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Sustainable Management of Fruit Orchards in the Soconusco, Chiapas, Mexico - Intercropping Cash and Trap Crops

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SUMMARY

South Mexico belongs to the Mesoamerican tropical region. The typical production systems are characterized on the one side by high diversity home gardens and by export orientated plantations like mangoes, avocados, papayas, and minor fruit crops. On the other side, subsistence agriculture remains the rule for the production of basic food crops like maize and beans, through traditional management systems. Both production systems integrate practices based on intensive use of agrochemicals, which eventually affect the natural resources in the medium and long term. The alarming agro-ecological conditions of the tropical fruit systems have awakened our interest to conduce field experiments during 2005-2007 in the Soconusco Region. Special attention has been given to the different effects of intercropped annual crops within the fruit plantations on the dynamics and structure of the weed and insect populations as well as on the chemical and biological parameters of soil fertility. Moreover, growth and yield parameters of the selected fruit crops, mango and rambutan and of the integrated annual intercrops were evaluated. The investigations have been carried out in two typical fruit orchards in the Soconusco, the humid tropical region of Mexico. The experiments are located in a mango orchard at 14 x 14 m in Cintalapa (15° 19' 431" N, 92° 37' 369" W, altitude 184 m.a.s.l) and in a rambutan plantation at 8 x 8 m in El Triunfo (15° 21' 147" N, 92° 33' 176" W, altitude 335 m.a.s.l). Each experimental orchard with a total area of 9408m^2 includes eight intercropping scenarios, arranged in four major crop rotations together with a control plot of mango/rambutan without annual intercrops. Since May 2005, the traditional maize - straw fallow rotation and the improved maize + pumpkin - straw fallow crop rotation have been compared in cycles 1-2 and 3-4 together with the same rotations to which a leguminous intercrop had been added in the fallow cycles 2 and 4. The maize crop lasted from May to August and the legumes intercrop within the fallow cycle from august to march. For each legume crop rotation, three leguminous scenarios were implemented: *Crotalaria spectabilis* and *Vigna unguiculata* in both orchards, *Crotalaria longirostrata* in Rambutan and *Phaseolus acutifolius* in Mango only. In each experimental unit, the growth and yield parameters of intercropped crops and their interactions with the yield parameters of the companion fruit trees have been determined. A sole fruit crop without any intercrop has been used as a control rotation.

The intercropped annual systems show a positive function as cash and trap crops, provide a substantial soil cover, and allow insect and weed populations to be optimized in the fruit x intercrop systems. The rotations combining a maize + pumpkin in the first cycle followed by a subsequent leguminous crop in the second cycle improve the soil fertility and carbon sequestration. However, soil K, Ca, and Mg nutrient levels are reduced by intercropping effects. Pumpkin cover reduces weed biomass more than legume intercrops. The weed diversity and its equal distribution are enhanced by maize + pumpkin intercrops in rotation with leguminous crops. Interestingly, insect dynamics and hence, mango and rambutan yields are enhanced by the dry biomass of *Crotalaria* spp. and *V. unguiculata* crops.

Nachhaltige Bewirtschaftung von Obstplantagen im Soconusco, Chiapas, Mexiko durch ausgewählte Systeme mit Zwischenfruchtanbau

ZUSAMMENFASSUNG

Der Süden Mexikos gehört zu den mittelamerikanischen tropischen Regionen. Die Systeme mit Obstanbau sind gekennzeichnet einerseits durch familiäre Obstanbauflächen mit hoher Diversität und andererseits durch exportorientierte Plantagen mit Mango, Avocado, Papaya und andere Obstarten. Typisch sind außerdem traditionelle Subsistenzwirtschaften mit Mais und Bohnen. In den letzten Jahrzehnten hat sich für alle Anbausysteme die intensive Nutzung von Pflanzenschutzmitteln durchgesetzt, die ernsthafte negative Auswirkungen auf die Umwelt ausüben kann. Diese alarmierende Situation für den tropischen Obstbau bildete die Grundidee zur Durchführung von Feldversuchen im Soconusco in den Jahren von 2005 bis 2007. Besonderes Augenmerk wurde darauf gelegt, dass unterschiedliche Systeme mit Zwischenfruchtanbau und deren Einflüsse auf die Struktur und Dynamik der Unkrautzönose, auf die Populationsdynamik von Insekten, auf unterschiedliche chemische und biologische Parameter der Bodenfruchtbarkeit, sowie of wachstums- und ertragsbildende Merkmale der annuellen Zwischenkulturen und der beiden Obstarten Mango und Rambutan, untersucht werden konnten. Als Versuchsstandorte wurden im subhumiden tropischen Gebiet des Soconusco, ein Mangostandort in Cintalapa (15° 19' 431" N, 92° 37' 369" W, 184 m über NN) und eine Rambutanplantage in El Triunfo (15° 21' 147" N, 92° 33' 176" W, 335 m über NN) ausgewählt.. Jeder Versuch hatte eine Gesamtfläche von 9408m², beinhaltete acht verschiedene Zwischenfruchtvarianten mit vier Hauptfruchtgliedern, welche mit dem traditionellen Obstanbausystem (Mango oder Rambutan) ohne Zwischenfruchtanbau verglichen wurden. Die Versuche begannen sowohl in Mango als auch in Rambutan im Mai 2005 mit den Zwischenfruchtsystemen Reinkultur Mais – Strohbrache und Mais + Kürbis – Strohbrache (1° und 3° Anbauzyklus) und wurden jeweils fortgesetzt mit drei verschiedenen Leguminosenzwischenkulturen und einer Bracheparzelle (2° and 4° Anbauzyklus). Die Anbauperiode der Maissysteme dauerte jeweils von Mai bis August und die Leguminosenzwischenkulturen und die Brache von August bis März. Die Fruchtfolgerotationen mit Leguminosen hatten jeweils drei Arten: *Crotalaria spectabilis* und *Vigna unguiculata* in beiden Obstarten, *Crotalaria longirostrata* nur in Rambutan und *Phaseolus acutifolius* nur in Mango. Für jedes Prüfglied erfolgte eine Datenerfassung der entsprechenden wachstums- und ertragsbildenden Faktoren und die Bestimmung der Einflüsse auf den Ertrag der jeweiligen Obstart. Als Kontrolle diente die Parzelle ohne jeglichen Zwischenfruchtanbau im Mango sowie Rambutan.

Der Zwischenfruchtanbau ermöglichte zusätzliche Einnahmen, bewirkte einen wirksamen Bodenschutz und trug zu artenreicheren Insektenpopulationen und konkurrenzschwachen Unkrautzönosen im Agrarökosystem bei. Das Fruchtfolgepaar Mais + Kürbis und nachfolgend Leguminosen erhöhte die Bodenfruchtbarkeit und hatte eine höhere CO_2 – Festlegung. Andererseits reduzierten die Zwischenfrüchte den K, Ca- und Mg-Gehalt im Boden. Der Kürbisanbau unterdrückte die Biomassebildung von Unkräutern und förderte die Diversität der Unkrautzönose. Die Varianten mit dem Anbau von *Crotalaria* spp. und *V. unguiculata* erhöhten die Insektenpopulationen und trugen mit der produzierten Biomasse außerdem zur Ertragssteigerung von Mango und Rambutan bei.

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I INTRODUCTION

It produces an immense sadness to think that nature speaks while humankind does not listen (Victor Hugo). The priority must be on maintaining and improving the capacity of the higher potential agricultural lands to support the expanding population. However, conserving and rehabilitating the natural resources on land with lower potential in order to maintain sustainable man/land ratios are also necessary. There is a need to intensify agriculture by diversifying the production systems for maximum efficiency in the utilization of local resources, while minimizing environmental and economic risks (FAO, 1993). Since, in annual crops the production and maintenance cost have become very high, fruit crops come into consideration as a viable alternative for many farmers to reduce production costs and off-set the environmental impact of the previous annual crops (Borgman *et al.*, 2000). In the later half of this century, the proportion between annual and perennial crops evolved more in favour of the latter ones, particularly in the last decade. However, in many parts of the world, particularly in developing countries, the diet of populations is based on the consumption of a cereal grain, usually maize, sorghum or rice, and on food legumes, either common beans or any other pulse. Results of many studies have shown that these two types of basic food complement each other nutritionally (Landry and Moureaux, 1980; Gómez-Brenes, 1972). Nowadays, the maize production occupies worldwide the first place among cereals (FAO, 2005). The use of this cereal is essential for the human consumption in Mexico and Central America unlike the rest of the main producing maize countries. By tradition and culture, the maize constitutes the basic diet of the Mexicans, and this forms part of a series of cultural, political, and economic phenomena that evolve around this.

South Mexico belongs to the Mesoamerican tropical region. The typical production systems are characterized on the one side by high diversity home gardens and export orientated plantations like mangoes, avocados, papaya and minor fruit crops; and on the other side by subsistence agriculture characterized by basic food crops like maize and beans, and by the traditional “milpa” management system also defined as RTQ – **R**osa (weed slashing with machete) – **T**umba (Tree logging) – **Q**uema (incineration). Both production systems integrate management based on the intensive agrochemical measures, which eventually affect the natural resources in the medium and long term. Likewise, farmers throughout Central America traditionally grow an intercrop of corn, beans, and squash. Grown together these three crops optimize the available resources. Nevertheless, the length of fallow period required to replenish the soil productivity has to be shortened. Indeed, the fallow systems have become impractical, because of increasing human and livestock population. Still in such conditions, the mixed crops are popular crop systems among small-scale farmers in the tropics (Vandermeer, 1989; Gomez and Gomez, 1983; Ruthenberg, 1980). Nowadays, ample information exists about crop rotations (e.g. Barber & Navarro, 1994), forage legumes (e.g. Cadisch *et al.*, 1989) or intercropping systems with annual crops (e.g. Tian *et al.*, 1999).

In tropical fruit systems though, little information is available about cover crops, apart from commercial tree crops like rubber (Watson, 1989) or oil palm (Broughton, 1976). Hence, it is crucial to develop sustainable intercropping options in fruit orchards, for balancing and diversifying both the natural insect fauna and the weed flora, and for integrating cash and trap crops into the fruit areas (Pohlan, 2002; Pohlan *et al.*, 2000; Gamboa and Pohlan, 1997; Nestel and Altieri, 1992). This awakened our interest for conducting field experiments between 2005 and 2007 in the Soconusco Region; with special attention for the various effects of the intercropped crops in fruit plantations on the weed and insect populations, on the soil fertility, and finally on the growth and productivity of the integrated fruit systems.

1.1. Economic, ecological and social problems in tropical agroecosystems

The vitamin content and the exquisite flavour of tropical fruits are recognized worldwide. Globalization and the efficient commercialization of the tropical fruit industry have successfully introduced an exotic character at the dinner table at home or in the restaurant throughout the world. World production of tropical fruits was estimated at 67.7 million t in 2004, about 2.3 % more that in 2003 and in the next decade is estimated to reach 82.1 million t by 2014 i.e. an annual increase of 1.7 % (FAO, 2004). Surfaces planted to tropical fruits have been characterized by either high diversity home gardens or export orientated plantations. The applied technologies, have caused on the one side, a strong ecological imbalance among fruit orchards and, on the other side, a very stringent erosion of fauna and flora (Marroquín *et al*., 2006a), worsening over time and space. One clear example is the case of fruit flies in the Soconusco region of Mexico. Owing to the severity of the fly damage, the MOSCAMED– programme is combating constantly the Mediterranean flies through massive chemical control and insect sterilization, politics, without any consideration for human health. These control measures, were coordinated politically between Mexico, Guatemala and USA at the expense of millions of dollars, but in reality, results demonstrated the contrary.

In the Soconusco region, the fruit growing extends actually over 60 000 ha, and it is oriented to export planting of mangoes (*Mangifera indica*), bananas (*Musa acuminata, M. paradisiaca*), papaya (*Carica papaya*) and rambutan (*Nephelium lappaceum*) (Vanderlinden *et al*., 2004; Pohlan *et al*., 2000). Home gardens and export orientated plantations are characterized by intensive mechanical and chemical management of soil and by indiscriminate use of chemical products for weed and insect control. This combination has generated temporary high incidence of pest, recurrent problems with fruit flies and hence, the increase of production costs in mango plantations (23 000 ha). The fruit agroecosystems have been turned unstable and unprofitable. In spite of all applied technologies, the average yield of the predominant mango variety "Ataulfo" is approximately 5 t ha^{-1}, which is lower than the national average (9 t ha^{-1}) and the world average (7 t ha^{-1}) (FAO, 2004). The applied measures on the mango and other fruit plantations in the Soconusco are very adverse to the sustainability model of the region. In case of mango, the fruits for export must be certified "fruit fly free" by the MOSCAMED – programs (SAGAR-DGSV, 1981). Consequently, strong campaigns are periodically undertaken against the fruit fly complex encompassing both *Anastrepha* spp.. and the Mediterranean fly (*Ceratitis capitata*), using chemical and biological measures. Moreover, the Regional Committee of Crop Sanitation forces the farmers to eliminate all plant species, that could be host of fruit flies.

