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Nutrient and quality analysis of coffee cherries in Huong Hoa district, Vietnam

Corine Pinkert

PPP Project "Improvement of Coffee Quality and Sustainability of Coffee Production in Vietnam"

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Foreword

This report is the result of a thesis and internship at Plant Research International in Wageningen (The Netherlands). The first part of this thesis and internship, which consisted of mostly practical field- and lab work, was implemented in Khe Sanh and Huong Phung (Vietnam) at the coffee factory of the Tan Lam Pepper Company. The second part, processing data and writing this report, was implemented in Wageningen at the office of Plant Research International. Although especially the second part passed off a little bit slowly, finally the result is there. Because I could not manage it all myself, I like to thank a lot of people who helped and supported me.

First of all, I like to thank my parents for their support before I went to Vietnam, during my stay in Vietnam and when I came home again. Secondly, I like to thank Mr. Tran Doan (Director Tan Lam Pepper Company), because without his support I couldn't come and stay in Khe Sanh. Apart from them, I like to thank Mr. Nguyen Van Thiet (Head Extension Group Tan Lam Pepper Company), because he showed and taught me a lot about coffee growing. He also helped me a lot with the, for me, social and cultural changes and feeling home in Khe Sanh. Next I would thank Mr. Ken Calvert (Expert Coffee Processing and wastewater treatment), for his tips and explanation of the theoretical back-ground about processing the coffee cherry samples in the laboratory. Also, I like to thank Mr. Jan von Enden (Expert Coffee Processing) for his ideas about coffee processing. In addition, I would thank him, Mr. Nguyen Nhat Tuan (translator) and Ms. Kristin Lindner (student) for all the friendly conversations in spare time. Further I would like to thank Mr. Le Anh Chuong, without him I surely got lost in the whole labyrinth of coffee fields. I would like to thank Mr. Erhard Leuchtman for the times we met.

Further I would thank the farmers in Huong Phung and Khe Sanh for always feeling welcome and their lessons in the Vietnamese language. Further, I like to thank Mr. Le Van Tuan (head department of quality and environment), Mr. Duong Ba Loi (engineer) and all the other employees of TLPC for having fun on the coffee factory. In addition, I like to thank Ms. Hoang Chi and Mr. Phan Trong Minh of the Khe Sanh Hotel, because they were great 'housemates'.

Also, I like to thank Mr. Jan Vos (Lecturer department Crop and Weed Ecology, WUR) for his constructive critics on the scientific aspects of this report. Finally, I would thank Mr. Don Jansen (Researcher Plant Research International) a lot for his support on theoretical, practical and social field. He was always open to questions or remarks and that's what I really appreciated!

Corine Pinkert | January 2004

Summary

Background

In Huong Hoa district in Vietnam a lack of knowledge exists about sustainable coffee cultivation. Information about good coffee management practices for this specific area with its specific growing conditions is not available, while coffee production in this area started only 5 to 8 years ago. The optimum amounts and time(s) of application of fertilisers are, for example, unknown. This can lead to a reduction of productive life of coffee trees (Op de Laak, 2002), a reduced yield and quality of the harvested crop, an increase of production costs and environmental problems. Therefor, it is important to look for sustainable ways of fertiliser application in Huong Hoa district, which contribute to a high yield of coffee cherries and green beans of high quality, reduced costs for farmers without harming the environment. To support this search, a first observational research was implemented in 2002 in Huong Hoa district at two locations (Huong Phung (HP) and Khe Sanh (KS)), with the goals to see whether differences, similarities and relations exist between locations considering yield and quality characteristics. HP has poorer soils (lower pH and CEC), a different climate (earlier start and ending of rainy season) and a longer growing season compared to KS. Coffee trees are in general two to three years younger in HP.

Activities

Between October 21 and December 9, 2002, 45 samples of cherries were taken from in total 20 coffee fields of farmers from both locations at different harvest dates. The samples were taken from fields for which farmers registered daily activities, thus application of N, P and K mainly as chemical fertilisers (kg/ha) as well as yield of fresh cherries (kg/ha) was known. In both locations, applications of N, P and K by the various farmers were in the same range.
The samples were analysed on nutrient content and quality of cherries and beans. During quality analysis 4 quality characteristics of green coffee beans were determined: 1. 'screen size17'-beans (%); 2. pea berries (%); 3. beans with black spots (%) and 4. 1000-bean weight of 'screen size 17'-beans (g).

Results

Dry matter production per ha (dm; kg/ha) is significantly lower in HP (2538 kg/ha) compared to KS (4809 kg/ha). Considering the four quality characteristics, 'screen size 17'-beans (%), beans with black spots (%) as well as 1000-beans weight (g) are significantly higher in HP (respectively 69.2%; 35.6% and 172.6g) compared to KS (respectively 54.2%; 29.4% and 158.7g), while pea berries (%) are significantly lower in HP (14.7%) compared to KS (19.0%). Only for P and Al a significant effect of nutrient content was found on 1000-bean weight in addition to the effect of the location.
The agronomic productivity in terms of cherries of nitrogen in HP as well as KS is about 56 kg dm/kg N in cherries, which is high compared to literature data, which is in the order of 30 to 40 kg dm/kg N in cherries. For phosphorus, it is 837 and 738 (kg dm/kg P in cherries) in HP and KS respectively, and for potassium 47 and 42 (kg dm/kg K in cherries). Both of these values are within the range found in literature, which for P is 600 to 1600 kg dm/kg P in cherries and for K 38 to 53 kg dm/kg K in cherries. For HP and KS the apparent agronomic nitrogen recovery (AANR) in terms of cherries is around 0.12-0.15 kg N in cherries/kg N applied. Per kg N applied, between 6.3 and 7.4 kg dm is produced. For HP as well as KS no clear relation was found between P- and K-application on one hand and P- and K content in cherries and dm (kg/ha) on the other.

Conclusions

Differences in soil, climate and plant age between HP and KS are the possible main causes for the observed differences in yield (kg dm/ha) and quality characteristics between these two locations, through an effect on the availability of N from the soil. Apart from this, it seems that nitrogen restricts the commercial yield of coffee cherries in Huong Phung as well as Khe Sanh, while the agronomic productivity of nitrogen is high compared to data found in literature. A low pH and CEC in HP as well as KS can play a role in the uptake of nitrogen.

Table of contents

1. General introduction

This report describes the results of research activities conducted in coffee in Huong Hoa district in Vietnam. The research was undertaken as part of activities in the PPP project. The term PPP refers to Public Private Partnership, which is a form of developmental aid in which public and private companies of both developed and developing countries work together and contribute financially to the project. This specific PPP project has as aim to improve the cultivation and processing of coffee. Collaborating private companies are Kraft Foods Germany and Sara Lee Douwe Egberts Netherlands, while the public side is represented by GTZ (Gesellschaft für technische Zusammen-arbeit, Germany) and Tan Lam Pepper Company, (TLPC, a state owned coffee processing factory, Vietnam). GTZ and Kraft Foods Germany focus on the improvement of processing at the factory, on a quality standard for Arabica coffee at TLPC as a model for the coffee sector on national level and on living conditions of small farmer house-holds in Huong Phung commune. Sara Lee Douwe Egberts focuses on the improvement of coffee cultivation for which it hired PRI (Plant Research International, Netherlands) to develop project plans and execute the activities. Activities implemented by PRI exist first of all of an analysis of the actual situation in the coffee producing area Tan Lam in co-operation with the relevant national institutions and organisations. A second activity by PRI is the support of field trials with TLPC and relevant national institutions on selected issues. At last, PRI will elaborate and publish a field manual and extension material on cultivation of coffee, as well as workshops on national level on sustainable coffee will be offered and conducted.

2. Coffee: cultivation and processing

2.1 Coffee in general

Coffee is the world's most popular beverage after water and, according to DE (2001) it is the second most traded commodity in the world after raw oil. Coffee is grown in around 70 countries in Asia, Africa and South America between 23° North latitude to 25° South latitude. Most of the coffee is consumed in the United States, Europe and Japan (Hao, 2001).

Coffee species and cultivars

The coffee comes mainly from two species, *Coffea arabica*, arabica coffee and *Coffea canephora*, robusta coffee, the former comprising almost 75% of world trade and the latter 25% (DE, 2001; Op de Laak, 1992). Arabica coffee is a tasteful coffee with a lot of aroma, bigger cherries and beans than robusta coffee, while lacking resistance to *Hemileia vastatrix* (coffee leaf rust) contrary to robusta, which its powerful taste (DE, 2001; Op de Laak, 1992). Apart from arabica and robusta coffee, several coffee species exist, three of which are:

1. Liberica coffee, which is only of local importance in West Africa, Malaysia and the Philippines, where its bitter flavour seems to be appreciated (Op de Laak, 1992).
2. Coffea excelsa, which importance is also confined to local consumption (Op de Laak, 1992).
3. Coffea congensis, which resembles arabica coffee most closely (Op de Laak, 1992).

Two main botanical varieties of arabica coffees exist, variety typica and variety bourbon. The former still provides the bulk of the world's coffee, but the latter was found to be equal to typica in cup quality (Op de Laak, 1992). The cultivar Caturra descends from a natural mutant of Bourbon and gives a high yield of small beans (Op de Laak, 1992). Hybrido de Timor is the descendant of a spontaneous hybrid between *C. arabica* and *C. canephora*, which has the phenotype of *C. arabica* and the resistance to all known races of coffee leaf rust from *C. canephora* (Op de Laak, 1992). Catimor is a contraction of the variety names Caturra and Hibrido de Timor and is characterised by high yields and resistance to all known races of coffee leaf rust. When coffee is mentioned in this report, it refers to arabica coffee, unless explicitly otherwise is mentioned.

Coffee trees, cherries and green beans

Coffee beans grow in a coffee cherry on a coffee tree. The appearance of a coffee tree depends on the variety and the way of pruning (Cambrony, 1992). By origin it is a shadow jungle tree which can grow to 10 m. or even higher (DE, 2001). For coffee cherry management the tree is pruned to a height of 1.5 till 3 m (Cambrony, 1992, Figure 1). A coffee tree exists of roots, branches, leaves and flowers (fruits). The roots exist first of all of a central root, called tap root, which has a length of 30-45 cm. of the soil surface. Axial roots grow underneath the tap root and branch in all directions to depths of 2.5 to 3 m. The surface lateral roots spread more or less parallel to the soil surface for a distance of 1.2 to 1.8 m. The lower lateral roots ramify evenly through the soil. Most of the lateral roots grow horizontal, but some of them grow downwards. The small root extensions of axial and lateral roots are called feeder bearers. They branch out in feeder roots.

A coffee tree produces two types of branches. First of all orthotropic (vertical) branches (suckers) and secondly lateral or plagiotropic (horizontal) branches. Every vertical branch has in the axle of each leaf a series of 4-6 buds and above them a bigger bud, called 'extra axillary'. This extra axillary bud develops into a lateral. The laterals growing out of a main stem are called primaries. The other 4-6 buds can't develop into laterals, but only into suckers when the main top is topped, the main bud is damaged or the coffee tree notices increased light penetration. Regeneration of primaries on main stems isn't possible (Op de Laak, 1992).

Each serial bud in the leaf axle on a primary can develop into an inflorescence or into a lateral, secondary branch. This secondary branch has the same structure as the primary branch, so it can only produce lateral branches or inflorescences and no suckers. Regeneration of secondaries on primaries is possible. The importance of the secondary branches for training and fruiting in the arabica varieties should be noted (Cambrony, 1992). The components of yield of coffee cherries can be described by the following 4 points:

1. yield/ha = number of trees/ha * yield/tree
2. yield/tree = number of cherries/tree * weight beans/cherries
3. number of cherries/tree = number of fruiting nodes/tree * number of cherries/node
4. weight beans/cherry = weight/cherry * bean/cherry-ratio

The leaves of a coffee tree are shiny and waxy and dark green in colour. Photosynthesis in coffee follows the C3 or Calvin cycle pathway (Wrigley, 1988). A coffee cherry contains two green beans, located in the centre of the cherry (Figure 2). Beans of arabica and robusta coffee have one flat side with a small grove in it and a ball side. Around each bean is a thin layer, called silver skin. The bean and the silver skin are surrounded by the parchment skin, which is enveloped by a slippery layer called mucilage. Finally the cherry consists of a thick pulp layer (mesocarp) and the skin (exocarp). The cherry is connected to the tree by the fruit stalk. During ripening the skin colours from green (unripe) to yellow/light red (under-ripe) to red (ripe) to dark red/black (overripe). The cherries of some cultivars colour light orange/yellow when they are mature. The yield of one coffee tree is on average 2.5 kg. fresh red cherries per year, which corresponds to 700 g. roasted beans, equivalent to 120 cups of coffee (DE, 2001).

Figure 1. A coffee tree.

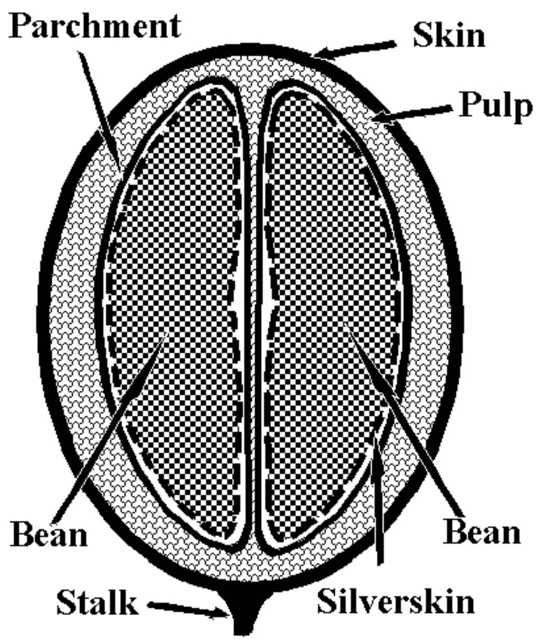

Figure 2. A coffee cherry.

Abnormalities of coffee beans

The majority of coffee cherries contains two symmetrical normal beans, but sometimes abnormalities occur because of genetical, physiological or environmental causes (Wrigley, 1988). When only one bean occupies the whole fruit, it has a round shape and is called 'pea berry' (Wrigley, 1988). It has been considered that genetic factors are the main cause of pea berries. Pea berries occur after fertilisation of only one loculus (Cambrony, 1992) or poor pollination in general (Clifford & Willson, 1985). There is no difference in quality between normal beans and pea berries (Wrigley, 1988), but for mainstream coffee roasting companies a mix of normal beans and pea berries is seen as low quality as roasting time differs between these two kinds of beans.

A coffee cherry can contain one normal bean and one empty bean (Wrigley, 1988). This empty bean is filled with air instead of proteins (Wrigley, 1988) and therefore it floats on the water and is called a 'floater'. A genetic factor as well as physiological factors can cause an empty bean.

A coffee bean can be infected with the Black Spots Disease, which causes black spots with a diameter of 1-2 mm. on the surface of the green bean, on the flat side as well as on the round side (Bieysse, 2001). The cause of this disease is unknown (Bieysse, 2001).

Damage to coffee trees also occurs by the larvae of the white stem borer (*Xylotrechus quadripes*, a beetle) and red coffee borer (*Zeuzera coffeae*, a moth), which tunnel into branches and into stems of coffee trees (Op de Laak, 2002).

Diseases and pests in coffee

Coffee leaf rust (*Hemileia vastatrix*) is caused by a fungus which produces powdery spots on the undersides of the leaves (Willson, 1999). When a leaf is infected it becomes necrotic and falls prematurely from the tree (Wrigley, 1988). If the leaves are unable to supply the needs of the developing coffee cherries, these draw on the carbohydrate reserves of the roots and stems resulting in early depletion of leaves (Wrigley, 1988). Heavy and repeated defoliation can cause die-back and general weakening of the whole plant, so that the yield is seriously reduced (Wrigley, 1988).

Brown Blight is caused by the fungal parasite *Colletotrichum gloeosporiodes*, which inhabits the bark of coffee as well as other tropical crops. It occurs as superficial lesions on ripe cherries, but never penetrate the bean or cause crop loss (Op de Laak, 2002). Ripe cherries that are affected are difficult to pulp (part of the processing of cherries) (Willson, 1999).

Berry Blotch or Brown Eye Spot is caused by *Cersospora coffeicola*, which attacks the green cherries through wounds or sun scorch injury, resulting in brown, sunken lesions surrounded by a bright red area on green cherries (Op de Laak, 2002).

Pink disease (*Corticum salmonicolor*), which occurs mainly in coffee at low altitudes, infects bearing branches and destroy the crop thereon (Willson, 1999).

2.2 Physiology and phenology of a coffee crop

Phenological development

Generally, after a dry period the rainfall starts and breaks the dormancy of the flower buds (Wrigley, 1988). Blossoming occurs a week to 12 days after the major rain stops and lasts around three days (Wrigley, 1988; Op de Laak, 1992). Arabica Coffee is largely self-pollinating (Op de Laak, 1992). The fruits, which are in a pin-head stage, don't grow for about 6 to 8 weeks after flowering (Clifford & Willson, 1985; Op de Laak , 1992). The duration of this period depends on the climate (Wrigley, 1988). As the fruits begin to grow, fruit drop (physiological shedding) occurs, which is increased by moisture stress (Wrigley, 1988). From then on the fruit swells rapidly for 8 till 10 weeks in general (Clifford & Willson, 1985), around 10 weeks in Northern Thailand (Op de Laak, 1992) and 10-17 weeks in Kenya (Wrigley, 1988). In Costa Rica it was found that cherries are larger when the period of expansion is longer (around 11 weeks) and cherries are smaller when the period of expansion lasts only about 7 weeks (Wrigley, 1988). At the end of this rapid growth of cherries, both the number of cherries the tree will carry and their potential size has been decided (Wrigley, 1988). To produce large beans it is important that sufficient moisture is available during this period of rapid expansion (Clifford & Willson, 1985; Wrigley, 1988; Op de Laak, 1992). Ripening of the fruit starts after these 10 weeks. When cherries have a red colour (yellow variants are known too) they are mature and can be harvested (Willson, 1999). When the crop is too heavy for the tree, overbearing results in die-back of shoots and roots (Wrigley, 1988).

The development of a serial bud on a branch into an inflorescence is triggered by shorter days (Op de Laak, 1992). These buds enter the dormant phase when they are approximately 6 mm. long (Wrigley, 1988; Op de Laak, 1992). In view of fertilising, it is important to notice that buds only develop on two-year-old branches, so branches that were established in the previous season (Cambrony, 1992; Wrigley 1988). A shortage of nutrients restricts vegetative growth, which reduces the number of buds available for flowering in the following year (Clifford and Willson, 1985). This can mean that yield is determined by fertiliser application of two years. For example, for the growing season 2002, the fertiliser application of 2001 determines the number, length and vigour of the new branches and the number of new inflorescences. The fertiliser application of 2002 determines mainly the size and filling of the cherries and green beans.

Although a particular leaf stays for 5 to 9 months on a coffee tree, the tree has a full canopy during the whole growing season (assumed there are no pests or diseases). Leaf growth continues on the branches as the internodes develop and the life of a leaf overlaps with that of leaves of the youngest nodes during successive rainy seasons. The coffee bush grows continuously, but the growth rate isn't continuously because rainfall, temperature and day length differ over the growing season. The dry season is the period for vegetative rest (Cambrony, 1992).

Demands of a coffee tree

Table 1 shows characteristics and requirements of arabica and robusta coffee and describes the characteristics of Huong Hoa district in Vietnam.

Table 1. Characteristics and requires of arabica and robusta coffee

Factor	*C. Arabica*	*C. Robusta*	Huong Hoa district
Flowering	After rain	Irregular	after rain
Rainfall	1200-2000 mm	2000-3000 mm	2400 mm
Rainfall distribution	Well distributed		Mainly in harvesting season
Dry period	Up to 6 months	3-4 months	4 months
Average temperature	15-24°C	24-30°C	25°C
Altitude	1200-1500 m	0-700	500-800 m
Wind	Strong winds can be harmful	Strong winds can be harmful	Fierce winds from Laos, but farmers have quite often a wind break of trees
Soil – drainage	Well drained	Well drained	Well drained
Root system	Deep	Shallow	Majority of the roots < 40 cm.
Soil – type	Loam		Silt loam
Soil – pH	5.4-6.0	4.5-7.0	4.2-4.55
Soil – CEC			Around 9.5
Hemileia vastatrix	Susceptible (Catimor variety resistant)	Resistant	Susceptible as well as resistant

From: www.ico.org (May 1, 2003); Wrigley (1988); Kuit (personal comments, 2002)

Huong Hoa district is marginally suitable for arabica as the altitude is too low and temperature too high. Therefore the quality of coffee beans will never be very high.

Coffee growing in Huong Hoa district

Crop phenological and climate characteristics show distinct perioicity in Huong Hoa district (Figure 3).

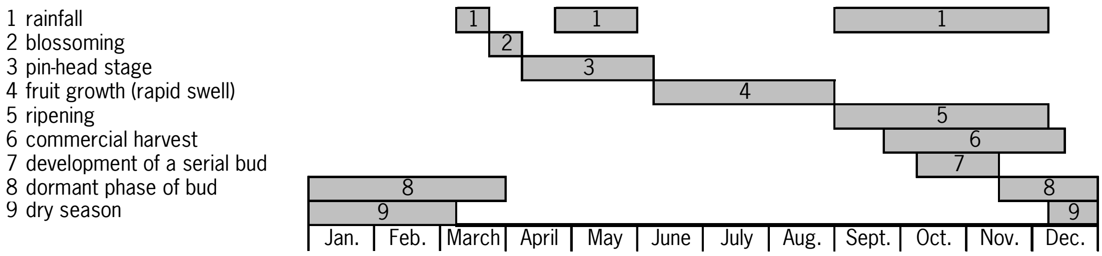

Figure 3. *Coffee growing in Huong Hoa district.*

Weather and soil data of Huong Hoa district

Weather data of Khe Sanh are shown in Figure 4 In general rainfall starts one month earlier in HP compared to KS. It is said that temperature is 5°C higher in Huong Phung compared to Khe Sanh (personal comments Mr. Thiet, coffee management specialist TLPC), but this is not sure, while it is also said that temperature is 1 or 2° higher in Huong Phung compared to Khe Sanh (personal comments Mr. Jansen, manager of the PPP-project). It is also said that the growing season in Huong Phung lasts longer compared to the growing season in Khe Sanh. Because temperature is higher in Huong Phung compared to Khe Sanh, one would expect a shorter growing season in Huong Phung than Khe Sanh. A reason can be that in Huong Phung the temperature is above the optimum temperature for the highest development rate and in Khe Sanh the temperature is closer to the optimum temperature needed for the highest development rate.

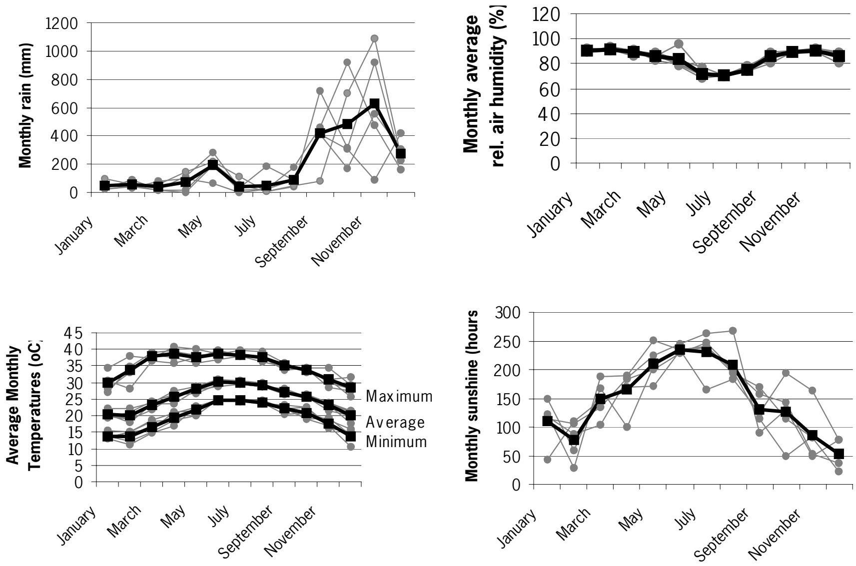

Figure 4. *Weather data of Huong Hoa district from Khe Sanh weather station,*
grey lines = data from 1995-1999; black lines = averages of 1995-1999.

Table 2 shows differences in soil characteristics between Huong Phung and Khe Sanh. In general soils in Huong Phung are poorer and more drought-sensitive compared to Khe Sanh.

Table 2. Soil characteristics in Huong Phung and Khe Sanh.

soil characteristic	soil depth	location	
		Huong Phung	Khe Sanh
soil type		pherolytic and podsoils	pherolytic (silt loam)
organic matter content	0-10 cm	3.0	2.51
organic matter content	10-20 cm	2.28	2.51
organic matter content	20-30 cm	1.41	2.32
pH	0-25 cm	4.2	4.5
CEC	0-20 cm	9.1	9.7

From: Kuit (2002, personal comment)

Coffee variety

Supposedly the farmers in Huong Hoa district grow only *C. arabica*, the leaf rust resistant Catimor variety. Because the abundance of rust infection and the variation in size, shape, leaf colour and degree of dieback, it is questionable whether all plants are of the true Catimor variety (Op de Laak, 2002). Observed defects of cherries and beans in Huong Hoa district are floaters, pea berries and infection with black spots. Diseases which occur in Huong Hoa district are coffee leaf rust, brown blight, berry blotch, pink disease, white stem borer and red coffee borer (Op de Laak, 2002).

