CHAPTER VII

DISCUSSION OF FIELD STUDY

7.1 Sustainable Land Use of *Miang*-based AFS

The study of one progressive farmer, who had modified his 6.4 ha *miang* plantation into more diversified *miang*-tree-fruit trees land use system, demonstrated that high and stable income could be generated by marketing the farm products throughout the year. It took the farmer 12 years to rehabilitate the old *miang* plantation into productive integrated farm which provided 265,600 baht of gross income in 1996.

The main income of the farm came from three components, i.e., rhetsa, *miang* and mango which contributing about 32%, 54% and 2% respectively (Table 6.2). During 1993-1996, income from rhetsa was increased, income from *miang* was stable but income from mango was fluctuated.

Preechapanya *et al.* (1985) *cited by* Preechapanya (1996) had ranked, according to durability, income, and adoptability, thirty agroforestry systems in northern Thailand and stated that *miang* tea garden in the hill evergreen forest yielded income of 22,969-42,656 baht ha^{-1} yr^{-1} which was classified as moderately high. Comparison with this farm, income from *miang* solely in 1996 was 22,500 baht ha^{-1}, which was a bit lower. However, the farm gained income from tree crops besides *miang*. The hectarage income in 1996 of the farm was 41,500 baht yr^{-1}. The durability of *miang* tea garden was more than 10 years, and would continue to be productive for many years, especially with newly planted *miang* row arrangement.

Miang consumption, in general, was thought to be declined because of its unpopularity among new generation. However, the case of Ban Phadeng had shown that with good quality and ability to seek new markets on the nearby provinces, *miang* consumption was still in high demand. The farmers had envisaged the bright marketing prospect for at least the next 10 years.

During the last five years, the farmer had witnessed the steady increase of *miang* price, reaching 7 baht kam^{-1} in 1996. This price and marketing trend had encouraged the farmer to improve planting arrangement and management of *miang* so that better harvest could be achieved with ease and effectively.

As the picking and processing required continuing working schedule, labour was the most important input and had became the constraint. Thus, benefit from *miang* had been equally shared between the owner operator and the hired labour. Therefore, within the Ban Phadeng community, the employment opportunity and income of the landless farmers who worked as waged labourers were not at stake.

The *miang* production system also produced opportunity for older generations to work for living. The working condition was considered to be better than field crop production on the arable land. Thus socially, the *miang* system had created an interactive working atmosphere and also withheld farmers to move to the city.

In case where *miang* production was no longer feasible economically, the shrub could be harvested as green tea. However, at the current price and marketing opportunity, the farmer still preferred the production of *miang* to green tea.

Production of mango as well as of the other fruit trees was not as stable as *miang* and rhetsa. Since, income from mango was fluctuated (Figure 6.2) especially in 1995 when farmer pointed that mango fruits were splitted caused by summer storm. Moreover, the alternative bearing habit of mango (Wangnai, 1986) as observed in the farmer's field could not provide full benefit. The phenomenon also reported by Radanachaless and Krasaechai (1992) when studying the fruit bearing among mango cultivars at Chom Thong land reform project area, Chiang Mai province. Accordingly, the Figure 6.2 showed the income from mango alternately low and high. The weak point of fruit tree management in this farm was the farmer chose mango as the main fruit tree which Wangnai (1986) pointed out that mango's yield would be reduced in the area of altitude more than 600 m from mean sea level.

The income trend of rhetsa became more and more important for the farm. Gross income was second to *miang* during 1993 to 1996. However, it would take almost 10 years, before rhetsa could produce stable yield, eventhough it could bear fruits at 5 years old.

7.2 *Miang*-based AFS in Different Stages

7.2.1 Income

Since, mature stage was more diversified than the other two stages, therefore, income came from many commodities, i.e., rhetsa, *miang*, mango, and peach. While incomes of middle stage and early stage came from rhetsa, *miang* and mango. The monthly distribution of income for each stage was from March to December, but the amount of monthly income was different. The present values of incomes of mature stage and middle stage were similar, but they were higher than early stage. The main income of mature stage and middle stage came from rhetsa, but early stage came from *miang*. Although the total number of rhetsa was 121 plant ha^{-1} in early stage, but the majority of rhetsa was in juvenile stage. The young rhetsa was only 1-2 year old, and still not productive yet. The early stage would generate high income when rhetsa was over five years old, and it would be expected to be the leading plot.

7.2.2 Cost

The cost items of the three stages were similar (Table 6.6). The present value of cost of the three stages were 16,066 baht ha^{-1} in mature stage; 21,925 baht ha^{-1} in middle stage and 15,835 baht ha^{-1} in early stage (Table a.3 in Appendix A). The difference came from the amount of activities which had relation with amount of product. The more product, the more activity such as *miang* picking in middle stage was the highest cost and the product of *miang* was the highest as well. Mature stage was the highest cost in picking mango, therefore, the mango's product was the highest. Among various costs of each activities, *miang* needed the highest cost per hectare, meanwhile rhetsa need very low cost, only picking the fruit and drying. However, rhetsa generated present value of income per hectare more than *miang* 4-8 times in middle stage and in mature stage.

7.2.3 Financial Return

Mature stage and middle stage provided similar financial returns expressed in NPV and clearly economically superior than early stage. However, the B.C. ratio of both stages were greater than one. Arayarangsan (1985) recommended that to make decision for investment for the project which had

B.C. ratio more than one and NPV more than zero. Additionally, Wannawong *et al.* (1991) pointed out that NPV was the preferred indicator to identify preferred alternatives in agroforestry. Therefore, given the financial benefits in the early stage until the mature stage of *miang*-based agroforestry system with rhetsa, fruit trees and *miang* proved attractive to farmers.

7.3 Above-ground Interactions in *Miang*-based AFS

7.3.1 Above-ground Biomass Affects on Microclimate

Rhetsa was the top storey, its volume of above-ground biomass in mature stage, middle stage and early stage were 11, 22 and 0.5 m^3 ha^{-1}. However, rhetsa in early stage was under storey by average. The crown width and height which also represented above-ground biomass, of rhetsa in mature stage were similar to middle stage but found to be very small in early stage. The above-ground biomass of the top storey was considered to be the subsystems of agroforestry and the site of fundamental interactions between vegetation and the physical environment. Precipitation was intercepted, retained and redistributed by the canopy.

Generally, between 10 and 30% of incident precipitation in the forest would be intercepted and evaporated from the canopy of the top storey (Parker, 1995). In *Leucaena leucocephala* and maize intercropping, the upper storey tree had a major influenced on the rainfall redistribution, the influence was greatest during small shower (<10 mm day^{-1}). The crop received only 55-75% of the rainfall fell in the open (Ong *et al.*, 1992). Rainfall modification effected by the trees only occurred for a distance away from the trees approximately equal to the tree height (Wallace, 1996).