On the other hand, areas with rambutan are relatively new in the Soconusco. Commercial productions were initiated in the 90ties and nowadays encompass 400 ha in such area. Most rambutan plantations integrate a monoculture model, i.e. a system that maintains a living soil cover management combined with integrated pest management. Results demonstrated that these rambutan crops harbour fruit flies of the *Anastrepha* species. However, these fruit flies never attacked the rambutan fruits (Pérez Romero and Pohlan, 2005).

It is generally accepted that the onset of agriculture came along with clearing of forested areas about 10000 years ago (Pääbo, 1999; Tanksley & Mc Couch, 1997) and the development of some of the major annual food crops like: wheat and barley in Mesopotamia; taro, amaranth and rice in South-East Asia; millets in China, and maize, quinoa, cassava, squashes, sweet potato and beans in Central and South America (Smith, 1998; Bretting, 1990; Ford-Lloyd & Jackson, 1986). Some industrial crops like sugar cane and cotton were also introduced. Nowadays, the worldwide production of maize outyields that of wheat and rice. The high yield levels of maize and its nutritional value all contributed to its geographic extension across a wide range of agro-ecological conditions. In Mexico and Central America the maize constitutes the principal diet for farmers (Marroquín *et al*., 2004) unlike the rest of the main producing maize countries. For that reason, this grain occupies a surface of 35 000 ha in the Soconusco region (SEFIPLAN, 2005).

Nevertheless, the management applied in these production systems has caused strong soil erosion and biological impoverishment, with increasing intensity over time. Among the main causes of the drastic effects of the Milpa system (roza-tumba-quema) one should mention the periodic incineration of the vegetation before sowing and erroneous practices of soil conservation. The Milpa system now intrudes progressively into the 75 000 ha of coffee cultivation, threatening to disrupt the ecological stability of the coffee based areas in the Soconusco.

Furthermore, the tendency of scientific research consists mainly of numerous studies made on the technological application in tropical agroecosystems, which are generally oriented towards analyzing the effects of herbicides, pesticides, and mineral fertilizers on yield of production systems. In reality, there are only a few studies that have been integrating analyses of intercropped fruit orchards and that have been assessing the multiple effects of intercrops (Marroquín *et al*., 2006b; Pohlan, 2002; Pohlan *et al.,* 2000*).*

1.2. Intercropping systems in the tropics

Mixed culture and different intercropping systems with legumes and cereals is an old practice in tropical agriculture that dates back to ancient civilization. Tropical travellers, from Darwin to my mother-in-law, will attest to the obvious fact that intercrops, i.e. two or more crops grown in association with one another, are common (Vandermeer, 1989). Quantitative estimates suggest that 98% of the cowpea grown in Africa are intercropped (Arnon, 1972), 90% of the beans in Colombia are intercropped (Gutierrez *et al.,* 1975), and the %age of cropped land in the tropics actually devoted to intercropping varies from a low 17% for India (Srivastava, 1972) to a high 94% in Malawi (Edje, 1979). Even in temperate North America before the widespread use of modern varieties and mechanization, intercropping was apparently common (e.g. 57% of the soybean acreage in Ohio was grown in combination with maize) (Thatcher, 1925), and recently there seems to be increased interest in the subject, at least in the research community. Advantage of legumes in crop rotations has long been recognized, nevertheless, the use of legumes as green manure crops in cropping systems has declined due to the availability of low-cost synthetic N fertilizers (Badaruddin and Meyer, 1990). Nowadays, drought risk and soil fertility decline are the major constraints of production and food insecurity in the tropical regions. For that reason the current trend in global agriculture is to search for highly productive, sustainable and environmentally friendly cropping systems (Crew and Peoples, 2004). This has resulted into renewed interest in intercropping research (Vandermeer, 1989). Nevertheless, the complex interactions in the traditional legume-cereal and cereal-pumpkin intercropped systems, have received little research attention (Marroquín *et al*., 2007; Zhang *et al*., 2004; Connolly *et al*., 2001).

1.3. Hypothesis

Central hypothesis
Integration of annual intercrops and crop rotations in fruits orchards modifies the combined productivity of the agroecosystems by changing the efficiency of both biotic and abiotic factors.

1.4. Objectives

General objective: To evaluate the effects of annual intercropped crops in fruit orchards on the productivity and sustainability of integrated fruit systems by enhancing the efficiency of both abiotic and biotic factors.

Specific objectives

1. Determine the effects of different intercropped systems on soil fertility.
2. Evaluate the effects of different intercropped crops on the dynamics of weed populations.
3. Study the interactions between cover crops and insect fauna.
4. Analyze the yield and biomass potential of different intercropping systems.
5. Find the influence of different intercropping systems on the productivity of fruit orchards.

II REVIEW OF MAJOR INTERCROP CONCEPTS

Soconusco, is situated in Chiapas, the extreme South- east region of Mexico. The Soconusco is a tropical region located in a polygon delimited between the northern latitudes of 16°11'24" - 14°31'48" and the western longitudes of 93°56'24" - 92°04'12". This region borders the Pacific ocean and represents a lowland area with distinct dry and wet seasons, where land use includes annual crop growing, cattle raising and banana, mango and papaya cultivation (Pohlan *et al.*, 1997). The hilly region next to the coastal plane is used for cacao, rambutan, and coffee cultivation in varying systems and, eventually culminates at the Tacana volcano.

Ecosystems

Ecosystems are very complex and composed of many individuals of multiple species of organisms, which interact with each other and their abiotic environment to produce complex structures, dynamics, and energy flows. Eco-volume has approached this problem by assuming that it is sufficient to abstract all this complex interactions, such among individuals in populations, and characterize ecosystem function simply in terms of net changes in numbers or bio-volume of individuals at the level of whole populations. Abstracting such individual-scale detail is reasonable if the effects of individual-level interactions attenuate on the time scale of changes in population density (Agrawal, 2001).

2.1 Tropical fruit crops and their structures

Demand of exotic tropical fruit species in the large supermarkets of Europe, Asia, and U.S.A is heavily contributing to the increase the tropical fruit production, as well as of the fruit orchard area. Actually, the world production of tropical fruits is estimated at 67.7 million t, about 2.3 % more that in 2003. Mango is the dominant variety with a global output of 24.3 million t and comprises 36 % of world tropical fruit production. World production of pineapples reaches 15.5 million t or 23 % of tropical fruit production, followed by papaya at 8.5 million t (12.6 %) and avocado at 3.3 million t (4.8 %). The minor tropical fruits i.e. those that were traded in smaller volumes, such as lychees, durian, rambutan, guavas and passion fruit, recorded an output of 16 million t in 2004, representing an annual growth rate of 3 % and accounted for 24 % of total fruit production (FAO, 2004). Interesting is the projected tropical fruit production in the next decade, estimated to reach 82.1 million t by 2014, i.e. an annual increase of 1.7 % from the base period (2002-2004). Major fruits would comprise 78 percents of this total and minor fruits the remainder (22 %).

The worldwide production of tropical fruit covers an area over 6.57 million ha whereby the Far East is leading the production of mango, pineapple and papaya, accounting for 72 %, 52 % and 46 % respectively of world production of these three tropical fruits. Latin America and the Caribbean countries are the next major tropical fruit producing area, accounting for 62 % of global avocado output, 37 % of world papaya production, 29 % of pineapple and 17 % of mango production (FAO, 2004). In Mexico, orange is the dominant fruit species with a national output of 4.11 million t. National production of banana planting reached 2.25 million t, followed by mango at 1.36 million t and avocado at 1.02 million t (SEFIPLAN, 2005). Although tropical fruits have traditionally been an important source of nutrition to developing countries, where 98 % of these fruits are produced, their importance in trade cannot be emphasized enough.

The increasing demand for fresh fruits in the growing urban markets, resulting from their highly recommended nutritional value led to an intensification of fruit production in the early nineties. Eventually, it caused a new increase in the use of agrochemicals in order to reduce labours hours per unit of product and to increase fruit production (Borgman *et al.*, 2000; Janssens and Subramaniam, 2000).

2.2. Fruit monoculture, a widespread culture in the Soconusco Region

When ´modern` agriculture involves varieties specifically adapted for production in monoculture, machines specifically adapted for production in monoculture, and research methodology specifically adapted for improvement of monoculture, what might one expect?

The small traditional farmer has a traditional mentality; that greater inputs in his production process would increase his crop production, without an understanding of the input functions and their interactions inside the production systems (Pohlan, 2006). In the Soconusco, the fruit-growing is also characterized by high diversity home gardens on the one hand, and by export orientated planting of mangoes (*Mangifera indica*), bananas (*Musa acuminata, M. paradisiaca*), papaya (*Carica papaya*) and rambutan (*Nephelium lappaceum*) on the other hand (SEFIPLAN, 2005; Vanderlinden *et al.*, 2004; Pohlan *et al.*, 2000). Labour in fruit home garden is completely family work. There is rarely a well-defined management plan and the agricultural methods are taken from the oldest neighbourhood farmer’s practices, following step for step the same agricultural activities and making the same errors. Orchard becomes a traditional manual management during the sowing and harvest, however when it comes to controlling weed, pest and diseases, the farmer quickly abides by chemical decisions. A lot of applied chemical products are prohibited according to the FAO, e.g Malation (Malathion), Tamaron (Metamidophos), Furadan (Carbufuran), Tordon (Picloram + 2,4-D acid).

On the other side, the export orientated planting practices are oriented to obtain a high production though high cultivation inputs. For that reason, the farmer abuses of agrochemical solutions whilst overlooking possible environmental side effects. Lamentably this system does not consider neither the role of the natural resources, nor the social, cultural, and ecological aspects (Fig. 1). The fruit agro-technologies have provoked strong effects on the environment, as well as on the farmer’s health, e.g. the poisoning cases of mango and banana farmers and workers in the Soconusco. There exists a positive correlation exists between pesticide use and human cancer disease (Castro, 2005).

Differences between small farmers and modern farmers in fruit yield are very high. This is also true for production costs. Actually, the tropical fruit demand is oriented to offer fruits with good presentation quality. Consequently, these marketing pressures have compelled the fruit farmers to intensify the mechanical and agrochemical cultivation practices (Marroquín *et al,* 2006a; Pohlan, 2001).

The mango fruit enjoys now a worldwide recognition. It has been cultivated for more than 4 000 years. *Mangifera indica* is one of the five more important cultivated fruits in the world, as well in surface as for consumption (Rehm and Espig, 1991). Mango crops play an important role in the tropical region, both economically and socially. Mango crop generates employment and a significant income in the Soconusco region. In the year 2005, the mango commercialization generated an economic income of US$ 32.8 millions. The Soconusco mango production is exported to the USA (15 600 t) and Canada (80 000 t) (Martinez, 2006). However, pests and diseases (Fig. 1) can reduce the potential mango yields. Only in the Soconusco region, fruit fly pest has caused in 2005 an economic loss of about 25% of the total production (Martinez, 2006). Therefore, Mexico and U.S.A work together to control the fruit fly pest in the Soconusco. Fruit flies impose worldwide a significant cost on the horticultural production every year. In Australia alone, these control costs are estimated at $130m-$140 millions per year. In fact, total losses encompass not only direct yield losses and prohibitive field prophylaxis costs, but also the loss of some export markets compounded with the costs of routine fruit treatment plants and eventually, quarantine eradication operation in case of infested lots. Indeed, in many countries, the export of most commercial fruits is severely restricted by quarantine laws to prevent the spread of fruit fly species (TFnet, 2003).

With reference to the above-mentioned export issue of mango, all other fruit crops must be certified “fruit fly free” by the MOSCAMED – programme (SAGAR-DGSV, 1981). Jointly to those fruit fly measures, the Regional Committee of Crop Sanitation forces the farmers to eliminate all plant species that could host these fruit flies. Many farmers even keep their orchards devoid of any weeds all year round. As would be expected, these intensive fruit production control systems have generated periodic high incidence of trips *(Frankliniella parvula)* populations, and anthracnose (*Colletotrichum gloeosporioides*). Finally, some weed species (e.g. *Rottboellia cochinchinensis*) developed resistance to herbicidal control rounds (Marroquín *et al*., 2006c).