2.3 Nutrients in the crop

Nutrients are removed from the plantation in the fruit (cherries) and in prunings when cuttings are removed out of the field. In Huong Hoa district in Vietnam pruned branches and leaves are left in the coffee field and their nutrient content is recycled. The waste of the harvested fruits (mainly pulp, mucilage and parchment skin) however are not used as fertiliser. Therefore nutrients in fruits disappear forever from the field. Applied fertilisers and decomposition of leaf fall, small prunings, shade tree leaves and mulch cause inputs to the soil, while leaching through the soil, rainfall runoff and the uptake of nutrients cause losses from the soil (Willson, 1999). It is important that the upper soil layer has a good structure and a high organic matter content, while most nutrients are absorpted by fine roots in the top 30 cm of the soil profile (Clifford & Willson, 1985). The quantity of the fertiliser applied should depend upon the expected yield, natural nitrogen level of the soil, conditions of the tree and soil moisture status (Njoroge, 1985).

Fertilisers applied on the field by farmers are mostly nitrogen, phosphorus and potassium.
Nitrogen (N) is essential for production of stems, leaves and fruit (Clifford & Willson, 1985). Under favourable conditions, nitrogen has most impact on yield. Nitrogen can be transported very efficiently from older leaves and branches to young growth and developing cherries, but this is irreversible. Nitrogen is most effective when given at a time of high demand and low nutrient availability in the soil during the wet season or under irrigation (Willson, 1999). The amount of nitrogen to apply varies between 50-400 kg N/ha, depending on the local conditions and the level of yield expected (Willson, 1999; Wrigley, 1988). Low total applications are often made in a single annual application, while higher levels should be split into several applications. Even then, efficiency of application will be low in hot and dry weather (Willson, 1999).

Only a small amount of phosphorus (P) is removed with the harvested crop and prunings (Willson, 1999). It is an important element for plant growth, but fixation in acid soils may prevent trees from absorbing sufficient phosphate (Clifford & Willson, 1985). P accelerates the development of young plants (Willson, 1999), mainly root growth (Wrigley, 1988). Compared with N and K not so much phosphorus is needed in adult plants, but deficiency can occur under extreme dry or wet conditions (Wrigley, 1988). P is required by developing flowers (before, at and after anthesis) and the coffee tree when it flowers and is setting fruit (Wrigley, 1988). On soils with pH lower than 5.6 a fertiliser with a low sulphur content should be used (Wrigley, 1988).

The amount of potassium (K) in the crop is at least as large as that of N (Wrigley, 1988). It is necessary for growth of all parts of the plant, but mainly for the development of the fruit (Clifford & Willson, 1985; Willson, 1999), during the cherry expansion period (Njoroge, 1985). Therefore deficiency occurs when the trees bear a heavy crop (Wrigley, 1988). It is mobile within the plant, so it can be withdrawn from leaves and branches by the fruits (Willson, 1999). K is antagonistic to Mg and Ca, which means a high level of one can restrict input of the other (Willson, 1999). On the other hand, N and K show positive interactions, which indicates the need to keep the nutrients in balance (Clifford & Willson, 1985).

A small quantity of calcium (Ca) is lost in the crop and prunings (Willson, 1999). Where the soil is very acid, lime is often applied, while it decreases soil acidity (Clifford & Willson, 1985; Willson, 1999).
The loss of magnesium (Mg) in crop and prunings isn't large. It plays a role as brick in chorophyll and takes part in various growth processes. It is highly mobile in the plant and can be transported from old to young leaves (Willson, 1999; Wrigley, 1988).

Sulphur (S) is necessary in a small quantity (Willson, 1999). Deficiency can reduce growth and fruit-set, but this isn't a general observation (Clifford & Willson, 1985).

A severe deficiency of zinc (Zn) will reduce yield. Ground applications aren't very effective, but foliar sprays are (Willson, 1999). Excessive amounts of manganese, copper and molybdenum restrict the uptake of zinc (Clifford & Willson, 1985).

Copper (Cu) can increase crop yield, while continuous use of copper fungicides has been found to do so (Willson, 1999). At soils with low pH excessive amounts of copper can reduce growth (Clifford & Willson, 1985).
Iron (Fe) deficiency occurs frequently on the more alkaline soils or soils with a high organic matter content and is often seasonal in drought and not serious. It is often associated with high phosphorus or manganese levels (Willson, 1999).

Manganese (Mn) deficiencies occur occasionally on alkaline soils and toxicity symptoms are found on acid soils (Willson, 1999).

Aluminium (Al) is freely available in acid soils, but it isn't essential for coffee, but toxicity effects can occur in Arabica species (Willson, 1999).

Both deficiency and toxicity symptoms are known for boron (B), while also ratio boron to calcium is important (Willson, 1999).

Quality is reduced when the balances between the various bases move away from the optimum.
Although yield will increase, a surplus of nitrogen reduces quality, as measured by size of beans (Willson, 1999).
Iron and manganese deficiency can cause deterioration of quality of coffee beans, causing
'amber beans' (Wrigley, 1988; Willson, 1999).

2.4 Harvesting, transportation and processing

In Huong Hoa district, coffee cherries on a coffee tree are picked by hand, put in a basket and when this basket is full it is emptied in a bag. For quality reasons bags are put in shadow instead of full sun. In general a farmer has a group of employers during harvest time, which help harvesting coffee cherries. The group of coffee pickers makes, in generally, a round through the coffee field(s) over 10-14 days. Although ripe (red) cherries are of highest quality, they gather ripe as well as under-ripe cherries, because under-ripe cherries ripen within 4 to 5 days. When they are not picked, they will be overripe in the next round and worthless.
At the end of the morning, afternoon or day the bags with coffee cherries are brought to the factory by the farmers themselves or are picked up by a van of the factory. Employers of the factory determine the weight of the bag and

the quality of the cherries. It is desired to process coffee cherries as soon as possible after harvesting, otherwise the juicy fruit start to ferment and the quality of the coffee beans deteriorates.

Processing of coffee cherries in general

After harvesting and transportation of the cherries, the quality of the end product is determined by the way of process of removing the skin, pulp, mucilage layer and parchment are removed (Von Enden & Calvert, 2002).

In general three different methods of processing can be distinguished, the dry method, semi wet method and the fully wet method (Von Enden & Calvert, 2002). Using the dry method, picked cherries are dried in the sun till the whole fruit reaches a moisture content of around 11%. Then the outer flesh and parchment is removed in one step (Von Enden and Calvert, 2002). In the semi wet as well as the fully wet method, first the skin and pulp are removed mechanically, which is called depulping. At this stage, using the semi wet method, the mucilage layer is first partly removed mechanically by a demucilator after which +the remaining mucilage is removed by fermenting. Using the wet method, after depulping, the mucilage layer is only removed by fermenting. After fermenting, the beans are washed with clean water, in the semi wet as well as in the fully wet method.

At this stage the wet beans are still covered by the silver skin and parchment. These so-called wet parchment beans are dried in the sun or in flat bed and rotary driers till they reach a moisture content of 10-12%. After drying the beans are hulled (removing of the parchment), sorted (broken or infected beans are separated from good beans) and the screen size is determined. The resulting green beans are ready to be exported.

Processing of the coffee cherries at the factory of TLPC

The following description about processing of coffee cherries at the coffee factory of TLPC is a summary of personal comments of Mr. Calvert (2002).

First part of processing coffee at the factory of Tan Lam Pepper Company (TLPC) is the mechanical processing line, which takes 10-20 minutes. This line exists of a hopper, a sorter, a depulper and a mucilator. The coffee cherries are collected in the hopper, a big box. From the hopper, the cherries go to the sorter where impurities like floaters, leaves and branches are removed. There after the cherries are cleaned from small impurities like sand. Then the coffee cherries are depulped and transported to the demucilator, which washes off the mucilage (semi-washed, not all the mucilage has been removed yet, particularly the mucilage at the flat bean side isn't washed off). Now the beans are pumped with a water stream into the first silo.

The second part exists of fermenting and washing, which takes around 6 hours. In the silo a chemical process by bacteria washes off the rest of the mucilage (fully washed). From here on the beans are transported to the flat bed dryers.

The third part exists of flat bed driers with forced heat flow from coal burners, on which the beans dry for around 12 hours, till the moisture content is decreased from 55% to 25% MCWB (= moisture content wet basis). When the sun shines, beans may be dried in the sun. The first advantage of sun drying is a better quality of the dried beans, because of bleaching by UV radiation. The second advantage is a lower energy price, because the heat to dry the beans comes from the sun. Disadvantage is that the beans should be covered by sudden rainfall and the alternation of wet and dry periods stimulates ochratoxine fungi growing on the beans. After this the beans go to the rotary driers.

In the rotary driers, the fourth part, the moisture content is reduced from 25% to 10-11% MCDB (= moisture content dried basis) in around 18-20 hours. Beans growing in a dry climate are called 'hard beans' and contain after drying 12% moisture (MCDB); beans growing a wet climate (like in Vietnam) are called 'soft beans' and contain after drying 10-11% mc. The reason for this is that in the wet climate fungus may grow on beans with a moisture content of 12%. For drying it is important not to exceed a temperature of 50 °C, while otherwise the outside of the beans will be very dry and the inside still very wet, which creates problems during storage when the outside of the beans becomes moist again and decreases quality. After the rotary driers, the dried clean parchment beans are loaded in bags (60 kg), which are transported to Tan Lam for storage and hulling.

Hulling, sorting and grading are the last part of processing coffee for TLPC. During hulling the parchment skin is removed from the beans, which are from now on called green beans. Beans can break during hulling. Green beans with defects (like broken beans, pea berries and beans with black spots) are separated from beans without defects, this is called sorting. Finally the beans are separated into different sizes. For The Netherlands this is mainly 17 (beans which are (bigger than) screen size 17) and 13 (beans with screen size 13, 14, 15 and 16).

2.5 Coffee crisis

The coffee production chain exists of producers (farmers), intermediaries (like millers, traders, exporters and importers), coffee roasters and consumers. The number of coffee farmers is estimated around 25 million, mostly smallholders who grow coffee on family plots (Oxfam, 2002). The intermediaries provide a lot of coffee-related jobs in the countries of origin. Five big coffee roasters (Kraft, Nestle, Sara Lee (DE), Procter&Gamble and Tchibo) buy almost half of the world's supply of green coffee beans. These companies shape the retail market (Oxfam, 2002), but monopolies or cartel like behaviour is not identified (ECF, 2002).

Coffee roasters made and still make a good profit from their products (www.saralee-de.com, 26 June 2003). Also farmers used to make a good profit from their crop, which meant they could buy enough food, could pay school for their children and live in a decent house (Oxfam, 2002). But this situation changed during the last ten years, due to different causes, which led to a coffee crisis. This crisis is characterised by decreasing prices on the world market (Oxfam, 2002). The price is at a thirty year low and there has been a shift in the buying by roasters from arabica to lower quality robusta. The quality of this robusta itself has fallen, because many farmers can not invest enough in their crop to maintain a good nutrient level.

Causes of the coffee crisis

According to Oxfam (2002), Sara Lee/DE (2002) and European Coffee Federation (ECF) (2002) the main cause of this crisis at the world coffee market is oversupply. For the production in 2001/02 the oversupply is estimated at 600 million kilogram, which is around 8% of the total production (Oxfam, 2002). Because oversupply already exists for several years, at the moment the stock of green beans is estimated at 24000 million kilogram (Oxfam, 2002), which is around 3.5 times the production of 2002 (Oxfam, 2002; www.ico.org, May 26 2003). One of the reasons for this oversupply is the end of the managed market in 1989. Till that year the market was regulated by the International Coffee Agreement (ICA) between producing and consuming countries that set export quotas. The ICA kept the coffee world market price relatively high and stable, but made it very difficult for producing countries to get larger quotas and for new producers to enter the market. Due to disagreement between members the agreement broke down in 1989, resulting in increasing production and falling prices which dropped even below the average cost of production. Big part of the increase in production took place in Brazil and Vietnam (Oxfam, 2002; Sara Lee/DE, 2002; ECF, 2002). Brazil, the world biggest coffee producer, increased yields by using better production technologies. Vietnam, in 1990 one of the smaller coffee producing countries, grew within 10 years to the second largest coffee producer, due to subsidies given by the government to encourage farmers to produce coffee. Apart from overproduction, the low production costs of Brazil and Vietnam have a big influence on the price setting for Arabica and Robusta (ECF, 2002). Finally, a lagging demand, which means a relatively slow growth of coffee consumption, has contributed to an oversupply of coffee on the world market (Oxfam, 2002; SL/DE, 2002; ECF, 2002).

A second cause of the coffee crisis is the imbalance of the world market, mainly between producers and coffee roasters. Farmers almost don't have any power to negotiate and just have to accept the (low) price offered by traders. Because of this (low) price farmers have to look for cost reducing farming techniques, which mainly result in reduced green bean quality, higher yields and less biodiversity. In general the importance of coffee beans to the final retail price has fallen (Oxfam, 2002). But according to the ECF (2002), referring to data of the International

Coffee Organisation (ICO), the value of the retail market has followed the same pattern as the value of exports. SL/DE (2002) and the ECF (2002) also say that ICO data indicate that roasters pass on lower green coffee prices to the consumer.

A third reason for the coffee crisis is that roasting companies created more efficient ways of roasting coffee beans and making coffee blends. For example, they have a better system for cost control, don't need to hold large stocks of coffee and have advanced ways to manage risks and minimise risks to their raw material costs. Roasters also developed technologies that make them less dependent on the quality of coffee beans, e.g. by steaming Robusta, which enhances the quality. Even though a lot of coffee roasters are concerned about the quality of green coffee beans they need for making their blends, a shift from arabica to robusta coffee has clearly taken place.

A lack of alternatives to coffee as a cash crop and a failure of rural development can be mentioned as the fourth cause of the coffee crisis. Farmers and governments know it is very dangerous to be dependent on only one cash crop. Reasons for not replacing coffee by other crops are high replacing costs for coffee trees, a lack of knowledge to grow other crops and in most cases the lack of savings to live off while waiting for the new crops to bear fruit. Apart from this, many alternative crops are in a crisis like coffee (Oxfam, 2002; ECF, 2002). Another factor is that very little of the potential value of the coffee bean is captured by producing countries themselves: 94% of all coffee exported from producer countries exists of green coffee beans, while processing and packaging (adding value) takes place in consumer countries. Logistical reasons explain most of this, while a coffee blend exists of coffee from different countries and after roasting the beans have to be consumed within a specific time. Apart from this tariff barriers make the import of roasted coffee more expensive. International traders are also increasingly active in producer countries taking over the role of the local traders. In a lot of coffee producing countries the national government played an important role on the coffee market. Deregulation has some benefits for farmers, because it reduces the costs in the marketing chain, which gives the farmers a higher price for their product. However, the low actual market price has strongly ended this advantage. In addition, no one replaced the role of the governments in the price setting, infrastructure, development, research and extension, which makes it for farmers even more difficult to grow high quality coffee and negotiate on the market. Small farmers' capacities seem not be able to fill these holes. Another cause for the failure of rural development is that many farmers don't receive enough information, for example about current prices or new harvesting techniques and a proper way of coffee growing. This technical know-how is, however, very important to increase yields, increase quality and add value. Farmers are also facing debts, which means a shrinking of new credit, putting them in a downward spiral. The weak rural infrastructure also plays a role, because it has resulted in very high export costs. For some farmers it is impossible to transport their crop to the market within the crucial processing time. Finally the support for rural development has declined from 1985 with an annual average rate of 7 percent, while most poor people are dependent on agriculture.

Solutions to the coffee crisis

As a solution to the current coffee crisis, niche or speciality coffees (coffees from certain places like 'Blue Mountain' or organically grown coffee) can be mentioned, but for only a small group of farmers. First of all, when all the farmers start producing speciality coffees, this commodity isn't anymore unique and loses therefore its added value. Secondly because of the current imbalance between supply and demand of green coffee beans (Oxfam 2002, ECF 2002).

Another solution is fair traded coffee, which means farmers can sell their coffee at prices that meet their basic needs. Fair Trade requires people in the coffee chain to work transparently and with decent production conditions. Fair Trade has also impact on the environment, while it puts emphasis on sustainable production techniques. Since Fair Trade makes people aware of production circumstances, it has created image problems for the main stream coffee industry. Fair Trade market is driven by people who are concerned about the living conditions of people in coffee producing countries and are willing to pay more to improve this. However, the market share of Fair Trade coffees is only around 1.5% in the Netherlands.
Another important solution is restoring the imbalance of supply and demand. According to Oxfam a first step could be destroying stocks of (low quality) coffee, the costs for this (to be paid by governments and companies) being

about $100m. According to SL/DE and the ECF, destroying stocks would only be a short-term solution, because it doesn't reduce the overproduction. It can even work adversely, because on short-term it improves the price and therefore triggers higher production when it is not followed by a reduction in area and/or productivity.

Companies should also pay more attention to expanding and developing the coffee market (Oxfam, 2002), but according to Sara Lee/DE the current low price level is caused by overproduction leading to an imbalance between supply and demand and this cannot be solved by the industry. The market is characterised by ups and downs (SL/DE). Moreover, low price levels and recovery have occurred also in the past (SL/DE). Price risk management can reduce the causes of price fluctuations (Oxfam, 2002). The development of an appropriate economical system is only a part of the solution and in this respect there is a fundamental and strong interrelation with the development of a constitutional state, a working democracy and civil society, as basic factors to establish the conditions for economic development (ECF, 2002). In the coffee market, producing countries compete with one another for market share and are understandably reluctant to restrict themselves if they have a competitive advantage (ECF, 2002).

In future, collaboration between coffee producers and consumers should avoid an imbalance between supply and demand. According to the ECF, the ICO can play a useful role in the management of supply.

Another solution is only trading in green coffee beans of a certain quality which are cultivated and processed in acceptable ways. This will remove 3-5% of produced coffee from the international market. Traders and roasters can be of assistance in this part (ECF, 2002). Extra attention should be paid to farmers who produce low quality beans, who have limited technologies and countries with limited internal markets (Oxfam, 2002; ECF, 2002). A better quality can be seen as a value-adding capacity and can be applied from the first steps of processing coffee cherries on. SL/DE (2002) agrees that coffee quality improvement will lead to higher prices and improved living conditions. SL/DE is able to pay higher prices for required higher quality beans, while always considering the world market price as its benchmark. Other examples of value-adding capacities are branding, marketing and a bigger consumer market in producing countries themselves (Oxfam, 2002; ECF 2002).

Also according to Oxfam, roaster companies should commit to paying prices that provide farmers with a decent income and manage their supply chains so as to ensure that farmers capture more of the benefits of the market. According to SL/DE (2002) and the ECF (2002) paying minimum or guaranteed prices isn't a solution, but (due to higher prices) will result in more overproduction. The social-economical position of coffee farmers can only be improved by combined efforts by farmers, local trade, roasters and (inter) national governments of producing and consuming countries, by focussing the recovery of the balance between supply and demand. Every regulation of prices will fail, which means, according to director Joost Manassen of DE, that the best solution is to let the market do its job (Trouw, 2002). This can be painful, but, he says, for long term solutions it is necessary to get healthy market proportions of which anyone can take advantages (Trouw, 2002). According to Mr. Manassen, the solution for the coffee market is to make sure farmers aren't dependent on one product. To achieve this is not a task for DE but for governments and the Worldbank (Trouw, 2002). DE wants to invest in improvement of coffee quality (Trouw, 2002). Also according to Mr. Manassen, persons with coffee related jobs in production countries should work together and there should be more co-operation between co-operations in producing countries (Trouw, 2002). Action should be taken by the WTO and a responsible attitude of developed markets in a future round of trade negotiations (ECF, 2002).

Apart from this, SL/DE points at strong regional differences in living conditions of coffee farmers. Both SL/DE and the ECF don't deny the lost of coffee related jobs in South- en Central America, but they also mention the explosive increase of coffee employment in Vietnam.

2.6 Coffee and quality

Coffee beans of higher quality should result in higher prices and should be part of the solution of the current coffee crisis (Oxfam, 2002; DE, 2002; ECF, 2002; Njoroge, 1997). Overall coffee quality depends on raw bean, roast bean and liquor quality or brewed flavour (Njoroge, 1998). Criteria used to measure quality of green beans are bean size, shape of the bean, density, colour and the bean chemistry of the raw bean (Njoroge, 1998). These criteria are influenced by a wide range of factors, namely plant growth, production, harvesting, and processing (Njoroge, 1998).

Before starting with coffee cultivation a stocktaking should be made of abiotic factors in the area where the coffee cultivation will take place, while ecological conditions affect the growth of coffee trees, and this is ultimately reflected in coffee quality (Njoroge, 1998). Important factors are described in Table 1. It is therefore important to grow coffee in the ecological zones that are highly suitable for coffee production in order to maximise the quality of the beans as well as quantity (Njoroge, 1998). Thus choice of species, varieties and genotypes of coffee to be grown and exhibit all the desirable characteristics of disease resistance, compact size, vigour, high yield and quality (Op de Laak, 1992) is very important (Njoroge, 1998). Breeding work has been geared to improve ecological adaptation, yield and quality (Njoroge, 1998).

After this, nursery procedures can start and should be implemented under optimal conditions as described by for example Op de Laak (1992), Cambrony (1992) and Njoroge (1997). Before planting out, a selection and marking out of the plots, soil preparation, choice of layout and density of planting should be made (Cambrony, 1992). Also the technical operation involved in transplanting should be kept in mind (Cambrony, 1992). The coffee plantation has to be maintained in excellent condition if the plants are to develop vegetatively, become mature, flower and bear fruit under the best conditions (Cambrony, 1992).

Factors affecting bean size

A big bean (AA or screen size 17) is considered as high quality (Njoroge, 1998). The bean size depends on several factors. First of all on genotype (Njoroge, 1998), for example arabica coffee has bigger beans than robusta coffee (Op de Laak, 1992). The potential bean size of every species is determined by the mother plant (Wrigley, 1988).

The proportion of large sized beans has been shown to decrease with increased nitrogen rates of application unless balanced with phosphate fertiliser (Njoroge, 1985). The size of the beans themselves is also decreased by nitrogen, but depends on the nitrogen status of the soil (Njoroge, 1998).

When the bearing wood becomes weak, the bean size deteriorates (Wrigley, 1988). Stumping, the change of cycle to raise new stems which is carried out after six or seven years, results in a production with a high proportion of large beans and therefore improved coffee quality (Njoroge, 1997).

The proportions of the large ‘screen size 17’ beans were not significantly different by the single stem system or two stem system at densities between 1600-4800 trees/ha during the first production cycle (Njoroge, Waithaka & Chweya, 1992). Production of high bean yield per tree tends to lead to a decline in bean size and hence quality (Njoroge, 1998). Close spacing decreases yield per tree and therefore increases the production of large beans (Njoroge, 1998). Fruit thinning can increase the production of large beans.

The bean size also depends on the availability of moisture during the rapid expansion following the pin-head stage (Njoroge, 1998). Irrigation can increase the proportion of beans of screen size 17 (Njoroge, 1998; Gathaara & Gitau, 1999) as well as average bean size (Njoroge, 1998).

Mulching has a significant positive effect on clean coffee yield and quality, while it can increase the production of large beans (Njoroge, 1998), because mulch preserves soil moisture for better nutrient absorption by plant. Apart from this, it improves soil structure, supplies mineral nutrients on decomposition, regulates soil temperature and suppresses weeds, leading to reduced herbicide use (Njoroge, 1997). It also prevents erosion, thereby avoiding transport of nutrient and pesticides to surface and underground water, and it minimises the use of inorganic nutrients (Njoroge, 1997). Excess K introduced through mulch can cause an excess of K in raw beans and therefore give poor quality coffee (Njoroge, 1997).

Shading increases production of large beans, while it decreases yield per tree. Shade conditions significantly improve the flavour of commercial coffee (Roubik, 2002).

Coffee trees produce smaller beans of low quality due to weeds (Njoroge, 1998). Apart from this, weeds have been shown to reduce coffee yields by over 50% (Njoroge, 1997; Njoroge and Kimemia, 1989) as compared to clean weeding.

Insect pests have a damaging affect on the coffee plant and leads to production of small, low quality cherries (Njoroge, 1998). Control of such pests should improve bean quality (Njoroge, 1998).
Trees which yielded the largest beans tended to be the latest to ripen (Wrigley, 1988).

Factors affecting the shape and appearance of the bean

Abnormalities in beans make the coffee considered to be of low quality, except pea berries which can be sold as a special grade (Njoroge, 1998). Abnormalities can occur due to genetic aberrations, poor pollination and physiological factors (Njoroge, 1998; Cambrony, 1992; Clifford & Willson, 1985). Arabica coffee as well as robusta coffee is wind-pollinated, but (naturalised, non-native) honeybees can increase pollination, resulting in higher yields and heavier ripe cherries (Roubik, 2002). Maybe pollination by insects can reduce the number of pea berries. But production of high bean yield per tree can lead to a decline in bean size. The number of abnormal beans produced on a coffee tree is also influenced by the age of the tree and the position of the fruit on the tree (Njoroge, 1998). Pests, like bean borers or antestia bug, affect the shape of the bean directly (Njoroge, 1998).

Factors affecting bean weight

A high mean bean weight is considered as a high quality characteristic (Njoroge, 1998; Gordian, 1963 and Northmore, 1965 in Clifford & Willson, 1985). Low moisture leads to production of light beans which are of poor quality (Njoroge, 1998). Nitrogen is important for protein synthesis, hence quality of beans. It increases yield, but decreases bean weight and therefore quality (Njoroge, 1998; Gordian, 1963 and Northmore, 1965 in Clifford & Willson, 1985). Apart from this, the period of bean filling can be shorter as mean daily temperature increases (in respect to °C days). Sink strength increases with temperature, because biosynthesis is the result of temperature sensitive enzymatic processes, while source strength (assimilation) increases with increase of radiation (Vos & Stomph, 2000). For coffee this means higher temperatures with the same amount of radiation results in a shorter period of bean filling.