The forest leaves would absorb more than 80% of the incident short wave radiation (Gates, 1980 *cited by* Parker, 1995).

Consequently, the above-ground interaction of rhetsa to fruit trees mainly mango was expected to be more pronounced in mature stage and middle stage while no interaction or less in early stage.

7.3.2 Phenological Characteristics and Interaction

Phenological characteristic was the alternative factor, which could indicate advantage or disadvantage of the canopy cover of rhetsa. Rhetsa is deciduous species which would cause no competition for light, nutrients and moisture during the period of leaflessness (Dwivedi, 1992), the longer period of leaflessness, the better for growth of lower layer crops.

Moreover, rhetsa had very tiny and loosen leaves. Additionally, the crown edge height of rhetsa was higher than the height of fruit trees, excepted jack fruit in mature stage. Therefore, the above-ground evaluation of suitability of rhetsa to fruit trees especially mango as lower storey was high. Among three stages, mature stage had more above-ground interaction more than middle stage, as middle stage had no jack fruit, while early stage was too early to consider.

Fruit trees was the middle storey in mature stage and middle stage, but it was the top storey in early stage. As mention earlier, there were many kind of fruit trees in mature stage, however, the main fruit tree was mango (Table 6.9). The volume biomass of fruit trees in mature stage, middle stage and early stage were 29, 10 and 5 m^3 ha^{-1}. The average crown width of mango in mature stage was higher than middle stage and early stage.

Consequently, crown of mango in mature stage had higher probability to block sunlight, redistribute rainfall, modify temperature, etc., than middle stage and early stage. Fortunately, the under storey was tea plant which Hadfield (1975) studied the yield of tea, Assam type, under shade and under full sunlight showed that the yield under shade was 40% higher than full sunlight. Hence, only one constraint was noted that was precipitation redistribution by mango canopy.

The gap between height of *miang* and crown edge height of mango in mature stage and middle stage were more or less 40 cm, where mango crown edge was higher. In early stage the crown edge of mango was lower than *miang* 's height. In this case mango might affect *miang* growth and yield which Dwivedi (1992) pointed out that trees having a low crown position which would not permit enough sunlight on the ground would effect adversely to the process of photosynthesis. The lower crown of mango also physically disturbed the *miang* growth as well as loss of the planting area.

With the same spacing of mango, the plot which had crown edge of mango higher than *miang*'s height could be allocated more *miang* than the plot which had crown edge of mango lower than *miang*'s height. Therefore, mature stage and middle stage could be allocated more number of *miang* in one unit area than early stage.

7.3.3 Fruit Tree Selection by Above-ground Criterion

Fruit tree selection is one factor that can be managed in agroforestry systems. In the studied farm, there were 5 species of fruit trees in the farm, i.e., jack fruit, seedling mango, marcotting mango, pomelo and peach. The 10 years old jack fruit was the highest tree followed by seedling mango which had touched the crown of rhetsa, thus causing the interaction in mature stage. Meanwhile the tall fruit tree caused the interaction with the top storey, the short fruit tree also caused the interaction with the lower storey. Peach was the shortest tree with low the crown edge height which interacted with *miang*. Pomelo had the same height as marcotting mango but higher crown depth and lower crown position. The marcotting mango had wider crown width than pomelo, thus it was a trade-off between crown width and crown position of mango and pomelo.

Although mango was not recommended by Dwivedi (1992) for general agroforestry (tree-field crop), since it has a deep set crown, but it was suited for *miang*-based agroforestry system in above-ground criteria.

The different propagated method had led to the different size of tree such as height, crown width, crown edge height and crown depth. The direct seedling mango had the taller tree, wider crown width and deeper crown set. However, the crown edge height was the same.

Among these 4 species, the degree of suitability to *miang*-based agroforestry system was different. Jack fruit and seedling root stock of mango were tall trees which interacted with top storey. Jack fruit had very low crown position with disturbed the growth of *miang*, meanwhile direct seedling mango had very wide crown.

The marcotting mango, pomelo and peach did not interact with top storey, but pomelo and peach would interact with under storey plant (*miang*) particularly the peach, as peach had very low crown position and the main branch originated from the low position trunk. Hence, pomelo would be more suitable in *miang*-based AFS than peach. However, between pomelo and marcotting mango, there were many factors to be considered since crown width of mango was wider than pomelo.

The above-ground characteristics of fruit tree are temporal characteristics such as canopy structure which changes seasonally and most dramatic in completely deciduous stands. All of fruit tree species in the farm were not deciduous species, therefore the quality of leaf area would vary over the year as commonly found in the evergreen forest (Hollinger *et al.*, 1994 *cited by* Parker, 1995). More substantial variation would also occur on a successional time scale (Parker 1995).

The height, crown depth and crown width of mango were significantly correlated with the age of mango. *Miang* would contact the lowest part of crown edge with mango when the mango was less than 7 years old. It was measured that at year sixth, crown edge height of mango was 151 cm which was the same as average height of *miang* from three stages (the assumption is *miang* established before mango). However, the crown closure of mango would be occurred at year ninth.

7.4 Below-ground Interaction in *Miang*-based AFS

7.4.1 Fractal Model

The fractal model used for studying root characteristics of rhetsa, mango, pomelo and *miang*, had shown no relationships between α, q and link length on root diameter. Van Noordwijk and Purnomosidhi (1995) tested on 19 multipurpose trees also obtained the same results. Accordingly, the assumption of fractal branching models hold that α, q and link length are independent of root diameter. The average of α, q and link length could be used to estimate the root parameters. However, there were certain restrictions for using and discussing this model.

There are two extreme root branching patterns, i.e., dichotomous and herringbone (Fitter, 1996). Dichotomous is the simplest representative of the class of proportionate branching rules and herringbone is the simplest representative of class of determinate branching rules. In the principle dichotomous root branching should have equal branching diameters ($q = 1$), two branching per branch event (N_k), true pipe stem model ($\alpha = 1$), constant link length (L_l) and 90° between subsequent link ($\beta = 45°$). However it is rare (Van Noordwijk *et al.*, 1994). As found in the study, all of species had constant α and q and not deviated from 1 and N_k was around 2, but β deviated from 45° and L_l especially of rhetsa had high variation.

7.4.2 Root System of Rhetsa

According to the fractal model, only roots with diameter more than 2 mm or woody root would be considered. Rhetsa had very long root system (L_t) compared with the other species. Moreover, its big proximal root would have more interaction especially near the tree trunk, as found in the woody roots of *Acacia barteri*, *Alchornea cordifolia*, *Cassia siamia* and *Gmelina arborea* which were generally concentrated near the tree trunk and decreased away from it and with depth (Ruhigwa *et al.*, 1992).