Figure 1: Agroecological results of the mango management in the Soconusco region.

The rambutan case is very different from the other tropical fruits like mango or bananas. Nowadays, pest and disease problems in rambutan orchards are low in tropical areas, specifically in the Soconusco region. Presently, 400 ha are growing in the Soconusco (Pérez & Pohlan, 1999). Further extensions are under development and in future further significant acreage increases are expected for the whole of Chiapas, as well as in neighbouring humid tropical states of Mexico (Pérez & Pohlan, 1999). The rambutan is widely propagated by seed, as this is the easiest and cheapest method. However, for commercial use the propagation by seed is not recommended (Gutiérrez, 2002). Trees grown from seed bear after five to six years. They present a high heterogeneity in quality and often produce sour fruit (McDonald & Low, 1984). Furthermore, the sexual propagation is not very recommendable as it gives about 60-70% non-productive male plants and 30-40% female or hermaphroditic plants, from which only 5% give a profitable production (Pérez, 1994). Thus, seedlings are used primarily as rootstocks for grafting, and not for orchard establishment (Brunner, 2001; Mc Donald & Low, 1984). There exist more than 100 varieties of rambutan in the world, which differ from each other for their characteristics in fruit quality, maturation, grade of alternation, climatic requirements, etc. Some important varieties on world scale are: R134, Muar Gading (R156), Khaw Tow Bak (R160), Dann Hijau (R162), Chai Tow Cheng (R167), Deli Cheng (R170), Rongrein (R191), Seematjan, Seenjonja, Maharlika, Jitlee and Seechompoo (Zee, 1995; Zee, 1993). It is not known which varieties are propagated in Mexico, but studies are being realized to develop and propagate a local variety that will satisfy the international quality standards (Pérez, 2000).

2.3 Agriculture of subsistence with basic tropical crops

"Shifting cultivation is the name we use for agricultural systems that involve an alternation between cropping for a few years on selected and cleared plots and a lengthy period when the soil is rested" (Ruthenberg, 1980). Expanding cash production and growing subsistence needs of an increasing population lead to gradual extension of arable farming at the expense of the fallow, so that short-fallow systems gradually replace long-fallow systems (Faucher, 1949). The characteristic R index indicates the proportion of an area under cultivation in relation to the area available for arable farming. If, for instance, 40 % of the available arable land in one holding is cultivated, then R is 40. Within a few decades, the reduction of fallow resulted in increased R-values from 17 in the traditional system to 31 in hoe systems and up to 54 in plough systems (Ruthenberg, 1980). Most fallow farmers practice hoe-cultivation, often in the form of soil conservation and steady yields. They usually cultivate a larger area than the traditional shifting cultivators in the tropical areas. In general terms, a reduction of the fallow period causes a reduction of yield per hectare, unless compensated by fertilizer application or manure, which is rarely the case in these systems.

Out of approximately 300000 plant species that exist in the world, about 3000 species have been used as food crops. At least 150 have been commercially cultivated, and only 15 of them make up the majority of the world's food crops (Beardsley, 1999). The world most important crops (based on crop production data) are sugar cane, maize, tropical fruits, wheat, rice, potatoes, sugar beet, soybean, cassava, barley, sorghum, sweet potatoes, oil palm, tomatoes, oranges, cabbages and coconuts (FAO, 2005). World acreage for maize increased from 105 million ha in 1961 to 127 million ha in 1987, up to 212 million ha in 2004, with a production from 724 million t (FAO, 2005). The tropical maize is cultivated in approximately 66 countries, with great economic importance in 61 from those. Yield in tropical countries is about 1.8 t ha^{-1}, below the world average of 3.41 t ha^{-1}, whereas the average maize yield in temperate areas is over 7t ha^{-1}. Although part of the maize production increase resulted from additional land area planted, significant increases in production resulted from genetic improvement and more efficient technological field practices and fertilizer applications, as well as from the introduction of new more highly reproductive varieties. (Jourdain *et al*., 2001)

However, developing countries have more area given to maize cultivation than developed countries, but yield in the latter is about four times higher. Since 1961, yields per ha in the United States have increased significantly, while yields in Mexico, Guatemala and Nigeria (selected as countries where maize intake by the human population is high, particularly in the first and two) have increased only slightly. While most of the production in developing countries is for human consumption, in the developed world it is mainly for industrial use and animal feed. For example, in Mexico the maize area covers about 6.6 millions ha and present a production of 18 million t, with an average yield of 2.7 t ha^{-1} (SEFIPLAN, 2005).

In the Soconusco, Chiapas, maize is grown mainly with traditional technologies, since the use of improved varieties is scarce. Given the population growth and the to increased demand, the food supply in the maize farming region has pushed the maize crops uphill in areas which are only marginal for agriculture, due to poor soil quality and steepness of the slope. As a staple food in the region, maize is the most cultivated crop in Mexico and Guatemala. Maize cropping consists traditionally of preparing the land by manually cleaning the soil and burning the remaining plants (see Milpa system, Chapter II). The burning or clearing is done to eradicate the weeds, whose roots spread widely. After burning, the stubble and the ashes are turned into the soil (Marroquín, 2003). During the last two decades, many agricultural systems of the Soconusco Region of Chiapas have been shifted from annual crops to permanent crops like fruits, oil palm or sugar cane. There are various reasons for this change, but the most probable one is the need to lower the production costs resulting from a prolonged cycle of annual crop cultivation (Pohlan, 2001; Borgman *et al.,* 2000).

2.4 Intercropped fruit orchards: little-visible systems in the tropics

Is there an advantage to growing intercrops? The simple answer to this question is a qualitative one. If so many traditional agriculturalists do it, there must be some advantage to it (Vandermeer, 1989). Whereas ample information exists about cover crops in crop rotations (Barber & Navarro, 1994), forage legumes (Cadisch *et al.,* 1989) or intercropping with annual crops (Tian *et al.,* 199), poor and little information is available about cover or intercropping in tropical fruit orchards.

Intercrop (organized form of policulture) – the cultivation of two or more species of crop in such a way that they interact agronomically (biologically). Crop intensification should be considered both in time and in space. There is intercrop competition during all or part of crop growth. Farmers manage more than one crop at a time in the same field. Under the general category of intercropping, there are four subcategories (Grossman and Quarles, 1993; Vandermeer, 1989; Ruthenberg, 1980):

- *Row intercropping*—growing two or more crops at the same time with at least one crop planted in rows.
- *Strip intercropping*—growing two or more crops together in strips wide enough space to permit separate crop production using machines but close enough for the crops to interact.
- *Mixed intercropping*—growing two or more crops together in no distinct row arrangement.
- *Relay intercropping*—planting a second crop into a standing crop at a time when the standing crop is at its reproductive stage but before harvesting

When two or more crops are growing together, each must have adequate space to maximize synergism and minimize competition between them (Sullivan, 2003). To accomplish this, four aspects need to be considered: 1) spatial arrangement, 2) plant density, 3) maturity dates of the crops being grown, and 4) plant architecture. The measurement most frequently used to judge the effectiveness of an intercrop is the land equivalent ratio (LER) (Mead & Willey, 1980). It takes its name from its interpretation as relative requirements for intercrops versus monoculture. Let us suppose that on one hectare of land it is possible to produce 10 unites of corn and 50 unites of beans if they are grown as a intercrop. What if one wanted to produce corn and beans as two separate monocultures. How much land would be needed to produce as much in monoculture as was produced on the one hectare of policulture? The amount of land is called land equivalent ratio (Vandermeer, 1989). Nevertheless, in complexes intercropping systems, like intercrops inside the fruit orchards, LER is difficult to implement.

Farmers throughout Central America traditionally grow an intercrop of corn, beans, and squash. Grown together, these three crops optimize available resources. The corn towers high over the other two crops, and the beans climb up the corn stalks. The squash plants sprawl along the ground, capturing light that filters down through the canopy and shading the ground. The shading discourages weeds from growing. This mixture was compared to the individual crops grown separately in a study near Tabasco, Mexico (Amador, 1980). Bean and squash yields suffered considerable yield reductions when grown in mixture. In this example if corn were the most important crop, it was beneficial to grow it in a mixture with squash and beans. The beans and squash were just a bonus. The Land Equivalent Ratio (LER) for the whole mixture was considerably higher (1.6) than any of the pure stands.

2.5. Eco-volume in the production systems

Eco-volume is the aboveground quantifiable space or volume limited by a uniform vegetation stand and its height, within which coexist wide interactions among biotic and abiotic components. This concept emphasizes the interrelationships between species living within the boundaries of a volume, and encompasses a biocenosis adapted to specific conditions in a given place.

Veco = land area x eco-height (Janssens *et al*., 2004)
Eco-height: Weighted average height of given phytocenose or agricultural system. It corresponds to average height in a mono-specific vegetation or crop stand. Weighting will be performed according to the abundance of each vegetation component

The eco-volume as unit contains many components that interact in large and complexes networks, higher trophic structure, nutrient fluxes, etc. It can be also distinguished in a vertical structure like the strata in forest. The eco-volume can suffer periodic or abrupt changes based on natural phenomena or man-made alterations. Eco-volume has additionally effect on precipitations (eco-precipitations), as well as on regulation of other ecological functions like microclimate and water cycles. Eco-volume leads directly into such areas as water cycling, Gross Primary Productivity (GPP), Net Primary Productivity (NPP), and energy flow.

Agroclimax

Janssens *et al*., (2006) compares the biomass production of orchards with natural systems in climax state, and propose the notion agro-climax as an alternative to that of eco-climax. Each agro-climax is characterised by a certain level of agro-diversity, contributing in its man-made way to biodiversity. Janssens *et al*., (2006, 2004), defines agroclimax like the relative stabile biomass production from an orchard or farming system and determinates the allometric relation to estimate the gross photosynthesis. He says that the aboveground gross photosynthesis is close to four-fold the litter fall.

$Bf \approx 4 * Lf$

Where: Bf = Gross photosynthesis; Lf = Litter fall

Eco-climax and Eco-volume potential

Eco-climax is defined by Odum (1969) as the culmination state after a succession in a stabilized ecosystem in which maximum biomass (or high information content) and symbiotic functions between organisms are maintained per unit of available energy flow. This *Eco-climax state* is considered the *eco-volume potential*. When the system approaches its climax, the rate of increase in net productivity of the plants is consumed by its own heterotrophs. The system comes into equilibrium and reaches peak efficiency at channelling the energy of the sun into the food web of the community (Whittaker, 1975).

A climax community is one that has reached the stable stage. When extensive and well defined, the climax community is called a biome. Stability is attained through a process known as succession, whereby relatively simple communities are replaced by ones that are more complex. Stable climax communities in most areas can coexist with human pressures on the ecosystem, such as deforestation, grazing, and urbanization. Polyclimax theories stress that plant development does not follow predictable outlines and that the evolution of ecosystems is subject to many variables.

III METHODOLOGY

3.1 Study sites

The investigations started in May 2005, in the first rainy season, and were concluded at the end of the second dry season (April 2007). The research was carried out in two typical fruit orchards in the Soconusco, Chiapas, in the extreme South- east region of Mexico (Fig. 2). The experiment with mango was located on the common land Cuauhtémoc Chachalaca, known as “Cintalapa” (15º 19´ 431´´N, 92° 37´ 369´´W, altitude 184 m.a.s.l) and that with rambutan on common land El Triunfo (15º 21’ 147’’N, 92º 33’ 176’’W, altitude 335 m.a.s.l) (Fig. 2).

