Chapter V

Farm Management Practices

5.1 Characteristics of the tree crops in the cropping systems

Different crop species have different vegetative characteristics and well develop in some certain climate conditions and soil types. In the study, the coffee trees are grown in association with durian, and with black pepper. And the intra-competition and inter-competition depends on the density of tree crops in the farm and the available of water, light and nutrient. Therefore, understanding the vegetative characteristics and basic requirements of tree crops in the system that will generate a good condition for farmer in managing farms.

5.1.1 Robusta coffee (*Coffea canephora* Pierre ex Fröhner)

Vegetative characteristics

The robusta coffee plant originally grew in African tropical forests from the West Coast to Uganda, chiefly between 10^{o} N and S of the equator. Coffee is a shrub type plant with several trunks, although the coffee plant may have one trunk.

Branch: coffee has a distinct dimorphic branching system. The vegetation part of the tree grows vertically to form the stem and the central axis. The lateral or primary branches are produced from the stem. These branches develop in succession from the base upward on the stem and grow out horizontally on the opposite of each node. The primary branches can not be replaced by another branches, if they die or are cut back to the main stem. And the secondary branches are developed from the primaries; likewise the secondary can produced the tertiary branches and so on.

Leaf is a bipolar leaf structure, where two leaves grow from the stem opposite each other. The distance between leaf pairs in the stem is about 1 to 3 inches. The leaf pairs generally are at 90-degree rotation for each pair on the stem. It is an evergreen (Op de Laak, 1992).

Flowers, the coffee plant flower is white, are produced in dense clusters, and formed in the axis of the leaves. (Where the leaf protrudes from the stem.) The coffee plant flowers have five-toothed calyx (outer wall of the flower), a tubular five-parted corolla (inner wall of the flower). Five stamens (pollen bearing organ) and a single bifid style (one piece pointed and divided in two equal parts). The coffee plant's flowers last only a few days. The coffee plant blooms shortly after irrigation or rainfall. The coffee flower has a strong pleasing smell. Sexually, the coffee is not autogamous, in that it can not pollinate itself (Nghiep, 1985).

Root system: taproot is a sturdy central root, often multiple, tapering more or less abruptly and rarely extending as a recognizable unit more than 80 cm from the soil surface. The lateral roots spread less or more parallel to the soil surface for a distance of 1.6 to 1.8 m from the trunk. Often they originate from the taproot. The feeder bearers are the small roots extensions of lateral roots are evenly distributed about 25 mm part. They are short and numerous. Finally is feeders developed from feeder bearers, they are white and turgid. They can be found at all depths, but more numerous at the surface soil (Thai, 1997 and Tu, 1998).

Climatic and soil requirements

Robusta can be planted at elevation up to 1,000 m above sea level and annual rainfall 1,500-2,000 mm, spread over nine to ten months. It requires optimum temperature of 20-25^{0}C and relative humidity of 80-90 percent, light wind, and needs uniform thin shade. Soil should be deep, friable well drained, slightly acidic in reaction (pH_{H2O}: 5.0-6.5), porous and rich in organic matter content. Soil should be moisture retentive (Nghi *et al.*, 1996; Nhan *et al.*, 1999 and Cambrony, 1992).

5.1.2 Durian tree (*Durio zibethinus* Murray)

Vegetative characteristics

Durian is a member of the plant family *Bombacaceae*. Duri is a Malaysian word meaning, "spike." In the genus *Durio* has at least 27 or 28 species.

The trunk of a durian tree is dark brown and peels off irregularly with many deep splits lengthways; the wood is softwood. Durian tree branches may be straight or curved, depending on the cultivar and on the amount of sunlight exposure. The trees' thin branchlets are coated with coppery or gray scales when young.

Leaf: the durian tree's simple, drooping, beautiful leaves are about 8 to 20 cm long and 2.5-7.5 cm wide. They are shiny smooth, light or dark green above; the underside is somewhat scaly, sometimes brown but more often with a golden sheen. The leaves are folded at their mid-rib when they first appear, then stretch out as they mature. The particular shades of green that durian leaves have, combined with the golden sheen of their undersides give the trees a very attractive and almost glowing appearance.

Flowers are strongly fragrant, about 50-70 mm long and grow in stalked clusters of 1 to 45 individual flowers per cluster. These flower clusters hang from the main and smaller branches, or directly from the trunk of the tree. A period of 3 to 4 weeks dry weather is needed to stimulate flowering. It takes about one month for a durian flower to develop from first appearance as a tiny bud to an open blossom. Durian flowers are hermaphrodites, each having a stamen and pistil in the same flower. However, self-pollination rarely happens, for when the flowers are open, normally from 3 p.m. to about midnight, the pistil and the stamen do not appear at the same time. The female stigma from the pistil usually comes out first, long before the anthers of the stamen appear and shed their pollen; by the time the pollen is active, the stigma is no longer receptive. By midnight most pollen has been shed and all flower parts except the pistil fall to the ground. Even if the female and male flower parts of durian flowers were active at the same time, most durian trees have a high degree of self-incompatibility. In other words, the flowers must be cross-pollinated from other trees in order to set fruit.

Root system: durian trees started from seed will have one primary taproot going directly down from the trunk and secondary roots growing out from it. If grown by vegetative propagation, the tree will not have a primary taproot; instead it will have adventitious or secondary roots growing directly from the base of the trunk. Durian does not have root hairs. The roots that absorb water and nutrients are fungus roots which grow out from the secondary or tertiary roots, and which grow only within about 50 cm of the soil surface.

Climate and soil requirements

The durian being a tropical fruit thrives well in humid climate. It can grow at elevation of lower 800 m above sea level. The best temperature range is from 25^{o}C - 30^{o}C. However, durian can not tolerate a prolonged dry period and ideally, nine to ten months evenly distributed rainfall of between 1,500 to 2,000 mm per annum is best suited for durian. It requires relative humidity over 70 percent, and light wind. Durian does best on deep, loamy, well-drained soils, rich in organic matter. Peaty or sandy and poorly drained soils should be avoided since the root system is very sensitive to standing water and is conducive to proliferation of durian disease. A pH_{H2O} range of 5.5-6.0 is ideal. Gently sloping to flat terrain is most suitable for durian cultivation. (Tan, 2001 and Phong *et al.*, 1994).

5.1.3 Black pepper *(Piper nigrum* L.*)*

Vegetative characteristics

Black pepper, the king of spices, is one of the oldest and the most popular spice in the world. It is a perennial, climbing vine indigenous to the Malabar Coast of India. The hotly pungent spice made from its berries is one of the earliest spices known and is probably the most widely used spice in the world today.

Apart from India, black pepper is widely cultivated throughout Indonesia, Malaysia, Thailand, tropical Africa, Brazil, Sri Lanka, Vietnam and China also. It is a branching vine with a smooth, woody, articulate stem swollen at the joints. A woody climber, it may reach heights of 10m by means of its aerial roots. But the main root system is underground and distributes chiefly in soil layer of 30 cm. Its broad, shiny green, pointed, petiolate leaves are alternately arranged. The sessile, white, small flowers are borne in pendulous, dense, slender spikes of about 50 blossoms each. The berry-like fruits, or peppercorns, are round, about 0.5 - 1.0 cm in diameter and contain a single seed. They become yellowish red at maturity and bear a single seed. The odour is penetrating and aromatic; the taste is hot, biting and very pungent.

Climatic and soil requirements

Black pepper can plant at elevation up to 1,500 m above sea level and annual rainfall 1,250-2,500 mm, with about one or two drought months after harvesting for developing flowers. Pepper is a tropical plant and can not tolerate frost. It will not grow where the temperature drops below 12°C. A moderate winter climate is essential. It requires optimum temperature of 18 - 26°C and relative humidity over 70 percent. But the black pepper can not suffer from strong wind, and needs uniform thin shade. Soil should have a good structure and water-holding capacity. Drainage must be good to prevent root rot. Soil depth should be more than 1m with slightly acidic in reaction (pH_{H2O}: 5.5 - 6.5), porous and rich in organic matter content. Soil should be moisture retentive (Sung, 2001).

5.2 Farmers' awareness about intercropping coffee

Coffee is traditionally grown as an understory plant, consistent with its shade tolerant nature. During the history of cultivation, most of the farmers have changed to grow coffee in full sun (monoculture) in order to improve yields and for easy management. The transformation has initially brought to producers the considerable results for the last two decades. However, this conversion has caused several problems and risks for growers, particularly small-scale farmers, during production process. So in recent years, many coffee growers have fought against the trend of shifting to full sun coffee farm by redesigning their farms with intercropping farms. Their ideas were that shifting in production method carried with it a wide scale of concerns, including loss of biodiversity, habitat fragmentation, insecticide poisoning, soil degradation and erosion, and economic resilience of small-scale farmers.

To understand the awareness of farmers about intercropping coffee-based farming system, the farmers of three coffee systems were asked about the advantages, disadvantages of intercropping farms. Surprisingly, not only the intercropping coffee farmers but also the monoculture ones responded many interesting answers of potentials of intercropping farms. The results obtained were listed in the Table 15.

Table 15. Farmers' awareness about usefulness of intercropping in coffee production

Role of coffee intercropping systems	P1	P2	P3
	--- Percentage of farmers ---		
Income stability	45.6	100.0	100.0
Income diversification	100.0	100.0	100.0
Labor generation	50.0	100.0	100.0
Shade and windbreak	63.0	47.8	69.6
Reduces insect attack	0.0	60.9	87.0
Reduces soil erosion	0.0	0.0	26.1
Returns organic matter	17.4	37.0	73.9
Provides firewood	82.6	30.4	60.9
Suppresses weed	23.9	47.8	60.9
Moderates temperature	15.2	56.5	73.9
Increases pests on-farm	100.0	10.9	4.3
Increases disease	100.0	26.1	15.2
Difficult management	89.1	0.0	0.0
Water competition	73.9	8.7	0.0
Nutrient competition	58.7	0.0	0.0
Decreases coffee yield	100.0	100.0	100.0
Increases total yield	32.6	100.0	100.0

Source: Survey, 2002.

Note: P_1(n=46): mono-coffee system, P_2 (n=46): coffee-durian intercropping system, P_3 (n=46): coffee-black pepper intercropping system

Although, there was no coffee farm under intercropping systems, the farmers of P_1 had good knowledge about the role of intercropping farms. They highly appreciated the positive contributions of intercropping systems to stabilizing family income (45.6 percent), creating shade and windbreak (63.0 percent), supplying firewood (82.6 percent), suppressing weeds (23.9 percent), generating employment (50 percent), and increasing total yield (32.6 percent) respectively. Oppositely, most of them also confirmed that increase in on-farm insect pests, and diseases, strong water and nutrient competitions among coffee trees with others, difficulty in management and in particularly decrease in coffee yield in intercropping farms were the crucial constraints in comparison with monocropping farms. Meanwhile, the farmers of P2 and P3 highly evaluated the roles of intercropping farms in forms of ecological and economical effects such as moderating microclimate, sustaining income, and generating more works. No one mentioned to the competition of nutrients, water of the trees on farm, because the farmers did not see any negative impacts on growth and yields of tree crops, although the inputs were provided with the same amount as monoculture farms. And the inetrcropping farmers did not faced with any difficulties in farm management, except, few of P2. Although, both farmers in monoculture system and intercropping systems reflected coffee planted underneath canopies of other cash trees decreased yield in comparison with sun coffee. But they also indicated that the coffee intercropping farms were properly designed and managed, the total yield was able to increase up to or over monocoffee yield level.

Generally speaking, the farmers have clearly recognized the positive effects of the intercropping systems, which were able to bring farm income stability, income diversification, and employment generation to the growers. In addition, the systems also increased total outputs and stabilize pests on farm.