Factors affecting green bean quality in general

Fertilisers are needed for both vegetative growth of tree and production of high quality coffee beans (Njoroge, 1997). Coffee bushes require constant application of nutrients for better yields and quality of beans (Njoroge, 1997). Nutrient imbalances may affect the coffee bean quality (Northmore, 1965 in Njoroge, 1997). A balance of nutrients (NPK, Mg, S, Zn, Cu, Fe, B, Mo) in the soil is important for better bean quality (Njoroge, 1998). The balance in the soil of Ca+Mg/K is especially important and should be between 4-10 (Njoroge, 1998). High levels of K and Ca in the bean reduce quality, due to imbalance with magnesium (Njoroge, 1998).

Use of organic manures has been reported to lead to increased coffee yields and quality especially on very poor soils (Mitchell, 1970 in Njoroge, 1997).

Control of diseases, weeds and insect pests has an obvious importance in preventing reduction in coffee quality. Intercrops can also reduce quality of the coffee crop.

To produce high quality coffee, careful picking, collecting and storing of coffee cherries should be practised (Njoroge, 1997). Quality of green beans is also determined by the way of harvesting. When harvested by hand a selection between ripe and unripe cherries can be made (see §1.7), when cherries are strippicked, this selection can't be made. Coffee cherries should be stored in the shadow, because in full sun cherries will start to ferment earlier.

Large differences occur between cultivars in their ability to produce well-formed beans, and bean size is also influenced by certain cultural measures such as nitrogen application, mulching or pruning, but the differences in average bean size between crops picked in different years and at different times in one year are far larger than any differences produced by cultural measures.

2.7 Coffee in Vietnam

Vietnam is located in the centre of South East Asia, bordered by China to the north, Laos and Cambodia to the west and the East Sea and Pacific Ocean to the South East. The total length from north to south is 1650 km. (from 23°22' to 8°30' North latitude and from 102°21' to 109°21' East longitude). Vietnam is therefore located in a tropical as well as in a temperate zone. In the north and centre of the country four seasons can be distinct, but in the south only two (www.vietnamtourism.com, 2-22-2003).

Although coffee was already introduced to Vietnam in the late 19th century, only during the last 25 years the production of coffee increased 100 times (Figure 5). Around 1980 the Vietnamese government wanted to develop the mountainous areas, by increasing the income of local populations (and valuable foreign currency for the State) through cash crop cultivation (Trebel, 1996). Around 1982, agreements were signed with the USSR, GDR, Bulgaria and Czechoslovakia, which funded infrastructures and the setting up of large state and provincial plantations (Trebel, 1996). In this way around 55,000 hectares were planted with coffee trees. In 1982, the Ministry of Agriculture set up a State company, Vinacafé, whose main role was to implement and monitor the contracts (Trebel, 1996). This company was the only means of access to Vietnamese coffee up to 1992, since it was the sole holder of a coffee export licence (Trebel, 1996). The state farms were managed with hired farm labour, which resulted in a lack of worker motivation, unwieldy and centralised management and low output (Trebel, 1996). To encourage agricultural development, in 1990 the large state and provincial plantations were split into 0.5 to 1.5 ha plots given to tenant farmers, who are generally required to reimburse the investments (Trebel, 1996). The effect of this and other measures (listed in Trebel, 1996) has been to increase the work effort of farmers and smallholders and largely explains the boom in Vietnamese coffee production and the high yields obtained (Trebel, 1996). In 1992 the Soviet bloc collapsed, which resulted in economic liberalisation and turned the coffee sector upside down (Trebel, 1996). Competition started between Vietnamese coffee producers, who didn't have experience on the international market and therefore failed on this market (contracts not honoured in quality or quantity). This resulted in a damaged brand image of Vietnamese coffee and discounts on the commodities futures markets (Trebel, 1996). However, in 1995 a general coffee company was created, which took over all structures of Vinacafé (Trebel, 1996). This new Vinacafé manages the funds (entrusted by the State, members and private or institutional sources) for production incentive, insurance savings and training schemes as well as direct control of coffee plantations (Trebel, 1996). In this way the Vietnamese government took the sector in hand again. Nowadays 10 million bags of coffee are produced annually, from half a million hectares of coffee fields (of which only 10-15% belongs to State farms). The two most important coffee species grown in Vietnam are *C. arabica* en *C. robusta*, which are exported to 60 countries and territories all over the world (Nhan, 2001). The coffee industry in Vietnam employs totally over 600 thousand of people (Nhan, 2001).

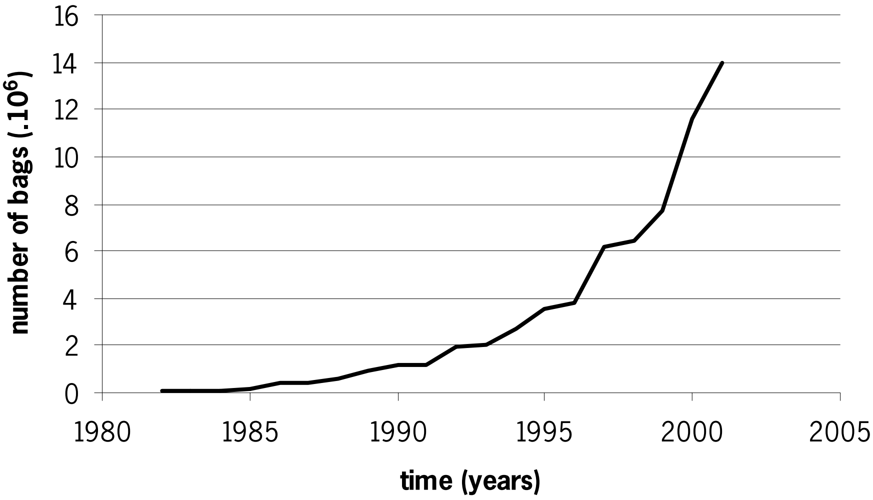

Figure 5. Number of coffee bags (60 kg/bag) exported by Vietnam (source: www.ico.org; June 2003).

2.8 Knowledge gaps regarding coffee cultivation in Huong Hoa district

In Huong Hoa district in Vietnam a lack of knowledge exists about sustainable coffee cultivation, mainly because of the following two reasons:

1. Information about good management practices for Arabica coffee does not exist for this area with its specific growing conditions, which is partially related to the fact that production of Arabica coffee in this area started less than 10 years ago. For example, the optimum amounts and time(s) of application of fertilisers, pesticides and fungicides are unknown. As a consequence, the coffee trees have a biennial bearing pattern with a heavy crop in one year causing overbearing and dieback which results in hardly or no yield in the succesive year. This in turn leads to a reduction of the productive life of coffee trees (Op de Laak, 2002).
2. In general, most farmers don't have a basic agricultural knowledge about crop management, related to the fact that most of them do not have a background in coffee farming while vocational education on farming doesn't exist in Vietnam. As a result, many farmers do not know (yet) how to prune the coffee tree in a good way.

This lack of knowledge may result in reduced quality of coffee cherries and green beans, and reduced yields of coffee cherries. Apart from this, it may result in reduced financial yields for farmers, while inadequate application of nutrients may cause environmental problems.

The cost of (chemical) fertilisers are considerable in view of total production costs of a coffee crop in Huong Hoa district (Table 3). A shortage or excess of nutrients can cause deficiencies or toxicities in the crop and consequently probably reduce yield and quality of the harvested product. Excessive amounts of fertilisers can also leach out to the ground and surface water, causing environmental problems. In addition, the costs for production increase. There is an optimum fertiliser (NPK) ratio that varies from area to area, which emphasises the need for site-specific nutritional recommendations (Njoroge, 1998). Therefore, it is important to look for sustainable fertiliser applications in Huong Hoa district in Vietnam, which will contribute to a high yield of coffee cherries and green beans of high quality. Apart from this, these fertiliser applications should also reduce costs for farmers without harming the environment.

Table 3. Fertiliser costs (%) of total production costs.

location	fertilizer costs (%)	sd
Huong Phung	60	18
Khe Sanh	45	16

sd = standard deviation

2.9 Goals and approaches of research

At the start of this research activity, no reliable and verifiable information existed regarding the efficiency of nutrient applications in Huong Hua district. Anecdotical information indicated differences in yield level and quality between Huong Phung and Khe Sanh, without clear indications whether this is related to fertilization. However, location specific information is needed to indicate the most important problems and directions of solution regarding nutrient application.

The goals of this research comprise

a. to make a quantitative description of the current situation in HP and KS regarding nutrient inputs and outputs and quality of cherries and beans on field level
b. to relate, where possible, nutrient applications and contents to quality of cherries and beans.

The approach followed in this research can be described as observational, where no experimental interventions were done. Instead existing crops were sampled, at different times during the harvest period. On basis of these samples, the following aspects were determined per field:

- yield characteristics of coffee cherries
- state of maturity of harvested cherries
- quality characteristics of green coffee beans
- nutrients removed from the field by coffee cherries
- nutrients removed from the field in coffee cherries per 1000 kg of green beans

Relations were tested between:

- harvesting date and state of maturity of harvested cherries
- harvesting date and quality characteristics of green coffee beans
- fertilizer applications and nutrient content in coffee cherries
- nutrient content of coffee cherries and dry matter yield of coffee cherries

The results of this stocktaking (2002) together with the stocktaking from year 2003 can give starting points for further (experimental) research.

3. Materials and methods

3.1 Sampling method

From October 21 until December 9 2002, 45 samples were taken from 24 coffee fields of farmers at two different locations, Khe Sanh and Huong Phung. Each of these 20 fields is subjected to different ways of field management, which the farmer noted every week in a field book. Amounts and times of fertiliser applications as well as the yield of fresh cherries per day were registred. Also background information like number of trees per hectare and year of planting was filled in on this paper. These data were converted to N-input (kg/ha), P-input (kg/ha), K-input (kg/ha) and yield of fresh cherries (kg/ha)
(see section 4.1).

Each sample existed of 5 kg (± 20 g) fresh coffee cherries, at random taken from the bags in which farmers collect harvested coffee cherries. The samples were brought to the lab in plastic bags with small holes in it, which were fastened on the back of the motorbike. Each sample has been divided at random into two sub-samples (0.5 kg (± 1 g) and 4.5 kg (± 20 g)). The sub-sample of half a kilogram has been used for nutrient-analysis, while the sub-sample of 4.5 kg has been used for quality-analysis.

3.2 Processing of samples

3.2.1 Nutrient analysis

Each nutrient-sub-sample (0.5 kg fresh cherries) was ground for 15 minutes (± 2 minutes) in a fruit juice machine (Sanex), which transformed the pulp as well as the beans to a slimy and sticky suspension. Because of the character of this suspension, in all cases a small part was left behind in the fruit juice machine and therefore the suspension taken out from the fruit juice machine was weighed again. The suspension was dried in a hot-air oven (MGBTS 100) at 55-60 °C till all the moisture was removed. The sub-samples were stored in sealed, plastic bags and were analysed by Wageningen University (The Netherlands), department environmental sciences (section soil quality, central laboratory). Analysed are the amounts of N, P, K, Ca, Mg, Mn, Zn, Al, Fe, Cu, S, B and Si (mmol/kg dry matter of cherries) or (mg/kg dry matter of cherries) (Appendix 1), according to analytical methods described in Soil and Plant Analysis (Temminghoff et al., Houba, Vark & Gaikhorst, 2000).

3.2.2 Quality analysis

The quality-sub-sample (4.5 kg fresh cherries, ± 20 g) was put in a basket full of water, to separate the floaters from the non-floaters and to sort out unwanted materials like leaves and branches. The floaters were counted, weighed (± 1 g) and thrown away. The weight of the unclean material (± 1 g) was determined.

The non-floaters were divided visually into 4 groups: 1. Unripe cherries (green and hard); 2. Under-ripe cherries (half green, half (light-)red, soft); 3. Ripe cherries (red and soft) and 4. Overripe cherries (dark red or black). The cherries of each group were counted and weighed (± 1 g). Groups 1 and 4 were discarded, while these cherries aren't economically interesting.

Groups 2 and 3 were processed separately according to the fully washed method: first of all they were pulped by a hand pulper. The weight of the pulped beans and removed pulp (± 1 g) was determined. Secondly, the beans were put in plastic bags for 12-15 hours to ferment over night. After fermentation, the beans were washed with clean water and dried in an hot-air oven at 50°C (MGBTS 100) till moisture content of 10-12% had been reached. This moisture content was empirically determined (after a lot of exercise) by biting in some beans of each sample, because at the stage of parchment beans moisture content can't be determined by a moisture measuring machine.

Only moisture content of green beans can be determined by a moisture measuring machine. If these bites felt like bites in a chewing gum, it was concluded the moisture content of the beans was higher than 10-12% and the sample was put in oven to reach the desired moisture content. If the beans cracked after these bites, it was concluded they were too dry, unfortunately nothing could be done to increase moisture content. If these bites didn't feel like bites in chewing gum and the beans didn't crack after these bites, it was concluded that all beans of the sample reached the desired moisture content.

The dried parchment beans were stored in sealed plastic bags in a fridge (temperature around 6°C) till the end of the harvest season (end of December 2002). In this way the coffee beans could be stored for at least 3 months without deterioration of quality.

After the harvest season, all the samples were hulled within two weeks. Hulling was done with a hulling machine (Dayton, model 2M168D; 1 minute, position '40'). After hulling, screen size (17, 13 and <13) of the beans was determined by hand screen sieves (Vicofa). The choice for these sizes has been made, because international coffee buyers (like Kraft Foods and Sara Lee/DE) use these sizes for green coffee beans. The beans of each screen size were divided into 5 groups: 1. Normal flat beans without black spots; 2. Normal flat beans with black spots; 3. Pea berries without black spots; 4. Pea berries with black spots and 5. Broken beans. Of group 1, 2, 3 and 4 the weight (± 0.02 g) and number (hand counting) of the beans has been determined, while of group 5 only the weight (± 0.02 g) was determined. The beans of group 1 and 2 were put separately in sealed plastic bags and the beans of group 3 and 4 were put together in sealed plastic bags, while the beans of group 5 were thrown away. Finally, per quality-sample from 4.5 kg. fresh cherries, 24 groups of dried green beans can be made (Table 4).

After regrouping, the dried green beans are send to DE for cup-tasting by professional coffee tasters, results where not in time to analyse (Appendix 2).

Table 4. 24 groups of dried green beans after processing of a quality-sample.

Group																							
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
H	H	H	H	H	H	H	H	H	H	H	H	R	R	R	R	R	R	R	R	R	R	R	R
17	17	17	17	13	13	13	13	<13	<13	<13	<13	17	17	17	17	13	13	13	13	<13	<13	<13	<13
N	N	PB	PB	N	N	PB	PB	N	N	PB	PB	N	N	PB	PB	N	N	PB	PB	N	N	PB	PB
G	Z	G	Z	G	Z	G	Z	G	Z	G	Z	G	Z	G	Z	G	Z	G	Z	G	Z	G	Z

H, R = beans from under-ripe and ripe cherries respectively; 17, 13, <13 = respectively beans with screen size 17, 13, <13; N, PB = respectively normal shaped beans and pea-berry-beans; G, Z = respectively beans not infected with black spots and beans infected with black spots.
For example: H17NG (group 1) = beans from under-ripe cherries, screen size 17, normal shape, not infected with black spots.

3.3 Conversions

The laboratory results of the amounts of analysed nutrients were in mmol/kg dry matter or in mg/kg dry matter, depending on the chemical element (Appendix 1). For reasons of comparison all are converted to nutrient-output in cherries (kg nutrients/ha), nutrient-output (kg nutrients/100 kg fresh cherries) and nutrient-output (kg nutrients in cherries/1000 kg green beans), depending on the used analysis (Appendix 3, Equation 1, Equation 2, Equation 3 and Equation 4).

The nitrogen use efficiency (NUE), phosphor use efficiency (PUE) and potassium use efficiency (KUE) was calculated. This is the physiological relation between the total dry matter production of cherries and the amount of nutrient taken up (Appendix 3, Equation 5; Vos & Stomph, 2000). Finally, the apparent agronomic nitrogen recovery (AANR) is calculated (Appendix 3, Equation 6). This is the relation between N-input and N in cherries, which is the result of the relation between soil processes and root functioning. If this relation is linear with a constant slope, it would indicate a constant marginal efficiency of uptake, while curvature indicates that the efficiency of uptake declines (Vos & Stomph, 2000).

3.3.2 Conversions of units of measurments in quality analysis

Coffee cherries can absorb water and consequently their weight in dry periods is less than their weight during wet periods. Therefore the percentage of floaters, green, under-ripe, ripe and overripe cherries in a sample has been calculated from the number (not weight) of total cherries in a sample (Appendix 3, Equation 7, Equation 8, Equation 9, Equation 10 and Equation 11 respectively).
Although during drying of the beans a lot of care has been taken to make sure the moisture content is between 10-12%, this didn't succeed for all the samples. During hulling some green beans broke. To compare the weights of green beans of different samples, they are corrected for moisture content (Appendix 3, Equation 12) as well as broken beans (Appendix 3, Equation 13).
The yield of green beans (kg/ha) and the yield of green beans (kg/tree) is based on the weight of beans from under-ripe and ripe beans (Appendix 3, Equation 14 and Equation 15 respectively).
The following characteristics are also calculated:

1. The weight based ratio 'kg green beans/kg fresh cherries' of beans from (under) ripe cherries (Appendix 3, Equation 16).
2. The weight based percentage of 'screen size 17'-beans of the total weight of beans from (under) ripe cherries (Appendix 3, Equation 17).
3. The weight based percentage of pea berries of the total weight of beans from (under) ripe cherries (Appendix 3, Equation 18).
4. The weight based percentage of beans infected with black spots of the total weight of beans from (under) ripe cherries (Appendix 3, Equation 19).
5. The 1000-beans weight of 'screen size 17'-beans is based on the weight and number of beans with screen size 17 from (under) ripe cherries (Appendix 3, Equation 20).

3.4 Statistical analyses

Analysis of data is done by comparison of data between location and linear regression (time ex- and included). Because 45 samples were taken from 20 farmer fields, this means there are repeated measurements in time for some fields. For comparison between location and linear regression (time excluded), for each field the average of these samples is calculated.

To allow linear regression of time series, the individual samples (i.e. each of the 45 samples) need to be independent, while the effects of factors (like time and field) need to be additive (i.e. do not show interaction) (Evert-Jan Bakker, statistician WUR). For percentage 'screen size 17'-beans' this assumption can be made, since the size of a bean is determined in the period of rapid expansion following the pin-head stage. The time when a 'screen size 17'-bean is harvested depends on the ripening period of the cherry and this period can be assumed equal for all farmers. For this reason, this assumption can also be made for percentages of unripe, under-ripe, ripe and overripe cherries. For pea berries this assumption can be made, since the cause of pea berries is mainly genetic and farmers use the same genotype. Although the cause of the black spot disease is unknown, for the number of beans infected with black spots the assumption of independence can be made, since the cause for black spots is assumed to be the same for all farmers. For the 1000-bean weight assumption of independence between all samples can be made, since the time till harvesting determines the period of bean filling (and finally bean weight) and this is for all samples the same.

3.4.1 Comparison of means

Comparison of response variables between location (Huong Phung and Khe Sanh), is done by using the Student's t-test (standard normal distribution, α = 0.05). This test is chosen, because it compares two or more populations in an observational research (Oude Voshaar, 1994).
Response variables are:

1. nutrient-output (kg nutrient/100 kg fresh cherries) of the following nutrients: N, P, K, Ca, Mg, Mn, Zn, Al, Fe, Cu, S, B and Si.
2. nutrient-output (kg nutrient in the cherry/1000 kg green beans), since this criteria is used generally in literature.
3. % floaters, unripe, under-ripe, ripe and overripe cherries
4. yield characteristics:
   - yield of fresh cherries (kg/ha)
   - yield of dry matter of cherries (kg/ha)
   - yield of green beans (kg/ha)
   - yield of green beans (kg/tree)
   - the ratio 'kg green beans/kg fresh coffee cherries'
5. quality characteristics:
   - % 'screen size 17'-beans
   - % pea berries
   - % beans infected with black spots
   - 1000-beans weight of 'screen size 17'-beans

3.4.2 Linear regression

3.4.2.1 General

Linear regression calculates a trendline which fits best through the observed data, by making the 'sum of the squared errors' as small as possible (the error is the difference between the observed value and the calculated value, it can be positive as well as negative). The analysis was performed in Excel 97 using its 'linest' function. The formula used for the trendline is:
$y = a*x + b$
y = response variable
x = predictor variable
a = slope of trendline
b = intercept

An F-test (standard normal distribution, α=0.05) was used to see whether a linear relation between response and predictor variable is statistically significant. If a relation is significant, it cannot be interpreted as a causal relation, especially so in observational research (Oude Voshaar, 1994).

3.4.2.2 Linear regression, time excluded

In the case of time excluded linear regression, response variables consist of:

1. quality characteristics:
   - % 'screen size 17'-beans
   - % pea berries
   - % beans infected with black spots
   - 1000-beans weight of 'screen size 17'-beans
2. N, P, K-output in cherry (kg/ha)
3. dry matter of cherries (kg/ha)
4. dry matter of cherries (kg/ha)
5. dry matter of cherries (kg/ha)

Predictor variables consist of (numbers refer to numbers of response variables):
1. kg nutrient/100 kg fresh cherries of the nutrients N, P, K, Ca, Mg, Mn, Zn, Al, Fe, Cu, S, B and Si
2. N, P, K-input (kg/ha)
3. N, P, K-input (kg/ha)
4. N, P, K-output in cherry (kg N/ha)
5. nutrient-output in cherry (kg/ha) of the nutrients: Ca, Mg, Mn, Zn, Al, Fe, Cu, S, B and Si

For variables is distinguished between Huong Phung and Khe Sanh.

In case 1 also multiple linear regression (MLR) was performed in Genstat 5.0 (release 3.2.2), to see whether each slope coefficient (for location and kg nutrient/100 kg fresh cherries) is useful in estimating the assessed value of the quality characteristic.

3.4.2.3 Linear regression, time included

In the case of time included linear regression, response variables consist of:
1. % floaters, unripe, under-ripe, ripe and overripe cherries
2. quality characteristics:
    - % 'screen size 17'-beans
    - % pea berries
    - % beans infected with black spots
    - 1000-beans weight of 'screen size 17'-beans

In all cases the predictor variable consists of time (days in the year) with January 1, 2002 as day 1.
For variables is distinguished between Huong Phung and Khe Sanh.

The significance of the results of the statistic tests is given by using indications for P-values (Table 5).

Table 5. Indications of significance (Oude Voshaar, 1994).

Indication	Definition	P-value
n.s.	no significant difference	$P > 0.05$
~	Indication for difference	$0.05 < P < 0.10$
*	Significant	$0.01 < P < 0.05$
* *	strong significant	$0.001 < P < 0.01$
* * *	very strong significant	$P < 0.001$

4. Results

Many graphs are used in this report to visualize results. Unlike stated otherwise, the symbols, used in the Figures in this Chapter, in the Discussion (Chapter 5) and in the Appendices, are described by the same legend (Figure 6). Abbreviations used for Huong Phung and Khe Sanh are respectively HP and KS.

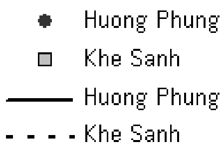

Figure 6. Legend used for figures.

4.1 Field characteristics

Fertilizer application rates were in the same range for both locations (Table 6). However, plant density were higher in HP, while plants were about two to three years older in KS.

Table 6. Some data of farmers included in field research (HP=Huong Phung, KS=Khe Sanh).

Farmer	Location	N-input	P-input	K-input	Yield fresh cherries	Plant density	Year of planting
		(kg/ha)	(kg/ha)	(kg/ha)	(kg/ha)	(# trees/ha)	
1	HP	298	163	159	2567	5000	1998
2	HP	975	525	680	5569	4600	1998/99
3[1)]	HP	368	66	378	3938	5200	1998
4	HP	275	190	95	12060	5000	1998
5	HP	828	281	232	16083	5000	1998
6[1)]	HP	1017	535	321	4394	5000	1998
7	HP	481	114	241	12015	5000	1998
8	HP	345	50	174	4424	5000	1998
9	HP	333	169	253	7329	5000	1998
10	HP	279	150	164	14430	4691	1998
11	HP	402	103	278	10425	4691	1998
12	HP	177	189	182	1577	4800	1998
13	KS	266	113	183	17020	4500	1996
14	KS	256	185	175	19672	4294	1996
15	KS	334	86	292	16371	4294	1996
16	KS	418	83	290	17031	4580	1996
17	KS	610	84	422	27329	4580	1996
18[2)]	KS	398	234	264	3977	4000	1995/96
19	KS	243	117	189	9254	4000	1996
20	KS	486	202	532	14947	4000	1995/96
21	KS	273	306	195	19643	4000	1995/96
22	KS	189	164	154	15804	4000	1995
23	KS	268	231	232	14704	unknown	1995
24	KS	361	287	205	23515	4270	1997

[1)] almost no management in year 2001
[2)] coffee trees in whole field were stumped about three years ago

4.2 Yield, cherry and green bean characteristics

4.2.1 Yield characteristics

The dry matter of cherries (kg/ha), yield of green beans (kg/ha) and yield of green beans (kg/tree) is significantly lower in Huong Phung compared to Khe Sanh. The ratio ‘kg green beans/kg fresh cherries’ is significantly higher for Huong Phung compared to Khe Sanh. No significant difference of yield of fresh cherries (kg/ha) exists between Huong Phung and Khe Sanh (Table 7).

Table 7. Yield characteristics of Huong Phung and Khe Sanh.