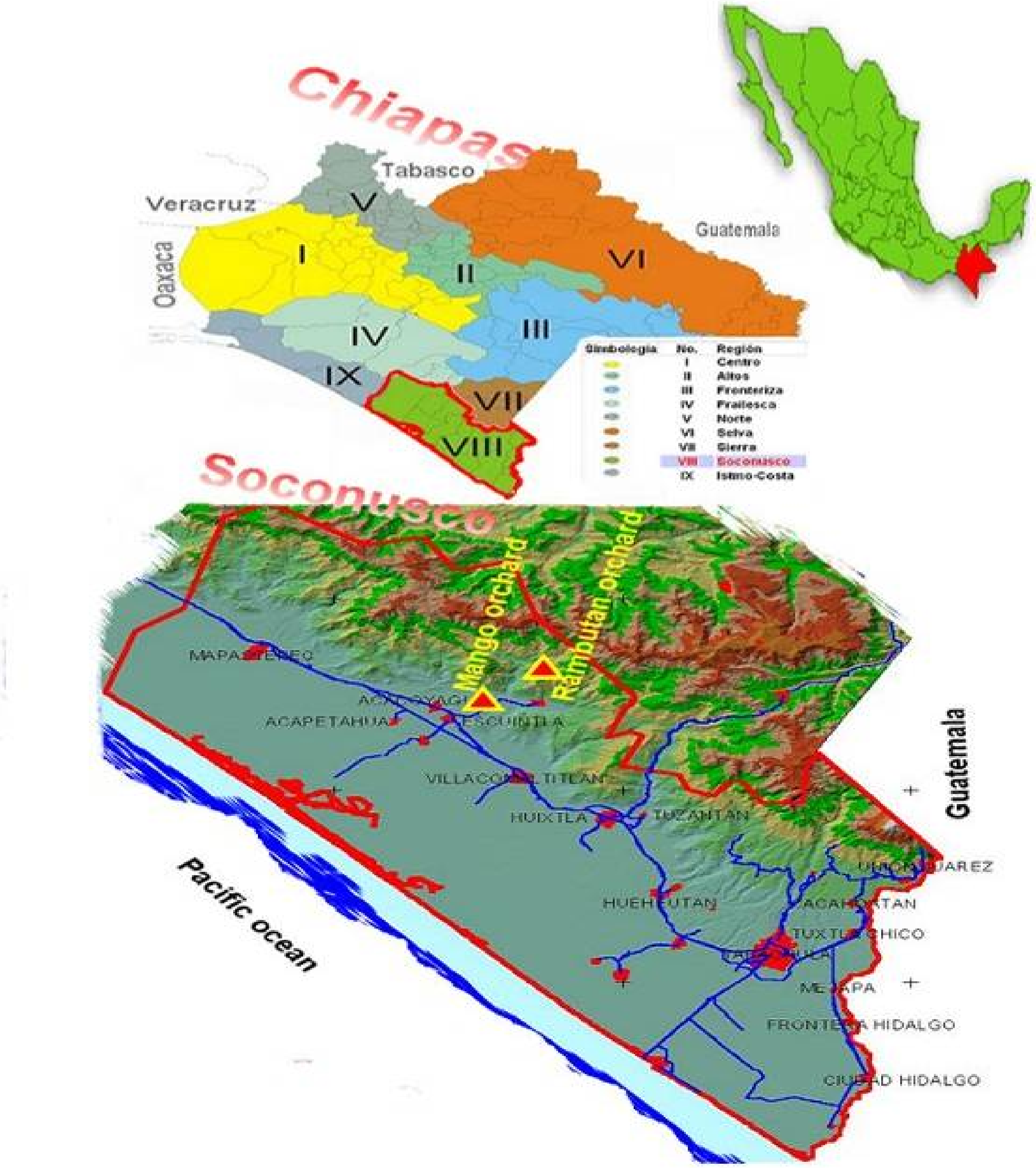


Figure 2: Localization of the experimental areas in the Soconusco region.

a) Climate

The Soconusco Region presents a rainy tropical climate, classified by Köppen as Aw (Pohlan *et al.*, 1997). The precipitation season has a length of approximately six months (May–October), and between the rainy seasons, there is a short dry period (August). That dry season is approximately 15 days (Caniculas), suggesting a weakly pronounced bi-modal rainfall distribution. Annual precipitations oscillate between 2500 to 3200 mm, and present strongest precipitations in September and October (Fig. 3). The maritime influence of the Pacific Ocean is strong. Along the Soconusco coastline, the daily average water temperature oscillates between 26.5 to 28.7 ºC, where the high temperatures are prevailing in March and April, whereas the colder temperatures are in December and January (Fig. 4).

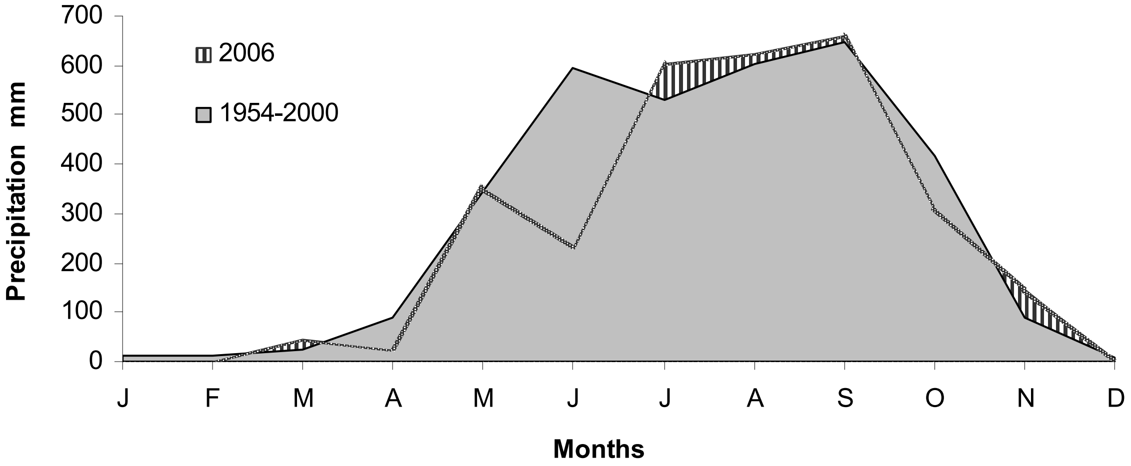


Figure 3: Monthly average precipitations in the study sites.

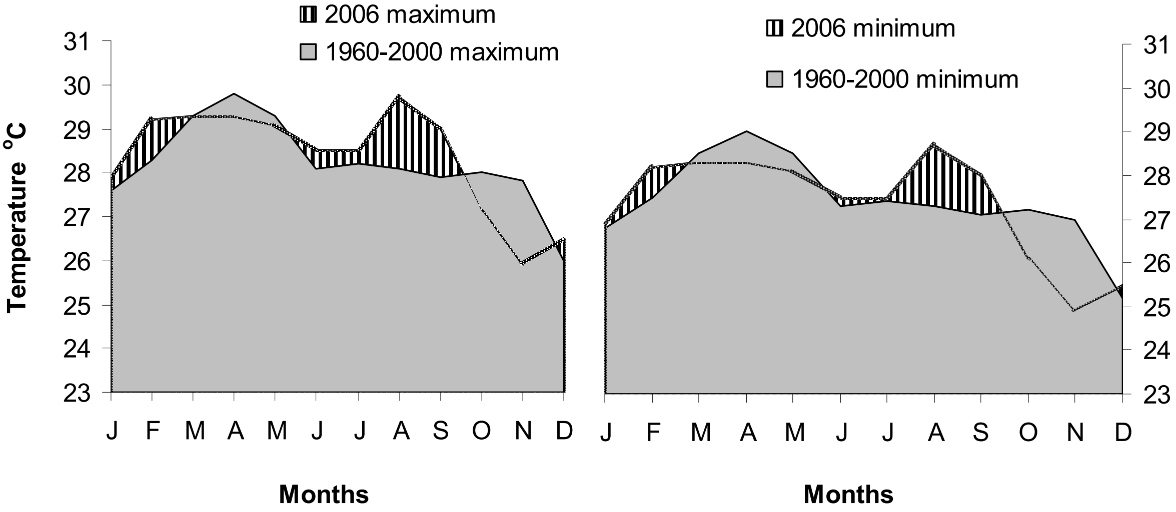


Figure 4: Monthly average temperature in the study sites.

b) Soil

The predominant soils in the study areas are Acrisols associated with Andosols, as well as Lithosols and Regosols (FAO-UNESCO FAO-UNESCO Soil map of the World 1:5,000,000 FAO, 1971 – 1981). Soconusco area is divided in two zones: (i) in the hills (200 - 2500 m.a.s.l.), soils are much eroded and soil fertility is very poor (Tab. 1); (ii) in lowland area (0 - 100 m.a.s.l.) the soil conditions are completely different, because this zone is covered by an alluvial soil, which was formed from the hilly region through soil erosion (Tab. 1). However, both areas endured intensive mechanical and chemical agricultural management, leading eventually into a strong ecological imbalance compounded by a pronounced relief.

Table 1: Soil characteristics in the study areas

Study sites	Altitude (m.a.s.l.)	pH $_{(KCl)}$	C $_{(\%)}$	N$_{total\ (\%)}$	CEC$_{effective}$	Texture
Cintalapa	184	4.5 – 5.0	2.0 – 3.0	0.19 – 0.26	110 - 170	Silt - clay
El Triunfo	335	5.0 – 5.9	1.6 – 2.6	0.16 – 0.23	90 - 120	Silt loam

(Marroquín, 2003)

c) Crops and vegetation

The Soconusco region comprises two regions: **(i)** a lowland area with distinct dry and wet seasons, where land use includes annual growing on 64112 ha, including the following crops in order of importance: maize, soybean, bean and others. In other sites, perennial crops cover 291947 ha, dominate the landscape with e.g., mango, plantain banana, sugar cane, African palm, and cacao here and there intermingled with cattle raising; **(ii)** the second region is the hilly zone next to the coastal plain, which integrates cacao, rambutan, coffee cultivation and forest in varying systems (Coffee area 75.374 ha) (SEFIPLAN, 2005; Marroquín, 2006b). The vegetation consists of scanty forest and coffee–shade trees associations with a big diversity of plant families and species, all having a good agricultural potential. However, experience regarding propagation, planting and other cultural practices is poor especially by smallholders (Marroquín, 2006b; Pohlan *et al.,* 1997).

3.2 Plot design and treatments

The treatments arrangement in this experimental research consisted of a multi-factorial design, fixed like a split-split-plot design, with a total area of 9408 m² for each of two sites. Each experimental site (168 x 56 m) includes eight intercropped treatments (Tab. 2 and 3), arranged as a strip design (first cycle) with six repetitions or small plots, each subplot measuring 14 x 14m (Fig. 7). Both experiments were installed within commercial fruit orchards with more than 5 ha. The mango plantation (Fig. 5) was planted in the year 1995 with cv. “Ataulfo” at a spacing of 14 x 14m. The rambutan orchard started in 2002 at a spacing of 8 x 8m (Fig. 6), providing corresponding subplots of 8 x 8m. The different intercropped crops were adapted between the fruit tree rows (Fig. 5 - 7). This arrangement allows analyzing interactions between systems and their effects on the weed and insect populations as well as on soil fertility. Moreover, it is possible to compare the multiple interactions between traditional fruit cropping systems without permanent soil cover, and alternative experimental fruit systems intercropped by cash and trap crops.

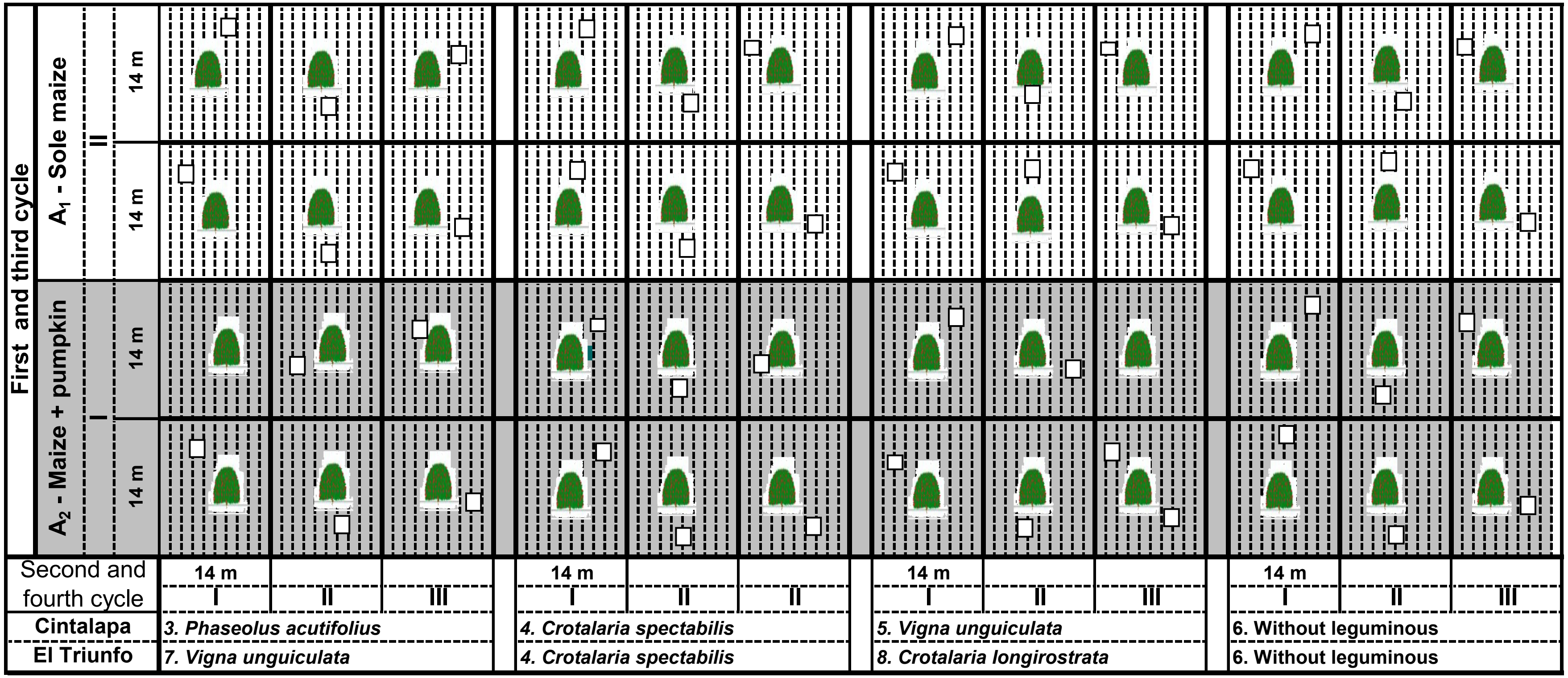
Figure 5: Intercropped forage chipilin in the mango orchard.