On the other hand, when tree crops were grown in associations, the outputs of the farm were not only one main product, but also at least two products, which gave more chances to farmers to get income diversification. Other factor of income was income stability, yield of main crop in intercropping was often lower than that of monofarm, but more stable, because yield instability was often caused by pests, diseases and environmental variabilities. In intercropping farms, the tree crops were less affected by these factors than others of monofarms were. Even the farms were seriously damaged by pest outbreak that only destroyed one species in the crop association, resulting in a yield decreased of this species, but not of the other species. Therefore the farmers had stable income from their farms. Another important factor that intercropping farmers regarded was year-round employment generation for family and others as well. This contributed to deal with a social problem of unemployment in the village.

5.3 Characteristics of the surveyed farms

All farmers interviewed had their own coffee farms ranging from 0.5 to 2.5 hectares. 24 farmers of P1 had coffee farms with area from 1.6 to 2.0 ha, 15 farmers from 1.1 to 1.5 ha, 8 farmers owned greater 2.0 ha, and 2 farmers had land less than 1.0 ha. In spite of, located in the same village, the farmers of intercropping systems owned the land less than that of P1 farmers. 32 farmers of P2 and 27 of P3 had land from 1.1 to 1.5 ha. 10 and 12 farmers of P2 and P3 respectively owned the land with area less than 1.0 ha. Less land for cultivation, maybe one of the reasons had forced the farmers to design their farms under intercroping systems (Table 16).

Table 16. Number of household in different land holding categories

Farm size (ha)	Overall	P1	P2	P3
	--- Number of farmers ---			
0.5 - 1.0	24	2	10	12
1.1 - 1.5	74	15	32	27
1.6 - 2.0	32	24	3	5

2.1 - 2.5	8	5	1	2

Source: Survey, 2002.

Note: P1(n=46): mono-coffee system, P2 (n=46): coffee-durian intercropping system, P3 (n=46): coffee-black pepper intercropping system

All of surveyed coffee farms were grown in 1990 and 1991, this was a period of rapid increase in coffee area of DakLak province. The some sixty thousand hectares of coffee were planted under one technical standard of Vietnam Coffee Association (Khai, 1996). So the farms were designed quite uniform in variety and density. Robusta coffee was the most important variety planted in the village as well as in the four central highland provinces. The row and tree spacing were 3 m x 3 m in square planting, 1,110 coffee trees per hectare in density. Through the yearly pruning, the tree was kept its height not over 2.5 meters in order to control the tree not developing its shape as an umbrella.

The durian trees, with the local varieties called "kho qua vang", and "kho qua xanh", were planted simultaneously with coffee trees when establishing the farms. Durian trees were intercropped with coffee trees in 12 m x 12 m spacing, 69 trees per hectare (Table 17). And it was located at the center of a square with 4 coffee trees in the corners. And among the durian trees were arranged in quincuncial method. The designing intercropping farm of coffee with durian is illustrated in the diagram below (Figure 9).

Table 17. Characteristics of coffee farm systems

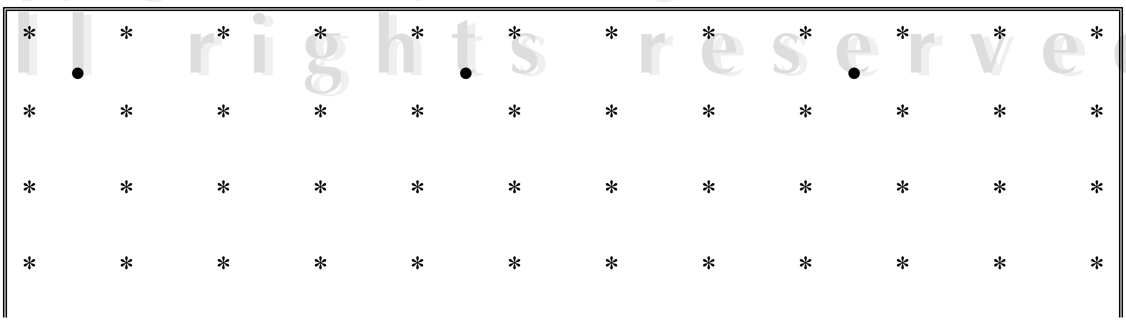
Indicator	P1	P2		P3	
	Coffee	**Coffee**	**Durian**	**Coffee**	**Pepper**
Age (year)	11 - 12	11 - 12	11 - 12	11 - 12	9 - 10

Tree spacing (m)	3 x 3	3 x 3	12 x 12	3 x 3	3 x 12
Tree height (m)	2.4	2.5	9.5	2.4	4.0
Soil type*	Rhodic Ferralsol	Rhodic Ferralsol		Rhodic Ferralsol	
Slope gradient * (%)	15 - 20	15 - 20		15 - 20	

Source: Survey, 2002. * Loan *et al*., 1989.

Note: P_1(n=46): mono-coffee system, P_2 (n=46): coffee-durian intercropping system, P_3 (n=46): coffee-black pepper intercropping system

The P_3, intercropping farms of coffee with black pepper was designed with 3 m x 3 m in square for coffee trees, 3 m in hill spacing and 12 m distance in between rows for black pepper, 278 pepper vines a hectare. The location of each black pepper hill was at the center of four coffee trees placed in the corner of a square (Figure 10). Designing the farm for developing coffee and black pepper together was carefully arranged, fistly, a *Leucaena leucocephala* and a *Leucaena glauca* trees were grown simultaneously with coffee at the positions designed for black pepper vines. And then two years after planting, the leucaena trees were big enough to play a role as living poles to support for black pepper planted adjacent leucaena trees. During the productive stage, *leucaena* trees were pruned to control tree height surrounding 4.0 m and return their biomass as an organic matter source to the soil. On the other hand, the *leucaena* also played role as windbreak tree for coffee.



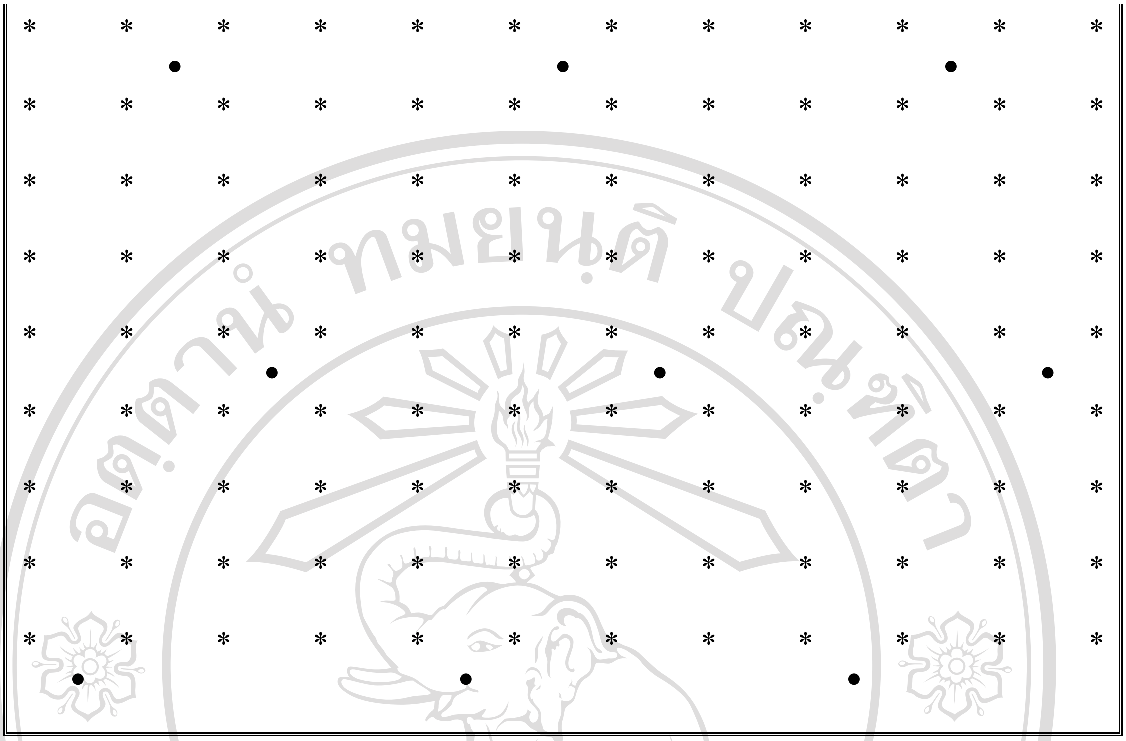


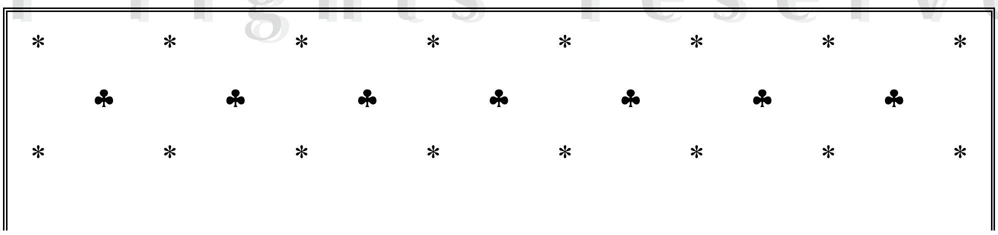
Figure 9. Spatial arrangement of coffee - durian intercropping (P2)

Source: Survey, 2002.

Note: * coffee: 3 x 3 meters in spacing

• durian: 12 x 12 meters in spacing

All farms were situated on basaltic soil (Rhodic Ferralsol), with the slope ranging from 15 to 20 percent, that was considered as a good soil type for coffee growth and development. The physical and chemical properties of the soil as stated, were evaluated to be quite suitable for perennial tree crops. According to Loan *et al*. (1989) the basaltic soil in Ea Ktur could meet the soil requirement of coffee tree. However, during the cultivation process, it was necessary to build up the methods of soil protection in order to prevent soil degradation from surface erosion.



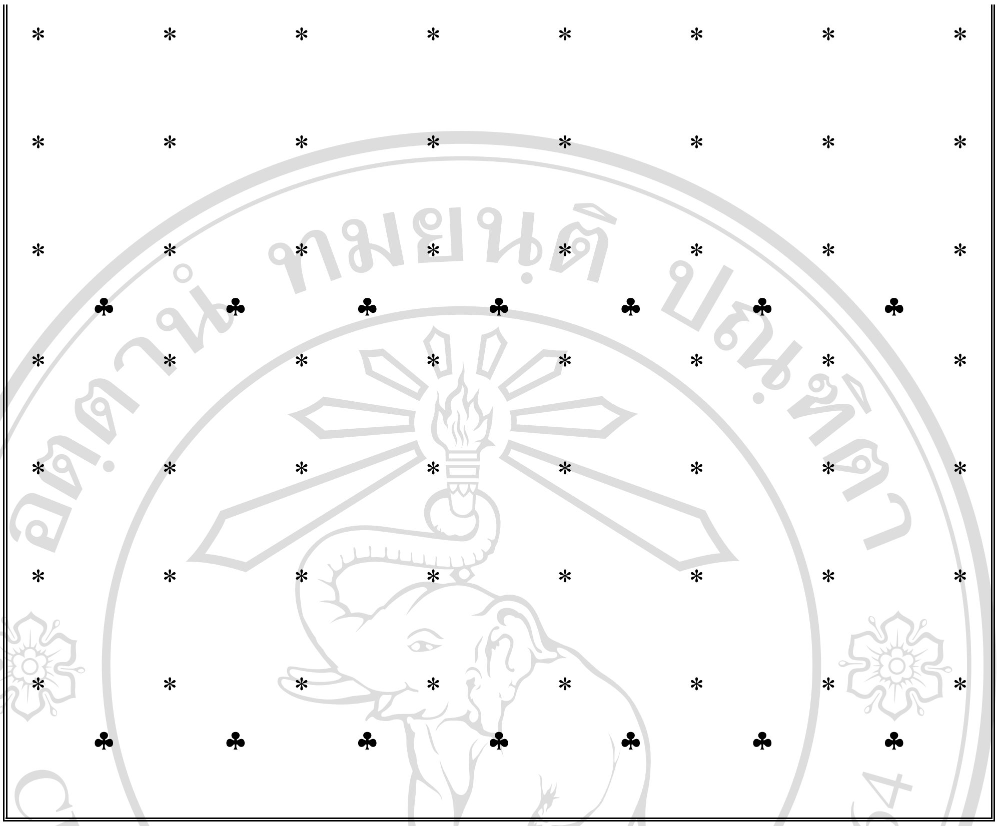


Figure 10. Spatial arangement of coffee-black pepper intercropping (P3)

Source: Survey, 2002.