Response variable	Average	s.e.m.	Average	s.e.m.	d.f.	Significance
	Huong Phung		Khe Sanh			α = 0.05
Yield fresh cherries (kg/ha)	7912	1784	13425	2259	18	n.s.
dry matter of cherries (kg/ha)	2538	561	4809	528	18	* *
Yield green beans (kg/ha)	1352	344	2740	369	17	*
Yield green beans (kg/tree)	0.28	7.17.	0.65	8.1	16	* *
kg green beans/kg cherries	0.18	3.69.	0.16	3.9	17	*

s.e.m. = standard error of means

4.2.2 Cherry characteristics

It was found that the percentage of under-ripe cherries is significantly lower in Huong Phung than Khe Sanh, while the percentage of overripe cherries is significant higher in Huong Phung compared to Khe Sanh (Table 8). For percentage floaters, unripe cherries and ripe cherries no significant differences exist between Huong Phung and Khe Sanh (Table 8).

Table 8. Floaters, unripe, under-ripe, ripe and overripe cherries (%) for Huong Phung and Khe Sanh.

Response variable	Average	s.e.m.	Average	s.e.m.	Significance
	Huong Phung		Khe Sanh		α = 0.05; d.f. = 17
% floaters	9.7	0.8	10.7	0.6	n.s
% unripe cherries	8.3	0.8	9.9	1.3	n.s
% under-ripe cherries	24.0	1.2	27.9	1.2	*
% ripe cherries	46.6	3.0	44.4	2.2	n.s
% overripe cherries	11.5	1.4	7.26	1.0	*

s.e.m. = standard error of means

It was found that for Huong Phung and Khe Sanh under-ripe and overripe cherries (%) decrease significantly with time, as for both locations ripe cherries (%) increase significantly with time. The floaters (%) and unripe cherries (%) don’t change significantly with time for Huong Phung and Khe Sanh (Table 9, Figure 7; Appendix 4, Figure 16).

Table 9. Relation between harvesting date and cherry characteristics.

Variables		Huong Phung			Khe Sanh		
X	Y	r^2	F-obs	Significance	r^2	F-obs	Significance
Time	Floaters (%)	0.17	3.09	n.s	0.04	0.88	n.s.
Time	Unripe cherries (%)	0.09	1.54	n.s	0.06	1.51	n.s.
Time	Under-ripe cherries (%)	0.67	30.85	* * *	0.55	28.93	* * *
Time	Ripe cherries (%)	0.67	30.63	* * *	0.51	25.29	* * *
Time	Overripe cherries (%)	0.57	20.04	* * *	0.18	5.25	*

F-critical Huong Phung (α=0.05, d.f.=15) = 4.54
F-critical Khe Sanh (α=0.05, d.f.=24) = 4.26

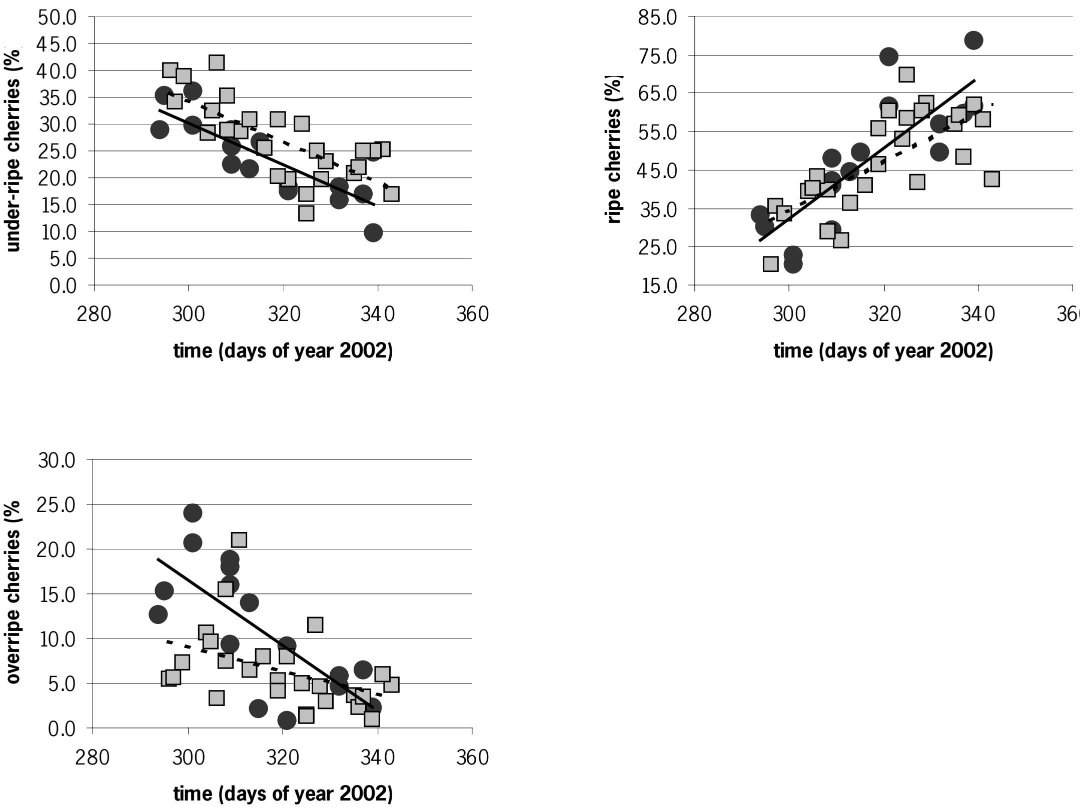

Figure 7. Relation between under-ripe, ripe and overripe cherries and time.

N.B. day 300 corresponds to October 27 (2002)
day 320 corresponds to November 16 (2002)
day 340 corresponds to December 6 (2002)

Table 10. Slopes and intercepts of statistically significant linear relations between descriptor (x) and dependent (y) variables (Figure 7).

Variables X	Y	Location	Slope	Intercept
Time	Under-ripe cherries	HP	-0.39	146.7
Time	Under-ripe cherries	KS	-0.38	149.0
Time	Ripe cherries	HP	0.92	-244.7
Time	Ripe cherries	KS	0.64	-158.9
Time	Overripe cherries	HP	-0.37	126.7
Time	Overripe cherries	KS	-0.13	49.5

4.2.3 Quality characteristics of green beans

It was found that 'screen size 17'- beans (%), beans with black spots (%) and 1000-beans weight of 'screen size 17'-beans (g) are significantly higher in Huong Phung than Khe Sanh. Pea berries (%) is significantly lower in Huong Phung compared to Khe Sanh (Table 11).

Table 11. Quality characteristics of green beans of Huong Phung and Khe Sanh.

Response variable	Average	s.e.m.	Average	s.e.m.	Significance
	Huong Phung		Khe Sanh		α = 0.05; d.f. = 17
'screen size 17'-beans (%)	69.2	2.0	54.2	1.9	* * *
pea berries (%)	14.7	0.7	19.0	1.0	* *
beans with black spots (%)	35.6	2.2	29.4	1.1	*
1000-bean weight (g)	172.6	2.8	158.7	2.2	* * *

s.e.m. = standard error of means

It was found that only for Khe Sanh 'screen size 17'-beans (%) as well as 1000-bean weight (g) increases significantly during harvest time and only for Huong Phung pea berries (%) decreases significantly during harvest time Figure 8; Appendix 5, Figure 17).

Table 12. Quality characteristics of coffee beans and time.

Variables		Huong Phung			Khe Sanh		
X	Y	r^2	F-obs	Significance	r^2	F-obs	Significance
time	%17	0.02	0.34	n.s.	0.19	5.55	*
time	%PB	0.27	5.54	*	0.01	0.12	n.s
time	%Z	0.06	0.89	n.s.	0.01	0.34	n.s
time	1000-b.w.	0.09	1.40	n.s.	0.58	32.32	* * *

F-critical Huong Phung (α=0.05, d.f.=15) = 4.54
F-critical Khe Sanh (α=0.05, d.f.=23) = 4.25

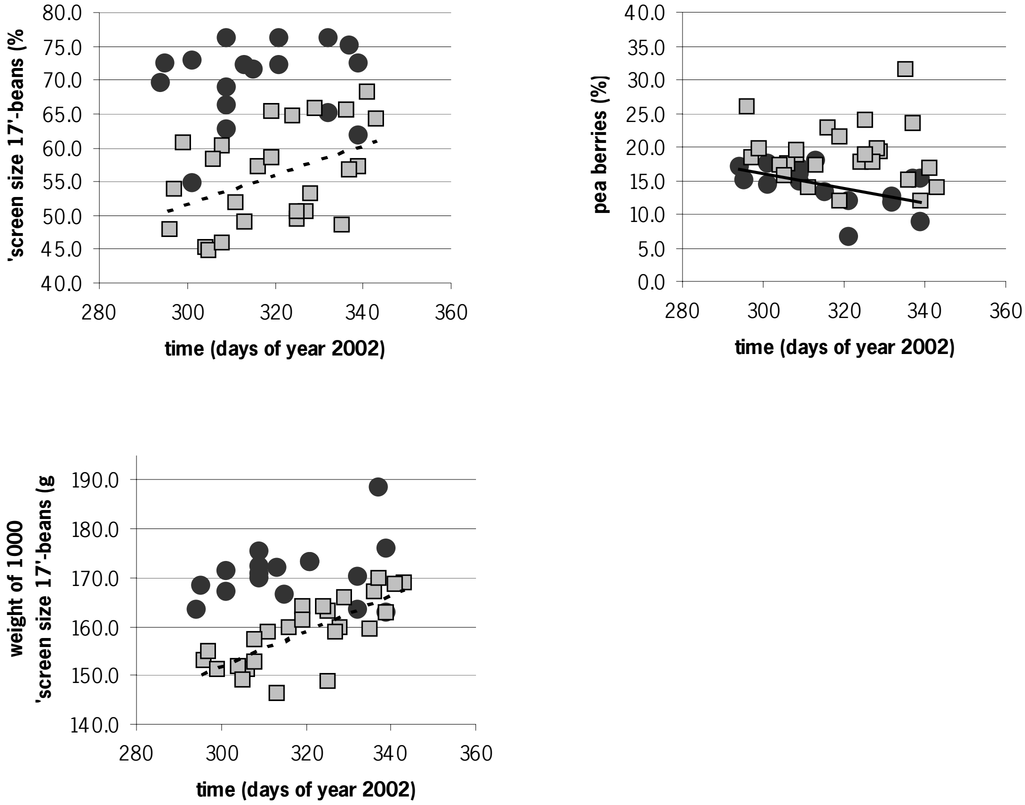

Figure 8. *Relation between time and 'screen-size-17-beans', pea berries, and 1000-bean weight of 'screen size 17'-beans.*

N.B. day 300 corresponds to October 27 (2002)
day 320 corresponds to November 16 (2002)
day 340 corresponds to December 6 (2002)

Table 13. *Slopes and intercepts of statistically significant linear relations between descriptor (x) and dependent (y) variables Figure 8).*

Variables		Location	Slope	Intercept
X	Y			
Time	%17	KS	0.22	-14.9
Time	%PB	HP	-0.11	47.5
Time	1000-b.w.	KS	0.37	42.1

4.3 Nutrients removed from the field by cherries and green beans

It was found that the amount of kg nutrients/100 kg fresh cherries of N, Ca, Mg, Al and Fe in fresh cherries are significantly different between HP and KS (Table 14). No significant difference was found in the contents of P, K, Mn, Zn, Cu, S, B and Si in fresh coffee cherries between Huong Phung and Khe Sanh.

Table 14. Nutrients in cherries removed from the field at harvest (kg nutrient in cherries/100 kg fresh cherries)

Response	Average	s.e.m.	Average	s.e.m.	Significance
variable	Huong Phung		Khe Sanh		$\alpha = 0.05$; d.f. = 18
N	0.55	$8.68.10^{-3}$	0.50	$7.34.10^{-3}$	* * *
P	0.039	$1.13.10^{-3}$	0.039	$4.95.10^{-4}$	n.s.
K	0.66	$2.14.10^{-2}$	0.67	$1.17.10^{-2}$	n.s.
Ca	0.070	$1.19.10^{-3}$	0.056	$1.76.10^{-3}$	* * *
Mg	0.037	$8.91.10^{-4}$	0.033	$1.00.10^{-3}$	* *
Mn	0.0015	$9.55.10^{-5}$	0.0014	$1.14.10^{-4}$	n.s.
Zn	0.00013	$1.52.10^{-5}$	0.00013	$1.10.10^{-5}$	n.s.
Al	0.0012	$1.80.10^{-5}$	0.0011	$1.73.10^{-5}$	* *
Fe	0.0018	$3.28.10^{-4}$	0.0081	$1.55.10^{-3}$	* *
Cu	0.0054	$1.42.10^{-3}$	0.0076	$1.42.10^{-3}$	n.s.
S	0.012	$4.65.10^{-4}$	0.013	$1.01.10^{-3}$	n.s.
B	0.00030	$7.76.10^{-6}$	0.00033	$1.36.10^{-5}$	n.s.
Si	0.018	$3.92.10^{-3}$	0.012	$1.56.10^{-3}$	n.s.

s.e.m. = standard error of means

It was found that the amount of kg nutrients in cherries/1000 kg green beans is significantly different between Huong Phung and Khe Sanh for the nutrients P, K, Ca, Fe and B (Table 15).

Table 15. Nutrients removed in cherries from the field by a yield of 1000 kg green beans (kg nutrient in cherries/1000 kg green beans).

Response	Average	s.e.m.	Average	s.e.m.	Significance
variable	Huong Phung		Khe Sanh		$\alpha = 0.05$; d.f. = 17
N	30.9	$8.97.10^{-1}$	30.7	$6.20.10^{-1}$	n.s.
P	2.14	$4.70.10^{-2}$	2.36	$3.60.10^{-2}$	* *
K	36.7	$9.45.10^{-1}$	41.0	$8.47.10^{-1}$	*
Ca	3.90	$7.50.10^{-2}$	3.41	$1.21.10^{-1}$	* *
Mg	2.04	$4.70.10^{-2}$	2.02	$5.70.10^{-1}$	n.s.
Mn	0.0862	$7.38.10^{-3}$	0.0873	$7.53.10^{-3}$	n.s.
Zn	0.00685	$9.33.10^{-4}$	0.00803	$7.04.10^{-4}$	n.s.
Al	0.0673	$9.17.10^{-4}$	0.0684	$1.03.10^{-3}$	n.s.
Fe	0.0940	$2.03.10^{-2}$	0.5002	$9.04.10^{-2}$	* *
Cu	0.280	$9.84.10^{-2}$	0.473	$9.89.10^{-2}$	n.s.
S	0.681	$3.01.10^{-2}$	0.780	$7.02.10^{-2}$	n.s.
B	0.0169	$5.82.10^{-4}$	0.0204	$8.60.10^{-4}$	* *
Si	0.934	$2.25.10^{-1}$	0.759	$9.87.10^{-2}$	n.s.

s.e.m. = standard error of means

Table 16 shows the amount of nutrients in cherries/1000 kg green beans, calculated from Table 14 by using an average 'kg beans/kg fresh cherries'-ratio of 1/5.9. This is the general ratio found in this research. Because amounts in Table 16 are calculated from Table 14, no s.e.m. is given.

Table 16. Amounts of nutrients (kg) in cherries per 1000 kg green beans.

Response variable	Average Huong Phung	Average Khe Sanh
N	32.5	29.6
P	2.27	2.28
K	38.7	39.6
Ca	4.13	3.29
Mg	2.20	1.96
Mn	0.0898	0.0839
Zn	0.00749	0.00773
Al	0.0713	0.0660
Fe	0.106	0.475
Cu	0.319	0.450
S	0.719	0.748
B	0.0177	0.0197
Si	1.09	0.72

Calculated from Table 14 using the average 'kg beans/kg cherries'-ratio of 1/5.9

4.4 Quality characteristics related to nutrients in fresh cherries

4.4.1 Bean size

According to MLR, in all cases a linear relation exists between 'screen size 17'-beans (%) and nutrients in fresh cherries. In all cases, except in case of Ca, this linear relation is due to a location effect and not due to a nutrient effect (Appendix 6a, Table 27). In case of Ca, the relation is not due to location, nor to nutrient effect. Equation used is: 'screen size 17'-beans (%) = constant + (α_{loc}*location) + ($\alpha_{nutrient}$*nutrient). Huong Phung is location 1 and Khe Sanh is location 2.
Only for Mg and Al a significant relation was found within Huong Phung between 'screen size 17'-beans (%) and the concentration of these nutrients in the harvested fresh cherries (Appendix 6a, Table 28, Table 29, Figure 18).

4.4.2 Pea berries

According to MLR, in all cases a linear relation exists between pea berries (%) and nutrients in fresh cherries. In all cases this linear relation is due to location and not due to a nutrient effect (Appendix 6b, Table 30). Equation used is: pea berries (%) = constant + (α_{loc}*location) + ($\alpha_{nutrient}$*nutrient). Huong Phung is location 1 and Khe Sanh is location 2.
Only within KS a significant relation was found between kg Si/100 kg fresh cherries and pea berries (%) (Appendix 6b, Table 31, Table 32, Figure 19).

4.4.3 Beans infected with black spots

According to MLR, in all cases a linear relation exists between beans infected with black spots (%) and nutrients in fresh cherries. In all cases, except for N, Ca and Fe, this linear relation is due to a location effect and not due to a nutrient effect (Appendix 6c, Table 33). In case of N, Ca and Fe the relation is not due to location, nor nutrient effect. Equation used is: beans with black spots (%) = constant + (α_{loc}*location) + ($\alpha_{nutrient}$*nutrient). Huong Phung is location 1 and Khe Sanh is location 2.
No relations between beans infected with black spots (%) and kg nutrients/100 kg fresh cherries exist within location for Huong Phung as well as Khe Sanh (Appendix 6c, Table 34, Figure 20).

4.4.4 1000-bean weight of 'screen size 17' beans

According to MLR, in all cases a linear relation exists between 1000-bean weight of 'screen size 17'-beans (g). In all cases, except for P, Ca and Al, this linear relation is due to a location effect and not due to a nutrient effect (Appendix 6d, Table 35). In case of Ca the relation is not due to location, nor nutrient effect. In case of P and Al, the relation is due to a location as well as a nutrient effect (Table 17, Figure 9). Equation used is: 1000 beans weight = constant + (α_{loc}*location) + ($\alpha_{nutrient}$*nutrient). Huong Phung is location 1 and Khe Sanh is location 2.

Only for P and Al a significant relation was found within Huong Phung between 1000-bean weight of 'screen size 17'-beans (g) and the concentration of these nutrients in the harvested fresh cherries.
Within Khe Sanh only a linear relation exists between 1000-beans weight of 'screen size 17'-beans (g) and kg P/100 kg fresh cherries (Figure 9; Appendix 6d, Table 36, Table 37, Figure 21).

Table 17. Output of MLR for 1000-bean weight (y) and kg nutrient/100 kg fresh cherries (x).

Variable		F probability	t probability		Estimate		
x	y		Location	Nutrient	Constant	Location	Nutrient
P	1000-b.w.	<0.001	<0.001	<0.001	111.5	-14.6	1978.0
Al	1000-b.w.	<0.001	<0.001	0.011	93.1	-7.8	72586.0

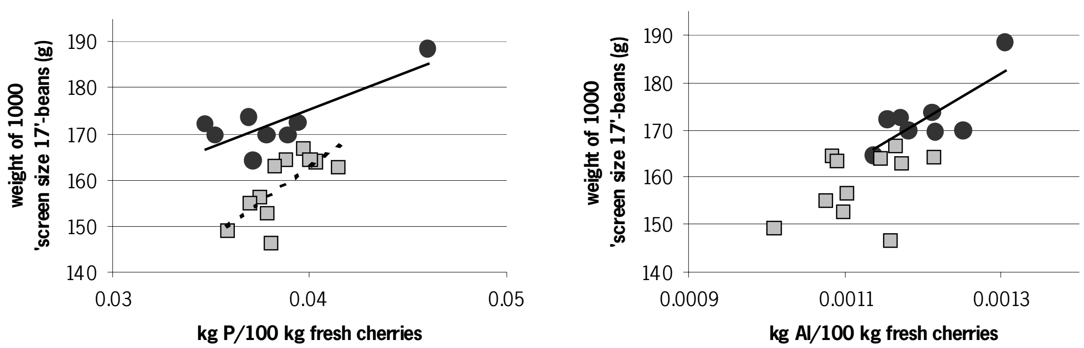

Figure 9. Relation between the weight of 1000 'screen size 17'-beans (g) and kg nutrient/100 kg fresh cherries for P and Al.

4.5 Dry matter of cherries, NPK-input and NPK in cherries

4.5.1 Nitrogen

It was found that for Huong Phung and Khe Sanh a significant linear relation exists between dry matter of cherries (kg/ha) and N-output in cherries (kg/ha) (see Table 18, Figure 10). For Huong Phung and for Khe Sanh a significant linear relation exists also between N-input (kg/ha) and N-output in cherries (kg/ha) and dry matter of cherries (kg/ha) (see Table 18, Figure 10). Nitrogen use efficiency (NUE (kg dry matter / kg N in cherries)) and apparent nitrogen recovery (ANR (kg $N_{coffee\ cherries}$ from fertilizer / kg N-input) are described in Table 19.

Table 18. N-input, N in cherries and dry matter of cherries

Variables		Huong Phung			Khe Sanh		
X	Y	r^2	F-obs	s.	r^2	F-obs	s.
N-output (kg/ha)	Dry matter (kg/ha)	1.00	1463.64	* * *	0.98	452.39	* * *
N-input (kg/ha)	N-output (kg/ha)	0.49	6.78	*	0.47	7.03	*
N-input (kg/ha)	Dry matter (kg/ha)	0.47	6.23	*	0.46	6.74	*

F-critical Huong Phung (α=0.05, d.f.=7) = 5.59
F-critical Khe Sanh (α=0.05, d.f.=8) = 5.32
s. = significance

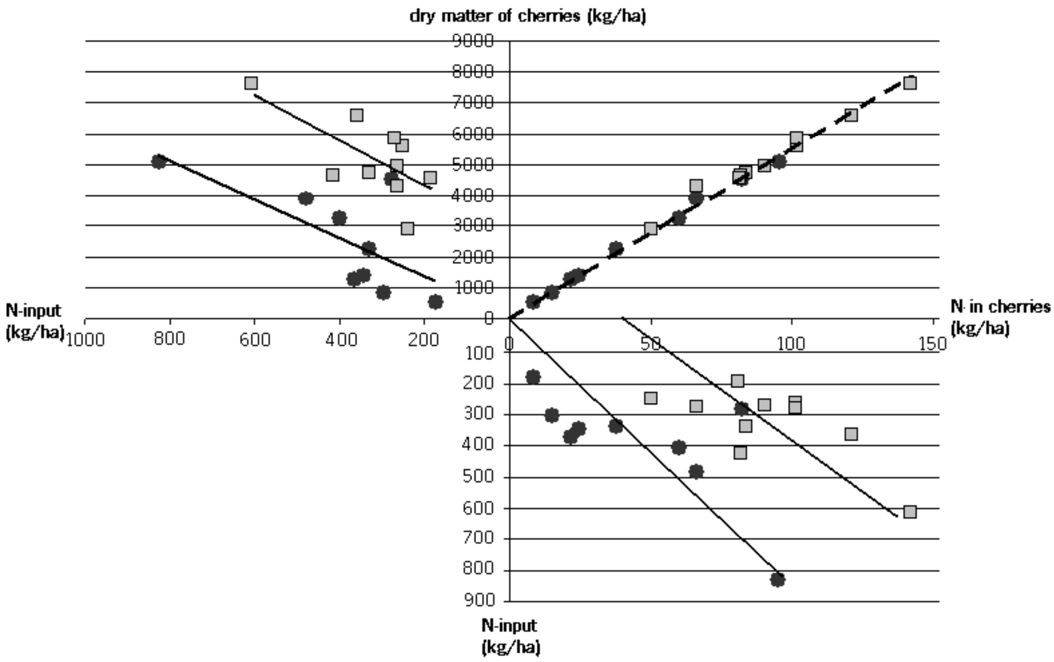

Figure 10. Three-quadrant diagram of nitrogen response.

Table 19. NUE and ANR for Huong Phung and Khe Sanh (see Figure 10).

	Huong Phung	Khe Sanh
NUE (kg dm / kg N in cherries)	56.7	55.8
ANR (kg $N_{coffee\ cherries}$ from fertilizer / kg N-input)	0.12	0.15

4.5.2 Phosphorus

It was found that for Huong Phung and Khe Sanh a significant linear relation exists between dry matter of cherries (kg/ha) and P-output in cherries (kg/ha) (see Table 20 and Figure 11). For Huong Phung and Khe Sanh no significant linear relations exist between P-input (kg/ha) and P-output in cherries (kg/ha) and dry matter of cherries (kg/ha) (see Table 20 and Figure 11). The use efficiency of P is for Huong Phung and Khe Sanh respectively 836.9 and 738.4 (kg dm/kg P) in cherries.

Table 20. P-input, P-output in cherries and dry matter of cherries.

Variables		Huong Phung			Khe Sanh		
X	Y	r^2	F-obs	s.	r^2	F-obs	s.
P-output (kg/ha)	Dry matter (kg/ha)	0.99	924.56	* * *	0.98	534.19	* * *
P-input (kg/ha)	P-output (kg/ha)	0.14	1.19	n.s.	0.01	0.11	n.s.
P-input (kg/ha)	Dry matter (kg/ha)	0.15	1.25	n.s.	0.05	0.40	n.s.