The L_t governs the exploitation of water and nutrient from the soil zone (Van Noordwijk *et al.*, 1994; Van Noordwijk *et al.*, 1996). Fitter (1996) pointed out that water and ion uptake were more closely related to L_t than root volume and Mackie-Dawson and Atkinson (1991) suggested that L_t was a better indicator of nutrient absorbing capacity and is more sensitive to soil factors than mass. The high L_t was an important characteristic for the acquisition of nutrients at low availability (Ryser and Lambers, 1995). Rhetsa had very long L_t and big proximal root which was likely to compete with the other fruit trees and *miang*.

For maximising carbon inputs into the soil through tree's root turnover at minimum competition cost, tree species that take up low amounts of nutrients per unit carbon investment in roots should be advantageous (Schroth, 1995). Maintenance costs of a root system will depend on the size and extent of its spread through out the soil profile (Bloomfield *et al.*, 1996). They also pointed out that large tree, the maintenance cost and total carbon expenditure is also higher than the small tree. The study showed W_t and above-ground woody biomass of rhetsa were higher than the other species.

The averaged size of root of rhetsa was the smallest indicated by the highest L_{rw} which factorised into root length per unit of root weight. It indicated the root fineness and pattern of diameter distribution (Ryser and Lambers, 1995). It decreased with increasing proximal root diameter for all branching pattern (Spek and Van Noordwijk, 1994). Rhetsa had also more fibrous root system than mango. However, this study concerned only the woody roots (>2 mm), which was only 20-38% of many fast growing trees contributed to the woody root, the rest fell within the diameter class 0-2 mm (Toky and Bisht, 1992). Besides the species, the root ratio of each class of root is nutrient supply contingency. Many plant produces finer roots when grown at low nutrient supply rates, can be demonstrated either by root diameter directly and by determining L_{rw} (Fitter, 1996).

L_{rw} is also linked to decomposition rate, Lehmann *et al.* (1995) stated that decomposition rates of leaves, twigs and roots as determined from the residual mass could be related to the initial polyphenol plus lignin to nitrogen ratio. Fahey *et al.* (1988) pointed out that decomposition rates for roots were found to decrease with increase root diameter, however, Lehmann *et at.* (1995) did not find the certain relation.

7.4.3 Roots of Mango in Different Age

The W_t per tree of mango was affected by the age, the W_t increased when the age of mango increased, which indicates that higher age of mango needed more amount of carbon for making and maintaining the roots more than the younger one. At the same time, it indicates the organic matter gain to the system. However, it depended on the root decomposition rate, the higher rate of root decomposition showed the higher net gain of organic matter (Lehmann *et al.*, 1995).

The age of mango also affected L_{rw} which indicated the size of root. The 4 years old mango had finer root system than 8 and 10 years old. The root size increased when mango become older, however, the root size of 8 years old of mango was similar to 10 years old.

The L_t and N_{max} axis were not shown to be significantly different among three ages of mango, which indicate of the ability of nutrient absorption and the occupied zone among the different age of mango were not different. However, the trend of L_t tended to increase with age of mango (Figure 7.1). It was measured that, from 4 years old to 8 years old L_t increased dramatically and become stable after 8 years old.

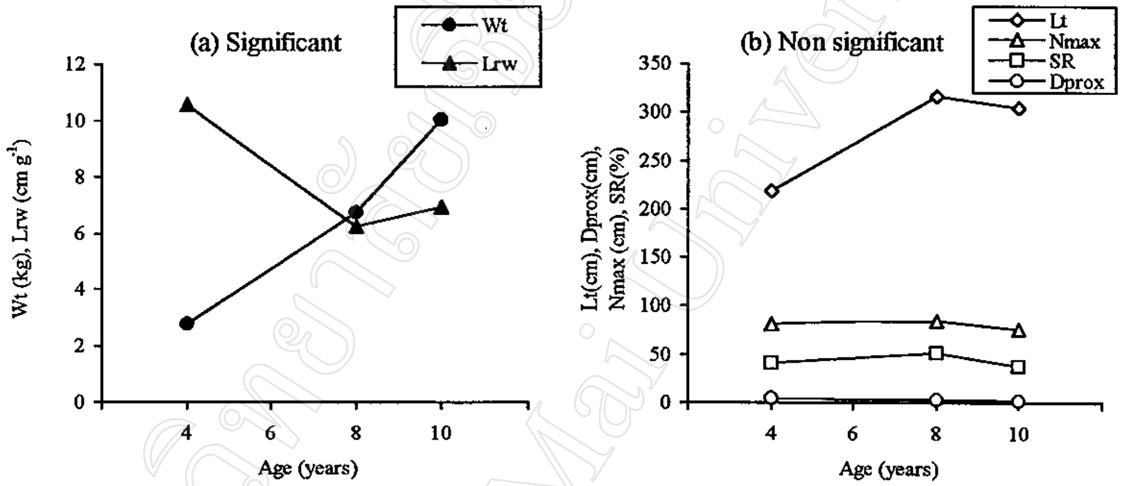

Figure 7.1 Total root length (L_t), total root dry weight (W_t)**, length of the main axis (N_{max}), specific root length (L_{rw})*, proximal root diameter (D_{prox}) and shallow rootedness (SR) of 4, 8 and 10 year old of mango.

The SR of mango was not affected by age. There were homogenous SR in range of 0.41, 0.52, 0.38 in 4, 8 and 10 years old. It might be a characteristic of the species and independent on age. SR has derived from the angle of proximal root, which is the primary root. From the study in 12 tree species by Toky and Bisht (1992), the primary roots is more horizontal than the secondary root. SR as measured by primary characteristics, would be one of the parameters used to select tree in agroforestry system.

7.4.4 Roots of Mango in Different Propagating Method

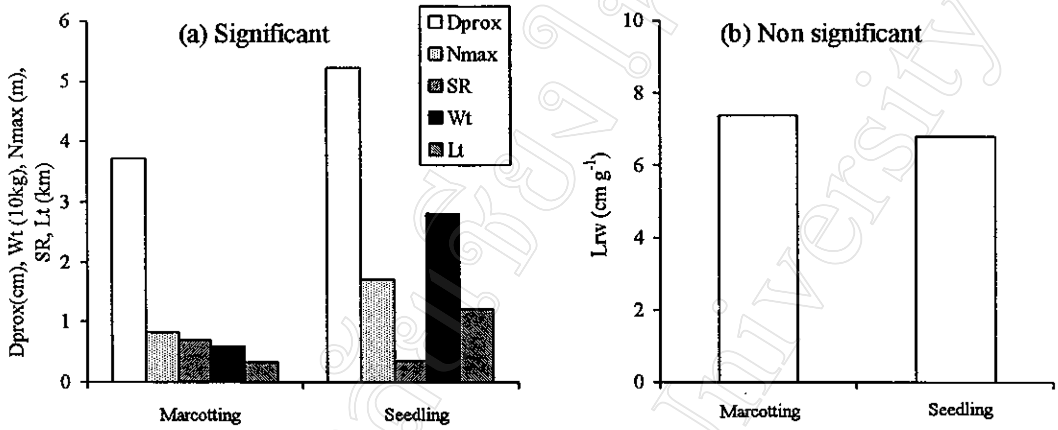

Figure 7.2 Total root length (L_t)**, total root dry weight (W_t)**, length of the main axis (N_{max})**, specific root length (L_{rw}), proximal root diameter (D_{prox})* and shallow rootedness (SR)** of 10 years old mango with 2 different propagated methods (** significant at 99%, * significant at 95%).