Note: ∗ coffee: 3 x 3 meters in spacing

♣ black pepper: 3 x12 meters in spacing

5.4 Farm management

Farm management is the science of optimizing the use of resources in the farm components and of achieving the optimal functioning of the farms in relation to household-specified objectives (McConnell *et al.*, 1997). In the study site, the farmers concerned to the operation of their farms in order to obtain high outputs and sustain the farm productivity in the case of to be negatively affected by internal and external factors. Four major management practices of irrigation in dry season, nutrient management, pest management and pruning, influencing to farm productivity have been paying attention in production.

5.4.1 Water management

Timing and volume of water application

Coffee needs a tropical climate with two separate seasons, rainy and dry seasons. Ideally, rainfall should be evenly distributed over a period of 9 to 10 months (cropping season) and with a single dry season of about 3 months coinciding with harvesting time and developing buds (Nghi *et al.*, 1996 and Nhan *et al.*, 1999). The rainy season in DakLak was not quite that long, but most years have shown a rainy season of 6 months, sometimes less than this number. The rest months were a drought period with strong monsoon blowing from the northeast that caused extreme drought for crops and coffee as well. So it was very important to irrigate coffee in dry season to break the dormancy of flowers for even blossoming as well as to maintain the health of the tree. Fortunately, durian could harvest water in the deeper soil layers to meet its demand, because its root system distributes down to deeper soil layers (Phong *et al.*, 1994). And black pepper required less amount of water in this period. Because as coffee tree, the black pepper needs a short critical drought period to develop its flowers if it is sufficiently applied water in this time, its physiological state does still remain in the growth phase, not transform into reproductive one. Therefore, total numbers of flowers developed are very less. As a result, a poor harvest will give to growers (Sung, 2001).

In fact, the issue of how to irrigate coffee in dry season both to meet the demand of the trees and reduce the cost of irrigation was always a top concern of the coffee growers because this work completely depended upon the weather condition. In addition, the risks of water shortage in the long drought years always threaten coffee production of the village and of the province as well. A lesson since 1995 of the water resource management in dry season has given much more experience in seeking the solutions for dealing with problem of water shortage. That year, some thousands hectares of monoculture coffee were cut down before age when the dry season ended, because water sources were exhausted during an eight-month long-hash drought season, from November to late June of 1995. Even though the farms had been applied enough water in 6 months but the severe problem occurred only in last two months of the season, in some regions all water sources from small streams, lakes, dams, reservoirs and wells were exhausted. Therefore, the farms were not irrigated in last two months. The main cause of this problem was climate condition, but other contribution of this was the oversupply of water for coffee, due to lack of knowledge of on-farm water management (Sung, 1997). In reality, water was pumped from the sources such as streams, dams, lakes, reservoirs and drill wells to the farms, with cost of average 5.4 US cents (equivalent to VND 822.8) per cubic meter, excluding the labor cost.

Of the 138 farms of three systems about the starting point of irrigation in dry season, of which 87.0 percent farms of P1, 58.7 percent of P2 and only 15.2 percent of P3 were irrigated the first time in January of dry season. Most of the farms (84.8 percent) of P3 were started irrigating in mid to late February when the development of coffee buds was matured enough for flowering (Table 18). The differences of the starting points for irrigating among the systems depended on the state of the coffee trees and development level of buds, normally coffee exposed under sun the process of bud development matured earlier than that of coffee understorey. So supply of enough water to meet the physiological demand in this period played very important role in forming high yield of coffee. On the other hand, later starting point of irrigation in dry season contributed a very important role in reduction of total water volume to be applied that found out in the farms of intercropping system (P3), although all the farms suffered from a similar climatic condition.

Table 18. The starting time of irrigation for coffee in dry season

Month	**P1**	**P2**	**P3**
		-- Percentage of farms --	
January	87.0	58.7	15.2
February	13.0	41.3	84.8

Source: Survey, 2002.

Note: P1(n=46): mono-coffee system, P2 (n=46): coffee-durian intercropping system, P3 (n=46): coffee-black pepper intercropping system

Determining of how much water should be supplied to one hectare of coffee per time to meet the requirement of the trees that are an important work of the coffee growers. Because, this work not only relates to cost of production but also affects to the water source, which provides water for agriculture production of the region. Normally, the farmers relied on their feeling and experience, which were accumulated in production, to define amount of water needed. But most of them thought that oversupply for the farms were better than shortage of water. So the amount of water irrigated largely varied from 500 to 930 m^3 per hectare per time. The maximum amount was found in P2 and the minimum one was of P3. But the amounts averaged about 610 m^3, 590 m^3 and 575 m^3 of P1, P2 and P3 respectively (Table 19). Most of the coffee-black pepper farms (34 farms) were irrigated with amount of water less than 600 m^3 per hectare per time. Especially, 21 farms under this system were supplied less than 550 m^3 of water per time (Table 20). The differences from the average amount of water irrigated were non-significant at 5 percent level for the pair of P1 and P2, P2 and P3 in the t-test for n = 46. But pair of P1 and P3 was significant. Thus coffee under intercropping farms can save about 20 m^3 (P2) and 35 m^3 (P3) of water per one irrigation time in comparison with the monoculture farms. These amounts seemed to be no significance in the small-scale at farm level, but if the numbers are calculated to larger scale of provincial level with 260,000 hectares of coffee, these volumes, maybe, are very significant in protecting the water resources in dry season of the region.

Table 19. The amount of water irrigated for one hectare per time (m^3)

Statistics	Coffee systems		
	P1	**P2**	**P3**
Max.	900	930	900
Min.	550	530	500
Mean	609.8	592.8	574.3
SD	61.2	60.3	71.3

Source: Survey, 2002.

Note: P_1(n=46): mono-coffee system, P_2 (n=46): coffee-durian intercropping system, P_3 (n=46): coffee-black pepper intercropping system

Table 20. Number of farms irrigating water at different ranges (m^3/ha)

Item	Range (m^3/ha/time)	P_1	P_2	P_3
		--- Number of farm ---		
Water	< 550	3	8	21
	550 - 600	27	26	13
	600 - 650	11	10	8
	650 - 700	3	1	3
	> 700	2	1	1

Source: Survey, 2002.

Note: P_1(n=46): mono-coffee system, P_2 (n=46): coffee-durian intercropping system, P_3 (n=46): coffee-black pepper intercropping system

Table 21. Number and interval of irrigation in dry season

Statistics	P_1	P_2	P_3	P_1	P_2	P_3
	--Number of irrigation--			-- Interval (days) --		
Max.	5.7	4.4	4.0	26.0	28.0	29.0
Min.	3.3	3	3.0	18.0	20.0	22.0
Mean	4.0	3.6	3.4	22.5	24.5	26.0

SD	0.6	0.3	0.4	1.8	2.1	1.6

Source: Survey, 2002.

Note: P1(n=46): mono-coffee system, P2 (n=46): coffee-durian intercropping system, P3 (n=46): coffee-black pepper intercropping system

Depending on the length of a critical period of dry season that the number irrigation was very different from year to year. In the past three-year data collected from three coffee systems indicated that the number of irrigation in a dry season of P1 was higher than that of P2 and P3. This number could reach up to 5.7 times in P1, 4.4 times in P2 and 4 times in P3 farms. The average numbers were 4.0 times, 3.6 times and 3.4 times, respectively. Despite, less amount water irrigated to intercropping farms than that of the full sun farms, the interval of irrigation in P2 and P3 was longer than of P1, with 22.5 days, 24.5 days and 26.0 days for P1, P2 and P3, respectively, on average (Table 21). There were significant differences between means of number of irrigation and of the interval at 5 percent level.

At present, there have been four irrigation methods being used in DakLak province. Overhead irrigation or sprinkler in recent years was used quite popular. Flood irrigation was only applied in flat areas, where abundant water sources were available. Drip method has been testing at some experimental stations and the individual basin irrigation method, was most commonly applied to coffee irrigation by the smallholders, because of its convenience, flexibility and efficiency. In the study site, two methods were used to irrigate, the basin and sprinkler, the individual basin irrigation was widely practiced and in simple form was easy to operate. Most of the intercropping farms, 30 farms of P2 and 42 farms of P3 (Table 22) applied this method. The advantages of the method were low water loss from evaporation, easy operation, and cheap cost of installation. But it is labor-intensive. Meanwhile, the sprinkler irrigation most closely mimics natural rainfall. Water was projected usually under considerable pressure and discharged over the crops. The sprinkler irrigation, if designed and operated properly, can be used over a wide range of soil conditions and on uneven terrain where others would be impossible (Barrow, 1987). But there were disadvantages with sprinkler application. Moisture losses could be quite high as droplets of water vaporized in flight and much was intercepted on leaves and evaporated before reaching the ground. As mentioned, the climate in the irrigation season was very windy, the sprinkler might be seriously hindered-attempts to apply water when the air was not enough still leads to uneven application. Therefore, under this method, water was often supplied to the farms with higher amount compared to individual basin one (Bau, 1995). The other disadvantage was relatively high costs of equipment, installation and required skilled-farmers for design, installation and management. For these reason it seemed to be not suitable with smallholders of the village.

Table 22. Irrigation methods used in the surveyed farms

Irrigation method	**P1**	**P2**	**P3**
		--- Number of farms ---	
Basin	21	30	42
Sprinkler	25	16	4

Source: Survey, 2002.

Note: P1(n=46): mono-coffee system, P2 (n=46): coffee-durian intercropping system, P3 (n=46): coffee-black pepper intercropping system

The methods for increasing water-use efficiency

Normally, the higher density of tree crops in a farm, the greater amount of water they needed. Looking on the amount of water applied for the three systems, the amount applied to intercropping farms were less than that of the mono-farm. This matter seemed to be adverse from the point of view of principal ecology of crop. But it can be explained clearly by analyzing the methods that were applied to increase water use efficiency of each system.

Most of the intercropping farmers reported that soil surface to be covered could reduce the rate of evaporation of the farm in dry season. From the data collected indicated most of farms of P2 and P3 applied the practices of keeping all the leafliters, crop residues and coffee pulp/husk on the surface as the mulching materials for coffee farms in dry season. Under this condition the amount of water loss from evaporation in these farms were less than that of in non-mulching farms (Bau, 1999). Therefore, the soil moisture level may slowly reduce to the wilting point, or in other word, the soil could retain its moisture level longer than that of non-mulched farms. This played a very significant role in retaining soil water availability for coffee in dry season, in addition it also reduced risk for the coffee growers in the case of long term drought taken place in the region.

Table 23. Farmers' knowledge on methods of improving in water-use efficiency

Method	P1	P2	P3
	--- Number of farmers ---		
Keep leaf-litters on surface	5	34	46
Incorporate all leaf-litters into soil	39	12	0
Keep pruned residues on surface	18	31	30
Remove all out of farm	28	15	16
Mulch by coffee pulp	5	34	46
Incorporate all coffee pulp into soil	39	12	0

Source: Survey, 2002.