F-critical Huong Phung (α=0.05, d.f.=7) = 5.59
F-critical Khe Sanh (α=0.05, d.f.=8) = 5.32
s. = significance

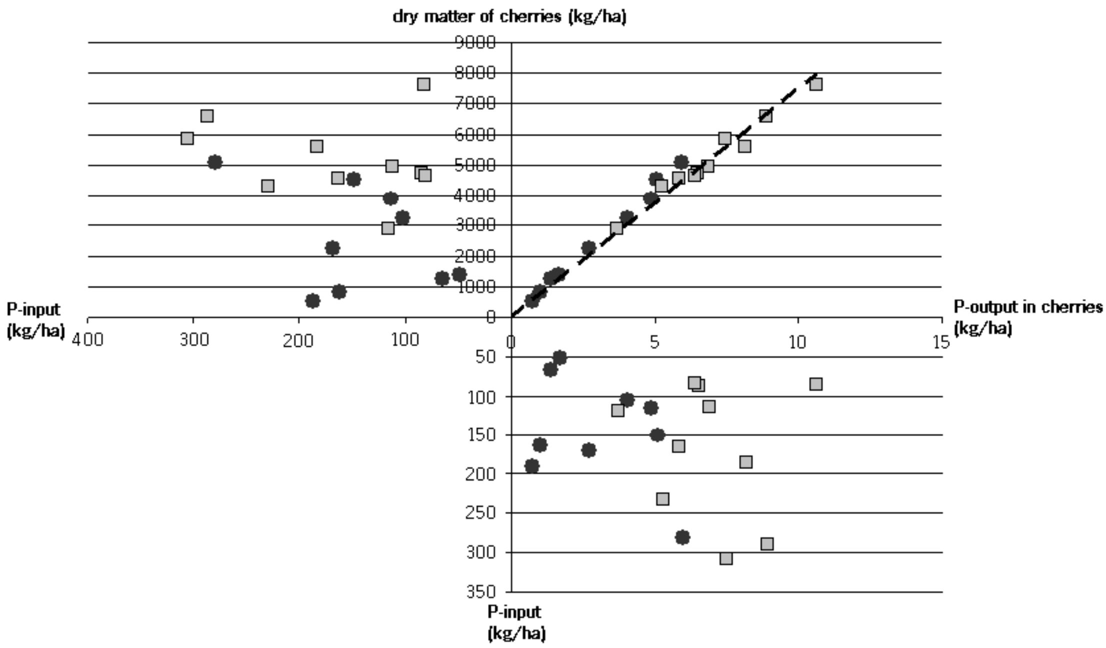

Figure 11. Three-quadrant diagram of phosphorus response .

4.5.3 Potassium

It was found that for Huong Phung and Khe Sanh a significant linear relation exist between dry matter of cherries (kg/ha) and K-output in cherries (kg/ha) (see Table 21 and Figure 12). For Huong Phung and Khe Sanh no significant linear relations exist between K-input (kg/ha) and K-output in cherries (kg/ha) and dry matter of cherries (kg/ha) (see Table 21 and Figure 12). The use efficiency for K is for Huong Phung and Khe Sanh respectively 47.2 and 42.2 (kg dm/kg K) in cherries.

Table 21. K-input, K-output in cherries and dry matter of cherries.

Variables		Huong Phung			Khe Sanh		
X	Y	r^2	F-obs	s.	r^2	F-obs	s.
K-output (kg/ha)	Dry matter (kg/ha)	0.99	472.37	* * *	0.97	297.63	* * *
K-input (kg/ha)	K-output (kg/ha)	0.00	0.01	n.s.	0.24	2.50	n.s.
K-input (kg/ha)	Dry matter (kg/ha)	0.00	0.00	n.s.	0.25	2.66	n.s.

F-critical Huong Phung (α=0.05, d.f.=7) = 5.59
F-critical Khe Sanh (α=0.05, d.f.=8) = 5.32
s. = significance

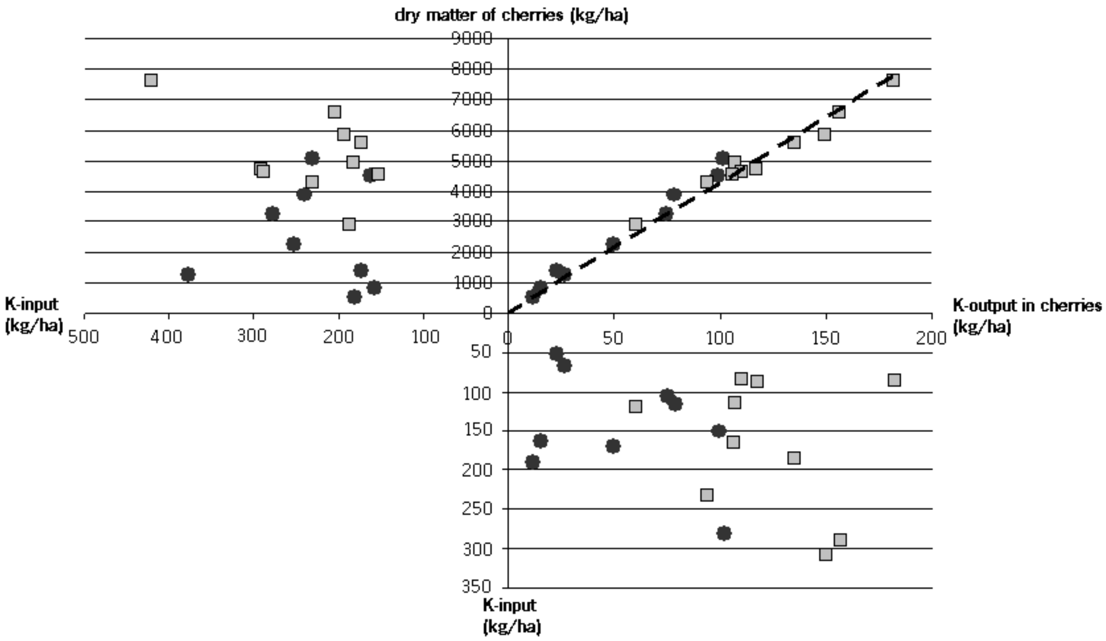

Figure 12. Three-quadrant diagram of potassium response.

4.6 Nutrients in cherries and dry matter of cherries

It was found that for Huong Phung as well as Khe Sanh significant linear relations exist between dry matter of cherries (kg/ha) and nutrients in cherries (kg/ha) for the nutrients Ca, Mg, Mn, Zn, Al, S, B. For Huong Phung also a significant linear relation exists between Fe in cherries (kg/ha) and dry matter of cherries (kg/ha) (Table 22; Appendix 7, Figure 22).

Table 22. Relation between nutrient uptake in cherries (kg/ha) and dry matter of cherries (kg/ha).

Nutrient	Huong Phung			Khe Sanh		
	r^2	F-obs	s.	r^2	F-obs	s.
Ca	1.00	2738.06	* * *	0.95	164.99	* * *
Mg	0.99	561.73	* * *	0.94	148.08	* * *
Mn	0.97	198.74	* * *	0.54	10.77	* *
Zn	0.89	56.74	* * *	0.53	10.25	*
Al	1.00	4438.11	* * *	0.99	670.32	* * *
Fe	0.77	23.83	* *	0.14	1.49	n.s.
Cu	0.37	4.05	n.s	0.13	1.35	n.s.
S	0.96	190.67	* * *	0.68	18.83	* *
B	0.99	820.21	* * *	0.91	96.45	* * *
Si	0.55	8.68	*	0.27	3.39	~

F-critical Huong Phung (α=0.05, d.f.=7) = 5.59
F-critical Khe Sanh (α=0.05, d.f.=9) = 5.12
s. = significance

5. Discussion

Observational research is used to create ideas about possible relations and not to conclude hard findings or to claim causal relations. In the beginning of a research (explorative phase) observational research can be very useful.

Accuracy of results of this observational research can be disputable for two reasons:
1. No replication of samples took place, because of limitations of time, labour and drying capacity.
2. For coffee research in general and this observational research in particular, it is important to take into account the management of the year in which the research is implemented as well as the year before, while buds only develop on two-year-old branches (branches that were established in the previous season). Because this report only describes the results of the first year (2002) of a larger observational study, only data of 2002 are available and the management of 2001 can, unfortunately, not be taken into account.

Yield characteristics of green coffee beans related to the structure of a coffee crop

Before starting the discussion about yield characteristics, first a reiteration of components of coffee yield:
1. yield/ha = number of trees/ha * yield/tree
2. yield/tree = number of cherries/tree * weight beans/cherry
3. number of cherries/tree = number of fruiting nodes/tree * number of cherries/node
4. weight beans/cherry = weight/cherry * bean/cherry-ratio

To start with point 4, the ratio 'kg green beans/kg cherries' is significantly higher for HP than for KS (0.18 and 0.16 respectively). This difference may result from the way of sampling, since it took more time to bring the samples from HP to the lab in KS than to bring the samples from KS to the lab in KS. This means more water in cherries from HP could evaporate on the way to the lab, than from cherry samples from KS. This results in a higher 'green bean/cherry'-ratio for HP. A way to minimise this problem, is to soak the cherries of a samples in the lab in KS in water and to make sure they absorb the maximum amount of water. Then data can be based on the maximum water content of cherries and are more useful to compare to each other. Apart from this, because of the higher 'bean/cherry'-ratio in HP compared to KS and the lower weight/cherry in HP compared to KS one can assume the weight of beans/cherry is the same for HP and KS. Data found in literature about ratio 'green beans/cherry' are 0.16, 0.2, 0.25 (Wrigley, 1988) and 0.19 (Facts and figures, PPP-project), so the values found for HP and KS are in the range found in literature.

The number of cherries/tree is determined by the number of fruiting nodes/tree and number of cherries/node (point 3). During our research no data were collected about these components. But because first of all the yield of green beans/tree is lower in HP than in KS, secondly the average percentage of 'screen size 17'-beans and thirdly the weight of 1000 'screen size 17'-beans are higher in HP compared to KS, it can be assumed that the number of cherries/tree is lower in HP compared to KS. This means that a difference between HP and KS can exist for number of fruiting nodes/tree and number of cherries/node. First of all, a shortage of nutrients can limit the number of fruiting nodes/tree available to flower the following year (Clifford & Willson, 1985). Shortage of nutrients can be more severe in HP compared to KS, because of poorer soils in HP compared to KS. This could be the case for N (Figure 10, Figure 13), that plays an important role in vegetative parts of the coffee tree on which the inflorescences grow. Unfortunately in the case of this observational research no such data exist from year 2001. Secondly, the age of a coffee tree has effect on the number of fruiting nodes/tree available to flower the following year, while the number of fruiting nodes/tree increases with age. As a coffee tree is considered to be fully mature after 5 to 6 years (Cambrony, 1992), it is possible that coffee trees in HP have not yet reached the maximum number of fruiting nodes/tree, contrary to those in KS. Although the number of fruiting nodes/tree increases with age, the number of cherries/node decreases (Wrigley, 1988). A decrease in number of cherries/node can probably be attributed to an effect of mutual shading on floral initiation, which is critically dependent on solar radiation receipt at the potential flowering nodes (Wrigley, 1988). Shading can reduce the percentage of nodes with flowers, the number of inflorescences per node and the number of flowers per inflorescence (Wrigley, 1988). The number of trees/ha is higher in HP compared to KS (5000 and 4000 respectively). Therefore in HP could be more shade compared to KS. But as trees in HP are smaller compared to KS because of their age, this will probably cancel each other out. Pruning plays also a role in mutual shading in coffee trees (Wrigley, 1988) and the way and measure in which pruning is done can differ between farmers from HP and KS.

The yield of green beans (kg/tree), which is determined by the number of cherries/tree and weight of beans/cherry (point 2), is lower in HP compared to KS. The weight of beans/cherry can be assumed to be the same for HP and KS (see paragraph about point 1) and the number of cherries/tree is assumed to be lower in HP compared to KS (see paragraph above). Together this results in a lower yield of green beans (kg/tree) in HP compared to KS.

Yield of green beans (kg/ha), which is determined by yield/tree and number of trees/ha (point 1), is higher in KS than HP. Therefore it seems that a higher number of trees/ha in HP compared to KS does not compensate completely the lower yield/tree in HP.

Yield characteristics of coffee cherries

Although one should expect a difference in average yield of fresh cherries (kg/ha) between HP and KS, as in KS yields are considered to be higher than in HP, statistical analysis doesn't show so. Probably because the yields of fresh cherries cover a large range within HP (from 1577 kg/ha to 16083 kg/ha) and within KS (from 3977 kg/ha to 27329 kg/ha). The fact that dry matter of cherries (kg/ha) is significantly different between HP and KS but fresh yield isn't, shows that the way data are collected and reported is important. Weather circumstances play a role in the weight of fresh cherries, since cherries absorb water. This should be taken into account next times and also in other researches. Another solution is to express results in 'green beans' (with same moisture content!) in stead of fresh weight of cherries.

As said in the paragraph above, a clear difference was found between HP and KS in terms of average yield level (kg dm of cherries/ha). This difference cannot be explained by a difference in fertiliser management since in both locations the average application of N, P and K was almost similar and similar ranges in supply were given by farmers in each region. In both areas most farmers applied two times a year (one farmer in HP applied three times in 2002). It seems therefore that differences in 1. age, 2. soil and 3. climate (which coincide with location) are the possible main causes for the observed average differences in yield (kg dm/ha).

1. The age of the coffee trees can effect yield in two ways. First of all, it may be assumed that older, full grown, coffee trees have a larger root system compared to younger, not yet full grown, coffee trees. Nutman (in Wrigley, 1988) found that Arabica coffee in East Africa developed the main lines of its rooting system in the five to six years after planting. Since coffee trees in KS are around 2 years older than coffee trees in HP, it can be assumed that in KS the root system is larger compared to HP. Probably a full-developed root system takes up more nutrients than a not yet fully developed root system. This could be a reason that yield in KS is higher compared to yield in HP. Secondly, it may be assumed that older (full-grown) coffee trees invest a smaller part of the nutrients taken up in vegetative materials and a bigger part in their cherries compared to younger (not yet full-grown) coffee trees. This can be also a reason that yield in KS is higher than yield in HP.
2. Considering soil characteristics, water availability (a), acidity of a soil (b) and nutrients in the soil (c) can play a role in average yield level. Shortage of water (a) as well as a more acid soil (b) can decrease yield. While the soil in KS is less drought sensitive and less acid than in HP, this can be a reason for a higher yield in KS compared to HP. Regarding nutrients (c), these age, soil and climate differences seem to have a major effect on the availability of N from the soil, which is lower in HP compared to KS (Figure 10). Regarding age, the effect could be due to a more dense and deep rooting system in older plantations. In addition, a longer period of growing coffee with fertilization, could have resulted in a higher amount of N available in the soil for older plantations. In addition, it should be realised that only fruits were sampled for the determination of nutrient content. If the distribution of N within the crop varies with age of the plantation, then this sampling method will cause differences in the determined availability of N from the soil even when in reality this does not necessarily be true. However, this can not be determined on basis of the data obtained in this research. For P and K no such effects were found (Figure 11, Figure 12). The fact that the observed N content in dry cherries is rather

low compared to estimates from literature (Figure 13), while the observed P and K content is within ranges reported elsewhere (Figure 14, Figure 15). This seems to suggest that productivity both in HP and KS is strongly related to N availability and less to that of P and K. To draw more specific conclusions however, it is needed to study the effects of various fertilization strategies, including those with less P and K than at present. As part of this research, also investigations of more efficient ways of application of N could take place. For example by applying three or more times N per year, shortly before the three raining times in May, September and December, instead of two as is currently the common practice. An increase of the ANR can be achieved by an increase of the mineralization rate. A low pH can hamper mineralization, so an increase of pH through liming is something to think about. Apart from this, the N supply in soil is coupled to organic matter and an increase of organic matter content can probably be reached by regularly applying organic manures with a low C/N-ratio, like the removed pulp from cherries. Organic matter also decreases leaching of nutrients, except anions, and plays a role in the clay-humus complex (which has a high CEC). It must be noticed that nitrate, NO_3^-, is not adsorbed to organic matter and can leach out. Ca can play a role in the forming of the clay-humus complex. Therefore it is advisable to apply Ca when organic manures are applied. It must be noted that the ANR from this observational research is determined from only harvested cherries and not the whole coffee tree or coffee crop. For coffee trees in HP and KS, the ANR can have different values than the ANR of harvested coffee cherries. Observations on Zn, S, Fe, Cu, Mn and B (Appendix 7) seem to suggest that the yield level does level off at higher concentrations of these elements. This indicates that at least at the higher production levels shortage of these nutrients is not to be expected and that therefore the availability in the soil is sufficient for the crop. For Ca, Mg and Al the yield-uptake relation follows a straight line. This implies that these elements either are limiting the yield and that the slope thus indicates the minimum contents of these elements in the cherries, or that their uptake is strongly related to that of one or more other limiting nutrients such that the slope indicates the maximum contents of these elements. Comparison with literature data suggests that Ca and Mg removed in 1000 kg green beans or 100 kg fresh cherries is low in HP and KS (Table 24). Mg deficiency is visible in leaves after a dry season (personal comments Mr. Thiet, coffee management specialist TLPC). Precipitation surplus can cause acidification of the soil, while base elements like Ca, Mg and K can leach out, and Si, Al and Fe stay in soil (Wijnja & Van Beusichem, 1995). This can be a reason that the straight lines for Ca and Mg indicate minimum contents, but for K this is not the case (Figure 15). In this way no clear reason can be given for Al. Apart from this, K is antagonistic to Ca and Mg, which means a high K-uptake can restrict the uptake of Ca and/or Mg. Because K content is within ranges reported elsewhere (Figure 15), this can be an indication that K restricts the uptake of Ca and Mg.

3. Climate conditions differ between Huong Phung and Khe Sanh, but in which way and measure isn't very clear (see chapter 2.2). Therefore it is difficult to say something about the relation between climate and yield of cherries (kg dm/ha). First of all, it must be noticed that in this observational research, for example, different amounts of N-input don't correspond to same amounts of P- and K-input and so on (like in experimental research should be the case). This means that, in this case, it is difficult to measure the specific influence of N. Apart from fertilisation, several other factors play a role as well in determining yield level (kg dm/ha). First of all the high agronomic productivity of N (high NUE) compared to estimates from literature, can probably also be explained by the unfavourable growing conditions of Huong Hoa district for coffee (Table 6). In this case one would expect high agronomic productivities for P and K as well, but that's not the case. Secondly, weeding can play a role in final yield, while weeds have been shown to reduce coffee yields by over 50% (Njoroge, 1998). Perhaps more weeds grew in the field of some farmers compared to fields of other farmers, which resulted in a lower yield for farmers who didn't weed that much. The way coffee trees are pruned in the previous season also plays an important role in the yield of this season. The appearance of acacia trees in the coffee field of farmers can also increase the available N for coffee trees and therefore influence the yield level of coffee cherries. Secondly, extrapolation of the trend between application and uptake in cherries shows that the N in cherries at zero application differs strongly between HP and KS, while the ANR doesn't differ that much between HP and KS. At zero N application, in KS is expected to be around 40 kg nitrogen/ha in the coffee cherries, while in HP this is about 0 kg per ha (Figure 10). This difference can be because of poorer soils in HP compared to KS, but also because of younger coffee trees in HP than in KS. Coffee trees in HP may still take up nitrogen from the soil when no fertiliser is applied, and
allocated this to vegetative organs. However, these organs were not analysed for nutrients in this observational research.

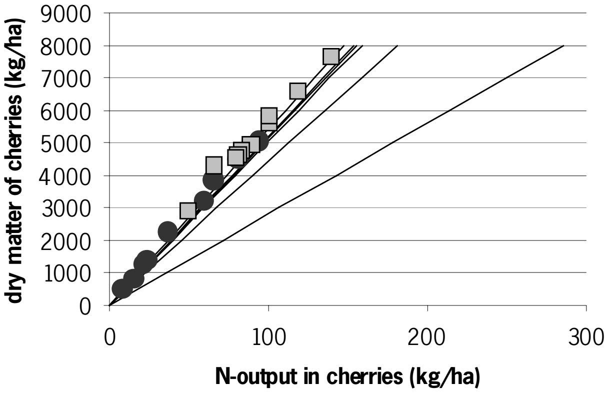

Figure 13. *Relation between dry matter of cherries and N in cherries; lines describe data found in literature, for sources see Table 23; filled circles: HP; squares: KS.*

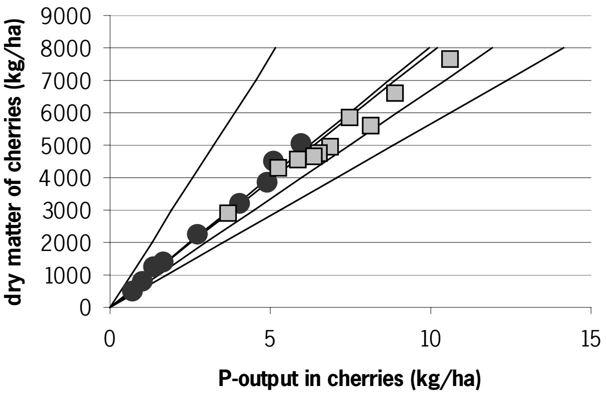

Figure 14. *As Figure 13 for phosphorus.*

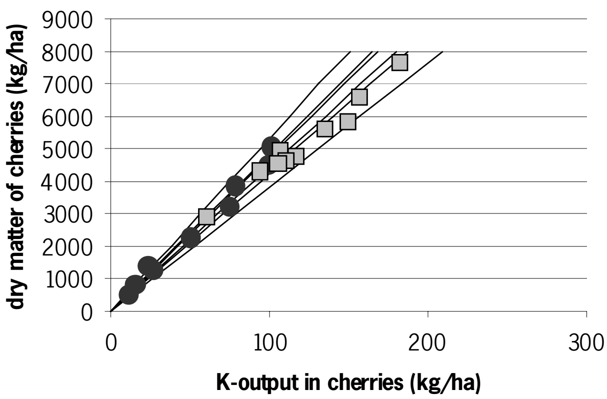

Figure 15. *As Figure 13 for potassium.*

Table 23. Nutrients in cherries removed from the field at a harvest of 1000 kg green beans (Data as found in literature).

Source	kg nutrients/1000 kg green bean							
	N-output	P_2O_5-output	K_2O-output	CaO	MgO	S	Fe_2O_3	B_2O_3
a	40	6	40	8	4	2	0.2	0.1
b	35	7	50	-	-	-	-	-
c	34	2.2	39.8	-	-	-	-	-
d	63.1	5.1	55.8	-	-	-	-	-
e	32.7	7.1	44.8	-	-	-	-	-
f	34.5	5.9	53.0	5.8	5	-	-	-

a Rothfos, 1980 (in Hofstede, 1989)
b Ahn, 1993
c Catani & De Moreas, 1958 (in Wrigley, 1988)
d Ripperton, Goto & Pahau; 1935 (in Clifford & Willson, 1985)
e Loué, 1957 (data about robusta coffee)
f Cannell & Kimeu, 1971 (in Wrigley, 1988)

Table 24. Nutrients in cherries removed from the field at a harvest of 1000 kg green beans.

source	kg nutrients/1000 kg green bean							
	N	P	K	Ca	Mg	S	Fe	B
a	40	2.6	33.2	5.7	2.4	2.0	0.14	0.03
b	35	3.1	41.5	-	-	-	-	-
c	34	1.0	33.0	-	-	-	-	-
d	63.1	2.3	46.3	-	-	-	-	-
e	32.7	3.1	37.2	-	-	-	-	-
f	34.5	2.6	44.0	4.1	3.0	-	-	-
g	30.8	2.3	38.9	3.7	2.0	1.1	0.3	0.02

For sources a till f see table 20. Source g = data from table Table 15 (this observational research)

Table 25. Nutrients in 100 kg fresh cherries, calculated from Table 23.

source	kg nutrients/100 kg fresh cherries							
	N	P	K	Ca	Mg	S	Fe	B
a	0.678	0.0447	0.563	0.0963	0.0407	0.0339	0.00237	0.000542
b	0.593	0.0522	0.703	-	-	-	-	-
c	0.576	0.0164	0.560	-	-	-	-	-
d	1.069	0.0382	0.784	-	-	-	-	-
e	0.554	0.0529	0.630	-	-	-	-	-
f	0.585	0.0441	0.746	0.0695	0.0508	-	-	-
g	0.522	0.0390	0.659	0.0627	0.0339	0.0186	0.00508	0.000339

For sources a till f see Table 23, for source g see Table 24
Ratio 'kg green beans/kg fresh cherry' = 1/5.9 (found in this observational research)

Table 26. Nutrients in 1 kg dried cherries, calculated from Table 23.

source	kg nutrient/kg dried cherry							
	N	P	K	Ca	Mg	S	Fe	B
a	0.0226	0.00149	0.0188	0.00321	0.00136	0.00113	0.000079	0.0000181
b	0.0198	0.00149	0.0234	-	-	-	-	-
c	0.0192	0.00124	0.0225	-	-	-	-	-
d	0.0356	0.00127	0.0261	-	-	-	-	-
e	0.0185	0.00176	0.0210	-	-	-	-	-
f	0.0195	0.00065	0.0206	0.00232	0.00169	-	-	-
g	0.0174	0.00130	0.0220	0.00209	0.00113	0.00062	0.000169	0.0000113

For sources a till f see Table 23, for source g see Table 24
Ratio 'green beans/kg fresh cherry' = 1/5.9 (found in this observational research)
Ratio 'dried cherry/fresh cherry' = 0.3 (found in this observational research)

Quality characteristics of coffee cherries

No difference was found between percentage floaters in HP compared to KS. Genetic as well as physiological factors can cause floaters. While no genetic differences exist between HP and KS, probably the physiological circumstances that cause floaters are the same in HP and KS. The observed differences in the percentages of under-ripe cherries and overripe cherries between HP and KS may be explained by the way of sampling, since it took around 30 minutes more to bring samples from HP to the lab in KS than to bring samples from KS to the lab in KS. Samples from HP could have been damaged on the way from HP to KS, while the road was bumpy and the samples were put at the back of the motorbike fastened with elastic strings. Damaged cherries (dark places on it) could have been seen as overripe cherries, which also have a dark colour. The percentage ripe cherries is around 45.5%, so not even the half of the picked cherries are ripe. Farmers consider under-ripe cherries also as ripe cherries, which brings the amount of ripe cherries for them to 70%. No literature was found about the picked percentages of unripe, under-ripe, ripe and overripe cherries as well as floaters.