Within mature stage, there were two propagating methods, i.e., marcotting and direct seedling. Eventhough, the spacing and age of the mango were the same, i.e., 10 years old and 4*4 m of spacing. The direct seedling mango had longer L_t as well as heavier W_t than marcotting, indicating that direct seedling mango exploited and needed more carbon for root growth and maintenance. The maintenance cost and total carbon expenditure were higher in the direct seedling mango than marcotting mango.

Mango with direct seedling was not suitable for agroforestry since it had very long L_t, amount of W_t, longer N_{max} and big proximal root diameter, which would compete for water and nutrients with rhetsa and *miang*. Moreover, the bigger proximal root leads to more physically competition near the mango's trunk. At the wider spacing, direct seedling seemed to be more suitable than marcotting, because the root system tended to penetrate deeper than the root of marcotting as shown by SR value (SR of marcotting was higher than direct seedling significantly).

7.4.5 Spacing and Roots of Mango

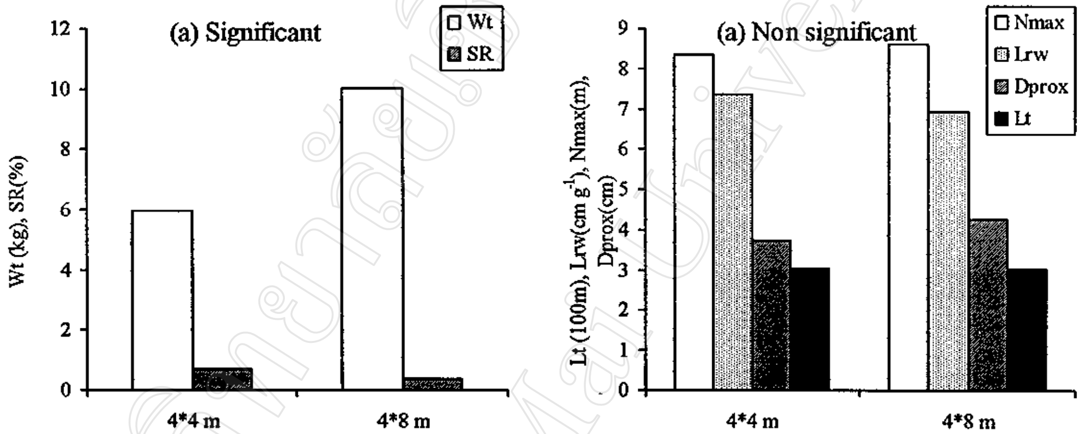

Figure 7.3 Total root length (L_t), total root dry weight (W_t)*, length of the main axis (N_{max}), specific root length (L_{rw}), proximal root diameter (D_{prox}) and shallow rootedness (SR)** of mango grown in spacing of 4*4 m and 4*8 m (** significant at 99%, * significant at 95%).

One strategy to eliminate the root competition is trees and crops are planted at sufficient distance (Schroth, 1995). However, one species such as mango showed the heterogeneity in many root parameters, i.e., mango with the spacing 4*4 m and 4*8 m were different in SR, and W_t. The root system of spacing 4*8 m was deeper than the spacing 4*4 m. However, the mango with 4*8 m was grown in terracing area, meanwhile mango with 4*4 m was grown in sloping area. So that it might be affected the measurement of root angle. The W_t of wider spacing mango higher than the narrower mango, because the former would have better resources availability both above and below-ground.

7.4.6 Fruit Trees Selection by Root Criterion

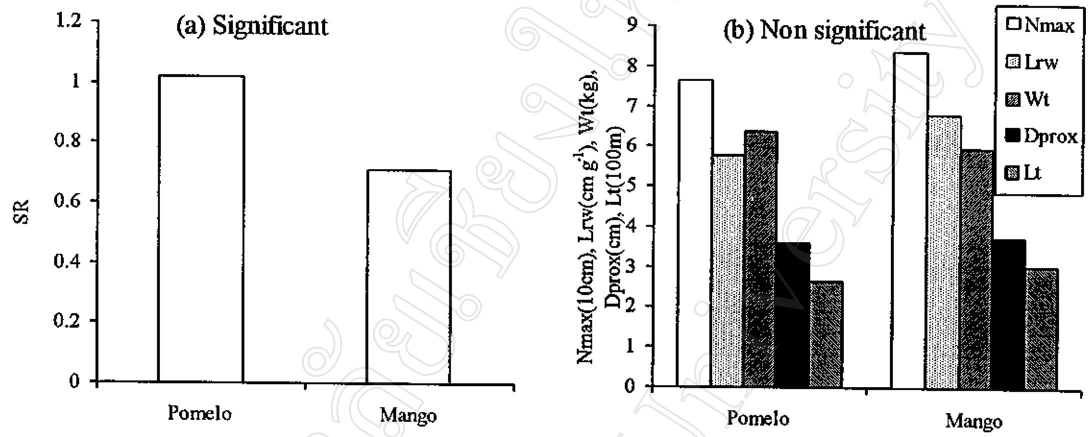

Figure 7.4 Total root length (L_t), total root dry weight (W_t), length of the main axis (N_{max}), specific root length (L_{rw}), proximal root diameter (D_{prox}) and shallow rootedness (SR)** of pomelo and mango (** significant at 99%, * significant at 95%).

Besides the above-ground criterion for selecting fruit tree species in any AFS as discussed earlier, the root system of species should be taken into consideration as well. In mature stage, there were many species of fruit tree, but the main species were mango and pomelo. Pomelo had similar root system as mango with the exception of SR. Roots of pomelo penetrated at the upper layer of the soil zone while mango penetrated deeper.

7.4.7 Root System of Randomly-planted and Row-planted *Miang*

The different conditions of the two *miangs* planting systems were spacing and age. *Miang* 1 came from the old orchard grown at random. *Miang* 2 had been established for 11 year old, and were planted with spacing 4*1 m. The root of *miang* 1 expanded further than the row planted *miang* thus exploiting nutrient and moisture more vigorously, as reflected by higher values of N_{max} and L_t (Figure 7.5).

