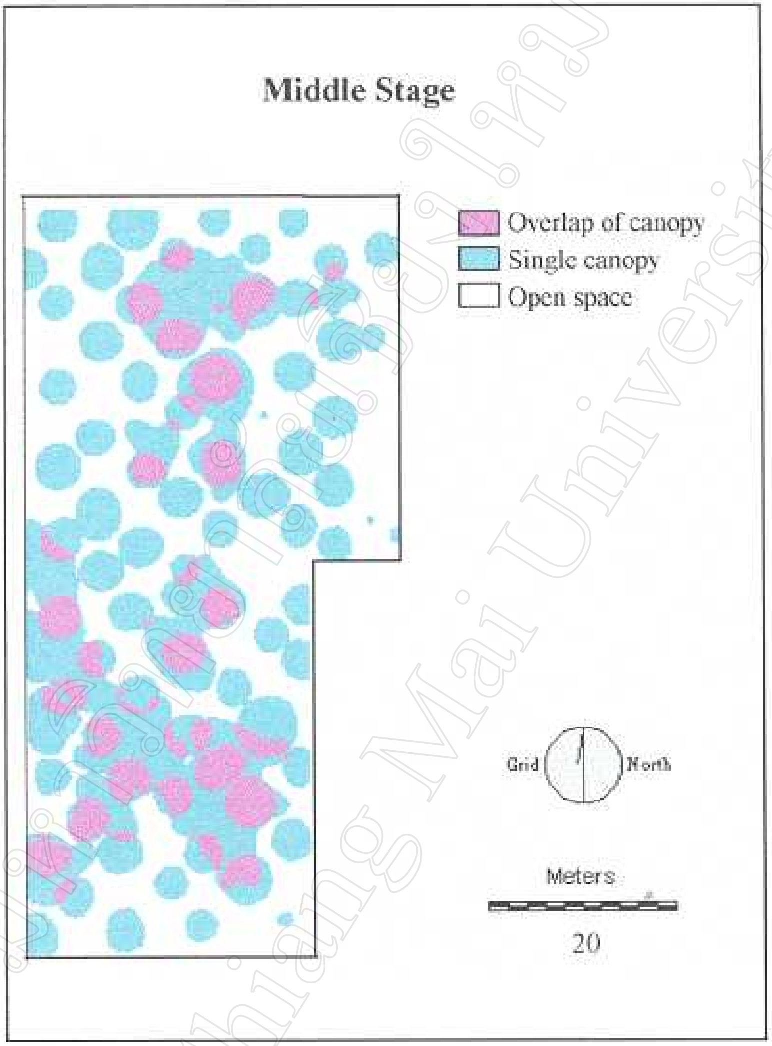


Figure 6.21 (continued)

6.9.2 Availability Space

The availability space, as determined by the empty space where there was not canopy cover of rhetsa, fruit trees and *miang*, was found to be highest in early stage with 54%. Mature stage and middle stage had similar gaps of 22% and 27% respectively.