Under-ripe as well as overripe cherries (%) decrease as ripe cherries (%) increases with time in HP as well as KS. At the peak of harvest (around day 330) a lot of red cherries ripened at the same time. For KS it seems if the percentage ripe cherries decreases after peak time (Figure 7, ripe cherries (%)). Another reason for a relatively high percentage of under-ripe and overripe cherries in the beginning of the harvest and a decrease during harvest season, can be the late start of the harvest in 2002 compared to preceding years. Because of this, the coffee factories in KS paid quite high prices and probably farmers wanted to start with harvest and picked more under-ripe cherries. During the first and second round of harvesting farmers pick ripe as well as 'bad' cherries, these latter being all cherries with brown spots etc. Because of this, the percentage of overripe cherries can be high in the beginning compared to the end of the harvest season.

Quality characteristics of green coffee beans

A clear difference was found between HP and KS in terms of 'screen size 17'-beans (%). This indicates a relation between location (soil, climate and age of coffee trees) and 'screen size 17'-beans. Factors that affect bean size are discussed in Section 2.6. First of all bean size is determined by genotype of coffee trees. Because genotype is the same in HP and KS, this can't be a reason for the difference found. Secondly, small beans are caused by insect pests, but as far as known, there is no difference in insect pests and their damage between HP and KS. Concerning bean size, the availability of moisture during the rapid expansion period of the cherry following the pin-head stage, is very important. In HP rain in March/April starts around one month earlier compared to KS. This can mean that the rains in May fall in another growth stage of the cherries in HP compared to KS. Maybe these rains play an important role in the rapid expansion period of the cherry and come in HP in a more favourable period. The period from half June till the end of August is relatively dry and while the soil in KS is less sensitive to waterstress, one would expect bigger beans in KS compared to HP, but this isn’t the case. Therefore it is likely that other factors play a role as well. Generally, a high bean size corresponds to a low bean yield/tree (kg/tree) (Njoroge, 1998). This corresponds to the results that yield/tree is lower in HP and percentage ‘screen size 17’-beans is higher in HP compared to KS. From Figure 8 it seems that during harvest season in KS the percentage harvested ‘screen size 17’-beans increased as well as their 1000-bean weight. For HP this was not the case.

The percentage pea berries is higher in KS than HP. Genetic aberrations can underly pea berries, but because the same genotype of coffee trees is used in HP and KS, this factor will probably not cause the found difference. Poor pollination is another factor underlying pea berries. As coffee is mainly pollinated by wind, insects can maybe cause better pollination and reduce percentage pea berries in HP as well as KS, but research should be done to find out.

The percentage of beans infected with black spots is higher in HP compared to KS, which creates the idea that a relation between location (soil, climate and age of coffee trees) and disease pressure of black spots exists. In HP the percentage of ‘screen size 17’-beans as well as their 1000-bean weight is higher compared to KS, so probably there is a relation between these two factors and beans infected with black spots. As little is known about this disease, it is difficult to say something about this relation. It seems that the harvested percentage of beans with black spots stays constant during harvest season (Table 12), which suggests that environmental conditions during harvest season have no influence on the percentage of beans infected with black spots.

A clear difference was found between HP and KS in terms of 1000-bean weight of ‘screen size 17’-beans, which indicated a relation between location (soil, climate and age of coffee trees) and 1000-bean weight could exist. The 1000-bean weight of ‘screen size 17’-beans, can be related to the amounts of nutrients taken up by the coffee trees and put in the coffee beans. As seen before, it can be assumed that in HP less cherries/tree are grown. This can mean that coffee trees in HP divides less nutrients over less cherries and beans than coffee trees in KS, but this still results in a higher bean weight. Apart from this, the period of filling the bean can be longer in HP than KS, because of the longer growing season in HP than KS. This can mean that coffee trees in HP have more time to fill their beans and for maturing of cherries compared to coffee trees in KS, which can results in a higher 1000-beans weight of ‘screen size 17’-beans. /tree is lower in HP and percentage ‘screen size 17’-beans is higher in HP compared to KS. From Figure 8 it seems that during harvest season in KS the percentage harvested ‘screen size 17’-beans increased as well as their 1000-bean weight. For HP this was not the case.

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6. Conclusions and suggestions

Yield characteristics of coffee cherries

Higher yields of coffee cherries were observed in KS compared to HP, at similar amounts and number of applications of N, P and K. Apparently differences between HP and KS in age of the plantations, soil characteristics (water availability, acidity of the soil and nutrient availability) and climate play a role in this. To get better insight in the exact causes for the difference in yield level between KS and HP additional and experimental research is needed.

It seems that the availability of nitrogen from the soil and through fertilization has a major effect on the coffee yield, while applications of P and K do not show any relation with yield. Since costs of N, P and K fertilization are high for farmers, it can be recommended to research the possibilities to increase the availability of nitrogen, at reduced phosphorus and potassium applications. For nitrogen, the efficiency of application may be improved by more frequent applications, for example three times a year instead of the current two. Especially for phosphorus and potassium, long-term effects on the possible depletion of soil stocks of these nutrients should be considered in this research, as well as the possible need for higher uptake of these nutrients at higher N application rates.

Enhancing the content of organic matter in the soil could be a way to improve the efficiency of fertilizer applications and the amount of nutrients available in the soil, through effects on pH and buffering capacity of the soil. Possible sources of organic matter include the solid wastes that result from the coffee processing, such as the pulp. When less potassium is applied, it may be that the uptake of magnesium increases, since potassium is antagonistic to magnesium. Alternatively, applications of magnesium, e.g. in foliar sprays, could be tested. Concerning age, it can be tried if this factor plays a role by planting coffee trees of the same age (and same background) in HP as well as KS and giving them a same treatment.

Apart from organic matter, also liming could be considered for improvement of soil pH. It can be tried on a small scale at first, whether an increase of pH effects the yield of coffee cherries.

It can also be tried whether water availability effects the yield of coffee cherries, but bringing a lot of water to, at first, a small part of a coffee field is probably a lot of work and can be complicated.

Quality characteristics of coffee cherries

At the beginning of the harvest season, the percentage harvested ripe cherries is around 25%. During the harvest season this increases to a maximum of 65%. Harvested under-ripe cherries decrease during harvest season from 35% to 15%. The total of 'good' cherries as seen by farmers, which is the total of under-ripe and ripe cherries together, increases during the harvest season from 60% to 80%. No data about percentages harvested cherries were found. Ripe cherries contain beans of best quality, while under-ripe cherries result in undesired flavours in roasted coffee. Since coffee roasters pay higher prices for beans of higher quality, coffee-processing factories will get higher prices for beans from ripe cherries. From the point of view of the coffee-processing factory TLPC it is important that farmers pick only these ripe cherries. Ripe cherries were found in samples throughout the harvesting season, which makes it technically feasible for farmers to do so. However, more hired labour will then be needed, since all plants in a field would have to be harvested more frequently, especially in the early part of the harvested season when currently farmers pick relatively a lot of 'undesired' cherries.

Quality characteristics of green coffee beans

Since coffee roasters pay more for bigger beans, it of interest to TLPC and farmers to research the factors that influence bean size. Two common measures for bean size are the percentage of 'screen size 17'-beans and the 1000-bean weight, which is higher in HP compared to KS. For both, the results from HP show higher values than for

KS. This can be due to several factors. First of all, the earlier rain and flowering in HP than KS could play a role, since probably the rain in May falls in HP in a more favourable period during the rapid expansion period of the cherries than in KS. Irrigation on critical times could be applied to check whether this indeed results in bigger beans. In HP generally a lower bean yield per tree is found compared to KS. In literature this lower productivity per tree is related to a higher percentage 'screen size 17'-beans. The productivity per tree is generally lowered when coffee trees are shaded, which leads to the suggestion that it could be worthwhile to study the possible effects of shadow trees on bean size.

In the samples a relatively high percentage of pea berries was found. For mainstream roasters, these berries are unwanted because they don't fit in the roasting way and time of normal beans. Their taste, however, is not worse than normal beans (Smits, personal comment, 2002). However, various companies of specialty coffees exist that market pea berries. Therefore, TLPC could sell them separately, but than a search should be made for a marketing area. When TLPC aims at minimisation of the percentage of pea berries and at maximisation of the percentage normal beans, it is needed to find the factors that cause pea berries. One such factor could be a low pollination rate, which could be increased by cultivating honeybees in the coffee growing areas. This could be tried out on small scale, where first is checked whether bees can survive in Huong Hoa district. In the results of this observational research, no indications were found that the percentage of pea berries is related to the content of the various nutrients.

Concerning the percentage of beans infected with black spots, it is very difficult to say something about causes or relations, since little is known about this disease or even whether it indeed is a disease and not the effect of malnutrition. Results from the observational research do not indicate any effect of nutrients, which makes the latter less likely. However, since the occurrance of black spots has a negative result on perceived quality by the coffee roasters (Smits, 2002), it is recommended to research when and how these black spots develop on the beans, and how the crop can be protected.

Yield characteristics of green coffee beans related to the structure of a coffee crop

The structure of the coffee tree affects the production of flowering buds and the production and distribution of leaves. In this observational research, no attention has been paid to the description of the structure of the coffee tree. However, from literature it is known that the number of cherries per tree (or per unit leaf area), the number of fruiting nodes per tree and the number of cherries per node have strong relations to yield and quality of coffee. Therefore, it is recommended to make an inventory of these components as well and to research which factors (for example soil, fertilization and other management) can influence these components.

References

Ahn, P.M., 1993.
Tropical soils and fertiliser use. Intermediate tropical agricultural series. Longman Scientific & Technical, London. 264 pp.

Barel, M. & Jacquet, M., 1994.
Coffee quality: its causes, appreciation and improvement. Plantations, recherche, développement July 1994: 5-13.

Bieysse, D. 2001.
Personal comment regarding Black Spots Disease. By email.

Cambrony, H.R. 1992.
Coffee Growing. The Tropical Agriculturalist. CTA and The Macmillan Press LTD: London. 119 pp.

Cannel, M.G.R. 1971.
Production and distribution of dry matter in trees of Coffea arabica L. in Kenya as affected by seasonal climatic differences and the presence of fruits. Ann. Appl. Biol. 67: 99-120

Clifford, M.N. & Willson, K.C. 1985.
Coffee. Botany, Biochemistry and Production of Beans and Beverage. Croom Helm: London. 457 pp.

Gathaara, M.P.H. & Gitau, K.M. 1999.
The influence of overhead irrigation on the yield and quality of arabica coffee cultivar ruiru II. Kenya coffee 64 (756): 2985-2987

Hao, N.D., 2001.
Effects of trade liberalisation on agriculture in Vietnam: the case of coffee production. Msc. thesis scriptie, Wageningen University, Wageningen, the Netherlands. 92 pp.

Hofstede, R. 1989.
Max Havelaar en het milieu. IVEM, studentenverslag 45. Interfacultaire Vakgroep Energie en Milieukunde, University Groningen, Groningen, the Netherlands. 34 pp.

Kuit, M., 2002.
personal comment on unpublished results of soil samples in Huong Hoa district

Loué, A., 1957.
Studies on the inorganic nutrition of the coffee tree in the Ivory Cost. International Potash Institute, Berne, Swiss. 68 pp.

Lövenstein, H., Lantinga, E.A., Rabbinge, R. & van Keulen, H., 1995.
Principles of production ecology. Department of theoretical producion ecology: Wageningen University, Wageningen, the Netherlands. 121 pp.

Menezes, H.C. De., 1994.
The relationship between the state of maturity of raw coffee beans and the isomers of caffeoylquinic acid. Food chemistry 50: 293-296

Doan Trieu Nhan, 2002.
Introduction to Vietnam Coffee Industry: achievements, challenges and adjustment of strategic orientation. Speech by the Director of VICOFA at the International Coffee Conference, February 2002, Hanoi, Vietnam.

Njoroge, J.M., 1985.
Effects of nitrogen rates and frequency of application on coffee yield and quality in Kenya. Acta Horticulture 158: 283-291

Njoroge, J.M., 1997.
Environmentally friendly and sustainable coffee management. 17th international scientific colloquium on coffee. ASIC, Paris, France. pp 481-494.

Njoroge, J.M., 1998.
Agronomic and processing factors affecting coffee quality. Outlook on agriculture 27 (3): 163-166

Njoroge, J.M., Waithaka, K. & Chweya, J.A., 1992.
The influence of tree training and plant density on growth, yield components and yield of Arabica coffee cv. Ruiru II. Journal of Horticultural Science 67: 695-702
Njoroge, J.M. & Kimemia, J.K., 1989.
A comparison of different of weed control methods in Kenya coffee. Kenya Coffee 55: 863-870.
Oude Voshaar, J.H., 1994.
Statistiek voor onderzoekers. Wageningen Pers: Wageningen, the Netherlands. 253 pp.
Op de Laak, J., 1992.
Arabica Coffee Cultivation and Extension Manual for the Highlands of Northern Thailand. Thanabhan Printer: Chiang Mai, Thailand. 111 pp + appendices
Roubik, D.W., 2002.
The value of bees to the coffee harvest. Nature 417: 708
Smits, R., 2002.
Cup taster of SaraLee-Douwe Egberts.
Temminghoff, E.J.M., 2000.
Plant analysis procedures. Wageningen University, Environmental Sciences, Wageningen, the Netherlands. 197 pp
Trebel, M.
Coffee cultivation in Vietnam. Plantations, recherche, développement January – February 1996: 5-14
Vos, J. & Stomph, T.J., 2000.
Ecophysiology of crop production. Department of Plant Sciences: Wageningen University, Wageningen, the Netherlands. 235 pp.
Vré, de K., 2002.
Koffie, een grillig product. Trouw (10-10-2002): 17
Wijnja, H. & Van Beusichem, M.L., 1998.
Inleiding bodemkunde A (J100) Inleiding bodemkunde (B) en geologie (J050-001). Wageningen University, Wageningen, the Netherlands.
Willson, K.C., 1999.
Coffee, cocoa and tea. CABI, Wallingford, England. 300 pp.
Wrigley, G., 1988.
Coffee. Longman: London, England. 639 pp.
www.ico.org, accessed May 1, 2003.
www.vietnamtourism.com, accessed 2-22-2003

Appendix I.

Data of analysed nutrients (to be continued on next page)

no.	day in year 2002	farmer	loca-tion	Y (kg fw/ha)	kg dm/ ha	kg N/ kg dm	kg P/ kg dm	kg K/ kg dm	kg Ca/ kg dm	kg Mg/ kg dm
1	309	Anh	hp	2567.2	806.1	0.0185	0.00125	0.0192	0.00221	0.00118
2	313	Dinh	hp	3938.0	1236.5	0.0174	0.00111	0.0215	0.00205	0.00124
3	309	Lan	hp	16083.0	5178.7	0.0169	0.00109	0.0189	0.00222	0.00114
4	339	Lan	hp	16083.0	4953.6	0.0202	0.00125	0.0213	0.00239	0.00118
5	310	Minh	hp	12015.4	3869.0	0.0168	0.00126	0.0203	0.00223	0.00134
6	309	Phong	hp	4424.0	1398.0	0.0172	0.00120	0.0166	0.00203	0.00111
7	301	Tan	hp	7329.3	2198.8	0.0159	0.00121	0.0217	0.00218	0.00123
8	339	Tan	hp	7329.3	2257.4	0.0174	0.00123	0.0229	0.00236	0.00100
9	295	Thi-e	hp	10425.3	3002.5	0.0177	0.00123	0.0229	0.00221	0.00125
10	332	Thi-e	hp	10425.3	3252.7	0.0182	0.00134	0.0230	0.00254	0.00116
11	315	Thi-e	hp	10425.3	3252.7	0.0186	0.00123	0.0231	0.00235	0.00123
12	321	Thi-e	hp	10425.3	3336.1	0.0191	0.00125	0.0241	0.00242	0.00125
13	301	Thi-n	hp	14429.8	4386.7	0.0174	0.00120	0.0212	0.00256	0.00115
14	309	Thi-n	hp	14429.8	4588.7	0.0170	0.00120	0.0212	0.00224	0.00118
15	294	Thi-n	hp	14429.8	4588.7	0.0179	0.00115	0.0212	0.00219	0.00120
16	332	Thi-n	hp	14429.8	4271.2	0.0195	0.00106	0.0247	0.00254	0.00119
17	321	Thi-n	hp	14429.8	4733.0	0.0182	0.00102	0.0217	0.00223	0.00116
18	337	Tu	hp	1577.0	510.9	0.0160	0.00142	0.0227	0.00221	0.00111
19	325	Ke	ks	17020.2	4629.5	0.0177	0.00137	0.0204	0.00183	0.00126
20	311	Ke	ks	17020.2	5514.5	0.0166	0.00130	0.0201	0.00188	0.00128
21	343	Ke	ks	17020.2	4765.7	0.0195	0.00148	0.0242	0.00219	0.00146
22	296	Loi-e	ks	16371.0	4714.8	0.0170	0.00135	0.0241	0.00202	0.00116
23	335	Loi-e	ks	16371.0	4452.9	0.0185	0.00144	0.0255	0.00187	0.00123
24	321	Loi-e	ks	16371.0	5042.3	0.0170	0.00133	0.0246	0.00188	0.00112
25	297	Loi-n	ks	19672.2	5665.6	0.0165	0.00139	0.0233	0.00204	0.00120
26	324	Loi-n	ks	19672.2	5429.5	0.0182	0.00147	0.0232	0.00169	0.00122
27	336	Loi-n	ks	19672.2	5744.3	0.0188	0.00149	0.0256	0.00218	0.00126
28	308	Luc-e	ks	27328.8	7488.1	0.0176	0.00133	0.0232	0.00203	0.00109
29	329	Luc-e	ks	27328.8	7214.8	0.0190	0.00140	0.0240	0.00183	0.00117
30	341	Luc-e	ks	27328.8	8198.7	0.0183	0.00144	0.0244	0.00218	0.00114
31	306	Luc-n	ks	17030.7	4598.3	0.0164	0.00134	0.0223	0.00190	0.00108
32	299	Luc-n	ks	17030.7	4462.0	0.0171	0.00142	0.0240	0.00204	0.00116
33	328	Luc-n	ks	17030.7	4700.5	0.0177	0.00139	0.0235	0.00169	0.00117
34	339	Luc-n	ks	17030.7	4870.8	0.0180	0.00133	0.0246	0.00221	0.00118
35	327	Mai	ks	3976.8	1073.7	0.0181	0.00140	0.0220	0.00219	0.00121
36	316	Mai	ks	3976.8	1097.6	0.0177	0.00141	0.0254	0.00236	0.00129
37	337	Mai	ks	3976.8	1129.4	0.0192	0.00134	0.0224	0.00216	0.00114
38	319	Nga	ks	9254.0	2850.2	0.0176	0.00131	0.0204	0.00187	0.00117
39	309	Nga	ks	9254.0	2924.3	0.0166	0.00126	0.0213	0.00204	0.00119
40	313	Phuong	ks	19643.1	5853.7	0.0171	0.00128	0.0255	0.00217	0.00120
41	325	Thuy	ks	15804.4	4045.9	0.0179	0.00122	0.0232	0.00165	0.00099
42	319	Thuy	ks	15804.4	4867.8	0.0167	0.00129	0.0229	0.00170	0.00097
43	304	Thuy	ks	15804.4	4804.5	0.0181	0.00131	0.0234	0.00183	0.00108
44	305	TTQuy	ks	14703.6	4293.5	0.0152	0.00123	0.0219	0.00150	0.00098
45	308	Xuan	ks	23515.1	6584.2	0.0181	0.00135	0.0238	0.00188	0.00106

Data of analysed nutrients (continue of previous page)

no.	kg Mn/ kg dm	kg Zn/ kg dm	kg Al/ kg dm	kg Fe/ kg dm	kg Cu/ kg dm	kg S/ kg dm	kg B/ kg dm	kg Si/ kg dm
1	4.67E-05	3.40E-06	3.73E-05	0.000038	0.000059	0.000329	1.11E-05	0.000235
2	5.20E-05	3.41E-06	3.68E-05	0.000012	0.000520	0.000327	8.58E-06	0.001263
3	5.72E-05	5.12E-06	3.68E-05	0.000128	0.000247	0.000276	8.88E-06	0.001056
4	4.00E-05	8.51E-06	4.02E-05	0.000026	0.000037	0.000439	9.93E-06	0.000210
5	4.53E-05	5.13E-06	3.89E-05	0.000092	0.000286	0.000384	9.13E-06	0.001069
6	7.01E-05	3.38E-06	3.74E-05	0.000112	0.000185	0.000379	9.37E-06	0.000709
7	4.27E-05	1.67E-06	3.80E-05	0.000042	0.000055	0.000324	1.00E-05	0.000391
8	3.62E-05	1.69E-06	3.69E-05	0.000049	0.000099	0.000596	1.07E-05	0.000381
9	4.33E-05	5.10E-06	3.99E-05	0.000027	0.000053	0.000376	1.13E-05	0.000217
10	4.98E-05	3.38E-06	4.05E-05	0.000054	0.000109	0.000436	1.01E-05	0.000535
11	3.94E-05	5.03E-06	4.14E-05	0.000041	0.000083	0.000383	9.52E-06	0.000385
12	5.08E-05	5.17E-06	4.07E-05	0.000045	0.000040	0.000496	9.89E-06	0.000152
13	5.03E-05	3.41E-06	3.87E-05	0.000027	0.000044	0.000383	8.95E-06	0.000179
14	4.21E-05	3.44E-06	3.85E-05	0.000076	0.000140	0.000386	8.41E-06	0.000456
15	4.80E-05	6.73E-06	3.92E-05	0.000035	0.000049	0.000374	9.61E-06	0.000180
16	3.64E-05	3.39E-06	4.08E-05	0.000061	0.000122	0.000485	9.18E-06	0.000485
17	4.19E-05	5.13E-06	3.71E-05	0.000043	0.000098	0.000600	9.19E-06	0.000441
18	4.32E-05	3.39E-06	4.03E-05	0.000048	0.000107	0.000384	8.87E-06	0.000284
19	8.62E-05	7.46E-06	3.79E-05	0.000490	0.000438	0.000401	1.21E-05	0.000483
20	5.80E-05	5.97E-06	3.85E-05	0.000900	0.000869	0.000406	1.33E-05	0.000954
21	5.22E-05	5.89E-06	4.13E-05	0.000248	0.000232	0.000509	1.12E-05	0.000463
22	3.77E-05	5.03E-06	3.97E-05	0.000106	0.000103	0.000322	1.01E-05	0.000147
23	3.32E-05	3.40E-06	4.15E-05	0.000165	0.000163	0.000378	9.46E-06	0.000216
24	3.33E-05	3.42E-06	3.98E-05	0.000043	0.000042	0.000328	1.05E-05	0.000070
25	3.14E-05	3.40E-06	3.96E-05	0.000068	0.000062	0.000325	8.74E-06	0.000126
26	2.95E-05	3.37E-06	4.09E-05	0.000096	0.000094	0.000379	9.25E-06	0.000483
27	3.43E-05	1.67E-06	4.28E-05	0.000100	0.000077	0.000380	9.91E-06	0.000118
28	4.31E-05	3.38E-06	3.77E-05	0.000097	0.000081	0.000412	1.05E-05	0.000322
29	3.91E-05	4.99E-06	4.00E-05	0.000308	0.000283	0.000612	1.26E-05	0.000428
30	4.09E-05	3.34E-06	3.87E-05	0.000064	0.000057	0.000407	1.05E-05	0.000127
31	4.23E-05	1.04E-05	3.98E-05	0.000141	0.000134	0.000323	1.09E-05	0.000399
32	4.32E-05	5.08E-06	4.09E-05	0.000089	0.000083	0.000324	1.08E-05	0.000213
33	4.12E-05	3.36E-06	3.96E-05	0.002055	0.001873	0.000409	1.03E-05	0.001246
34	5.01E-05	5.09E-06	4.09E-05	0.000067	0.000067	0.000354	1.14E-05	0.000335
35	4.88E-05	4.21E-06	4.00E-05	0.000229	0.000225	0.000568	1.36E-05	0.000479
36	5.30E-05	8.42E-06	3.93E-05	0.000382	0.000376	0.000569	1.39E-05	0.000565
37	5.72E-05	3.31E-06	3.89E-05	0.000092	0.000083	0.000522	1.20E-05	0.000484
38	4.42E-05	5.94E-06	3.95E-05	0.000155	0.000170	0.000457	1.38E-05	0.000311
39	5.25E-05	4.23E-06	3.83E-05	0.000167	0.000146	0.000521	1.29E-05	0.000219
40	3.67E-05	4.17E-06	3.89E-05	0.000150	0.000144	0.000411	1.30E-05	0.000349
41	7.23E-05	7.39E-06	3.82E-05	0.000586	0.000555	0.000458	1.16E-05	0.000601
42	6.11E-05	5.94E-06	3.66E-05	0.000398	0.000364	0.000354	1.17E-05	0.000735
43	6.82E-05	4.16E-06	3.69E-05	0.000285	0.000256	0.000404	1.22E-05	0.000629
44	5.31E-05	2.49E-06	3.46E-05	0.000227	0.000254	0.000302	1.12E-05	0.000601
45	6.84E-05	4.28E-06	3.92E-05	0.000421	0.000381	0.000730	1.13E-05	0.000456

Appendix II.