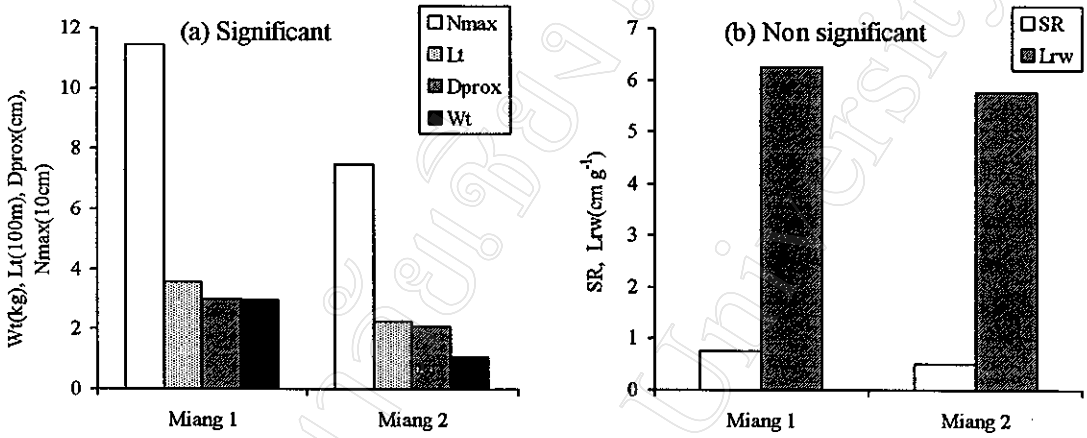

Figure 7.5 Total root length (L_t)**, total root dry weight (W_t)**, length of the main axis (N_{max})*, specific root length (L_{rw}), proximal root diameter (D_{prox})** and shallow rootedness (SR) of randomly-planted *miang* (*miang* 1) and row-planted *miang* (*miang* 2) (** significant at 99%, * significant at 95%).

7.4.8 Root Arrangement in Different Stage

In mature stage, the root system of rhetsa occupied the deeper soil zone with direct seedling mango and *miangs*, while pomelo and marcotting mango in mature stage showed the rather shallow root system. Therefore, the area where rhetsa located near direct seedling mango or *miang* would show relative high interaction. The area with rhetsa and marcotting mango and *miang* showed relative medium interaction (Table 7.1). The area with rhetsa, pomelo and *miang* would have the least interaction. The root of rhetsa was deep, the root of pomelo was shallowest and shortest (N_{max} = 0.76 m), and root of *miang* 1, in mature stage was moderately shallow. However, the three combinations were intermingled within mature stage. The narrow spacing of fruit tree would enhance root interaction, e.g., the root of direct seedling mango almost touch the neighbour trees (N_{max} = 1.72 m). Therefore, it was certainly interacting with rhetsa (N_{max} = 3.07 m) and *miang* (N_{mx} = 1.17 m).

Table 7.1 Sources of interaction, parameters and ranking of relative severity of interaction of each species in each stage.

Sources of interaction	Para-meter	Mature stage						Middle stage				Early stage			
		Rhetsa	Mango1	Mango2	Pomelo	*Miang*1	*Miang*2	Rhetsa	Mango3	*Miang*1	*Miang*2	Rhetsa	Mango4	Mango5	*Miang*2
Root occupation zone	SR	3	3	2	1	2	3	3	3	2	3	-	3	3	3
Exploitation	L_t	1	2	3	3	3	4	1	3	3	4	-	3	3	3
Carbon cost	W_t	1	2	4	4	5	6	1	3	5	6	-	4	5	6
Exploration	N_{max}	1	2	3	3	3	4	1	3	3	4	-	3	3	4
Root size	L_{rw}	1	2	2	2	1	1	1	2	1	1	-	2	1	1
Physical interaction near tree's trunk	D_{prox}	1	2	3	3	3	4	1	3	3	4	-	3	4	4

Remark: Root occupation zone: 1 - Upper zone, 2 - Medium zone, 3 - Lower zone
Exploitation: 1 - More, ..., 4 - Lesser
Carbon cost: 1 - Higher, ..., 6 - Lower
Exploration: 1 - Longer, ..., 4 - Shorter
Root size: 1 - Smaller, 2 - Bigger
Physical interaction: 1 - More, ..., 4 - Lesser

The soil zone occupied by roots of rhetsa, mango and row planted *miang* 2 in middle stage were the same, viz., all of them classified as deep root system. Only the randomly-and wide-planted *miang* had the moderate shallow root system. Compared with rhetsa-direct seedling mango-*miang* in mature stage, middle stage had better advantage. Eventhough the two combination occupied the same soil zone, but the combination in middle stage had lesser in exploitation, carbon cost, exploration and less interaction near the mango's trunk

(Table 7.1). If substituted with pomelo in stead of direct seedling mango in mature stage, then the middle stage become less advantage. Since, the mango was planted with spacing 4*8 m, so that the root interaction in middle stage was reduced.

Rhetsa in early stage was at juvenile stage, around 1-2 years old. Hence, the interaction came only from mango and *miang*. Mango aged 8 years old induces more interaction with row-planted *miang* than the 4 years old. Although both of them had the same root zone with *miang*, but carbon cost of the 8 years old was greater. Moreover, the primary root diameter is greater. Undoubtedly, the early stage had least distinct in root interaction as compared to mature stage and middle stage.

7.5 Root Management Effects on Root Distribution

There are many parameters used to study the root, however, one specific tree might have one parameter in conflict with the other parameters. Fertility maintenance and competition are the key properties in agroforestry in which fertility will be indicated by root dry matter and competition will be indicated by total root length. Consequently, the more root dry matter means the more total root length. To avoid the inherent conflict between fertility maintenance through tree roots and competition from tree root, Schroth (1995) suggested the four possible strategies for alleviating this dilemma as follows:

(1) Planted at sufficient distance

Root competition can be avoided if tree and crops are plant at sufficient distance, so that the root system do not intermingle, but this would necessarily also negate the favourable effect of tree roots. Therefore, in mature stage where *miang and* rhetsa were planted not in the row as well as rhetsa in middle stage, created the competition. The length of main axis of root of rhetsa was approximately 3.07 m and of 10 year old of direct seedling mango was 1.72 m, hence the minimum distance is 4.79 m. The minimum distance in pomelo and *miang* was shorter, but then, the canopy width had to be considered.

(2) Tree's root distribution complementary to the crops

An ideal tree from nutrient cycling perspective should possess a deep root system with limit lateral extension in the top soil, thus recycling nutrients from the subsoil and forming a safety net against nutrient leaching below the crop rooting zone without interfering much with the crop root system in the top soil (Van Noordwijk *et al.*, 1996).