Note: P1(n=46): mono-coffee system, P2 (n=46): coffee-durian intercropping system, P3 (n=46): coffee-black pepper intercropping system

In contrary with mulching, the crop residues, leaf-litters, and coffee pulp/husk were incorporated into the soil to accelerate the decomposition process to release nutrients for crops. 28 farmers of P_1 removed all the residues from pruning process out of the farms to burn in order to eliminate pests and diseases harbor in these residues (Table 23). Actually, it was very difficult to point out which method (mulching or incorporating) was better of the two. Depending on the certain circumstances of the farm and the area that the specific method should be selected. In the case of pest and disease outbreak in the farm and region, the methods of burying all crop residues on-farm and eliminating all pest and disease-infested branches by cutting and burning should be done. Otherwise, place all residues to cover soil surface, as mulching materials for retaining soil moisture is better.

In general, irrigating for coffee in dry season was the most important activity in coffee production, because this is a main yield-limiting factor, contributing to form, stabilize and increase coffee yield. Many field experiments had conducted in three provinces of DakLak, Gia Lai and Kon Tum came up with a conclusion of prerequisite condition for coffee grown. That in the climate condition of region, coffee should be grown in the areas, where there are plentiful water sources to supply enough water for the farms in dry season, otherwise should not do (Nhan *et al*., 1999 and Nghi *et al*., 1996).

In theory, actual evapotranspiration of intercropping systems with higher population in the same unit of land is often greater than that of mono-farm in similar condition of climate. The water consumption of a system is defined as the sum of the water evaporated from the ground surface and that transpired by the crop canopy during a certain period of time. However, in the intercropping systems of coffee with durian, and coffee with black pepper contained higher population than coffee monoculture system, but the amount of water to be applied was less than one of monoculture system, and the interval of irrigation was longer than mono-system's. This can be explained that, because the intercropping farmers have applied more organic maters in forms of coffee pulp/husk and kept all the crop residues on surface as mulching materials, instead of burying as monoculture farms. As stated, total crop residues from pruning shade trees and coffee trees, leaf litters, grasses on and surrounding farm could be gained up to 25 tons of fresh weight per hectare per year for intercropping coffee farms on basaltic soils (Loan *et al.,* 1995). Therefore, the organic maters played a role as the mulching materials to cover soil surface in dry season. As a result, the soil surface dried more slowly because the cover prevented water loss from evaporation process. And the tree crops could suffer less from moisture stress than the monoculture (Bau, 1995). On the other hand, mulching or applying with a suitable organic materials might help to improve soil conditions by increasing soil fertility, conserving soil moisture, protecting the soil from compaction, and reducing soil acidity. Mulch might help to conserve the soil by reducing loss to surface run off water. High soil fertility normally enhanced plant growth, which meant good root system development. The better the root system developed, the easier the plant could extract the water and the less susceptible it was to drought. The root system, except taproot, of robusta coffee could extend no further than 50 cm below the soil surface. About 80 to 90 percent of the feeder root was in the first 40 cm of soil and was 160-180 cm away from the trunk of the tree. However, the volume of roots in the 0 to 40cm depth could be changed and heavily affected by the type of soil and soil fertility. The better soil structure and fertility the deeper the coffee root system could penetrate (Thai, 1997 and Tu, 1998). Therefore, the trees could harvest water from deeper soil layers better than those of in the mono-farms, which were able to take up water in soil surface layer only. The other issue should be concerned that application of large amount of organic fertilizers and organic maters could improve the water-holding capacity of the soil. The annual application of 5 tons of organic fertilizer and organic matter could positively improve the soil water holding capacity (WHC) and reduce the level of permanent wilting point (PWP) of the soil in the mono-coffee system (Loan *et al.*, 1996). Conversely, a decline of organic mater led to degradation of root penetration, erosion resistance, and reduction of soil water-holding capacity (Young, 1997). Therefore, it was easy to infer that the available water capacity (AWC = WHC - PWP) was higher for tree crops in intercropping systems than that of mono-system.

From all mentioned above, that could answer the question of why the intercropping farms were applied less water than that of monocultural system. But could still meet the water requirement of the tree crops in dry season.

5.4.2 Soil and crop nutrient management

Soil erosion control

Soil surface erosion caused by rainfall is a serious problem found in most countries, particularly in the upland regions of tropical regions. It is recognized as a major cause of degradation of soil productivity in both chemical and physical properties of agricultural land.

Table 24. Two simplest methods for erosion control in coffee farms

Method	P_1	P_2	P_3
	--- Percentage of farms ---		
Basin	91.3	60.9	50.0
Basin + bund	8.7	39.1	50.0

Source: Survey, 2002.

Note: P1(n=46): mono-coffee system, P2 (n=46): coffee-durian intercropping system, P3 (n=46): coffee-black pepper intercropping system

Perhaps realizing the serious damage from soil surface erosion, the farmers have paid attention on developing the methods for soil protection in the first year of established farms. The most efficient and simplest soil erosion control methods were to make individual earthen basins in each coffee tree, and basins in combining with earthen bunds made across the hillside on the farm. The distance between bunds was 12 m. The basin designed with 2.20 m in diameter and 0.20 to 0.25 m height was a laborious work. The field observation result showed that 8.7 percent, 39.1 percent and 50.0 percent farms of P_1, P_2 and P_3 respectively had been built up the basins in combination with bunds in the whole farms. The rests were adopted basin method only (Table 24). Fertilizers, organic matters, FYM, and even irrigation water were placed in the surface basins and tended to remain longer. On the other hand, to increase the level of soil protection, all leaf litters were left on surface as a material for mulching. There was no soil surface erosion on the coffee farms with soil slope less than 25 percent in the normal climate condition of DakLak, if the basin method was applied. But in the case of heavy rainstorm, often occurred in the region, the basin-bund in intercropping farms prevented runoff and soil loss better than basin ones (Truc and Loan, 1997). However, a problem with both basin and basin-bund methods was that if care was not taken year-round, the basins and bunds were broken in heavy rainfalls causing very serious damage. So, in order to guarantee the role of basin for long-run soil protection as coffee life, the maintenance works should be frequently done in combination with weeding task in the rainy season.

Following is the diagram of earthen basins and bunds built in the coffee farms.

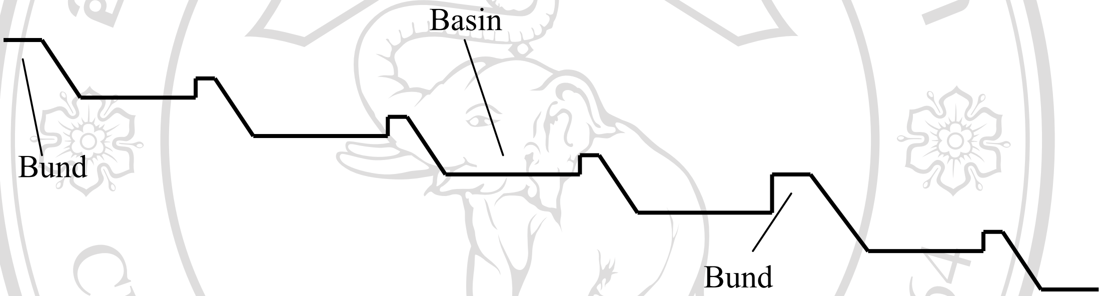


Figure 11. Spatial arrangement of individual earthen basins and earthen bunds

Source: Survey, 2002.

Crop nutrient management through chemical fertilizer application

- **Timing of application**

Whether coffee cultivation under mono-system or intercropping systems, all farms were under a type of intensification farming systems with a goal of obtaining the highest output in terms of yield or income per unit of land. In order to gain the goal, crop nutrient management through fertilizer application was one of the vital methods. At present, application of synthetic fertilizers was a main source to provide nutrients for the trees.

Crop nutrient management by applying fertilizer types was a common tool not only in the study site but also in the whole province. Through this process the trees were met the nutrient demand for growth, development and yield. But the problem was how to determine exact amount of fertilizers to apply and timing of application. Normally the coffee scientists suggested analyzing soil chemical properties and coffee leaf nutrient contents to identify the demand of trees in a seasonal production (Son *et al.*, 1990). But in practice, the growers had no available tools to do it, and this work was costly. So, the farmers only relied on their experience and knowledge accumulated in production and some available documents to manage their farms.

Fertilizers were mainly applied for tree crops in farms during 6 months of rainy season when soil moisture content was high enough to support for the uptake of the trees and the nutrient demand of the trees was high. All fertilizer types were split to add to farm in February, March, May/June, July/August, September and October. 100 percent farms of P1, P2 and P3 were applied nitrogen and potassium in May/June and September. 41 farms, 45 ones and 46 ones respectively were added those in July/August. 10 farms of P1, 19 farms of P2 and 26 farms of P3 were provided nitrogen and potassium in October, these nutrient sources were used to feed the branches, which will bear fruits in the next season. In rainy season, nitrogen and potassium fertilizers were mixed to apply simultaneously. There were two months in dry season that nitrogen was added with fewer amounts in order to supply nutrient for the trees to be better flowering, pollinating and forming berries. On the other hand, that was the nutrient source provided to strengthen the crop health for resisting the harsh climate condition. The first application was in February with 4 farms of P1, 5 farms of P2 and 6 farms of P3. Secondly, in March, with 7 farms, 6 farms and 14 farms respectively were fertilized. To reduce nutrient loss through volatilizing that took strongly place in dry season and to increase nitrogen use efficiency, nitrogen application was done simultaneously with irrigation. But be careful when providing nitrogen to crops in this time, because nitrogenous fertilizers tend to increase leaf growth that raises evaporation rate. So the dosage of 10 percent of total amount of nitrogen for each application that was the optimum quantity for raising crop yields without increased applications of water (Tu, 1998).

For phosphorus, the application concentrated in the wet season when the soil moisture was high enough to dissolve nutrients as well as to reduce the reactions between phosphate with other elements to form insoluble compounds, which was not available for taking up by plants. 100 percent interviewees said that the first phosphorus application was in May/June, and 13 farmers of P1, 24 of P2 and 28 of P3 reported they had the second time of application in July/August, especially 9 growers in P3 fertilized phosphorus in September (Table 25).

Table 25. Number of farms applied fertilizers in a given month

Month	N			P_2O_5			K_2O		
	P1	P2	P3	P1	P2	P3	P1	P2	P3
	--- Number of farms ---								
Feb.	4	5	6	-	-	-	-	-	-
Mar.	7	6	14	-	-	-	-	-	-
May/Jun.	46	46	46	46	46	46	46	46	46
Jul./Aug.	41	45	46	13	24	28	41	45	46
Sep.	46	46	46	-	-	9	46	46	46
Oct.	10	19	26	-	-	-	10	19	26

Source: Survey, 2002.

Note: P1(n=46): mono-coffee system, P2 (n=46): coffee-durian intercropping system, P3 (n=46): coffee-black pepper intercropping system

As mentioned above, fertilizer was divided into smaller parts to apply during seasonal production. Farmers applied nitrogen fertilizer with a maximum of 6 times and minimum of 2 times a year. Phosphorus was added a maximum of 3 times and a minimum 1 time respectively. And potassium ranged from 2 to 4 times.

About 65 percent of farms of monoculture coffee system (P1) were applied nitrogen fertilizer 3 times a year, 21.7 percent for 4 times and 8.7 percent for 5 times, only 4.3 percent for 2 times. While, 50 percent of farms of coffee-durian system (P2) and 56.5 percent of farms of coffee-black pepper system (P3) were provided nitrogen fertilizer at least 4 times in a seasonal production. One time of phosphorus application in May/June was identified in 71.7 percent of P1 farms, 47.8 percent of P2 and 39.1

percent of P3. The rest applied 2 times of application, except in P3, where 60.9 percent of farms were added phosphorus fertilizer at least 2 times a year. Over 41 percent and 56 percent farmers interviewed of P2 and P3 respectively answered that potassium fertilizer should be separated into smaller amount to supply for 4 times in the rainy season (Table 26).