Figure 6: Intercropped maize x pumpkin in the rambutan orchard.

Since 2005, different intercropping systems with maize (1° cycle) in rotation with leguminous crops (2° cycle) were evaluated weekly, as to their effects on abundance, biomass and diversity of weeds, as well as to their impact on insect diversity, soil fertility and on growth parameters of the corresponding annual crops and fruit species

Table 2: Characteristics of intercropped treatments in the fruit orchard experiments

First research year (2005)			Treatment description
Factor A	Year	Summer	First crop cycle intercropped with:
First cycle			
A_1	1	a	1. Sole maize (*Zea mays*)
A_2	1	a	2. Maize + pumpkin (*Cucurbita maxima*)
Second cycle	Year	Autumn	Second crop cycle intercropped with leguminous crops
B_1	1	b	3. *Phaseolus acutifolius*, Genotype "Frijol Escumite"
B_2	1	b	4. *Crotalaria spectabilis* (Forage chipilin)
B_3	1	b	5. *Vigna unguiculata* (Cowpea)
B_4	1	b	6. Without legumes (only maize straw fallow)
Second research year (2006)			Treatment description
Third cycle	Year	Summer	First crop cycle intercropped with:
A_1	2	a	1. Sole maize (*Zea mays*)
A_2	2	a	2. maize + pumpkin (*Cucurbita maxima*)
Fourth cycle	Year	Autumn	Second crop cycle intercropped with leguminous crops
B_1	2	b	7. *Vigna unguiculata* (Cowpea)
B_2	2	b	4. *Crotalaria spectabilis* (Forage chipilin)
B_3	2	b	8. Rambutan orchard: *Crotalaria longirostrata* (Chipilin)
			3. Mango orchard: *Phaseolus acutifolius* (Frijol escumite)
B_4	2	b	6. Without legumes (only maize straw fallow)
C	1-2	a-b	9. Black plot: sole fruit trees



Mangifera indica trees: 14 x 14 m.	Sowing: June - 1995
Nephelium lappaceum trees: 8 x 8 m.	Sowing: June - 2002
☐ Sampling point	
Density of maize (*Zea mays*) : 0.70 x 0.40 m.	Sowing: 20 - May
Density of pumpkin (*Cucurbita maxima)* : 3 X 3 m.	Sowing: 13 - May
Density of *Phaseolus acutifolius* : 0.70 x 0.40 m. (between maize plants)	Sowing: 20 - August
Density of *Crotalaria spectabilis* : 0.70 x 0.10 m. (between rows)	Sowing: 20 - August
Density of *Vigna unguiculata* : 0.70 x 0.40 m. (between rows)	Sowing: 20 - August
Density of C*rotalaria longirostrata* : 0.70 x 0.10 m. (between rows)	Sowing: 20 - August

Figure 7: Experimental design of first and second crop cycles.

Intercropping cycles in both fruit orchards:

- ⇒ The first cycle started in May 2005 with the maize and pumpkin sowing. Crop duration spanned over 4 months (Tab. 3). This cycle ended with the harvest of pumpkin and with the traditional bending of maize tops (dobla). During this first cycle, the effects of the intercropping on the weed population, soil fertility, as well as on the growth and yield crops parameters were analyzed. The agricultural management of the intercropped plants was based on weed control and fertilizer supply, as detailed in chapter 3.5 (Tab. 6).
- ⇒ Legume sowing in August initiated the second cycle whilst harvest occurred in December. Leguminous crops were sown between maize rows, themselves lined up between mango rows. Agricultural management integrated only weed control (Tab. 6). Growth and yield parameters, weeds and insect populations as well as soil fertility were recorded during the field experiment time. Likewise, the effects of the different intercropped crops on the yield parameters of fruits crops were analyzed. These intercropping arrangements were analyzed and studied during 2 years, i.e., from May 2005 until March 2007.

Table 3: Synthesis of intercrop systems and/or rotations

Cropping system		**Crop Rotation**		**Dry season Scenario**	
	N°*	**Rain season**	**Dry season**	**Modification**	**N°***
Cintalapa (Mango)	1	Maize	straw		1
	2	Maize/pumpkin	straw		2
	3	Maize	legume		3
				P. acutifolius	3a
				C. spectabilis	3b
				V. unguiculata	3c
	4	Maize/pumpkin	legume		4
				P. acutifolius	4a
				C. spectabilis	4b
				V. unguiculata	4c
	5	Mango (sole)	Mango (sole)		5
El Triunfo (Rambutan)		**Crop rotation**		**Dry season Scenario**	
	nr	**Rain season**	**Dry season**	**Modification**	**nr**
	1	Maize	straw		1
	2	Maize /pumpkin	straw		2
	3	Maize	legume		3
				V. unguiculata	3a
				C. spectabilis	3b
				C. longirostrata	3c
	4	Maize /pumpkin	legume		4
				V. unguiculata	4a
				C. spectabilis	4b
				C. longirostrata	4c
	5	Rambutan (sole)	Rambutan (sole)		5

N°* = Number of treatment

3.3 Measurements and methods

The present research work reports the results of two years growing annual crops in four cropping cycles and their effects on fruit yield of intercropped mango and rambutan. The leguminous crops were sown after early maize harvest between the rows of bent over maize (dobla). Each treatment plot was divided in three sub-plots and repeated twice following the strip design (Fig. 7). In each sub-plot, one evaluation point for weed and crop measurements were fixed (Fig. 7). The growth of intercropped plants was measured weekly and yield parameters were taken at harvest time for each crop (Chapter 3.3.1)

3.3.1 Field measurements and methods

Analyses of weed and insect population dynamics

The weed dynamics parameters were taken four weeks after sowing (WAS) (June and September) and insect population was analyzed at the flowering beginning (January) in each sub plot (six repetitions). The determinations of the insect and weed communities include:

- Weed abundance (number of individuals / species and per m^2)
- Biomass (dry biomass (g m-^{2}) per species and per m^2)
- Weed diversity (Shannon Diversity Index) (Magurran, 1988)
- The weed homogeneity (The Evenness “E”) (Magurran, 1988)
- Insect abundance (number of individuals /species and per plot)
- Insect diversity (number of species per plot)

Productivity parameters of the intercropped and fruit crops

Yield and growth parameters of maize, pumpkin, leguminous and fruit crops were determined weekly and yield parameters were taken at harvest time for each crop (Tab. 4 and 6). The maize growth measurements started 15 days after sowing (May) and finalized at maize tassel (August). Likewise, 15 days after sowing of the leguminous crops the analyses of the growth parameters were initiated (August) and concluded at the flowering beginning (October). The growth and yield parameters of the intercropped crops maintain Table 4.

Table 4: Parameters and methods for the growth and yield analyses of the crops

Crops and parameters	Methods
Maize(*Zea mays*)	
Plant height (cm)	Carpenter’s rule
Leaf number per plant	detailed count
Maize ear number per m^2	detailed count
Row number per maize ear	detailed count
Grains per row	detailed count
Yield (kg ha^{-1})	electronic weight
Dry biomass (t ha^{-1})	electronic weight
Pumpkin (*Cucurbita maxima*)	
Fruit number / m^2	detailed count
Dry biomass (t ha^{-1})	electronic weight
Yield (kg ha^{-1})	electronic weight

Fríjol Escumite (*Phaseolus acutifolius*),	
Forage Chipilin (*Crotalaria spectabilis*),	
Cowpea (*Vigna unguiculata*),	
Chipilin (*Crotalaria longirostrata*),	
Plant height (cm)	Carpenter's rule
Plant number per m^2	detailed count
Pod number per plant	detailed count
Seed number per pod	detailed count
Yield (kg ha^{-1})	electronic weight
Dry biomass without generative parts (t ha^{-1})	electronic weight
Mango (*Mangifera indica*)	
Rambutan (*Nephelium lappaceum*)	
Panicles per tree	detailed count
Fruits per panicle	detailed count
Fruit weight (g)	electronic weight
Brix degree (%)	Refractometer
Yield (kg tree)	electronic weight

3.3.2 Soil fertility measurements and laboratory analyses

Soil samples were collected from the selected treatments and an adjacent mango traditional management site (black plot) on the two sampling dates, i.e. (i) May 2005, before planting maize and, (ii) November 2006, after harvesting field leguminous crops. In each subplot, two soil samples at depths of 0-10 and 10-30 cm were taken. The parameters analyzing soil fertility integrate chemical and biological indicators (Tab. 5)

Table 5: Parameters and methods for the analysis of soil fertility

Parameters	Methods
pH	1 N KCl (Richards, 1954)
E.C. (µS/cm)	Saturated paste extraction (Richards, 1954)
Organic matter (%)	(FAO, 1974; Walkley, 1974)
CIC	Index Cation Extraction (Richards, 1954)
Total nitrogen (%)	Kjeldahl-N (Bremner and Mulvaney, 1982; Buresh *et al*., 1982)
Phosphorus (mg P/100 g)	(Olsen *et al*., 1954)
Potassium (mval K/ 100g)	(Olsen and Sommers, 1982).
Calcium (mval Ca/ 100 g)	Index Cation Extraction (Richards, 1954)
Magnesium (mval Mg/ 100 g)	Index Cation Extraction (Richards, 1954)
Sodium (mval Na/ 100 g)	Index Cation Extraction (Richards, 1954)
Soil respiration (g Co_2 m^2 ha^{-1})	CIRAS-1 Portable Photosynthesis System (Soil respiration Chamber) (PP Systems, 2000)
Earthworm number / m^2	detailed count

3.3.3 Eco-Volume and Bio-Volume

Eco Volume (V_eco): Soil surface of given phytocenose or agricultural system multiplied by the eco-height. Eco-Volume normally to be expressed on ha basis. It is expressed in m^3 ha^{-1}.

Eco-height (H_eco): It is the average height of a plant community, across community components, weighed over time and relative abundance.

Bio-Volume (V_bio): Bio-volume, is the total volume of living plants (trees, bushes, herbaceous cover, etc) that occupy a certain space. The concept is based on the hypothesis that plants mainly compete for space. It is expressed in m^3 ha^{-1}. A very quick approach proposed by Janssens *et al.* (2006) was assumed: that a plant is an assembly of tubes and that all parts could be squeeze within a cylinder formed by: ***Vbio = Basal area x Heco***.

Crowding intensity (Ci) measures the colonized volume by a crop, weeds, trees, etc. ***Ci= Vbio/Veco***

Wesenberg factor (Wf): Is the opposite of the ***Ci. Wf= V_eco/V_bio = 1/Ci***

Volume efficiency (Ve): Relates the yield expressed in $US or energy with the lost Veco w.r.t. the maximal eco-volume at eco-climax in the same locality. It measures the efficiency in relation to the potential V_eco (V_pot). It is expressed in m^3 MJ^{-1} or m^3 $\$US^{-1}$.
Ve= (V_pot - V_eco)/Yield

The quality of eco-volume (V_{eco}) can be measured in the easiest way by estimating the total exposed plant bio-surface of the latter eco-volume of and by the annual production of litter fall, which in turn determines gross photosynthesis at equilibrium when multiplied by 4. Hence, Pb= 4 x Litter fall (Janssens *et al.*, 2004)

3.4 Statistical analysis

All data were tested for normal distribution. Taking succession as one factor and legume crops as a second factor (dry season scenario), analyses of variance (ANOVA) were performed and means separated with the LSD 0.05 statistics. All statistical analyses were implemented using the SPSS 11.0 and Statgraphics Version 5.1 packages.