Cup tasting schedule (to be continued on next page)

no.	Beans (from under-ripe or ripe cherries)	bean size (13 or 17)	kind of bean (flat bean or pea berry)	black spots (yes or no)	Location (Khe Sanh or Huong Phung)	time of harvest (before peak, at peak or after peak)	Input (low, medium, high)
1	ripe	17	flat bean	no	Huong Phung	after peak	low
2	ripe	17	flat bean	no	Huong Phung	after peak	medium
3	ripe	17	flat bean	no	Huong Phung	after peak	high
4	-	-	-	-	-	-	-
5	-	-	-	-	-	-	-
6	ripe	17	flat bean	no	Huong Phung	at peak	high
7	ripe	17	flat bean	no	Huong Phung	before peak	low
8	ripe	17	flat bean	no	Huong Phung	before peak	medium
9	ripe	17	flat bean	no	Huong Phung	before peak	high
10	ripe	17	flat bean	no	Khe Sanh	after peak	low
11	ripe	17	flat bean	no	Khe Sanh	after peak	medium
12	ripe	17	flat bean	no	Khe Sanh	after peak	high
13	ripe	17	flat bean	no	Khe Sanh	at peak	low
14	ripe	17	flat bean	no	Khe Sanh	at peak	medium
15	ripe	17	flat bean	no	Khe Sanh	at peak	high
16	ripe	17	flat bean	no	Khe Sanh	before peak	low
17	ripe	17	flat bean	no	Khe Sanh	before peak	medium
18	ripe	17	flat bean	no	Khe Sanh	before peak	high
19	ripe	17	flat bean	yes	Huong Phung	after peak	low
20	ripe	17	flat bean	yes	Huong Phung	after peak	medium
21	ripe	17	flat bean	yes	Huong Phung	after peak	high
22	ripe	17	flat bean	yes	Huong Phung	at peak	high
23	ripe	17	flat bean	yes	Huong Phung	before peak	low
24	ripe	17	flat bean	yes	Huong Phung	before peak	medium
25	ripe	17	flat bean	yes	Huong Phung	before peak	high
26	ripe	17	flat bean	yes	Khe Sanh	after peak	medium
27	ripe	17	flat bean	yes	Khe Sanh	after peak	high
28	ripe	17	flat bean	yes	Khe Sanh	at peak	low
29	ripe	17	flat bean	yes	Khe Sanh	at peak	medium
30	ripe	17	flat bean	yes	Khe Sanh	at peak	high
31	ripe	17	flat bean	yes	Khe Sanh	before peak	low
32	ripe	17	flat bean	yes	Khe Sanh	before peak	medium
33	ripe	17	flat bean	yes	Khe Sanh	before peak	high
34	ripe	13	flat bean	no	Huong Phung	after peak	low+medium
35	ripe	13	flat bean	no	Huong Phung	after peak	high
36	ripe	13	flat bean	no	Huong Phung	at peak	high
37	ripe	13	flat bean	no	Huong Phung	before peak	low+medium
38	ripe	13	flat bean	no	Huong Phung	before peak	high
39	ripe	13	flat bean	no	Khe Sanh	after peak	medium
40	ripe	13	flat bean	no	Khe Sanh	after peak	high
41	ripe	13	flat bean	no	Khe Sanh	at peak	low
42	ripe	13	flat bean	no	Khe Sanh	at peak	low
43	ripe	13	flat bean	no	Khe Sanh	at peak	High
44	ripe	13	flat bean	no	Khe Sanh	before peak	low
45	ripe	13	flat bean	no	Khe Sanh	before peak	medium
46	ripe	13	flat bean	no	Khe Sanh	before peak	high

Cup tasting schedule *(continue of previous page)*

no.	Beans (from under-ripe or ripe cherries)	bean size (13 or 17)	kind of bean (flat bean or pea berry)	black spots (yes or no)	Location (Khe Sanh or Huong Phung)	time of harvest (before peak, at peak or after peak)	Input (low, medium, high)
47	ripe	13	flat bean	yes	Huong Phung	after peak	low+medium
48	ripe	13	flat bean	yes	Huong Phung	after peak	high
49	ripe	13	flat bean	yes	Huong Phung	before peak	low, medium+high
50	ripe	13	flat bean	yes	Khe Sanh	after peak	low, medium+high
51	ripe	13	flat bean	yes	Khe Sanh	at peak	low
52	ripe	13	flat bean	yes	Khe Sanh	at peak	medium+high
53	ripe	13	flat bean	yes	Khe Sanh	before peak	low+high
54	ripe	13	flat bean	yes	Khe Sanh	before peak	medium
55	ripe	13+17	pea berry	no	Huong Phung	after peak	low, medium+high
56	ripe	13+17	pea berry	yes+no	Huong Phung	at peak	high
57	ripe	13+17	pea berry	no	Huong Phung	before peak	low+medium
58	ripe	13+17	pea berry	no	Huong Phung	before peak	high
59	ripe	13+17	pea berry	no	Khe Sanh	after peak	medium
60	ripe	13+17	pea berry	no	Khe Sanh	after peak	high
61	ripe	13+17	pea berry	no	Khe Sanh	at peak	low
62	ripe	13+17	pea berry	no	Khe Sanh	at peak	medium
63	ripe	13+17	pea berry	no	Khe Sanh	at peak	high
64	ripe	13+17	pea berry	no	Khe Sanh	before peak	low
65	ripe	13+17	pea berry	no	Khe Sanh	before peak	medium
66	ripe	13+17	pea berry	no	Khe Sanh	before peak	high
67	ripe	13+17	pea berry	yes	Huong Phung	after peak	low, medium+high
68	ripe	13+17	pea berry	yes	Huong Phung	before peak	low, medium+high
69	ripe	13+17	pea berry	yes	Khe Sanh	after peak	low, medium+high
70	ripe	13+17	pea berry	yes	Khe Sanh	at peak	low, medium+high
71	ripe	13+17	pea berry	yes	Khe Sanh	before peak	low, medium+high
72	under-ripe	17	flat bean	no	Huong Phung	after peak	low+medium
73	under-ripe	17	flat bean	no	Huong Phung	after peak	high
74	under-ripe	17	flat bean	no	Huong Phung	at peak	high
75	under-ripe	17	flat bean	no	Huong Phung	before peak	low
76	under-ripe	17	flat bean	no	Huong Phung	before peak	medium
77	under-ripe	17	flat bean	no	Huong Phung	before peak	high
78	under-ripe	17	flat bean	no	Khe Sanh	after peak	medium
79	under-ripe	17	flat bean	no	Khe Sanh	after peak	high
80	under-ripe	17	flat bean	no	Khe Sanh	at peak	low
81	under-ripe	17	flat bean	no	Khe Sanh	at peak	medium
82	under-ripe	17	flat bean	no	Khe Sanh	at peak	high
83	under-ripe	17	flat bean	no	Khe Sanh	before peak	low
84	under-ripe	17	flat bean	no	Khe Sanh	before peak	medium
85	under-ripe	17	flat bean	no	Khe Sanh	before peak	high
86	under-ripe	17	flat bean	yes	Huong Phung	after peak	low, medium+high
87	under-ripe	17	flat bean	yes	Huong Phung	before peak	low
88	under-ripe	17	flat bean	yes	Huong Phung	before peak	high

Cup tasting schedule *(continue of previous page)*

no.	Beans (from under-ripe or ripe cherries)	bean size (13 or 17)	kind of bean (flat bean or pea berry)	black spots (yes or no)	Location (Khe Sanh or Huong Phung)	time of harvest (before peak, at peak or after peak)	Input (low, medium, high)
89	under-ripe	17	flat bean	yes	Khe Sanh	after peak	low, medium +high
90	under-ripe	17	flat bean	yes	Khe Sanh	at peak	low, medium +high
91	under-ripe	17	flat bean	yes	Khe Sanh	before peak	medium
92	under-ripe	17	flat bean	yes	Khe Sanh	before peak	high
93	under-ripe	13	flat bean	yes+no	Huong Phung	after peak	low, medium +high
94	under-ripe	13	flat bean	no	Huong Phung	before peak	low+medium
95	under-ripe	13	flat bean	no	Huong Phung	before peak	high
96	under-ripe	13	flat bean	no	Khe Sanh	after peak	low, medium +high
97	under-ripe	13	flat bean	no	Khe Sanh	at peak	low
98	under-ripe	13	flat bean	no	Khe Sanh	at peak	medium+high
99	under-ripe	13	flat bean	no	Khe Sanh	before peak	low
100	under-ripe	13	flat bean	no	Khe Sanh	before peak	medium
101	under-ripe	13	flat bean	no	Khe Sanh	before peak	high
102	under-ripe	13	flat bean	yes	Huong Phung	before peak	low, medium +high
103	under-ripe	13	flat bean	yes	Khe Sanh	at peak	low, medium +high
104	under-ripe	13	flat bean	yes	Khe Sanh	before peak	low, medium +high
105	under-ripe	13+17	pea berry	no	Huong Phung	before peak	low, medium +high
106	under-ripe	13+17	pea berry	no	Khe Sanh	after peak	low, medium +high
107	under-ripe	13+17	pea berry	no	Khe Sanh	at peak	low, medium +high
108	under-ripe	13+17	pea berry	no	Khe Sanh	before peak	medium
109	under-ripe	13+17	pea berry	no	Khe Sanh	before peak	high
110	under-ripe	13+17	pea berry	yes	Huong Phung	before peak	low, medium +high
111	under-ripe	13+17	pea berry	yes	Khe Sanh	before, at, after	low, medium +high

Appendix III. Equations

Equation 1. Nutrient-output (kg nutrients in cherries/ha):
Kg nutrients/ha = kg nutrient/kg dry matter * kg dry matter/ha

Equation 2. Nutrient-output (kg nutrients in cherries/100 kg fresh cherries):
kg nutrient/100 kg fresh cherries = (kg nutrient/ha) / (kg fresh cherries/ha) * 100

Equation 3. Nutrient-output (kg nutrients in cherries/1000 kg green beans):
kg nutrient/1000 kg green beans = (kg nutrient/ha) / (kg green beans/ha)

Equation 4. Nutrient-output (kg nutrients in cherries/1000 kg green beans), calculated on alternative way:
kg nutrient/1000 kg green beans = kg nutrient/100 kg fresh cherries / 100*5.9*1000
5.9 = average ratio 'kg fresh cherries/kg green beans'

Equation 5. NUE, PUE and KUE (kg dry matter / kg nutrients in cherries)
NUE = $Y_{\text{coffee cherries}}$ / N-uptake$_{\text{coffee cherries}}$
PUE = $Y_{\text{coffee cherries}}$ / P-uptake$_{\text{coffee cherries}}$
KUE = $Y_{\text{coffee cherries}}$ / K-uptake$_{\text{coffee cherries}}$
$Y_{\text{coffee cherries}}$ = yield of coffee cherries (kg dm/ha)
N, P, K-uptake$_{\text{coffee cherries}}$ = N, P, K in cherries (kg/ha)

Equation 6. ANR
ANR = $(Nu_{tf} - Nu_{to}) / N_f$
Nu_{tf} = total nitrogen uptake by coffee cherries of a fertilized crop (kg/ha)
Nu_{to} = total nitrogen uptake by coffee cherries of a non-fertilized crop (kg/ha)
N_f = the amount of fertilizer N added (kg/ha)

Equation 7. Floaters (%)
Percentage floaters = #floaters / (#floaters + #unripe cherries + #under-ripe cherries + #ripe cherries + #overripe cherries)) * 100

Equation 8. Unripe cherries (%)
Percentage unripe cherries = #unripe cherries / (#floaters + #unripe cherries + #under-ripe cherries + #ripe cherries + #overripe cherries)) * 100

Equation 9. Under-ripe cherries (%)
Percentage under-ripe cherries = #under-ripe cherries / (#floaters + #unripe cherries + #under-ripe cherries + #ripe cherries + #overripe cherries)) * 100

Equation 10. Ripe cherries (%)
Percentage ripe cherries = #ripe cherries / (#floaters + #unripe cherries + #under-ripe cherries + #ripe cherries + #overripe cherries)) * 100

Equation 11. Overripe cherries (%)
Percentage overripe cherries = #overripe cherries / (#floaters + #unripe cherries + #under-ripe cherries + #ripe cherries + #overripe cherries)) * 100

Equation 12. Correction for moisture content
FW = DW + W
DW = FW – W
%W/100 = W / (DW + W) = W / FW
W = FW * %W/100
DW = FW – (FW*%W/100)
DW = FW * (1 - %W/100)
FW = DW / (1 - %W/100)
$FW\alpha = DW\alpha / (1 - \%W/100/\alpha)$

FW = Fresh Weight (g)
DW = Dry Weight (g)
W = Water (g)
%W/100 = fraction water

Moisture content of 11% has been chosen because in dried green beans the moisture content differs between 10-12%. For equation 1 this means:
$FW(11\%) = FW\alpha\ (1 - \alpha/100) / (1 – 11/100)$

Equation 13. Correction for broken beans
$W_{corr} = W + (W / W_{tot} * W_{bb})$

W_{corr} = corrected weight
W = weight of beans
W_{tot} = weight of the beans of all the different groups
W_{bb} = weight of the broken beans
Assumption made is that samples have relatively the same percentage of broken and not-broken beans.

Equation 14. Yield of green beans (kg/ha)
Yield of green beans (kg/ha) = (kg fresh cherries/ha) * (kg beans/kg fresh cherries)

Equation 15. Yield of green beans (kg/tree)
Yield of green beans (kg/tree) = (kg green beans/ha) / (number of trees/ha)

Equation 16. Ratio 'kg green beans/kg fresh cherries'
Ratio 'kg green beans/kg fresh cherries' = (kg green beans from (under)ripe cherries) / (kg fresh (under)ripe cherries)

Equation 17. Percentage of 'screen-size-17-beans'
'Screen-size-17-beans' (%) = **(**R17NG+R17NZ+H17NG+H17NZ**) / (**R17NG+R17NZ+R17PBG+R17PBZ+R13NG+R13NZ+R13PGB+R13PBZ+R<13NG+R<13NZ+R<13PBG+R<13PBZ+H17NG+H17NZ+H17PBG+H17PBZ+H13NG+H13NZ+H13PGB+H13PBZ+H<13NG+H<13NZ+H<13PBG+H<13PBZ**)***100
For explanation of letters and numbers, see table 3

Equation 18. Percentage of pea berries
Pea berries (%) = **(**R17PBG+R17PBZ+R13PBG+R13PBZ+R<13PBG+R<13PBZ+H17PBG+H17PBZ+H13PBG+H13PBZ+H<13PBG+H<13PBZ**) / (**R17NG+R17NZ+R17PBG+R17PBZ+R13NG+R13NZ+R13PGB+R13PBZ+R<13NG+R<13NZ+R<13PBG+R<13PBZ+H17NG+H17NZ+H17PBG+H17PBZ+H13NG+H13NZ+H13PGB+H13PBZ+H<13NG+H<13NZ+H<13PBG+H<13PBZ**)***100
For explanation of letters and numbers, see table 3

Equation 19. Percentage of beans infected with black spots

Beans with black spots (%) = **(**R17NZ+R17PBZ+R13NZ+R13PBZ+R<13NZ+R<13PBZ+H17NZ+H17PBZ+H13NZ+H13PBZ+H<13NZ+H<13PBZ**) / (**R17NG+R17NZ+R17PBG+R17PBZ+R13NG+R13NZ+R13PGB+R13PBZ+R<13NG+R<13NZ+R<13PBG+R<13PBZ+H17NG+H17NZ+H17PBG+H17PBZ+H13NG+H13NZ+H13PGB+H13PBZ+H<13NG+H<13NZ+H<13PBG+H<13PBZ**)***100
For explanation of letters and numbers, see table 3

Equation 20. 1000-beans weight of 'screen-size-17-beans'

1000-beans weight of 'screen-size-17-beans' (g) = **(**wR17NG+wR17NZ+wH17NG+wH17NZ**) / (**#R17NG+#R17NZ+#H17NG+#H17NZ**) *** 1000
For explanation of letters and numbers, see table 3 (w = weight, # = number)

Equation 21. Dry matter of cherries (kg/ha)

Kg dry matter/ha = (kg fresh cherries/ha) / (kg fresh weight$_{sample}$/kg dry weight$_{sample}$)

Appendix IV.
Harvesting date and cherry characteristics

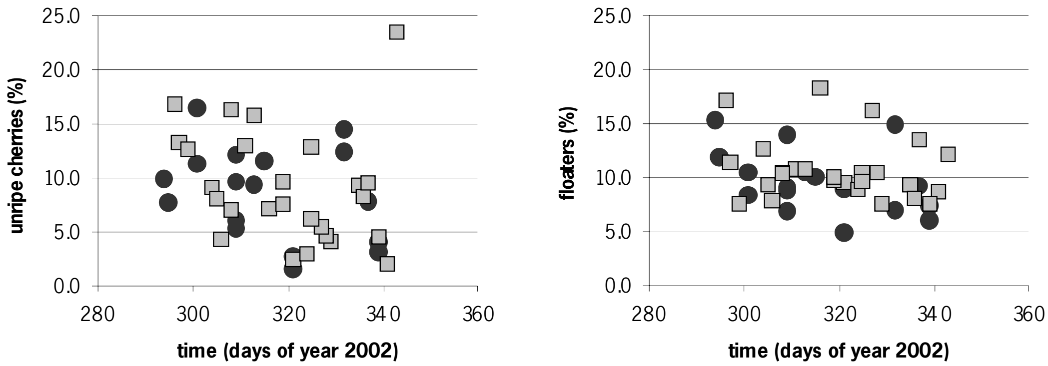

Figure 16. *Relation between under-ripe, ripe and overripe cherries and time.*

N.B. day 300 corresponds to October 27 (2002)
day 320 corresponds to November 16 (2002)
day 340 corresponds to December 6 (2002)

Appendix V.

Harvesting date and beans infected with black spots (%)

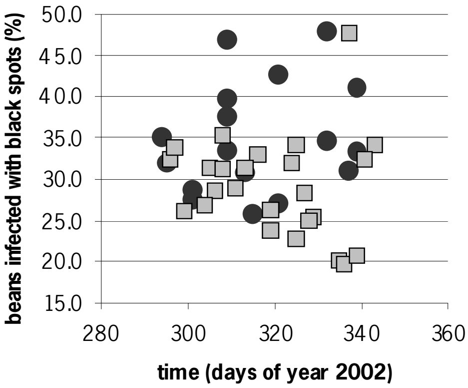

Figure 17. Relation between beans infected with black spots (%) and time.

N.B. day 300 corresponds to October 27 (2002)
day 320 corresponds to November 16 (2002)
day 340 corresponds to December 6 (2002)

Appendix VI.
Relations between quality characteristics and kg nutrients/100 kg fresh cherries

Appendix Via.
'Screen size 17'-beans and kg nutrient/100 kg fresh cherries

Table 27. Output of MLR for kg nutrient/100 kg fresh cherries (x) and 'screen size 17'-beans (y).

Variables		F-probability	t probability		Estimate		
X	Y		Location	Nutrient	Constant	Location	Nutrient
N	%17	<0.001	0.015	0.094	26.0	-10.3	96.9
P	%17	<0.001	<0.001	0.119	50.1	-15.3	900.0
K	%17	<0.001	<0.001	0.472	70.8	-15.3	20.9
Ca	%17	<0.001	0.078	0.147	48.3	- 9.0	429.0
Mg	%17	<0.001	0.002	0.097	48.3	-12.0	904.0
Mn	%17	<0.001	<0.001	0.268	92.5	-15.6	-4995.0
Zn	%17	<0.001	<0.001	0.217	79.0	-15.4	45888.0
Al	%17	<0.001	0.005	0.058	20.6	-10.9	49421.0
Fe	%17	<0.001	0.002	0.620	83.3	-13.8	-192.0
Cu	%17	0.001	0.002	0.564	83.0	-13.5	-246.0
S	%17	<0.001	<0.001	0.654	87.1	-14.9	-252.0
B	%17	<0.001	<0.001	0.558	90.6	-14.2	-23866.0
Si	%17	<0.001	<0.001	0.212	88.4	-14.9	-369.0

Table 28. Relations between kg nutrient/100 kg fresh cherries (x) and percentage 'screen size 17'-beans (y)

Variables		Huong Phung				Khe Sanh			
X	Y	r^2	F-obs	d.f.	Significance	r^2	F-obs	d.f.	Significance
N	%17	0.15	1.07	6	n.s.	0.18	1.99	9	n.s.
P	%17	0.10	0.69	6	n.s.	0.30	3.82	9	~
K	%17	0.32	2.82	6	n.s.	0.04	0.42	9	n.s.
Ca	%17	0.18	1.36	6	n.s.	0.11	1.11	9	n.s.
Mg	%17	0.60	9.15	6	*	0.10	1.00	9	n.s.
Mn	%17	0.04	0.21	5	n.s.	0.11	1.06	9	n.s.
Zn	%17	0.24	1.92	6	n.s.	0.03	0.27	9	n.s.
Al	%17	0.50	6.10	6	*	0.09	0.93	9	n.s.
Fe	%17	0.18	1.31	6	n.s.	0.01	0.11	9	n.s.
Cu	%17	0.05	0.27	5	n.s.	0.02	0.21	9	n.s.
S	%17	0.06	0.38	6	n.s.	0.01	0.06	9	n.s.
B	%17	0.08	0.55	6	n.s.	0.01	0.10	9	n.s.
Si	%17	0.17	1.04	5	n.s.	0.07	0.66	9	n.s.

F-critical values (α=0.05) are 6.61 (d.f.=5); 5.99 (d.f.=6); 5.12 (d.f.=9)

Table 29. Slopes and intercepts of statistically significant linear relations between descriptor (x) and dependent (y) variables.

Variables		Location	Slope	Intercept
X	Y			
Mg	%17	HP	2858.2	-35.0
Al	%17	HP	72604.0	-18.2

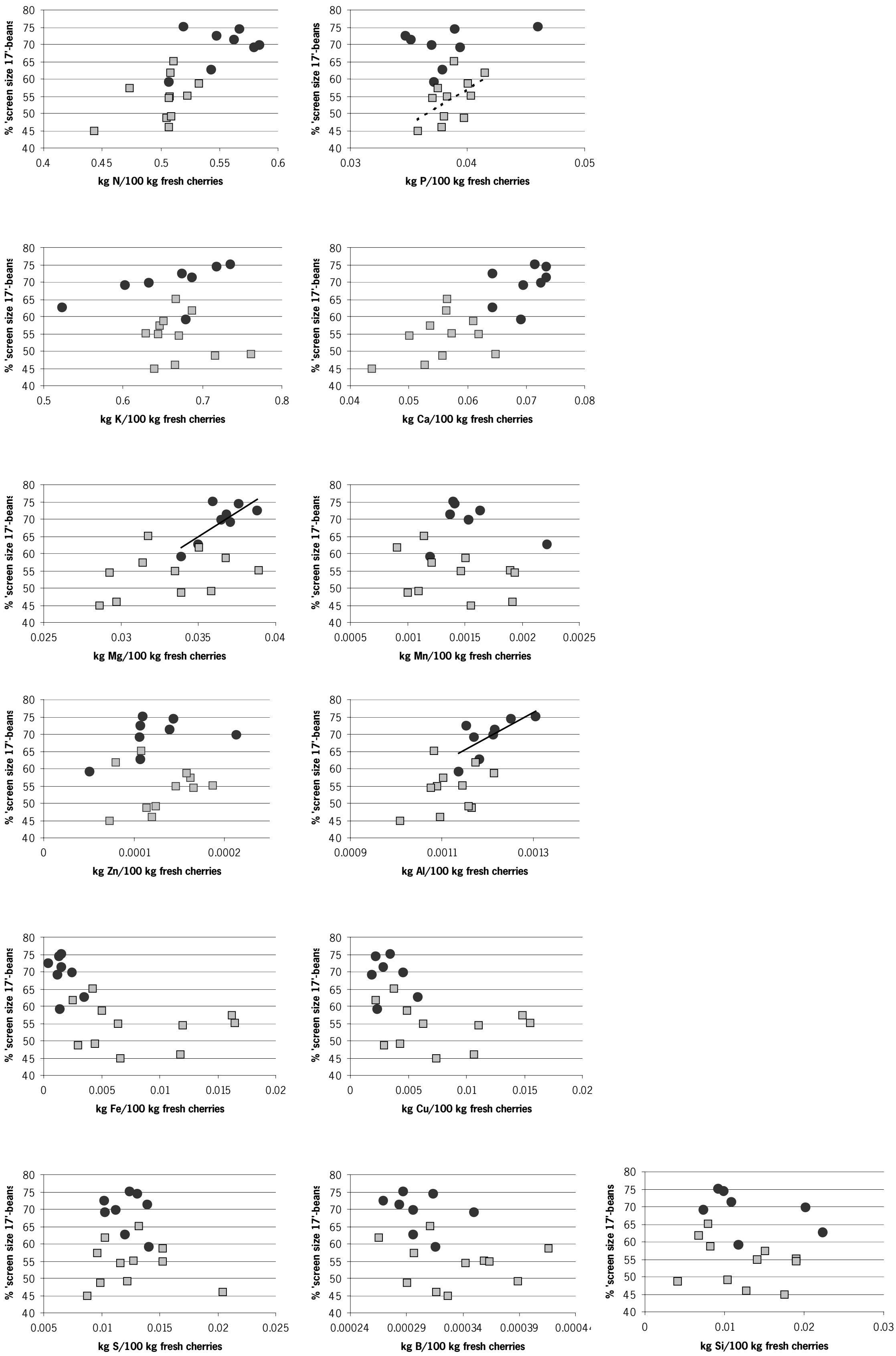

Figure 18. *Relation between % 'screen size 17'-beans and kg nutrient/100 kg fresh cherries of the nutrients N, P, K, Ca, Mg, Mn, Zn, Al, Fe, Cu, S, B and Si.*

Appendix VIb.
Pea berries and kg nutrient/100 kg fresh cherries

Table 30. Output of MLR for kg nutrient/100 kg fresh cherries (x) and pea berries (y).