From the root point of view, intercropping of rhetsa-pomelo-*miang* system were better than rhetsa-mango-*miang* system. Root of rhetsa was deep, thus forming the safety net, root of pomelo was shallow, thus consuming the nutrient pumped and *miang* was in the middle with short total root length. However, the non woody root is the temporal characteristics such as Wangnai (1986) stated that mango's root grows very well at the beginning of rainy season and penetrates deeper during rainy season, then interrupts at dry season, only the deep root develops in dry season.

(3) Reduction tree's root density

The direct root management is tree's root pruning. Yadav and Khanna (1992) showed that by removing the lateral roots of *Prosopis cineraria*, did not appear to affect the tree growth adversely but could enhance crop production. Ong *et al.* (1992) used the root barriers to reduce the interaction between *Leucaena leucocephala* and maize, had shown that the yield on plots with upper storey trees were 12% higher than the barriers than without. The elimination of root by digging a trench of *Dalbergia sissoo* and *Acacia nilotica* increased the yield of cotton. However, Ong *et al.* (1992) suggested that the effect of root on the yield of maize was minor compared to the effect of canopy. The other one method which has always been suggested is soil tillage. However, in sloping area, it is not the suitable, since it increases the soil erosion.

Several factors are likely to reduce the rooting depth of fruit trees in agroforestry association such as fertilisation, mulching and shoot pruning. Fertilisation makes topsoil more attractive for tree roots and may favour the formation of shallow root systems (Schroth, 1995). Mulching has been shown to reduce the rooting depth of fruit trees in temperate climates, and increase the lateral root extension (Schroth, 1995).

There were significant relationship between root volume and tree volume across species (rhetsa, mango, pomelo and *miang*). However, there were different ratio among the different species. Therefore, pruning of the trees may affect subsequent root distribution and root association. Shoot pruning of tree, a common practice in many associations, seems to increase root branching in the top soil and to restrict tree to shallower soil depths compared with the unpruned trees (Rao *et al.*, 1991). However, Van Noordwijk and Purnomosidhi (1995) pointed out that stem pruning had no consistent effect on the index of shallow rootedness, as the relative importance of the tap root remained constant.

7.6 Spatial Arrangement of Canopy in *Miang*-based AFS

Percentage of crown closure value varies with the density of tree, i.e., the higher density of tree the bigger percentage of crown closure. It was exceptional that, in early stage the density of rhetsa was 121 plant ha^{-1} but the majority was at the younger stage, therefore the above relationship did not hold. Meanwhile mature stage had the highest density of rhetsa and fruit trees with the crown closure of 67% which was higher than middle stage and early stage with 57% and 19% respectively. The percent of sunlight is related to percent crown density (Figure 7.6). Figure 6.21 showed the interaction of rhetsa and fruit trees in the sense of overlap of canopy. It had no overlap of canopy in early stage. Meanwhile 16% and 13% of the total area in mature stage and middle stage have overlapped between canopy of rhetsa and fruit trees.

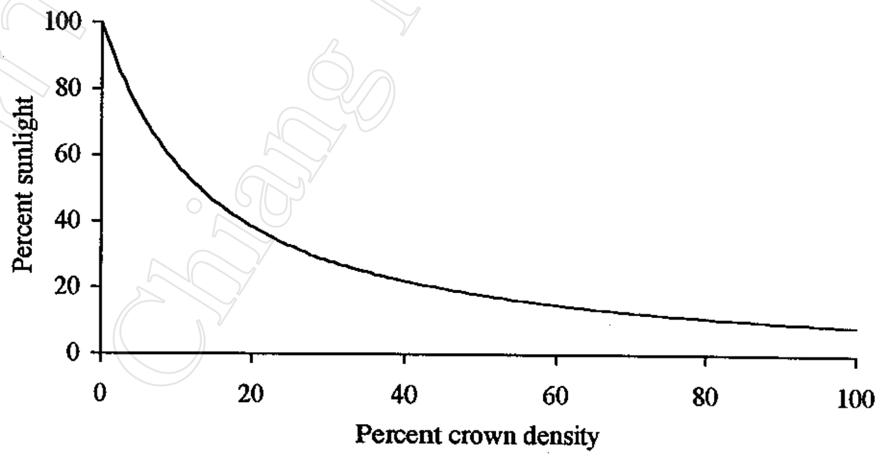

Figure 7.6 Effect of crown density on penetration of solar energy into conifers plantation (Spurs and Barnes, 1980).

Mature stage had more interaction both above- and below-ground than middle stage and early stage. Early stage had the highest area about 81% of the totals which has no canopy from rhetsa and fruit tree. Mature stage had the lowest area, about 34% of the total, which had no interaction from canopy of rhetsa and fruit trees.

There were some *miang* existed in the no interaction area of all stages. The establishment of the new *miang*, one has to consider the randomly-planted *miang* plants, size of each gap, and the height of tree around the area. The valuable index to compare the suitability gap is the ratio of diameter of a gap (D) and the height of tree around a gap (H) (Geiger, 1965 *cited by* Hinchaem, 1986). The sunlight increases in correlation with the D/H ratio (Mickle and Woerheide, 1965). The relative illuminance of the same size gap is different, if they were different in tree height around the gap, higher the tree, lower the relative illuminance (Hinchaem, 1986). Early stage which had bigger canopy gap than middle stage and mature stage (Figure 6.21) and at the same time the average height of tree is lower, therefore the relative illuminance should be higher. She also pointed out that within the gap, the relative illuminance is highest at the center of gap and declining far away from the center. Nevertheless, it is assumed that the area should be flat land. As the study site was a sloping land, the interpretation should be different.

To introduce the new plant one then has to consider open space, Figure 7.7 shows the area of availability space. It was highest in early stage, but it comprised of small gaps. The big gap was in mature stage, eventhough the total gap area was smaller than the others.