Table 26. Percentage of farms with different number of fertilizer applications per year

Fertilizer type	Number of applications	P1	P2	P3
		--- Percentage of farms ---		
Nitrogen	2	4.3	2.2	0.0
	3	65.2	47.8	43.5
	4	21.7	34.8	26.1
	5	8.7	15.2	17.4
	6	0.0	0.0	13.0
Phosphorus	1	71.7	47.8	39.1
	2	28.3	52.2	41.3
	3	0.0	0.0	19.6
Potassium	2	10.9	2.2	0.0
	3	67.4	56.5	43.5
	4	21.7	41.3	56.5

Source: Survey, 2002.

Note: P1(n=46): mono-coffee system, P2 (n=46): coffee-durian intercropping system, P3 (n=46): coffee-black pepper intercropping system

- **Amounts of fertilizers and balanced fertilization**

Before 1998 the coffee price was quite high, ranging from US$ 1,000 - 1,500 per ton of green bean (dry weight). That has stimulated the coffee growers in the province to invest so much money in chemical fertilizers in order to gain as high as possible coffee yield. They thought that the more fertilizers were added the greater yield they got. Total amount of major nutrient elements applied to one hectare reached to 1,400 kg of N, P_2O_5 and K_2O, accounting to 1,300 kg urea, 1,350 kg thermal phosphate (fused magnesium phosphate - FMP), and 1,000 kg potassium chloride (KCl) (Tu, 1998). As a consequence, the farms had given so high yield after some years of high chemical input application. And then, the series of problems such as pests and diseases outbreak, soil degradation (including chemical, physical and biological degradation), and environment contamination attacked the coffee farms in large scale of the province, and some thousand hectares of coffee lost their productivity and were cut down.

In the past 4 years, the coffee price had sharply fallen forcing the coffee growers to make some adjustments in management for better production. The chemical materials, especially fertilizers still played the main role in providing nutrients for tree crops but used with fewer amounts than before. As a result, many necessary lessons about farm management have been evolved from these works for present and future production. And the farmers recognized that their farms have been better producing than some years ago.

The amount of fertilizers applied in the past three years is presented in Table 27. In the mono-coffee system (P1), these amounts averaged about 336 kg N, 115 kg P_2O_5, and 332.5 kg K_2O. In the coffee-durian system (P2), the chemical fertilizers were applied with an average of 290 kg N, 96 kg P_2O_5, and 295 kg K_2O per hectare per year. Actually, these were chiefly applied to coffee trees in P2 and P3 farms, the durian of P2 farms could take up nutrients leached in deeper soil layers. Moreover, the maximum amount of nutrients, which a durian needs, was not so much, about 0.5 kg N, 0.25 kg P_2O_5 and 0.25 kg K_2O per year (Phong *et al.*, 1994). Account for one hectare of P2, 69 durian trees, total amount of fertilizers devoted to durian was 35 kg N, 17.5 kg P_2O_5 and 17.5 kg K_2O. These quantities, the durian might harvest from the source of deeper soil layers beyond coffee root system. For the coffee-black pepper system (P3), total amount of chemical fertilizers applied was less than that of P1 and P2. Nitrogen fertilizer was used with dosage of 261.3 kg N per hectare per year in average, maximum 460 kg N and minimum 200 kg N. For phosphorus was added to farms with amount of 76.2 kg P_2O_5 in average, approximately 500 kg thermal phosphate. The amount of K_2O application ranged from 210 to 450 kg per hectare per year, with an average of 268.5 kg. These amounts should be extracted about 20 kg N, 30 kg P_2O_5 and 28 kg K_2O to provide for 278 pepper vines and be applied simultaneously with coffee (Sung, 2001). Testing for difference between the means of two independent populations P1 and P2, P1 and P3, P2 and P3 indicated that there were significant differences at 5 percent level between each pair of populations.

Table 27. The amount of fertilizers applied per year (kg per hectare)

Statistics	**P1**			**P2**			**P3**		
	N	**P_2O_5**	**K_2O**	**N**	**P_2O_5**	**K_2O**	**N**	**P_2O_5**	**K_2O**
Max.	610	150	600	420	150	480	460	145	450
Min.	250	90	220	200	60	220	200	60	210
Mean	335.9	115.1	332.5	290.3	96.5	295.5	261.3	76.2	268.5
SD	88.7	19.6	68.5	46.4	20.2	48.1	47.2	17.6	41.5

Source: Survey, 2002.

Note: P1(n=46): mono-coffee system, P2 (n=46): coffee-durian intercropping system, P3 (n=46): coffee-black pepper intercropping system

Looking on certain coffee-based system in terms of the number of farms applying different dosages of chemical fertilizers, it was indicated that 35 of 46 P1 farms and 35 farms of 46 P2 respectively were added N with amount ranging from 250 to 350 kg per hectare per year. While the P3 farmers used less N than that of P1 and P2, less than 250 kg N application per year was found in 22 farms of P3. For phosphorus, 44 farms of P1 were provided P_2O_5 with amount greater than 90 kg per hectare. This figure was recorded in 27 farms of P2 and only 5 farms of P3. 23 farmers of P3 said that they applied maximum 70 kg P_2O_5. For their reasons, application of organic matters and organic fertilizers were able to release P_2O_5 in the insoluble forms into soluble forms for uptake of tree crops. According to the available data, the basaltic soils (Rhodic Ferralsol) are very rich in total phosphorus, but poor in available one (Truc and Loan, 1997). So any types of organic matter application to the farm were able to contribute to reduction of phosphorus fixation from fertilizer sources. For potassium, most of the coffee intercropping farms were applied less than 300 kg per hectare. Meanwhile, 33 of 46 mono-coffee farms were added more than 300 kg per hectare (Table 28).

Table 28. Number of farms applying fertilizer at different ranges (kg/ha)

Fertilizer type	**Range (kg/ha)**	**P1**	**P2**	**P3**
		--- Number of farms ---		
N	< 250	1	7	22
	250 - 300	22	25	19
	300 - 350	13	10	2
	350 - 400	1	3	2
	> 400	9	1	1
P_2O_5	< 70	0	4	23
	70 - 90	2	15	18
	90 - 110	21	20	2
	110 - 130	10	2	2
	> 130	13	5	1
K_2O	< 250	2	7	16
	250 - 300	11	29	26
	300 - 350	26	7	2
	350 - 400	3	1	1
	> 400	4	2	1

Source: Survey, 2002.

Note: P_1(n=46): mono-coffee system, P_2 (n=46): coffee-durian intercropping system, P_3 (n=46): coffee-black pepper intercropping system

With the average amount of major nutrients applied above, it seemed to be very high in comparison with amounts of nutrient demands of the tree crops. One hectare of coffee with over 10 years of age (an average yield of 17 tons of fresh beans) under monoculture took up about 165 N, 20 P_2O_5 and 180 K_2O from soil for development, growth and yield. But the chemical fertilizer-use coefficients of robusta coffee on basaltic soil were not so high, about 43 percent of N, 7 percent of P_2O_5, and 48 percent of K_2O applied (Nam *et al.,* 1999). So, with the average fertilizer amounts of P1, for example, the coffee trees could take up about 145 kg N, 8 kg P_2O_5 and 160 kg K_2O. The rests were lost through leaching, volatizing, eroding and fixing. Therefore, to increase the fertilizer-use efficiency, minimize nutrient losses, and to meet sufficient nutrients to crops, a series of following useful methods have been done.

Fertilizer application to the farms has to meet not only optimum quantity but also appropriate ratio of N: P_2O_5: K_2O. Reasonable and balanced fertilization contributes to stabilize and to improve soil fertility, to increase quality and crop yields, to conserve water resources from contamination, and to reduce toxic substances emission to the air, because the amount of fertilizer application is used by tree crops with the highest efficiency. In addition, the amount of nutrient losses through harvesting, leaching, and washing out soil surface will be compensated by fertilizer application to maintain soil fertility and to guarantee nutrient supply for the trees (Tu, 1998). The optimal ratio of N : P_2O_5 : K_2O application suggested to robusta coffee on basaltic soil of four central highland provinces was of 2.5 : 1 : 2.5 (the Vietnam National Agriculture and Forest Extension Department or NAFED, 1998). The results from the PPI-PPIC East and Southeast Asia Program on-farm research on coffee showed the significant effect of balanced fertilization on yield. Potassium was the most yield -limiting nutrient for robusta coffee on basaltic soils in southern Vietnam. Among the nutrients tested, potassium had the largest impact on cherry production from robusta coffee (Dibb *et al*., 1999). The second was nitrogen and phosphorus was the third. Many coffee researchers had suggested the ratio of three macronutrient elements (N : P_2O_5 : K_2O) should be 3 : 1 : 3, or 2 : 1 : 2. They found that the coffee tree positively responded to these ratios. Because balanced fertilization stimulated the plant better taking up nutrients provided, therefore leading to increasing in fertilizer-use efficiency. Crop yields and nutrients were accumulated at optimal level under these ratios rather than other ones of 2 : 1 : 4; 3 : 1 : 2; and 4 : 1 : 4 (Tu, 1998 and Y-Kanin *et al.*, 2001 and Nam *et al.*, 1999). However, the survey results showed that many farmers applied imbalanced ratios to their farms, the N : P_2O_5 : K_2O ratio reached to 6.5 : 1 : 4.8 in mono-coffee farms, 4.1 : 1 : 4.4 in coffee-durian farms, and 4.9 : 1 : 4.7 in coffee- black pepper farms. Even though on average ratios were at an appropriate level of 3 : 1 : 3, except coffee-black pepper farms with 3.5 : 1 : 3.6 ratio (Table 29), which seemed to be an imbalanced ratio. Maybe not, if looking ahead to the amount of organic materials applied to the coffee-pepper farms, it could be explained that this ratio could be balanced. The phosphorus fertilizer applied to soils, especially acid soil (Rhodic Ferralsols), reacted with Fe, Al and Mn ions and their oxides and hydroxides to form insoluble precipitates, this increased as soil acidity increased. Therefore the phosphorus was not available for uptake by plants (Schoroth *et al.*, 2003). But when the soil was annually added organic fertilizer and organic matters that could increase the solubility of phosphorus in the soil and reduce phosphorus fixation by competing with phosphate ions for sorption sites such as oxides of irons and aluminum and clay mineral. These reactions rarely take place in organic matter-poor soils (Can, 1976; Lich *et al.*, 1997 and Palm *et al.*, 2001). Moreover, organic matters played very important role in increasing phosphorus-use efficiency of coffee trees on organic matter-rich soils compared with organic mater-poor soils (Nam *et al.*, 1999). For all reasons above showed that the phosphorus was released to the soil with a considerable amount in form of available ones that met the requirement of the trees under coffee-black pepper farms in nutrient balance ratio.

Table 29. Ratio of nitrogen, phosphorus and potassium application

Statistics	**P1**	**P2**	**P3**
	N:P_2O_5:K_2O	**N:P_2O_5:K_2O**	**N:P_2O_5:K_2O**

Max.	6.5 : 1 : 4.8	4.1 : 1 : 4.4	4.9 : 1 : 4.7
Min.	1.9 : 1 : 2.0	1.9 : 1 : 2.0	2.4 : 1 : 2.2
Mean	3.0 : 1 : 2.9	3.1 : 1 : 3.1	3.5 : 1 : 3.6

Source: Survey, 2002.

Note: P1(n=46): mono-coffee system, P2 (n=46): coffee-durian intercropping system, P3 (n=46): coffee-black pepper intercropping system.

Generally speaking, splitting chemical fertilizers, particularly nitrogen and potassium fertilizers, into smaller parts for applying that was a good technique in increasing fertilizer-use efficiency of plants. The N and K_2O should be added 4 times in rainy season, P_2O_5 was applied 2 times in late May and early August. And at least one time of N application in dry season was an effective way to meet nutrient requirement of the tree crops during flowing and pollinating period (Tu, 1998). As having said the topography and climatic conditions in Ea Ktur were slope and concentrated rainfall respectively, so the problem of nutrient loss through soil surface erosion and leaching caused by these factors take place regularly in both the study site and the whole province in rainy season. To reduce the losses and to meet the nutrient demand of plants in vital stages in a seasonal production as well as to prevent phosphorus fertilizer formed in insoluble compounds, it is very important to add chemical fertilizer with small dosages in some given months of the season.