3.5 Agricultural management of the fruit orchards and their intercropped systems

The cropping methods of each crop during the research include the customary regional tradition and on farmer's knowledge. The objectives of this integrated management were to reduce the agro-chemical inputs and to improve the diversity of flora and fauna. It encompasses the improvement of orchard profitability and of farmer's income. Moreover, this rich diversity of indigenous plants will enhance the quality of the farmer's diet. The agricultural management is as in Table 6.

Table 6: Characteristics and management of the intercropped crops in the fruit orchards

Crops	Agricultural management of each intercropped species
Maize only	Sowing: May Density: 0.70 x 0.40 m., 2 seeds per hole. Weed control: “Post-Emergence Gramocil” application 10 DBS {Paraquat (20%) + Diuron (10%)}, application rate 18 %, approx. 2 l / ha (180 ml / 20 l H_2O) Fertilization: First app. between 4 - 6 leafs per plant, watery solution 1.5 % (46-0-0). Second: Manual application, between 10-12 leafs per plant (17-17-17, aprox. 104 kg/ha). Plant bending (dobla): August Harvest: Maize ear harvest in July or Maize grains in November
Maize + Pumpkin	Sowing of maize : May Sowing of Pumpkin: 10 Days before maize sowing Density of maize: 0.70 x 0.40 m., 2 seed per hole. Density of pumpkin: 3 x 3 m., 4 seed per hole Weeds control: “Post-Emergence Gramocil” application 10 DBS {Paraquat (20%) + Diuron (10%)}, application rate 18 %, approx. 2 l / ha (180 ml / 20 l H_2O) Fertilization: Mineral application for both crops; 1^{o} app. 4 - 6 leafs per planta, watery solution 1.5 % (46-0-0). Second application between 10-12 leafs per plant (17-17-17, approx 104 kg/ha). Maize plant bending: August Maize harvest: Maize ear harvest in July or Maize grains in November Pumpkin harvest: Fruit harvest in July
Legumes *Phaseolus acutifolius* “Fríjol Escumite” *Crotalaria spectabilis* (forage Chipilin) *Crotalaria longirostrata* “Chipilin” *Vigna unguiculata* (Cowpea)	Sowing of legumes : August Density of Fríjol Escumite and Cowpea: 0.70 x 0.40 m., sowing between maize plants, with 4 seed per hole Density of forage Chipilin and Chipilin: 0.70 x 0.10 m. 1^{o} Weed control: “Post-Emergence Gramocil” application 5 DBS {Paraquat (20%) + Diuron (10%)}, application rate 18 %, approx. 2 l / ha (180 ml / 20 l H_2O) 2^{o} Weeds control: Mechanical weeds control 40 DAS Cowpea harvest: December Fríjol Escumite harvest: November Forage Chipilin harvest: February
Without legumes (only maize straw fallow)	Without agricultural management, only one chemical control with Gramocil. It is the traditional maize or “Milpa” management in the zone, which is called maize straw fallow.

DAS = Days After Sowing
DBS = Days Before Sowing

IV RESULTS AND DISCUSSION

4.1. Effects of the intercropping systems on the soil properties inside the fruits orchards

Tropical soil, being like all others the product of climate, parent material, and age, vary enormously in type and suitability for farming (Ruthenberg, 1980). By testing or analyzing a soil, - especially its acidity or alkalinity and its nutrient status -, one may obtain important information about its properties. These normally include pH, salinity, organic matter, CEC, calcium carbonate (CaCo3), macronutrients, micronutrients, and texture (Ryan *et al*., 2001).

The importance of cover crops for the nutrient cycle of the whole cropping systems depends on how many and how fast the nutrients are recycled. The magnitude of nutrient cycling is a function of (i) the biomass incorporation, (ii) the nutrients content, and (iii) the decomposition rate (Lehman *et al.,* 2000). Legumes generally have high foliar N content typically ranging from 20 to 45 mg g^{-1}. They are also rich in other nutrients like P, K and Ca (Szott, 1987). However, the leguminous intercrops may induce nutrient competition for other nutrients than N, which cannot be supplied by the legume as for P (Lehman *et al.,* 2000)

4.1.1. Effects of intercrops and cover crops on the soil fertility in the mango orchard

Soil resources include water and minerals, possibly oxygen in some cases (Greenwood, 1969). Water relations are especially interesting because water is a resource that carries all the other soil resources. It is thus in some sense quite basic (Kowal & Andrews, 1973). Generally, erosion risk and therefore soil nutrients and organic matter losses can be decreased through the permanent soil cover whereas soil humidity can be improved (Marroquín *et al.,* 2007; Lal *et al*., 1991). Effects of intercropping and cover crops on soil fertility are poorly documented for complex intercropped fruit systems (Lehman *et al.,* 2000).

4.1.1.1 Chemical properties of the soil

Soils are porous media created at the land surface by weathering processes derived from biological, geological, and hydrologic phenomena (Garrison, 1989). It is over 1000 years since the first farmer discovered the effect of the organic matter on the soil. Organic matter influences on some soil properties like structure, field capacity, content and availability nutrients, CEC, pH, and in the long-term on the texture (Benzig, 2001). The addition of a second crop to some monoculture has also a potential for improving the water environment through the reduction in evaporation in two ways. Firstly, if the soil is covered with vegetation, as is the case with cover crops, evaporation is likely to be reduced; secondly, if a windbreak is created, the input of advected energy is lowered, thus lowering evaporation. Either or both cases could operate in intercropping systems (Vandermeer, 1989).The cover plant may also have direct and indirect impact on the nutrient transformations through the change of the microclimate. In consequence, cover crops may decrease nutrient mineralization in comparison to bare soil (Watson, 1989b).

Results of soil parameters in the mango orchard confirm that the intercrops provoke long-time effects on the soil fertility. Nevertheless, such effects can only be observed in depth of 0-10 cm (Tab. A-3), whereas in deeper depth like 10-30 cm (Tab. 2 and A-3) the intercropping effects are not clearly expressed in the second year of this investigation.

Results of soil fertility at a depth from 0-10 cm in mango orchard demonstrate, that pH value in the maize x pumpkin intercropped plots is lower than that in sole maize systems suggesting a more active growth, and hence respiration both above and below ground level (Tab. 7). The scenario with *V. unguiculata* presented the lowest acidity in both rotation systems (Tab.

7). However, the scenario with *P. acutifolius* in the intercropped system and the maize straw fallow plot in sole maize system shown highest acidity (pH 5.31 and 5.52) (Tab. 7). The black plot rotation was slightly more acid than that of *V. unguiculata* plots. Nevertheless, the black plot was less acid than the maize straw fallow, *P. acutifolius* and *C. spectabilis* plots (Tab. 7). The cation uptake by the intercrops contributed to the soil acidity dynamics. For that reason, the productivity in the plot with *V. unguiculata* (pumpkin yield 6.44 t ha^{-1}, mango yield 9.60 t ha^{-1}) strongly contributed to overall soil acidity. Likewise, the pH value in the *V. unguiculata* and maize straw fallow plots are positively correlated with high C/N ratio (Tab. 7) and negatively with total biomass production and, hence respiration (Chapter 4.5.1). Similar results were found by Benzig (2001), confirming that the nutrient uptake of the crops will contribute to the reducing of the cation content in the soil. Other authors report that the legume crops may improve the N content of an associated crop, but results can be completely different for other nutrients, such as P, Ca, and K (Lehmann *et al*., 2000; Canto, 1989).

The organic residues serve mainly as source of nitrogen, but may also contribute significantly as source for other essential nutrients. The incorporation of such residues in the production systems is an attractive alternative to improve yield (Marroquín *et al*., 2007; Pohlan *et al.,* 2006; Ayuke *et al.,* 2004). The actual measurement of organic mater is the oxidizable organic carbon. The carbon data are normally converted to organic matter (OM) using a constant factor; assuming that OM contains 58% organic carbon. However, as this portion is not constant, we prefer to report the results as total organic carbon (i.e. oxydizable carbon multiplied by 1.334) (Ryan, 2001). Plots with *P. acutifolius* presented the highest amount of soil organic carbon in both systems (Fig. 8). Similar results are recorded in the black plot and maize straw fallow plot, where the organic carbon was 3.16 and 3.06 % respectively (Fig. 8). Opposite cases are found in plots with *V. unguiculata* and *C. spectabilis,* which provided the lowest soil organic matter in both systems (Fig. 8). The results of total organic carbon (TOC) in the maize x pumpkin intercropped systems were higher that in the sole maize system. The C/N ratio in the plots with *P. acutifolius* (13 and 12) and maize straw fallow (11.25 and 11.29) contributed to the TOC contents (Tab. 7 and A-3). Likewise, the plots with *P. acutifolius* and maize straw fallow produced high maize/legume biomass ratios, induced by differential soil mineralization (Chapter 4.5.1). To the contrary, the *C. spectabilis* and *V. unguiculata* plots produced lower maize/legume biomass ratio than the other plots (Chapter 4.5.1).

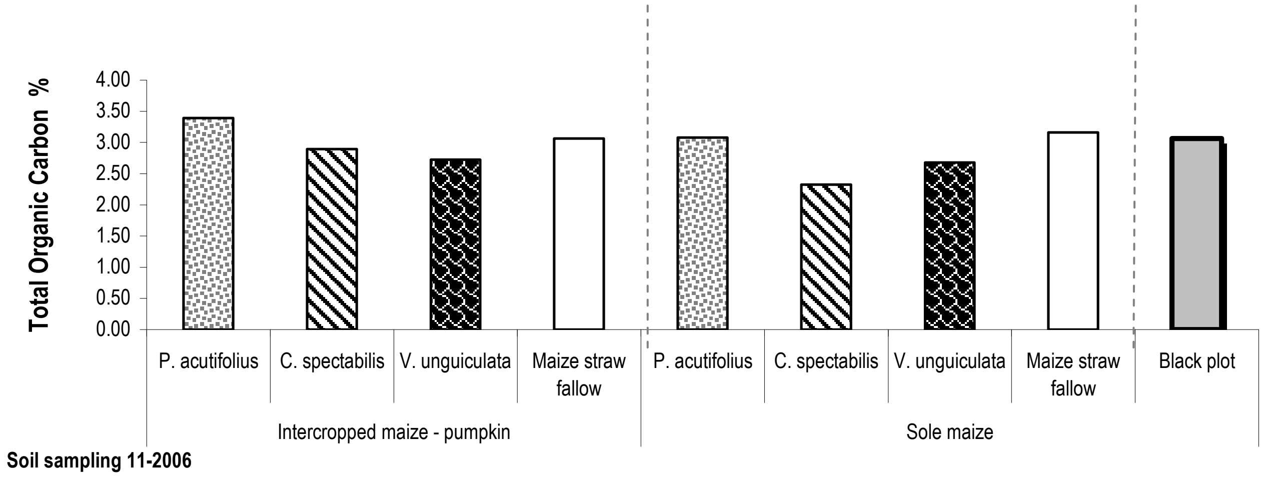


Figure 8: Effects of intercrops on the soil TOC in depth of 0-10 cm in the mango orchard.

Similarly, the capacity of any agro-ecosystems to enhance nutrient cycling is reported to depend both on soil conditions and on management factors (Ayuke *et al.,* 2004). Likewise, Lehmann *et al.* (2000), report that the cycling of nutrients depends on the rate of litter decomposition and nutrient release. Due to the high contents and the low C-to-N ratio, litter decay is usually very rapid. However, Tian *et al.* (1999) reported a lower soil matter decline with a *Pueraria* spp. simultaneous cropping systems that with conventional cropping in Nigeria. The reason for the frequently lacking effect on soil organic matter contents is the high quality of the plant material with high N, low C-to-N and polyphenol-to-N ratios (Lehmann *et al*., 1999) Certain organic compounds also contribute to cation exchange capacity (CEC). Additionally, CEC is influenced by soil pH. A certain portion of the total negative charge is permanent, while a variable portion is pH-dependent (Ryan, 2001). According to Kass (1978) it can generally be concluded from the small number of experiments in which measurements were taken, that crop mixtures will contain greater amounts of P, K, Ca and Mg than pure stands of the component crops grown under the same conditions.