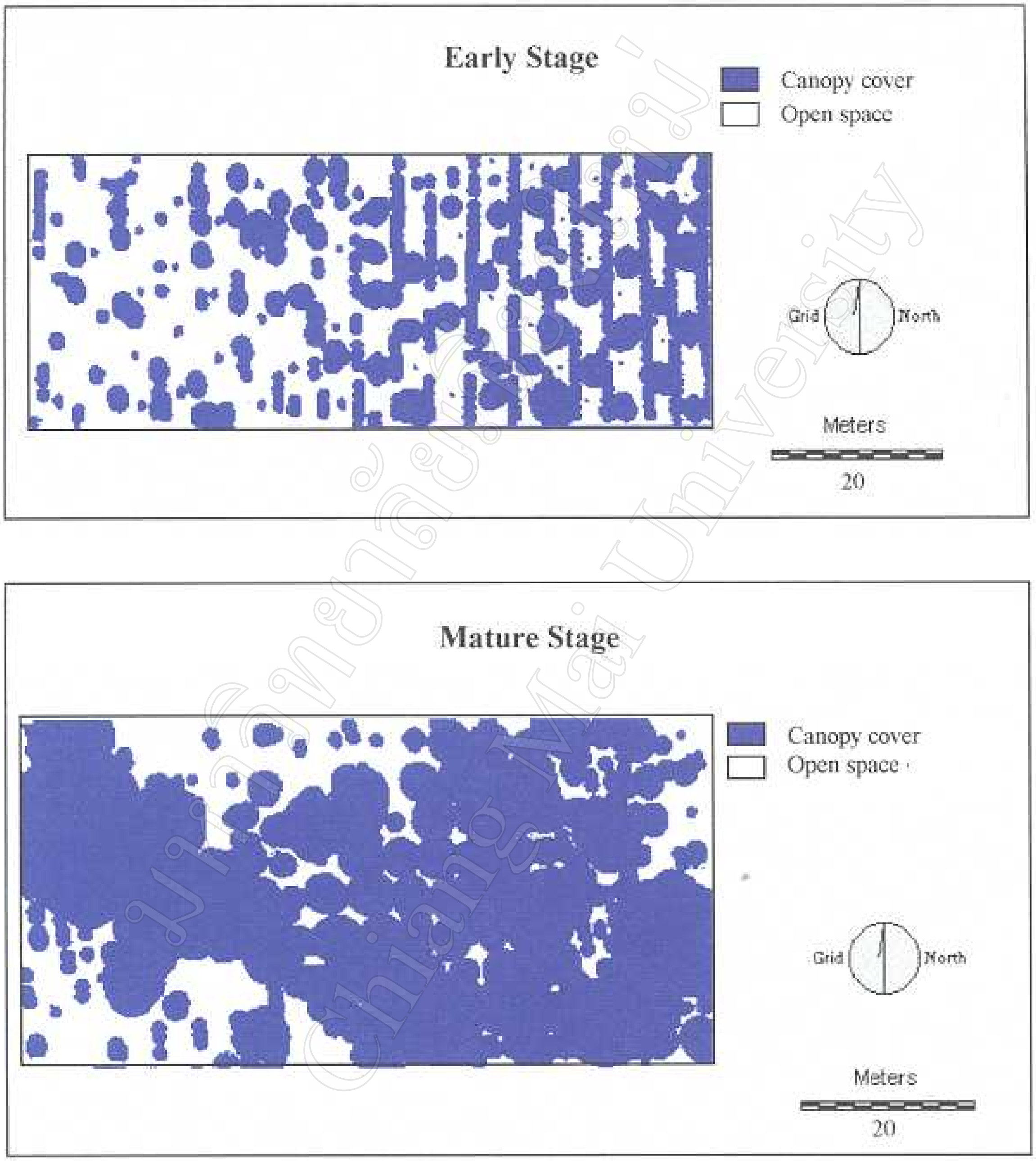

Figure 7.7 Availability space (open space) of early stage, middle stage and mature stage plots.

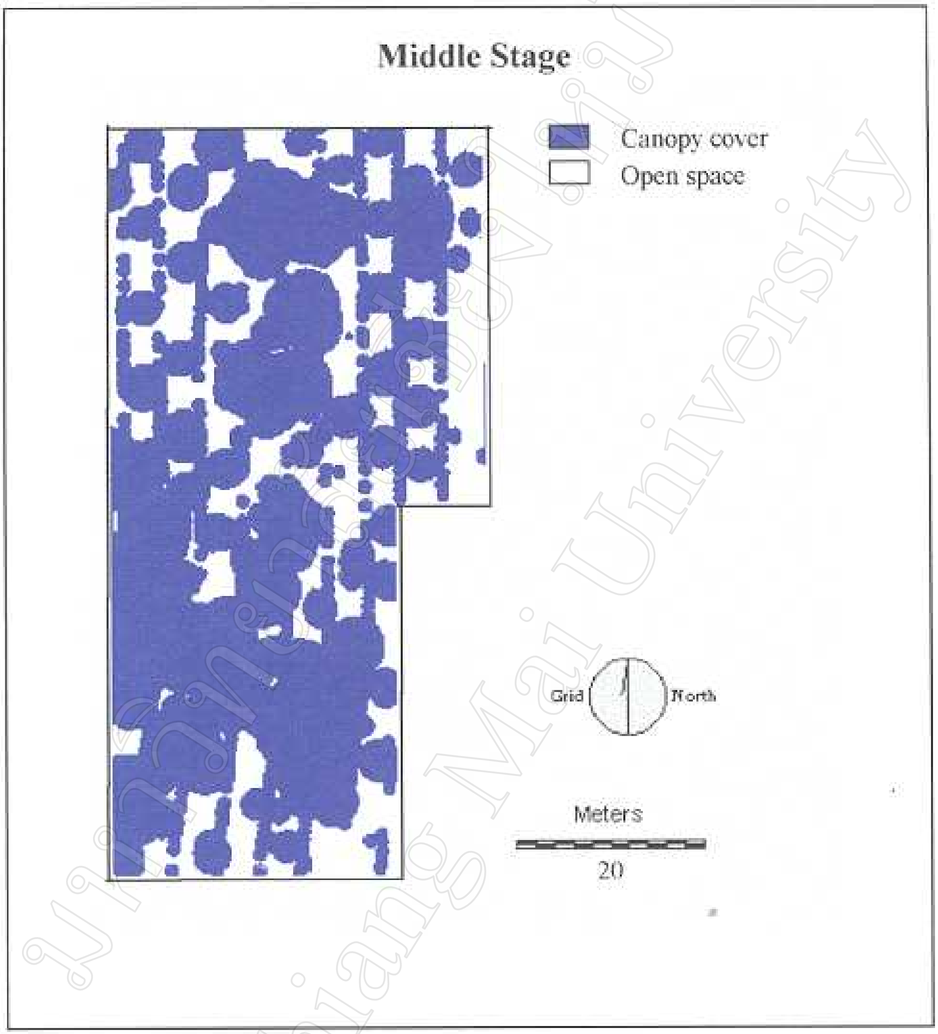

Figure 7.7 (continued)

7.7 Tree-crop Interaction in Sloping Land

Tree-crop interactions on flat land normally are complex phenomena in their own right. Since, the agroforestry is very often practised on sloping lands, a key issue is how slope alters the relationship. The tree-crop interaction in sloping area will be modified by the slope and the aspects which will in turn affect light competition and soil redistribution.

7.7.1 Competition for Light in Sloping Land

On the flat land, intercrops of dissimilar height are ideally laid out in a north-south direction, i.e., perpendicular to the solar path (Garrity, 1996). This maximises direct sunlight penetration down to the row.