- **Types of chemical fertilizer used**

At the village, the agricultural services such as pesticides, insecticides, fertilizers, and market of agricultural products, were plentiful and accessible. According to a village leader, there have been at least 15 types of fertilizers sold in the village. N.P.K (16.16.8), N.P.K (16.8.16), N.P.K (20.10.20), N.P.K (15.5.15), N.P.K (14.7.14), urea, ammonium sulfate, diammonium phosphate, thermal phosphate, super phosphate, potassium chloride, potassium sulfate, some kinds of bio-fertilizers and several kinds of foliar fertilizers could be found in any fertilizer shops around the village.

Data from survey indicated that the farmers used only urea, ammonium sulfate, thermal phosphate and potassium chloride to apply for their farms. The reasons for these selections were cheap prices and nutrient element content diversification. Normally, N nutrition was supplied in the forms of urea and ammonium sulfate in combination with the ratio of 3:1 in order to provide N as well as S (Sulfur) as the fourth major nutrient element for plants. K_2O was applied in form of potassium chloride (KCl) due to its cheap price and plentiful supply source. 100 percent farmers used thermal phosphate, because besides P_2O_5 content, this fertilizer contains about 28 percent of CaO and 18 percent of MgO as the secondary nutrients for crops, in addition these elements (CaO and MgO) are the vital materials in neutralizing soil acidity, which is quite high in basaltic soil. No one used D.A.P (diammonium phosphate) because its price was high and the supply sources were not stable. Super phosphate was not used, because in super phosphate content contains a part of sulfuric acid, which could increase acidity level of soil (Yem, 1995) (Table 30).

Table 30. Type of fertilizers to be used

Fertilizer type	**P1**	**P2**	**P3**
		--- Number of farmers ---	
Urea	46	46	46
S.A	31	27	38
Thermal phosphate	46	46	46
Potassium chloride	46	46	46
Bio-fertilizer	21	31	40

Source: Survey, 2002.

Note:

- P_1(n=46): mono-coffee system, P_2 (n=46): coffee-durian intercropping system, P_3 (n=46): coffee-black pepper intercropping system
- The contents (concentrations) of each kind of fertilizer as follows:

- Urea: 46 % N

- Ammonium sulfate (S.A): 21 % N, 24% S

- Thermal phosphate: 16.5 % P_2O_5, 28% CaO, and 18% MgO

- Potassium chloride : 60 % K_2O

- Bio-fertilizer: 20% OM, 1% P_2O_5, 1.3×10^6 cellulose composed microorganism per gram, 25% moisture, and others

Organic matter and organic fertilizer

All farmers interviewed had a good knowledge of the role of organic matter in maintaining and improving soil fertility. All materials include livestock manure, crop leaves, pulp from coffee berries, grass clippings, weeds, and corn stalk residue that can be used as the nutrient sources to supply for the farms. All of those thought that organic matter application was beneficial to the soil and tree crops, despite apparent constraints in time, energy and sometimes money.

Farmers had an excellent understanding that soil fertility was partially derived from leaf litter, especially from the *leucaena* trees that defoliate year-round. Farmers had a good knowledge that organic matters decomposed, releasing nutrients into the soil substrate. Without indicating a knowledge of relatively advanced concepts used by the scientific community, farmers were quick to describe the observable improvement in health of coffee plants that were found beneath shade trees that deposit great amounts of decomposing litters.

Table 31. The property of nutrients in organic matters and cattle dung (% dry weight)

Property	Cattle dung	Coffee leaf	Coffee pulp	Leucaena leaf

N	2.15	2.98	1.59	4.23
P_2O_5	0.54	0.24	0.18	0.51
K_2O	3.07	2.02	3.50	2.56
CaO	0.98	1.06	0.42	1.38
MgO	0.83	0.90	0.26	0.23
S	0.25	0.20	0.31	-

Source: Tu, 1998.

Some documents related to the properties of some crop residues like coffee leaf, pulp of coffee, and *leucaena* leaf showed that the mineral nutrient contents are so high in these materials that range from 0.18 to 4.23 percent of dry weight. N and K_2O occupy high proportions with amount of 2.98 percent N, 2.02 percent K_2O in coffee leaf. Coffee pulp contains 1.59 percent N and 3.50 percent K_2O. 4.23 percent N, and 2.56 percent K_2O are found in content of *leucaena* leaf (Table 31). So, if these sources are returned to the soil, not only release a considerable amount of available nutrients for plants through decomposing processes, but also improve soil properties, especially physical properties. For instance, application of one ton of cattle dung and one ton of coffee pulp that release average of about 35 N and 75 K_2O to soil in form of available nutrients for plants. Therefore, organic matters can meet a part or entire of nutrient demand of plant, if the amount of organic matters supplied is in enough quantity and of good quality.

Bio-fertilizer made from peat, city-refused substances and microorganisms has been receiving attention from the farmers in replacing a part of chemical fertilizers to apply to the farms. In recent years, the farmers started using bio-fertilizers with the hope of improving soil structure and fertility for better production. Although its price was so high in comparison with FYM, the farmers applied, on average, about 800 kg per hectare per year in P3 farms. In P1 and P2 the quantity applied was about 300 kg and 430 kg per hectare, respectively. Cattle dung, poultry manure as FYM that are the valuable organic fertilizer types supplying pure nutrients for plants without harming environment and human health. The FYM was applied with amounts of 735 kg per hectare to P1 farm, 787 kg per hectare to P2 farm, and 822 kg per hectare to P3 farm in average.

Table 32. The amount of organic matter and organic fertilizer applied (kg/ha)

Statis	**Bio-fertilizer**			**FYM**			**Coffee pulp**		
-tics	**P1**	**P2**	**P3**	**P1**	**P2**	**P3**	**P1**	**P2**	**P3**
Max.	1,000	1,900	2,200	1,500	4,400	2,000	2,000	5,500	6,000
Min.	0.0	0.0	0.0	0.0	0.0	0.0	1,000	1,000	3,000
Mean	302	429	798	735	787	822	1,463	2,806	3,811
SD	359.3	419.7	521.5	418.0	969.0	544.8	259.4	714.4	694.2

Source: Survey, 2002.

Note: P1(n=46): mono-coffee system, P2 (n=46): coffee-durian intercropping system, P3 (n=46): coffee-black pepper intercropping system

Actually, FYM was added once every two years with double amount in order to take long time for FYM to decompose to release nutrients as well as to save labor cost. But the sources of the FYM are now becoming gradually scarce in DakLak. So the coffee growers had to seek other sources to replace FYM. They knew that all kinds of grasses, leaf litters, coffee pulp, organic wastes of the city that can be produced to become valuable organic fertilizers. Nevertheless, they have been facing with the problems such as collecting, treating, and producing processes. Therefore, they have applied the simple methods of burying all kinds of grasses clipping in wet season, in addition placing coffee leaf litters and returning coffee pulp to soil surface as mulching materials in dry season and supplying nutrients through decomposition processes in wet season for coffee trees. The amount of coffee pulp/husk returned to the farms depends on each farm but averaged about 1,500kg, 2,800kg and 3,800kg for P1, P2 and P3 respectively (Table 32).

In summary, soil surface erosion is one of the main causes that result in soil degradation, especially in sloping land. In DakLak, with the hilly and gully topography, and high amount of precipitation of 6 months, therefore the problem of soil surface erosion regularly happened in the large scale and caused the serious damage for agricultural production. The setting up the methods of soil protection from surface erosion such as basin, and basin-bund on coffee farms that played very important roles in keeping the soil in place and preventing the nutrient and organic matter losses associated with surface erosion.

High organic matter in soil contents contributed to a vital role in maintaining the soil productivity. Not only abiotic contents but also biological properties were improved to generate a favorable soil environment condition for growth and development of crop plants in both above and under ground. So application of organic matters in form of compost, FYM, crop residues, coffee leaf, and coffee pulp/husk was a sustainable way to guarantee for long-term productivity of the farms. In this case, the inorganic fertilizer-use coefficient was increased, leading to reduce total amount of chemical fertilizer application. The inorganic fertilizer-use coefficient of coffee farms with organic matter application was 30.2 percent higher than that of in control farms of without organic matter application (Nam. *et al.*, 1999). On the other hand, a long-term application of coffee pulp/husk and crop residues as mulch, cow-dug and optimal synthetic fertilizers could increase coffee yield. Mulching coffee farm with husks and cow-dung improved soil-water conservation regime and uptake of nutrients significantly. The application of coffee pulp/husk and cow-dung in soil amendment revealed their potential substitutes for mineral fertilizers [Onzima *et al.*: URL. 4].

Therefore, the intercropping coffee systems have a potential of reducing amount of synthetic fertilizers application without affecting on farm productivity. Because besides the nutrient sources from mineral fertilizers, the farms were provided other nutrient sources coming from outside and inside farm in the forms of organic materials, which were the considerable nutrient amounts to replace a part of chemical fertilizers. In addition, it contributed to prevent negatively environmental impacts, and protect human health, especially to sustain coffee production that was an indicator of sustainable coffee production.

5.4.3 Pest management

Pest and disease are always the main problems of agricultural production and coffee production as well. Insect pests and diseases damage coffee and reduce its yield, robbing the farmer of his profits. To prevent such losses, the farmer should know the insect pests and diseases characteristics and how to control and manage them. At present, according to the plant protection scientists, the problem of disease damage is not a serious issue of the coffee growers, because only coffee leaf rust, caused by the fungus *Hemileia vastatrix,* B and Br., is considered to be the most serious leaf disease of robusta coffee. But this disease was completely controlled by several technologies and resistance varieties (Loang, 1999). So in this report, only insect pests, a regularly serious menace to robusta coffee production in the study village are concerned to deal with.

Farmers' knowledge on pest and natural enemies

Asking the coffee growers about their awareness of harm of insect pests and the benefits of natural enemies with the tree crops in their farms, the results showed that, the P1 farmers could identify insect pest species better than that of in P2 and P3. However, there was no relationship between the number of years of coffee production experience with pest identification, although some growers had more than 20 years of experiences.

The majority of farmers interviewed could easily recognize all kinds of serious coffee pests that they have ever seen in their farms. By showing the color pictures of 12 insect pests, including 8 serious pests and 4 non-serious ones that were identified by plant protection scientists, and asking the farmers what they have known about these insects. Surprisingly, the respondents not only recognized all kinds of serious pests, but also described accurately the characteristics, behaviors and performance of insect pests. Their knowledge about these insect pests could be considered as the coffee plant protection experts'.

Table 33. Farmers' perception about serious pests

Insect pest		**P1**	**P2**	**P3**
English name	**Scientific name**	**--Percentage of farmers--**		
Red coffee borer	*Zeura coffeae* Nietner	100	95.6	100
Coffee stem borer	*Xylotrechus quadripes* Chevrolet	100	100	97.8
Coffee branch borer	*Xyleborus morstatti* Haged	95.6	100	91.3
Coffee berry borer	*Hypothenemus hampei* Ferr	100	100	95.6
Green scales	*Cocccus vidiris* Green	100	100	100
Brown scales	*Saissetia coffea* Walker	91.3	82.6	89.1
While scales	*Pseudococcus citri*	100	100	100
Black aphids	*Toxoptera aurantii* Fonse	89.1	91.3	100

Source: Farmer interview, 2002.

Note: P1(n=46): mono-coffee system, P2 (n=46): coffee-durian intercropping system, P3 (n=46): coffee-black pepper intercropping system

100 percent of P1 farmers, 95.6 percent of P2 and 100 percent of P3, immediately realized and described the damage of red coffee borer, it attacks the tree by making the tunnels in the stem and branches, causing dieback of upper parts of the tree. The eggs were laid in clusters on the tree bark, then hatch to become the larvae and started boring stem and branches.