The CEC in a mango orchard follows the same principles as above mentioned. The CEC in the leguminous plot was higher than in the control plots (maize straw fallow and black plots). The leguminous effects on the CEC were present in both systems (Fig. 9). The CEC is strongly influenced by Ca and Mg content. The Ca and Mg contents in the leguminous plots were also higher than in the maize/straw fallow plot and black plot (Tab. 7). The dynamics of cations (Ca and Mg) is based on the relation of biomass production and maize yield. The leguminous plots produced lower maize yield than the maize/straw plots. Likewise, the leguminous plots incorporated higher dry biomass than the maize/straw fallow plots. According to Violic (2001), the maize plant requires 7.5 kg Ca and 5 kg Mg to produce 2.5 t ha^{-1} of maize (1 t grain + 1.5 t dry biomass). Low soil fertility has been attributed to low organic matter, intensive erosion and successive crop harvests (Marroquín *et al*., 2004; Gachene *et al.,* 1997; Palm *et al.,* 1997; Pfeiffer, 1990).

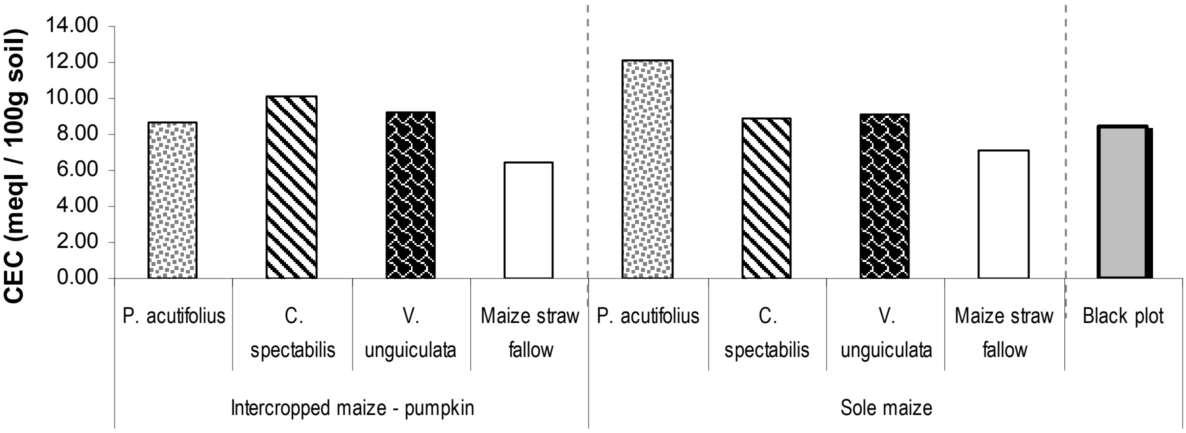


Figure 9: Effects of intercrops on the soil CEC at a depth of 0-10 cm in mango orchard.

While such an assumption was certainly unwarranted, it however led to several experiments, most of which demonstrated the same thing: the legume apparently does transfer nitrogen from the air to the agro-ecosystem (Clark & Francis, 1985; Kass, 1978, Andrew, 1978). The nitrogen results in the mango orchard also confirm the aforementioned reference. Nevertheless, the values of plots with legume rotation present lower nitrogen than the maize/straw fallow and black plots in both systems. The plots with leguminous crops present the lowest nitrogen content in the mango orchard (Fig. 10). This surprising N reduction in all legume scenarios is present in both rotation systems 3 and 4 (Fig. 10), although more pronounced in the former one. It demonstrates that most of the available N has been exported out of the orchard through the harvested products. On acid soils, the nodulation will strongly depend on the soil Ca, Mo and Al contents (Andrew, 1978). Surprisingly, no active nodules were observed in none of the leguminous crops. The nitrogen content of the leguminous plots is very similar in both evaluated systems, ranging from 0.22 to 0.26% (Fig. 10). Often, total soil N content may not be increased by legume cover, although N availability may well be improved (Lehmann *et al.,* 2000). Interesting is the N content of black plot, which presents the highest total N in the mango orchard. The low N content of the legume plots can be caused by the N uptake of maize and pumpkin components. Likewise, the biomass quality is also an important factor that influences the N content. The leguminous crops present different compositions of nutrient, lignin and polyphenol. In contrast to our results an improvement of soil N content has been frequently observed in systems with cover crops (Lal *et al*., 1979; Watson *et al*., 1964). The amount of active nodules may explain these seemingly contradictory results. Nevertheless, our results share the soil fertility paradigm of Sanchez (1994), contending that there is a need for both mineral and organic inputs to sustain crop production.

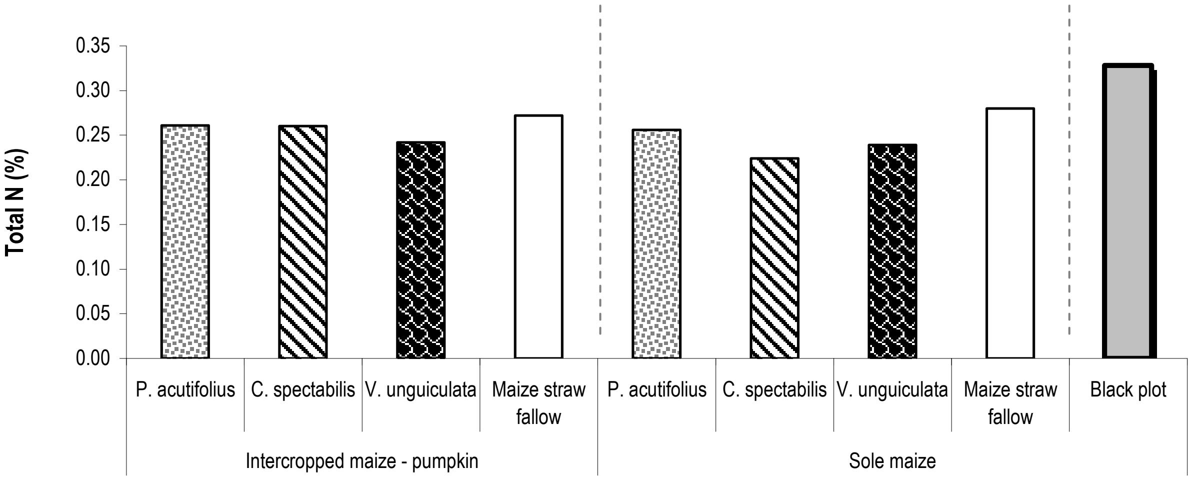


Figure 10: Effects of intercrops on the soil N in depth of 0-10 cm in the mango orchard.

The general P transformation processes are the combination of weathering and precipitation, mineralization and immobilization, and otherwise adsorption and desorption. Weathering, mineralization and desorption increase plant available P. Immobilization, precipitation and adsorption decrease plant available P. Mineralization is the microbial conversion of organic P to H_2PO_4 forms of plant available P known as orthophosphates (Hyland *et al*., 2005). Nevertheless, the P compounds in soils are highly variable and related to soil type and/or parental material (Ryan, 2001).

The total P results in the mango orchard confirm that biomass adds P to the whole system (Hyland *et al*., 2005; Benzig, 2001; Kass, 1978). The treatments with legume rotation add high P amount into the systems. The P content in the leguminous plots are higher than in the maize/straw fallow plots. This P dominance of the leguminous plots is present in both intercropped systems and maize monoculture (Fig. 11). However, the content of P of the leguminous plots in sole maize systems is higher that in the maize x pumpkin intercropped systems (Fig. 11). The P uptake by the biomass production and yield of *C. spectabilis* and *V. unguiculata* decreases soil P. Opposite cases are found in scenarios with *P. acutifolius*, whereby climate conditions (excessive precipitations) prevented good grain yield so that total biomass was quickly incorporated back into the orchard system.
Interesting is the P content in the traditional black plot system, which offers the highest P content (70.45 mg/100 g) (Fig. 11). The higher biomass in the legume plots contributes to increase the P

content. Indeed, leguminous crops are known for their efficient assimilation of P. The lack of soil cover in the maize/straw fallow plots contributes to a rise in soil temperature and evaporation. In the maize/straw fallow plot one could notice a high nutrients uptake (maize) and a low biomass recycling. In the neighbouring mango monoculture, P uptake is lower than in the intercropped system. For that reason the traditional systems leaves more P in the soil. It also demonstrates the influence of pH on P content. Hyland *et al.* (2005) report that at higher pH, could precipitate P with Ca; at lower pH, P tends to be adsorbed to Fe and Al compounds in the soil.

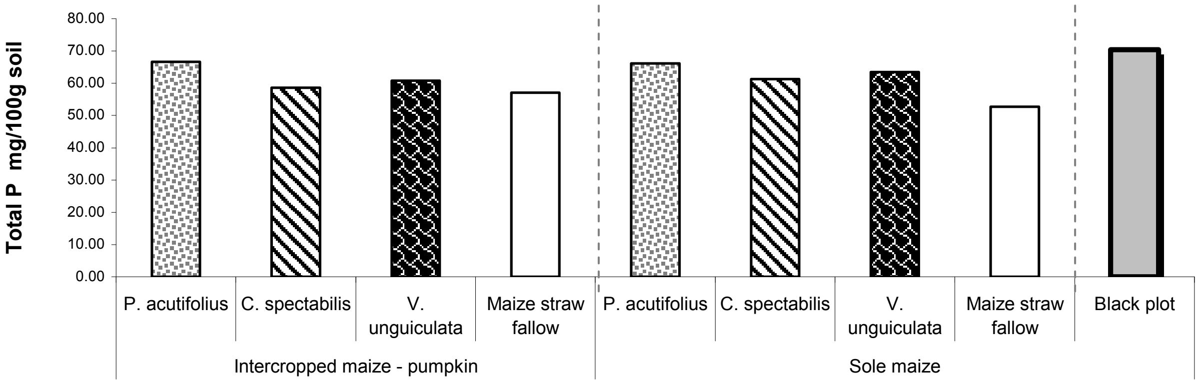


Figure 11: Effects of intercrops on the soil P at a depth of 0-10 cm in the mango orchard.

The K content in the mango orchard does not concur with the dynamics of CEC. The soil K content in the maize x pumpkin intercropped system is higher than in the monoculture (sole maize), where the scenario with *V. unguiculata* exhibits the highest K content in both evaluated systems. To the contrary, the *P. acutifolius* scenarios offer the lowest K content (Tab. 7).

Table 7: Effects of intercropping systems on the soil parameters in the mango orchard

Intercrops	Rotation	Depth (cm)	Soil parameters in depth of 0-10 cm in the second sampling (11.2006)					
			pH	C/N	K (meq/100g)	Ca (meq/100g)	Mg (meq/100g)	Na (meq/100g)
Intercropped maize - pumpkin	*P. acutifolius*	0-10	5.31	13.00	0.36	6.85	1.31	0.09
	C. spectabilis	0-10	5.47	11.12	0.49	7.96	1.52	0.11
	V. unguiculata	0-10	5.75	11.26	0.59	7.01	1.58	0.08
	Maize straw fallow	0-10	5.56	11.25	0.39	4.96	1.05	0.09
Sole maize	*P. acutifolius*	0-10	5.78	12.02	0.37	9.69	1.98	0.08
	C. spectabilis	0-10	5.58	10.38	0.43	7.01	1.41	0.08
	V. unguiculata	0-10	5.85	11.22	0.46	6.85	1.72	0.09
	Maize straw fallow	0-10	5.52	11.29	0.45	5.35	1.19	0.08
Black plot		0-10	5.75	9.34	0.36	6.54	1.43	0.09

The maize straw fallow and black plot present similar K content, but K concentrations of the control plots in the sole maize system are higher than in the leguminous plots (Tab. 7).

The K nutrient is one of the primary macronutrients required by the plant. The maize crop requires approximately 40 N, 9 P, 33 K, 7.5 Ca, and 5.0 kg Mg to produce 1 t ha^{-1} of maize grain, in tropical area according to Skora Neto (1993). It demonstrates that K uptake by crops like maize and pumpkin (see Chapter 4.4.1) and the proportion of cations in the soil behaviour are the principal factor of the K dynamics.

4.1.1.2. Biological properties of the soil

Soil respiration, a common measure of soil biological activity, represents the amount of CO_2 evolving from roots, soil microbes, and to a lesser extent by oxidation of root exudates, plant detritus, and humified organic matter (Raich and Schlesinger, 1992). Organic matter in detritus and mineral soil organic matter, collectively referred to here as SOM, is the major reservoir of carbon in terrestrial ecosystems, storing some 1500 Pg (1 Pg = 10^{15}g) of carbon in the upper meter of mineral soils (Jobbágy and Jacksonn, 2000). This is slightly more than twice the amount of carbon present in the atmosphere as CO_2.