Variables		F probability	t probability		Estimate		
			Location	Nutrient	Constant	Location	Nutrient
N	%PB	0.016	0.009	0.292	-7.6	5.7	30.2
P	%PB	0.025	0.009	0.692	6.1	4.2	114.0
K	%PB	0.027	0.009	0.918	11.4	4.3	-1.5
Ca	%PB	0.023	0.041	0.566	3.4	5.4	84.0
Mg	%PB	0.015	0.005	0.284	-1.0	5.2	289.0
Mn	%PB	0.041	0.015	0.811	11.3	4.2	-531.0
Zn	%PB	0.027	0.009	0.806	10.0	4.2	4503.0
Al	%PB	0.015	0.006	0.283	-7.6	5.4	14015.0
Fe	%PB	0.010	0.004	0.162	9.3	5.9	-255.0
Cu	%PB	0.009	0.003	0.225	9.3	5.8	-237.0
S	%PB	0.027	0.009	0.861	9.9	4.2	48.0
B	%PB	0.026	0.010	0.710	12.5	4.5	-7349.0
Si	%PB	0.008	0.005	0.209	12.0	4.6	-173.0

Table 31. Relations between kg nutrient/100 kg fresh cherries (x) and percentage pea berries (y).

Variables		Huong Phung				Khe Sanh			
X	Y	r^2	F-obs	d.f.	Significance	r^2	F-obs	d.f.	Significance
N	%PB	0.01	0.06	6	n.s.	0.13	1.33	9	n.s.
P	%PB	0.02	0.12	6	n.s.	0.13	1.36	9	n.s.
K	%PB	0.13	0.89	6	n.s.	0.05	0.47	9	n.s.
Ca	%PB	0.35	3.29	6	n.s.	0.12	1.25	9	n.s.
Mg	%PB	0.11	0.74	6	n.s.	0.07	0.63	9	n.s.
Mn	%PB	0.27	1.87	5	n.s.	0.07	0.68	9	n.s.
Zn	%PB	0.02	0.14	6	n.s.	0.00	0.00	9	n.s.
Al	%PB	0.03	0.17	6	n.s.	0.21	2.33	9	n.s.
Fe	%PB	0.00	0.02	6	n.s.	0.16	1.67	9	n.s.
Cu	%PB	0.47	4.43	5	~	0.17	1.81	9	n.s.
S	%PB	0.49	5.80	6	~	0.03	0.33	9	n.s.
B	%PB	0.28	2.32	6	n.s.	0.00	0.00	9	n.s.
Si	%PB	0.24	1.62	5	n.s.	0.40	5.99	9	*

F-critical values (α=0.05) are 6.61 (d.f.=5); 5.99 (d.f.=6); 5.12 (d.f.=9)

Table 32. Slopes and intercepts of statistically significant linear relations between descriptor (x) and dependent (y) variables.

Variables		Location	Slope	Intercept
X	Y			
Si	%PB	KS	-420.30	24.2

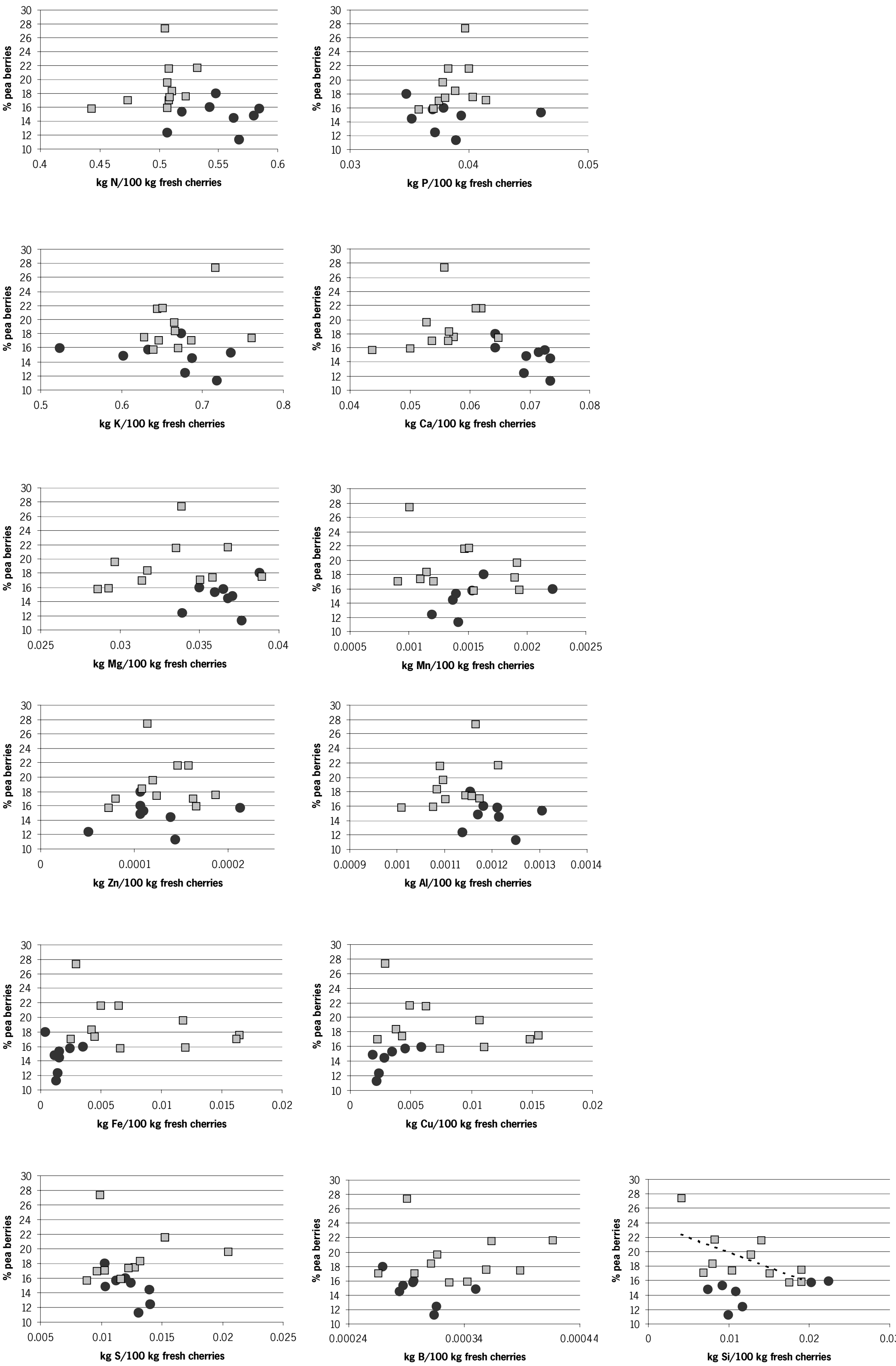

Figure19. Relation between % pea berries and kg nutrient/100 kg fresh cherries of the nutrients N, P, K, Ca, Mg, Mn, Zn, Al, Fe, Cu, S, B and Si.

Appendix VIc.
Beans with black spots and kg nutrient/100 kg fresh cherries

Table 33. Output of MLR for kg nutrient/100 kg fresh cherries (x) and beans with black spots (y).

Variable		F probability	t probability		Estimate		
			Location	Nutrient	Constant	Nutrient	Location
N	%Z	0.027	0.229	0.301	13.0	48.1	-3.9
P	%Z	0.036	0.015	0.470	54.7	-337.0	-6.1
K	%Z	0.007	0.014	0.055	68.6	-41.6	-5.7
Ca	%Z	0.047	0.148	0.965	41.0	11.0	-6.1
Mg	%Z	0.040	0.018	0.564	52.1	-256.0	-7.1
Mn	%Z	0.048	0.040	0.267	33.5	3103.0	-4.3
Zn	%Z	0.048	0.016	1.000	41.9	16.0	-6.3
Al	%Z	0.015	0.005	0.132	82.3	-31405.0	-8.9
Fe	%Z	0.046	0.070	0.813	41.6	-72.0	-5.8
Cu	%Z	0.032	0.031	0.776	43.2	-93.0	-6.6
S	%Z	0.047	0.015	0.891	41.2	60.0	-6.3
B	%Z	0.034	0.011	0.426	35.1	25325.0	-7.1
Si	%Z	0.028	0.011	0.556	41.4	136.0	-6.9

Table 34. Relations between kg nutrient/100 kg fresh cherries (y) and percentage beans infected with black spots (x).

Variables		Huong Phung				Khe Sanh			
X	Y	r^2	F-obs	d.f.	Significance	r^2	F-obs	d.f.	Significance
N	%Z	0.31	2.73	6	n.s.	0.02	0.19	9	n.s.
P	%Z	0.01	0.09	6	n.s.	0.12	1.24	9	n.s.
K	%Z	0.48	5.53	6	~	0.00	0.01	9	n.s.
Ca	%Z	0.00	0.02	6	n.s.	0.00	0.04	9	n.s.
Mg	%Z	0.00	0.01	6	n.s.	0.07	0.63	9	n.s.
Mn	%Z	0.30	2.15	5	n.s.	0.01	0.13	9	n.s.
Zn	%Z	0.03	0.18	6	n.s.	0.07	0.65	9	n.s.
Al	%Z	0.07	0.43	6	n.s.	0.28	3.52	9	~
Fe	%Z	0.11	0.78	6	n.s.	0.03	0.31	9	n.s.
Cu	%Z	0.01	0.06	5	n.s.	0.03	0.25	9	n.s.
S	%Z	0.14	0.99	6	n.s.	0.07	0.69	9	n.s.
B	%Z	0.25	2.03	6	n.s.	0.00	0.02	9	n.s.
Si	%Z	0.01	0.07	5	n.s.	0.04	0.42	9	n.s.

F-critical values (α=0.05) are 6.61 (d.f.=5); 5.99 (d.f.=6); 5.12 (d.f.=9)

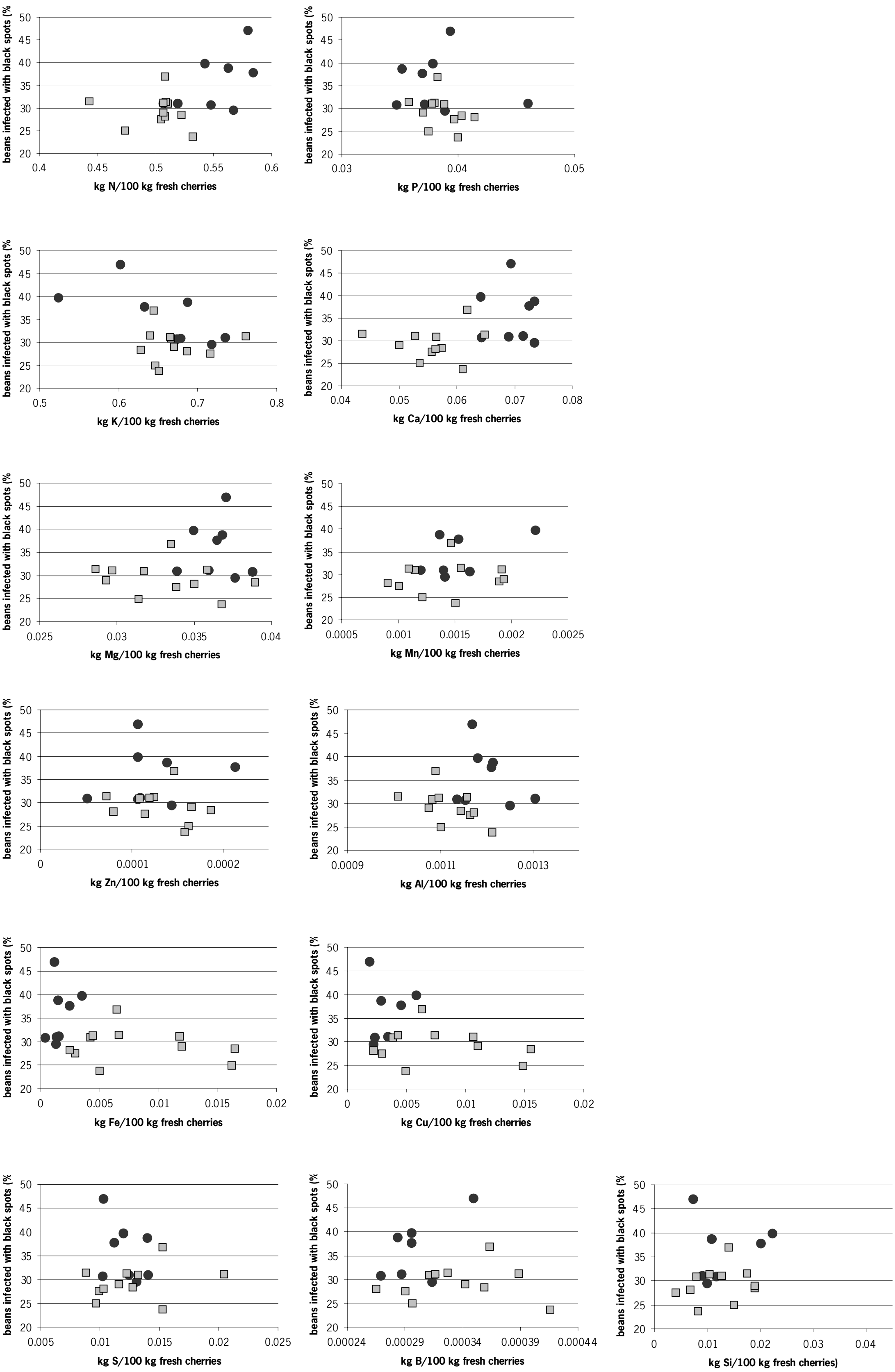

Figure 20. *Relation between beans infected with black spots and kg nutrient/100 kg fresh cherries of the nutrients N, P, K, Ca, Mg, Mn, Zn, Al, Fe, Cu, S, B and Si.*

Appendix Vid.

1000-bean weight of 'screen size 17'-beans and kg nutrient/100 kg fresh cherries

Table 35. Output of MLR for kg nutrient/100 kg fresh cherries (x) and 1000-bean weight (y).

variable		F probability	t probability		Estimate		
X	Y		Location	Nutrient	Constant	Location	Nutrient
N	1000-b.w.	0.002	0.033	0.399	147.2	-10.7	65.3
P	1000-b.w.	<0.001	<0.001	<0.001	111.5	-14.6	1978.0
K	1000-b.w.	0.003	<0.001	0.818	181.6	-14.0	7.7
Ca	1000-b.w.	0.002	0.128	0.317	157.6	-9.1	345.0
Mg	1000-b.w.	<0.001	0.010	0.136	149.1	-10.8	940.0
Mn	1000-b.w.	0.005	0.001	0.587	191.3	-14.3	-2856.0
Zn	1000-b.w.	0.002	0.001	0.423	182.6	-14.2	34606.0
Al	1000-b.w.	<0.001	<0.001	0.011	93.1	-7.8	72586.0
Fe	1000-b.w.	0.003	0.011	0.596	185.4	-12.4	-235.0
Cu	1000-b.w.	0.005	0.007	0.629	186.4	-13.0	-239.0
S	1000-b.w.	0.003	<0.001	0.871	187.7	-13.9	-105.0
B	1000-b.w.	0.002	<0.001	0.481	195.3	-12.9	-32877.0
Si	1000-b.w.	0.002	<0.001	0.198	192.8	-14.4	-439.0

Table 36. Relations between kg nutrient/100 kg fresh cherries (x) and 1000-bean weight of 'screen size 17'-beans (y).

Variables		Huong Phung				Khe Sanh			
X	Y	r^2	F-obs	d.f.	Significance	r^2	F-obs	d.f.	significance
N	1000-b.w.	0.02	0.10	6	n.s.	0.28	3.52	9	~
P	1000-b.w.	0.66	11.73	6	*	0.54	10.42	9	*
K	1000-b.w.	0.12	0.80	6	n.s.	0.08	0.82	9	n.s.
Ca	1000-b.w.	0.03	0.20	6	n.s.	0.08	0.83	9	n.s.
Mg	1000-b.w.	0.02	0.15	6	n.s.	0.21	2.44	9	n.s.
Mn	1000-b.w.	0.00	0.01	5	n.s.	0.04	0.39	9	n.s.
Zn	1000-b.w.	0.04	0.23	6	n.s.	0.05	0.43	9	n.s.
Al	1000-b.w.	0.60	9.13	6	*	0.21	2.33	9	n.s.
Fe	1000-b.w.	0.00	0.01	6	n.s.	0.03	0.28	9	n.s.
Cu	1000-b.w.	0.00	0.00	5	n.s.	0.04	0.37	9	n.s.
S	1000-b.w.	0.06	0.39	6	n.s.	0.00	0.00	9	n.s.
B	1000-b.w.	0.07	0.42	6	n.s.	0.02	0.22	9	n.s.
Si	1000-b.w.	0.04	0.20	5	n.s.	0.18	1.97	9	n.s.

F-critical values (α=0.05) are 6.61 (d.f.=5); 5.99 (d.f.=6); 5.12 (d.f.=9)

Table 37. Slopes and intercepts of statistically significant linear relations between descriptor (x) and dependent (y) variables.

Variables		location	slope	intercept
X	y			
P	1000-b.w.	HP	1620.8	110.6
P	1000-b.w.	KS	3128.3	37.9
Al	1000-b.w.	HP	99217.0	53.2

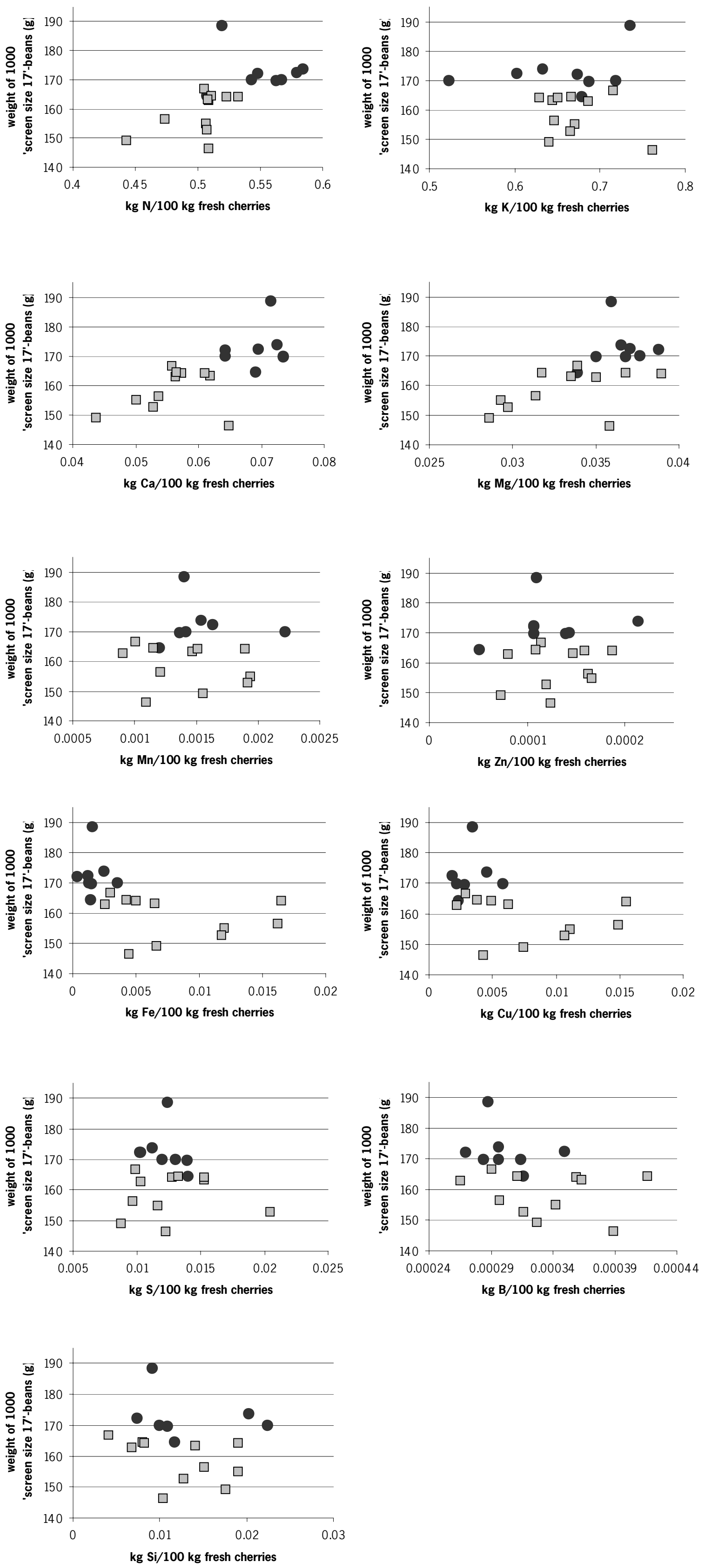

Figure 21. *Relation between 1000-beans weight of 'screen size 17'-beans and kg nutrient/100 kg fresh cherries of the nutrients N, P, K, Ca, Mg, Mn, Zn, Al, Fe, Cu, S, B and Si.*

Appendix VII.
Yield of cherries (kg dm/ha) and nutrients in cherries (kg/ha)

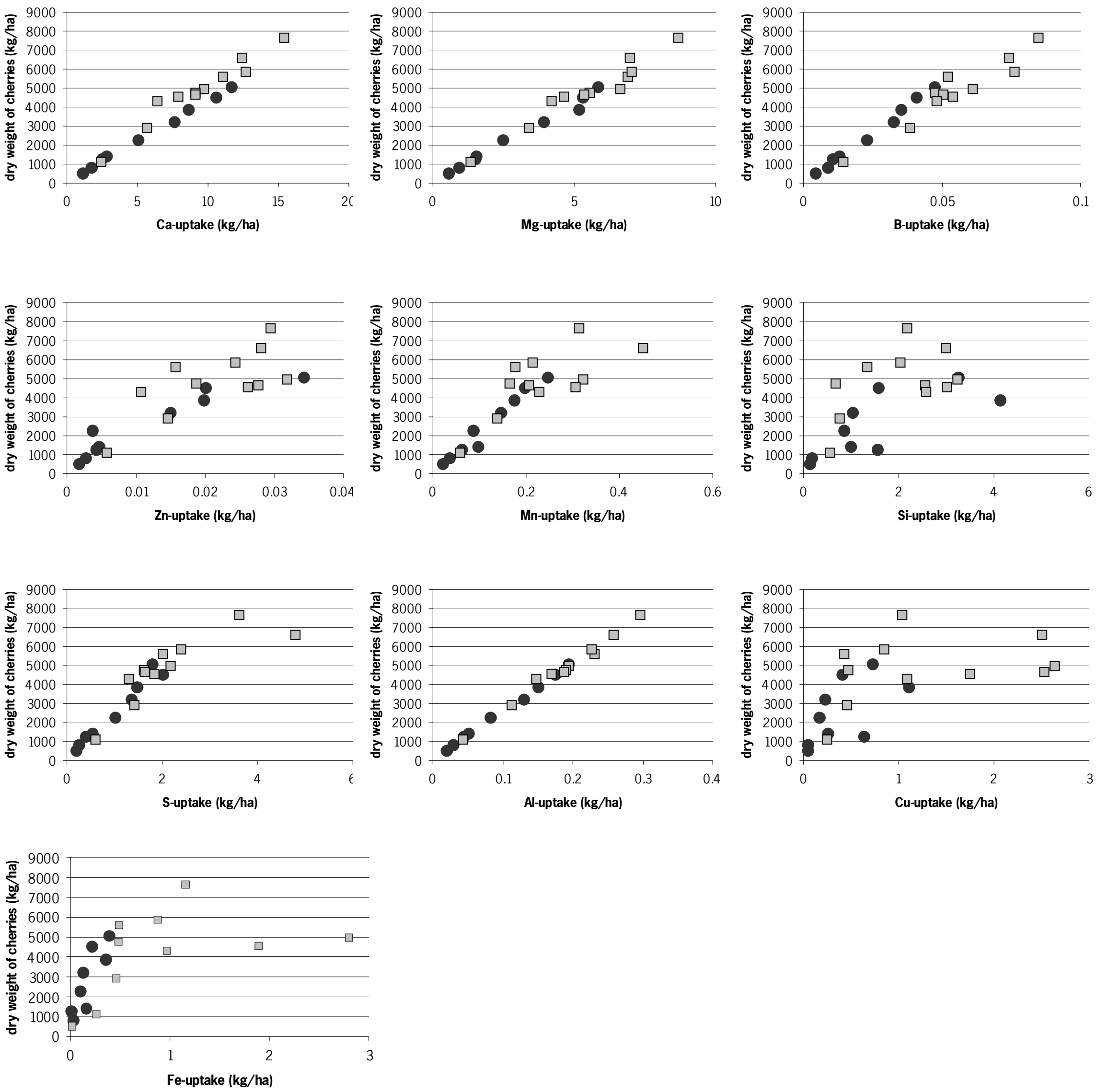

Figure 22. *Relation between dry weight of cherries (kg/ha) and nutrient uptake (kg/ha) of the nutrients Ca, Mg, Mn, Zn, Al, Fe, Cu, S, B and Si.*