There were *miang* hedgerow in middle stage and early stage as well as the fruit trees of all stages which were planted in rows. These rows were laid in north-south direction (Figure 6.8) and aspect of slope was west facing. The study area was sloping area with the slope of 38%, 40% and 35% in mature stage, middle stage and early stage, respectively. All of stages had the configuration analogous to north-south on the flat land. Eventhough the row of fruit tree in early stage laid out in contour lines, but it tended to optimise sunlight penetration to *miang* because the rows are more or less in north-south direction. *Miang*, the under storey crop, planted in rows would optimise the use of sunlight as well.

The north-south row in the sloping area has more advantage than the flat area, i.e., eventhough the height trees are the same, but the slope effect on the height will be different. For instance, average height of mango in mature stage, middle stage and early stage were 434, 370 and 292 cm, respectively and the rows were 4 m apart. Therefore, with the slope as mentioned earlier, the height of mango was 1.52, 1.60 and 1.40 cm different between the adjacent row, expanded the vertical gap. As model in Figure 6.12, on the event of canopy contact with each other in flat area such as at year ninth of mango, but it was not occurred in sloping area. Hence, the advantage of agroforestry in sloping land over flat land are prolonging crown closure time, inducing less light interception at the aspect direction, redistributing less rainfall, and less modifying humidity and temperature. The more sloping gradient, the wider canopy gap and the longer crown closure time. However, the aspect of slope should be east-west only, with slopes facing the sun, e.g., north facing fields in the north hemisphere and south facing in the south hemisphere, light penetration to the dominated species is most securely reduced (Garrity, 1996).

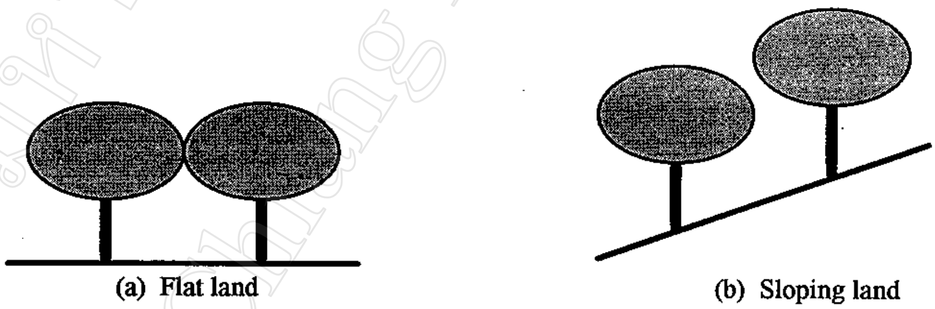

Figure 7.8 The spatial arrangement of hedgerow of fruit trees in flat land and slope land.

Between the east and the west aspect, the west aspect has higher temperature and higher rate of evapotranspiration than the east aspect, since it is higher temperature in the afternoon. However, it depended on the ambient favourite of the lower storey plant.

7.7.2 Root Interaction in Sloping Land

Solera (1993) found out that the density of roots was considerably higher in the upslope above 3 year old pruned hedges of *Cassia spectabilis* than in the soil down slope below the hedges. This is particular true for the density of fine roots (Garrity, 1996). However, from the experiment, the woody root (>2 mm) the upslope showed no different in L_t, W_t, L_{rw}, N_{max}, and root from the downslope across the species, i.e., rhetsa, mango, pomelo and *miang*.

Normally, the upslope over the hedge (lower part) will have more nutrient and moisture than the down slope below the hedge (upper part) (Solera, 1993), e.g., soil organic carbon in a *Cassia spectabilis* hedgerow was found to vary from 1.7% near the hedgerow in the upper part of the alley and of 2.8% near the lower hedgerow (Garrity *et al*., 1995 *cited by* Garrity, 1996). Available phosphorus was twice as high in the lower zone compared to the upper zone. Nitrogen increased from 0.20% to 0.27% as well as aluminium.

There are many reasons for this experiment to be differed from those results. Firstly, the root measurement concerned only woody root which was less sensitive to nutrients than fibrous root. Secondly, those measures were done on the shrub hedgerow intercropped field crop which had no grass cover, so that the surface erosion was occurred. The studied farm did not have terraces formed by the hedgerow intercropping, but the field was covered with grass thoroughly, therefore surface erosion was considered to be minimum.

Miang was planted in hedgerow in middle stage and early stage, and scatteringly and in short row in mature stage. *Miang* hedgerow was laid on the middle line between row of mango which considered the distance free from root interaction. Although 4 m apart was not enough for separating root contact (evaluated by SR and N_{max}), the slope would lead to widen the root gap and differentiate soil layer for root.

There was no proximal root which had penetrated angle less than zero degree with horizontal plane, eventhough there was some root which had degree less than 45° with horizontal plane. Those roots were generally concentrated near the tree trunk for all species and decrease away from it and with depth (Ruhigwa *et al.*, 1992; Yadav *et al.*, 1993).

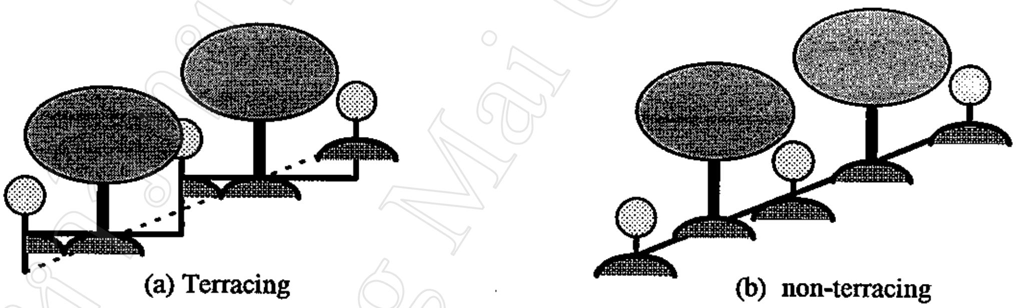

Figure 7.9 Model of canopy and root interaction in sloping land with terracing and non-terracing.

With terracing strategy, either manual terracing or natural terracing, the organic matter could be retained in the surface soil or in the upper zone, soil loss control was apparently effective (Young, 1989). On the contrary, the terracing increased root competition between mango and *miang* when their roots occupied the same zone of soil, as depicted in Figure 7.9. Therefore, roots of mango and *miang* in middle stage were more severely interacted than in early stage, because the middle stage had the terracing practice, while early stage has no terracing practice, and both of stages had the same spacing of *miang* and mango.

However, fruit trees in middle stage and early stage was allocated in triangular arrangement which increased the row distance. While fruit trees in mature stage were arranged in normal spacing.

To eradicate the root interaction in any agroforestry system, Schroth, (1995) recommended to reduce the root density by root trenching or tillage. Although it was successful for tree-crop interaction, via soil tillage destroying tree roots in the top soil, there by protecting the crops for some time from the tree competition. In the *miang*-based AFS, it was not feasible, considering *miang* was permanently planted on the land covered by grass and there was no tillage.