Nearly 100 percent interviewees said that the stem borer's initial damage was the larvae feeding on the stem bark at the soil level, followed by boring deeper into the wood. The tree infected with borer may wilt and die. This borer would rather live in the full sun coffee farms than in shade ones, many farmers reported.

The coffee branch borer was a small insect with about 1mm long, the female perforated and laid her eggs in the pith of branches. Only female emigrates into open air to attack young branches. Her complete lifecycle covered 30 - 35 days with several generations a year. Those were the answers of 95.6 percent, 100 percent and 91.3 percent farmers interviewed of P1, P2 and P3 respectively.

The coffee berry borer was an insect pest that damages on the coffee berries by perforating at the opposite end to the stalk, and placed her eggs in the bean. Yield and quality might be severely reduced due to holes made in infested beans. 100 percent farmers of P1, P2, and 95.6 percent of P3 answered.

Most of the farmers said that green scale and black aphid were not so serious pests of coffee trees in productive stage. Those often lived on young branches, leaves, and shoots and produce a large amount of excreta in the form of a sweet exudation, which attracted ants and some black fungus developed. Consequently, branches and leaves were covered with sweet exudation and fungus, preventing photosynthesis process of the tree.

White scale damaged coffee berries from young ones until harvesting. The tree infested with while scale had low yield because the cherries were damaged and dropped so many. Normally the while scale lives in and lay her eggs the inflorescence or flower initiation and start damaging cherries from initial stage. That was a serious pest that 100 percent coffee growers have been facing with (Table 33).

With regard to the farmers' knowledge about the natural enemies, whether or not they could identify and recognize the beneficial insects on their farms; firstly, the respondents were encouraged to name all insects that they thought those were natural enemies. And then, 20 color photographs of 12 beneficial insect species (*Ectrychotes* sp., *Rodolia* sp., *Scymnus* sp., *Chrysopa* sp., *Ischiodon Scutellaris, Leptomastix* sp., *Gasteracantha* sp., *Phidyppus* sp., *Oxyopes javanu thorell, Argiope, Atypena formosana, Lycosa pseudoannulata*) and 8 insect pest species classified by the plant protection scientists were given the farmers to realize the insects that regularly occurred in their farms. The results showed that numbers of natural enemies listed were equal to those recognized through photographs. They also agreed that there were many beneficial insects co-existing with the harmful insects on farms.

Table 34. Farmers' perception about natural enemies in coffee gardens

Beneficial insect (Scientific name)	P_1	P_2	P_3
	--- Percentage of farmers ---		
Ectrychotes sp.	4.3	10.9	8.7
Rodolia sp.	15.2	21.7	71.7
Scymnus sp.	26.1	73.9	65.2
Chrysopa sp.	0.0	34.8	63.0
Ischiodon Scutellaris	0.0	26.1	21.7
Leptomastix sp.	30.4	54.3	47.8
Gasteracantha sp.	43.5	52.2	69.6
Phidyppus sp.	17.4	41.3	37.0

Source: Survey, 2002.

Note: P_1(n=46): mono-coffee system, P_2 (n=46): coffee-durian intercropping system, P_3 (n=46): coffee-black pepper intercropping system

The results show that 4.3 percent, 10.9 percent and 8.7 percent of farmers of P_1, P_2 and P_3, respectively, could recognize the role of *Ectrychotes* sp. classified in the order Hemiptera in killing some species of scales and insects when encountering. Two species of *Rodolia* sp. and *Scymnus* sp. of the order Colepoptera, the dangerous enemies of green scale, occurred in so many intercropping farms with 21.7 percent and 73.9 percent of farms of P2, 71.7 percent and 65.2 percent of farms of P3. While these species were recognized by only 15.2 percent and 26.1 percent of farmers of P1. The *Rodolia* sp. and *Scymnus* sp. could eat at least seven green scales a day for each (Phat, 2002). Even the rare species, *Chrysopa* sp. of order Neuroptera, could be found in 34.8 percent of farms of P2 and 63.0 percent of farms of P3, without this insect found in P1 farms. Presence of the *Chrysopa* sp. on-farm contributed to stabilize coffee yield, because the *Chrysopa* sp. prevented the damage of coffee cherries from white scale. One *Chrysopa* sp. could eliminate at least 55 white scales per day (Phat, 2002) out of her habitat. Of which 26.1 percent and 21.7 percent of farmers of P2 and P3, respectively, reported that they had ever seen *Ischiodon Scutellaris* of the order Diptera, an enemy of some scale species, on their farms, but did not understand them so much. When looking the photography of one bee species, namely, *Leptomastix* sp. of the order Hymenoptera, 30.4 percent of farmers of P_1, 54.3 percent of P_2 and 47.4 percent of P_3 said that this bee species could use the white scales to be likely her daily food. The last two species, addressed by the interviewees were two spider species namely *Gasteracantha* sp. and *Phydippus* sp. classified in the order Araneidae. These insects could be found in 43.5 percent and 17.4 percent of farms of P_1, 52.2 percent and 41.3 percent of P_2, 69.6 percent and 37.0 percent of P_3 (Table 34).

Pest management practices

In some cases the application of broad spectrum insecticides could actually lead to an increase in pest levels, by killing off the beneficial insects (natural enemies), which normally keep pests in check. A study in Vietnam showed that applications of a relatively high dosage of the organophosphate dicrotophos had led to outbreaks of the coffee leaf miner caterpillar two months after spraying, due to drastic reduction in the activity of predatory wasps which feed on the pest (Sung, 1995). Using what kinds of insecticides is able to kill insect pests and to minimize environment hazard, especially human health, have been the concerns of coffee growers. A lesson by applying endosulfan insecticide is widely used against many insects that has caused so many problems to pest control. In coffee, endosulfan was used for the control of the coffee berry borer (CBB), a serious beetle pest worldwide which reduced coffee parchment quality by boring into coffee berries and feeding on the developing bean. However the breakdown products of this chemical were very persistent and in some systems might remain in the environment for several months after its application. Endosulfan was also relatively poisonous to mammals, including humans, and very toxic to fish. On top of these problems, CBB has become resistant to endosulfan in some districts of DakLak province where resistance levels of 10 to 20 fold have been detected (Chap, 1995).

Table 35 reports the farmers' awareness about levels of infested trees on farm to control pests by spraying insecticides. There were 37.0 percent mono-coffee farmers planned to spray insecticides annually. Their reason for that was to prevent insect pests occurring on their farms and this schedule was repeated at least 3 years. No one let the farm to be infested over 40 percent total trees. Only 4.3 percent farmers of P2 sprayed insecticides to kill insect pests when having over 30 percent infested trees. But they said that total numbers of infested-trees on farms were not as important as the level of insect pest population in a tree.

Table 35. Farmers' strategies about pest control threshold

Variable	**P1**	**P2**	**P3**
	--- Percentage of farmers ---		
Schedule spray	37.0	0.0	0.0
31 - 40 % infested trees	0.0	4.3	0.0
21 - 30 % infested trees	17.4	30.4	28.3
10 - 20 % infested trees	23.9	50.0	60.9
< 10 % infested trees	21.7	15.3	10.9

Source: Survey, 2002.

Note: P1(n=46): mono-coffee system, P2 (n=46): coffee-durian intercropping system, P3 (n=46): coffee-black pepper intercropping system

Normally, the densities (population) of insects on farm were paid more attention to daily monitor in order to make timely decision, when insect pest populations were able to destroy the tree. One more reason for that was the farmers would like to protect the natural enemies of insect pests from killing by insecticides. The coffee producers relied chiefly on experience to manage pests on farm. 17.4 percent, 30.4 percent and 28.2 percent, i.e. 8 farmers, 14 farmers and 13 farmers of P_1, P_2 and P_3, respectively, said that when the total infested trees of the farms ranging from 21 percent to 30 percent were able to negatively influence on coffee yield. Therefore it was necessary to apply insecticide for controlling pests. Most of the farmers took so much time to manage the population of insect pests in individual crop tree by other methods. Meantime, 23.9 percent of P_1 farmers, 50.0 percent of P_2 and 60.9 percent of P_3 argued that over 20 percent-infested plants on farms were too late to control. It was better to treat insect pests on farms by integrated methods instead of insecticides or insecticides use only, when the total number of infested trees ranged from 10 to 20 percent. 21.7 percent of farmers of P_1, 15.3 percent of farmers of P_2 and 10.9 percent of farmers of P_3 often sprayed insecticide to kill insects when total number of infested plants on-farm was around 10 percent (Table 35).

Table 36. Methods of using insecticides to control pests

Method	P_1	P_2	P_3
	--- Percentage of farmers ---		
Using bio-insecticides	0.0	4.3	13.0
Using selective insecticides	17.4	37.0	63.0
Using nonselective insecticides	82.6	58.7	24.0
Treating only infested trees	26.1	47.8	67.4
Treating whole farm	73.9	52.2	32.6

Source: Survey, 2002.

Note: P1(n=46): mono-coffee system, P2 (n=46): coffee-durian intercropping system, P_3 (n=46): coffee-black pepper intercropping system

As having known, a certain insect species was very sensitive with some specific insecticides. So the issues were how to control pests on farm without harming the natural enemies already present in the environment that were the important works. In many systems the elimination of natural enemies have resulted from using broad spectrum insecticides. Insecticides should be used only as a last resort when other controls have failed to achieve sufficient control: minimally, efficiently and carefully targeted application was the main strategy for conserving natural enemies of the intercropping farmers. However in case of insecticides to be used what were the ways applied on farm to increase insecticide use efficiency as well as to reduce negative affect on natural enemies and environment. Following was the way used by the coffee growers in the study area.

Some insecticides were intrinsically less harmful to natural enemies than others. Bio-insecticides such as bacillus thuringiensis were often safer to natural enemies than many synthetic chemicals, that were chosen by 4.3 percent and 13.0 percent farmers of P_2 and P_3 respectively to control insect pests in the past three years. The selective insecticides used were quite prevalent on the farms of P_3 with 63.0 percent. Meanwhile this figure was only 37.0 percent in P_2 and 17.4 percent in P_1. However the respondents had no answer for what kinds of insecticides for a certain insect pest. Because they often got the guidelines of insecticide use from the insecticide sellers who have been trained in insecticide use.

Choosing the ways to spray on farm that enable to conserve natural enemies and workers' health were the concern of the intercropping farmers. 26.1 percent of farmers of P_1, 47.8 percent of P_2 and 67.4 percent of P_3 have chosen the method of spraying only to infested-trees to wipe out all kinds of insects on the trees. Oppositely, spraying insecticide in the whole farm was applied by 73.9 percent of farmers of P_1, 52.2 percent of P_2 and 32.6 percent of P_3 (Table 36). The reasons for former selection were not only to annihilate pests on infested trees but also to conserve harmless insects on others. Thus they were able to reduce amount of insecticide use that protected farmers, crops and environment from insecticide poisoning. For the later selection aimed at eliminating the spread of insect pests to the larger scale.

In order to measure the frequency of insecticides application to the farm a year, the respondents were encouraged to remember how many times insecticides have been used for the past three years. The result is shown in Table 37. For some farmers of P1, perhaps, controlling pests by insecticides was the first alternative, with 5.6 times of spraying a year. Meanwhile others have prayed only one time. An average of the last three years, the farmers of P1 have used insecticides and insecticides at least 3 times to control pests on farms. In contrast, the farmers and environment of intercropping farms were safer than those of P1, because they took less time to contact directly with insecticides. The number of sprays averaged 2.4 times and 1.6 times a year in the farms of P1 and P2 respectively. Maybe, the presence of the abundant natural enemies on farm as the agents contributed to control insect pests in check over time, so it was not necessary to use so much amount of insecticide to kill insects when not necessary. The average numbers of insecticide application were significantly different at 5 percent level.

Table 37. The average of number of insecticide application (times/year)

Statistics	**P1**	**P2**	**P3**
Max.	5.6	3.1	3.0
Min.	1.0	1.9	1.0
Mean	3.3	2.4	1.6
SD	0.8	0.3	0.5

Source: Survey, 2002.

Note: P1(n=46): mono-coffee system, P2 (n=46): coffee-durian intercropping system, P3 (n=46): coffee-black pepper intercropping system

Table 38 presents the common insecticides and numbers of farmers used insecticides above. Three groups of farmers commonly reported 6 types of insecticides used, by trade name, which were grouped into 5 different common name.

Methyl parathion, a trade mane was the common insecticide used by 46, 33 and 46 farmers of P1, P2 and P3 respectively. Folidol, a trade name, was applied by 42, 20 and 16 farmers of P1, P2 and P3 respectively. Although above two insecticides were encouraged to limit use in the large scale. 36 farmers of P1, 34 farmers of P2 and 27 farmers of P3 have ever chosen azodrin to control insect pests since 1999. For thiodan a trade name, or endosunfan a common name, as mentioned above, was still widely used by 25 farmers, 40 farmers and 21 farmers of P1, P2 and P3, respectively.

Table 38. Common insecticides and percentage of farmers using them

Insecticide name		**Hazard**	**P1**	**P2**	**P3**
Trade name	**Common name**	**Class**	-- **Number of farmers**--		
Folidol	methyl parathion	Ia	42	20	16
Azodrin	monocrotophos	Ib	36	34	27
Methyl Parathion	methyl parathion	Ia	46	33	46
Cymerin	cypermethrin	II	40	31	5
Thiodan	endosulfan	II	25	40	21
Basudin	diazinon	II	0	26	44

Source: Survey, 2002.

Note: P_1(n=46): mono-coffee system, P_2 (n=46): coffee-durian intercropping system, P_3 (n=46): coffee-black pepper intercropping system.

5.4.4 **Pruning**

Purpose of pruning

Pruning plays very important roles in growth, development, pest management, plant nutrient management and yield of coffee and other trees in the cropping system. The purpose of pruning is to provide a plentiful supply of health, leafy wood on which the following season's crop will be borne. In addition, it maintains the correct balance between leaf area and crop to prevent overbearing and dieback as well as to reduce or eliminate biennial bearing (Op de Laak, 1992). Beyond this, the pruning also contributes to eliminate the small, weak branches, and heavy pest and disease-infested branches. Normally, all suckers developed from the stem are taken off to prevent the nutrient competition among bearing branches, preserving ones with suckers (Bau, 1999). So it is essential to prune annually the tree crops to ensure that the tree has a well-developed fruit-bearing framework and is robust, balance and capable of producing a good crop.

Not only coffee trees but also most of perennial plant trees, pruning is a compulsory management practice to control the trees following multi-purposes of the growers. Through the answers of the interviewees about the pruning purposes, the results were summed up as follows:

The growers had quite clear knowledge about the usefulness of pruning, all of them implemented the pruning practices with purposes of eliminating all unproductive branches, generating a robust and well-balanced framework and stabilizing the yield or completely removing biennial bearing. Although most of the farmers have never used a terminology " photosynthesis" to respond our questions, they said that pruning generates a good environment for the leaves in different layers to be able to capture the sunlight for life. 39.1 percent, 65.2 percent and 84.8 percent of farmers of P1, P2 and P3 respectively reported the impact of pruning to photosynthetic efficiency. 34.8 percent of P1 farmers, 69.6 percent of P2 farmers and 89.1 percent of P3 farmers thought that pruning was a technology to manage pests and diseases on farm. Under this work, most of the heavily infested branches, particularly coffee branch borer-infested branches, were cut down and removed out of the farms and burnt to destroy the sources of pests and diseases in the forms of eggs, larvae, fungus and spores. 45.6 percent, 76.1 percent and 89.1 percent of farmers of P1, P2 and P3 respectively said pruning was a process of plant nutrient management due to eliminating all unproductive branches, controlling overbearing and alleviating impacts from pets and diseases. Multi-purpose pruning, including all mentioned above, that was chosen by 34.8 percent of farmers of P1, 60.9 percent of P2 farmers and 76.1 percent of P3 farmers (Table 39).

In spite of having different awareness about usefulness of pruning, but in general it was considered as an integrated method of several purposes, which have the interrelationship. Eliminating all unproductive branches that meant the nutrients concentrated on the bearing branches and developed the strong branches for the next season. Robust and well-balanced frameworks of the trees were able to generate a favorable condition for photosynthesis process and to stabilize the plant yield. So a good pruning method was to satisfy all of the purposes mentioned.

In each coffee system, the farmers worked in intercropping systems might have better knowledge on pruning. Thus, P2 farmers managed their farms with two species of trees, coffee and durian. The P3 ones managed their farms with three plant species, coffee, black pepper and *leucaena*. The intraspecific and interspecific competition of water, light, nutrient and space occurred quite strongly in these farms because of high plant density per unit of land and same resource needs. So requiring the growers had to design and to manage their farms with suitable ways in order to gain the highest output, but minimum external inputs for optimal yield. And pruning was one of the technical activities, contributing to the success in managing of these systems.

Table 39. Farmers' knowledge about usefulness of pruning

Purpose	P1	P2	P3
	--- Percentage of farmers ---		
Eliminating unproductive branches	100.0	100.0	100.0
Creating well-balanced framework	100.0	100.0	100.0
Increasing photosynthesis efficiency	39.1	65.2	84.8
Controlling pests and diseases	34.8	69.6	89.1
Controlling plant nutrient	45.6	76.1	89.1
Stabilizing plant yield	100.0	100.0	100.0
Combining all purposes above	34.8	60.9	76.1

Source: Survey, 2002.

Note: P1(n=46): mono-coffee system, P2 (n=46): coffee-durian intercropping system, P3 (n=46): coffee-black pepper intercropping system.

Pruning practices

For coffee producers' opinion, the number of pruning is not so important as the "art" of pruning (Sung, 1999). The farmers of P_3 paid more attention in pruning than those of P_1 and P_2, with average of 2.4 times a year, maximum of 3 times and minimum of 2 times. The coffee farms of P3 with three species of plants grown together, space for each species was limited, so that the farms required to be regularly pruned to adjust the branch system and shape of the trees in order to meet the sunlight for optimal photosynthesis process. For the farms of P1 and P2, the number of pruning ranged from 1 to 3 times a year, with an average of 2.2 times (Table 40).

Table 40. The number of pruning per year

Statistics	P_1	P_2	P_3
Max.	3.0	3.0	3.0
Min.	1.0	1.0	2.0

Mean	2.2	2.2	2.4
SD	0.5	0.5	0.5

Source: Survey, 2002.

Note: P1(n=46): mono-coffee system, P2 (n=46): coffee-durian intercropping system, P3 (n=46): coffee-black pepper intercropping system

Although the maximum number of coffee pruning was only 3 times a year, The activity was done in different months, the first time of pruning in January, the second in April and June, the third in July and August. 100 percent of farms had the first pruning of a seasonal production in January, after finishing coffee harvest around 15 to 20 days. This time, all weak, dead branches were cut out. The all kinds of suckers (orthtropic shoots), which were developed from the main stem and primary branches, were removed to concentrate nutrient to blossoming process and the branches bearing berries in following season. In addition, durian in P2 farms was also pruned in this month (January) by cutting out all weak, dry, and heavily disease-infested branches. 54.3 percent, 65.2 percent and 4.3 percent of farms of P1, P2 and P3 respectively were carried out the second time in April. As the first time, in the second one, all suckers and dead branches emerged during some months of dry season were eliminated. 39.2 percent farms of P1, 30.5 percent of P2 and 95.6 percent of P3 were done the second pruning in June when the rainy season stated for 2 months and the climate condition was not so harsh. Therefore, the trees were able to resist the attack of insects or diseases through the injuries caused by cutting (Chat, 1995). For the farmers of P3, this time was a combination of pruning coffee trees and trimming branches of *leucaena* trees. It was a reasonable labor distribution of the farmers. On the other hand, in April was the harvesting month of black pepper. And after harvesting, it took so many labors for pruning black pepper. The technique for pruning black pepper was done as follows: after harvesting, at least two-third of total matured leaves - sometimes all leaves - of the black pepper were cut down in order to stimulate the flower development for even flowering, which was very important for black pepper planted under shade. In addition all weak and dry branches, and heavy pest and disease-infested branches were eliminated from the vine. If pruning were not carried out before rainy season, the flower development would take place slowly and unevenly in wet season. As a consequence, a poor season would be waiting for farmers at harvesting time. So implementing the second time of coffee pruning in June was the way of suitable labor distribution in seasonal production.

The third one with 6.5 percent and 15.2 percent of farms of P1 was pruned in July and August respectively. For the P2 farms: 4.3 percent and 23.9 percent, for the P3 farms: 4.3 percent and 39.2 percent, were done this work in July and August (Table 41). The technology applied for the third pruning was the weak, dead, infested branches were continuously eliminated. And all the secondary and tertiary branches, which develop too near the trunk, were cut out to permit the circulation of air and penetration of more sunlight through the tree and the farm as well. Reducing the number of secondary and tertiary fruiting branches that avoids overbearing. This technique was applied not only to coffee but to durian also. However, it was very important to carefully monitor and calculate for decision-making of how many fruiting branches should be left for harvesting a desirable yield in following year and which positions of branches should be kept or cut off to maintain the trees in well-balanced framework. This required the growers not only to have good skills in pruning "art" but also to understand the physiological characteristic of the trees (Bau, 1999).

In fact, there were coffee and durian in P2 system, and coffee, black pepper and *leucaena* in P3 system. But the farmers focused mainly on pruning coffee rather than durian, black pepper and *leucaena* that were done one main time as mentioned above, the following pruning was of combination with coffee pruning and did not take much time for durian and black pepper.

Table 41. Percentage of farms pruned in a given month

Order	Month	P1	P2	P3
		--- Percentage of farms ---		
1st	January	100.0	100.0	100.0

2nd	April	54.3	65.2	4.3
	June	39.2	30.5	95.6
3rd	July	6.5	4.3	4.3
	August	15.2	23.9	39.2

Source: Survey, 2002.

Note: P1(n=46): mono-coffee system, P2 (n=46): coffee-durian intercropping system, P3 (n=46): coffee-black pepper intercropping system

Table 42. The number of pruning per year

Number of pruning	**Overall**	**P_1**	**P_2**	**P_3**
	--- Percentage of farms ---			
1	3.6	6.5	4.3	0.0
2	65.2	71.8	67.5	56.5
3	31.2	21.7	28.2	43.5

Source: Survey, 2002.

Note: P_1(n=46): mono-coffee system, P_2 (n=46): coffee-durian intercropping system, P_3 (n=46): coffee-black pepper intercropping system

As stated above, the maximum number of pruning was three times and the minimum was one time. The Table 42 presents the farms with number of pruning a year. For overall of 138 farms, of 65.2 percent were pruned 2 times a year in the past three years. 31.2 percent were carried out 3 times and the rest was done only one time a year. For individual coffee system, 71.8 percent of P1 farmers focused on pruning their farms two times a year and 21.7 percent did 3 times. For the P2 farms, one time pruning was done in 4.3 percent of farms, two times in 67.5 percent and three times in 28.2 percent. There were 56.5 percent and 43.5 percent of P3 farms to be done with 2 times and 3 times of pruning a year respectively

In short, although having differed from the number and timing of pruning among the systems, even amongst the farms, the most important factor was the farmers' skill in pruning. Which branches of which positions were cut, how many branches were left and how to create a well-balanced frame that require the producers to have a good knowledge about physiology and morphology of tree crops in farm. Only with this knowledge and skill, the pruning practice could be able to bring a good result to farmers. On the other hand, an easy activity in pruning process of coffee trees should be paid year-round attention that is to remove all suckers (orthotropic shoots), which arise from the main stem and drain the plant of a lot of nutrients and moisture. Especially, this should be regularly done in dry season because this is a critical and sensitive period with nutrients and moisture of crops.