Soil respiration is a major pathway for carbon cycling in terrestrial ecosystems. Yet little is known about its response to natural and anthropogenic disturbances (Concilio *et al*., 2006). Soils are major carbon pools (Schlesinger, 1995) and management strategies that maximize soil carbon sequestration may help offset predicted increase in atmospheric CO_2 (Chen *et al*., 2004). The majority of previous studies have focused on soil carbon cycling in undisturbed systems. Due to the thorough modification of our current landscapes by natural and/or anthropogenic disturbances, it is crucial that we understand the consequences on carbon cycling both under undisturbed environments and in disturbed production systems.

A limited number of studies have examined the effects of thinning (e.g., Scott *et al*., 2004; Kowalski *et al*., 2003; Gordon *et al*., 1987) and burning (e.g., Hubbard *et al*., 2004; Litton *et al*., 2003; Pietikäinen and Fritze, 1993; Weber, 1985) on soil respiration rate (SRR) in forest ecosystems. However, few have measured SRR in perennial and annual ecosystems to follow the temporal changes and spatial variability (i.e. due to climate, crop managements, soils, etc.).

Results of mango orchard indicate that soil respiration is completely different in all scenarios at the beginning of the experiment. It signifies that soil CO_2 concentration is dynamic over time and space. In the last sampling (September-06), soil respiration of the sole maize scenario is higher than for the maize x pumpkin intercrop scenarios (Fig. 12). Rotation systems with sole maize and *P. acutifolius* (Fríjol Escumite) produce highest CO_2 (9.10 g CO_2 m^{-2} h^{-1}), whereas intercropped maize x pumpkin and maize/straw fallow present lowest CO_2 values (5.18 g CO_2 m^{-2} h^{-1}). The CO2 values of the scenarios with legume rotation in maize x pumpkin intercropped system range from 3.55 (June 2005) to 7.62 g CO_2 m^{-2} h^{-1} (September 2006). Leguminous plots in the sole maize system range from 7.55 to 8.73 g CO_2 m^{-2} h^{-1} (Fig. 12). Adverse soil respiration tendencies are found in the fields with maize/straw fallow; which decreased from an initial 8.60 to a final 3.18 g CO_2 m^{-2} h^{-1} (Fig. 12). Thus, CO_2 curve in the legume scenarios present an increased tendency over time as opposed to maize/straw fallow plots.

The soil humidity conservation by cover crops like pumpkin and legume crops maintains a slightly increased of soil respiration over time, whereas in the system without cover crops like maize straw fallow, the soil respiration is very unstable and quickly regresses. Results of this study show the dependence of macro- and micro-organisms from the soil humidity. According to Trumbore (2000), soil C stores are predicted to respond to climatic change because organic matter decomposition rates are linked to soil temperature and moisture regimes. Nevertheless, the changes in C storage occur not only in upper soil layers, but also at lower depth (Jackson *et al*., 2000).

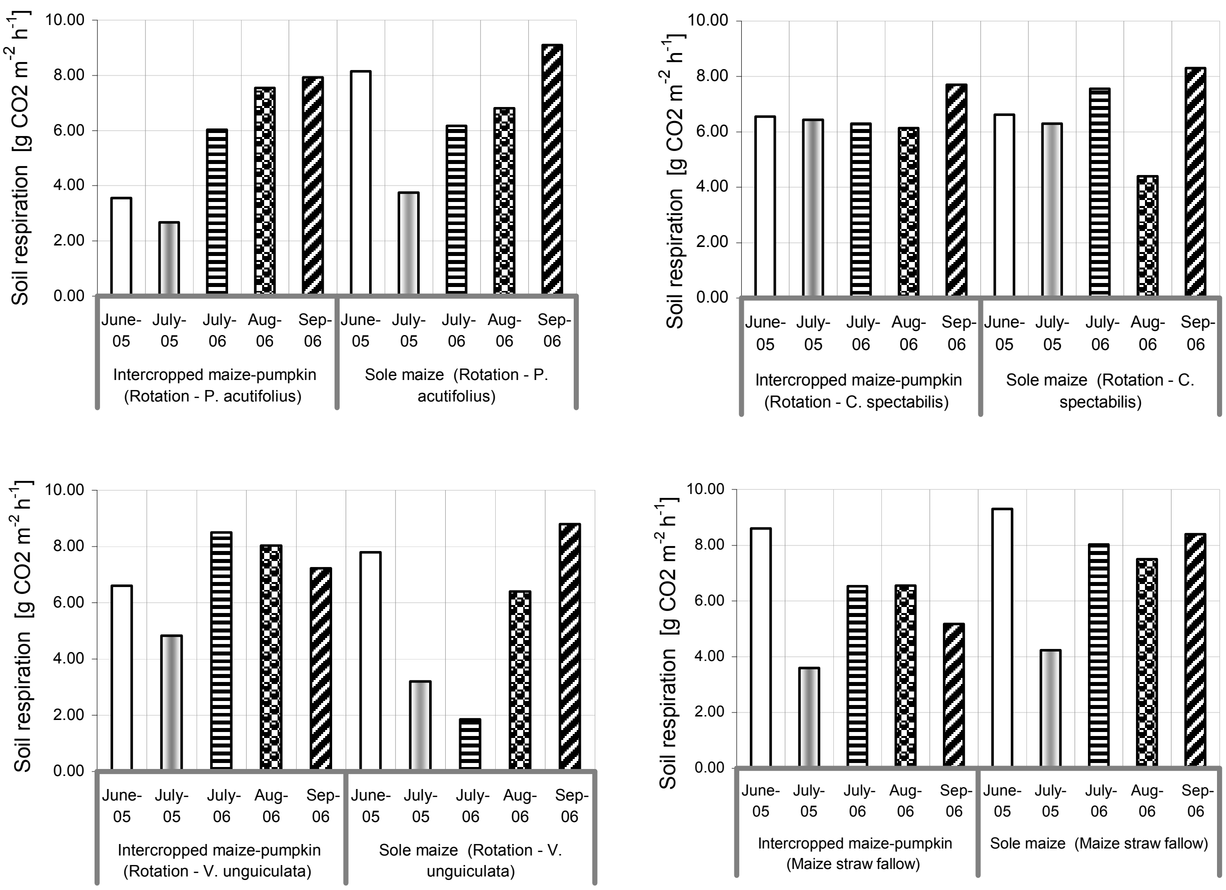


Figure 12: Effects of intercropping systems on soil respiration in the mango orchard.

These CO_2 results demonstrate that the effects of intercrop management and organic matter on the soil respiration or on the soil microbial biomass can be more clearly expressed and quantified in the long-term. Biomass incorporation has favourably influenced soil microbial biomass C and N in agreement with other reports (Goladi & Agbenin, 1997; Goyal *et al*., 1992; McGrill *et al*., 1986). The positive effects of organic matter on soil microbial biomass are corroborated as in the case of soil respiration of leguminous scenarios. According to other authors, legume-based crop rotation is also essential in sustaining the N content of the soil. These improvements can have favourable influences on soil microbial properties and crop yield (Belay *et al*., 2001; Ketcheson and Beauchamp, 1978).

4.1.2. Effects of intercrops and cover crops on soil fertility in the rambutan orchard

Intensive cultivation and cropping may have negative effects on the chemical, physical, and biological properties of the soil, due to the induction of changes in temperature, water and aeration fluxes, decreasing organic matter content and increasing aggregate disruption and soil erosion (Migliena *et al.,* 1988). The organic matter and its management play an important role in maintaining physical, chemical and biological properties of the soil, and therefore on the crop productivity (Ayuke *et al.,* 2004; Micheni *et al*., 2004)

4.1.2.1 Chemical properties of the soil

Soils are multi-components, open and biological systems containing solids, liquids, and gases from the point of view of chemistry. The organic matter is itself an important constituent of solid portion of soils (Garrison, 1989).

Results of the pH in rambutan orchard are irregular in each rotation system (Tab. 8). In the intercropped system, the pH values are higher than in the sole maize system, with the exception of the plot with *C. spectabilis*, which presents higher pH value in the sole maize system (4.85 versus 5.01). The lowest pH value is found in the plot with *C. longirostrata* in the sole maize system, whereas, the plot with *C. spectabilis* produces the lowest pH value in the maize x pumpkin intercropped system (Tab. 8). However, the maize straw fallow plot offers the highest pH value in all experiment (Tab. 8). Comparison between black plot and all evaluated plots, it indicates that the black plot presents the second highest pH value after *V. unguiculata* (Tab. 7). The biomass production and the K, Ca, and Mg uptake by the crops are influencing the pH dynamics. The plot with *V. unguiculata* produces high biomass and low pumpkin and maize yield in the intercropped systems, whereas the plot with *C. spectabilis* in sole maize systems produces higher biomass and higher pumpkin and rambutan yield.

Soil organic matter serves as indispensable source of plant nutrients and enhances soil biological, chemical, and physical properties (Mokwunye *et al.,* 1996). The amount of organic matter in the soil is dependent on the annual inputs of organic materials and the rate of decomposition, the later being the highest in hot, humid climatic regions (Rowel, 1994; De Ridder and Van Keulen, 1990). Plant residues are the main source of soil organic matter, while animal remains and their wastes are secondary sources (Rowell, 1994). In the rambutan research, the legume biomass is reflected on the total organic carbon (Fig. 13).

The total organic carbon (TOC) in the legume plots is higher that in the maize straw fallow and black plots. The effects of the leguminous species are present in both systems. The plot with maize straw fallow produces the lowest content of organic carbon in both systems (Fig. 13). Likewise, the organic carbon content in the black plot is slightly higher than in the maize/straw fallow plot. Micheni *et al.* (2004) also reports that soil organic matter (MO) is dependent on the annual inputs of organic materials. In both systems, the rotation with *V. unguiculata*, *C. spectabilis* (Chipilin) and *C. longirostrata* produces the highest carbon content (Fig. 13). Biomass production (see Chapter 4.5.2) (*V. unguiculata* 10.72 t ha^{-1}, *C. spectabilis* 13.34 t ha^{-1} and *C. longirostrata* 7.71 t ha^{-1}) in this study is the principal provider of TOC. For that reason, leguminous plots produce higher TOC, whereas the maize/straw fallow and black plots present the lowest content of TOC. Several studies have shown that crops residues can also be used as a source of nutrients to the next crops (ICRAF, 1997; Niang *et al.,* 1996; Palm, 1996).

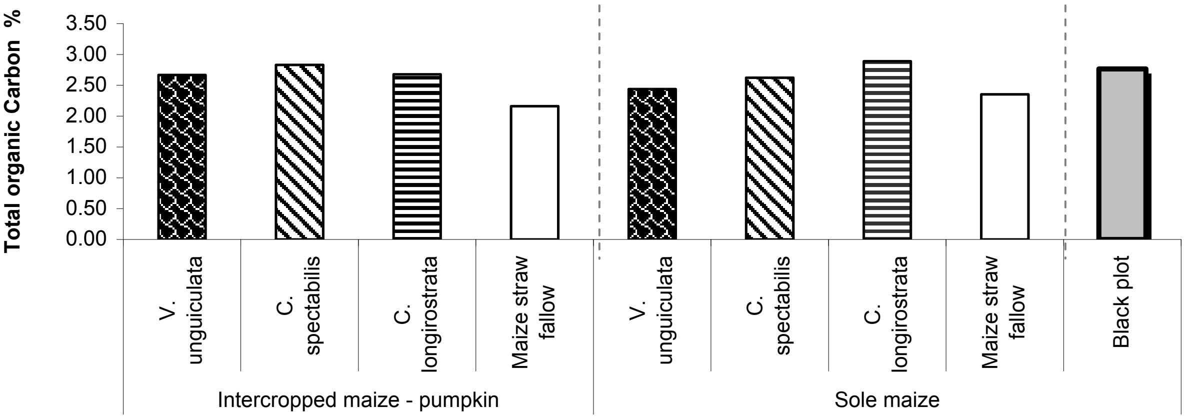


Figure 13: Effects of intercrops on the TOC at a soil depth of 0-10 cm in rambutan orchard.

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Although legumes may improve N nutrition of an associated crop, results can be completely different for other nutrients, such as P, Ca, or K. The intercrop has a very high nutrient uptake, and therefore nutrient competition occurs specially at crop establishment (Lehmann *et al.,* 2000; Broughton, 1976). Comparable results are found in the cation exchange capacity (CEC) in the rambutan orchard, where the maize x pumpkin intercrop systems present lower CEC than the sole maize system, while the black plot produces the highest CEC (Fig. 14).

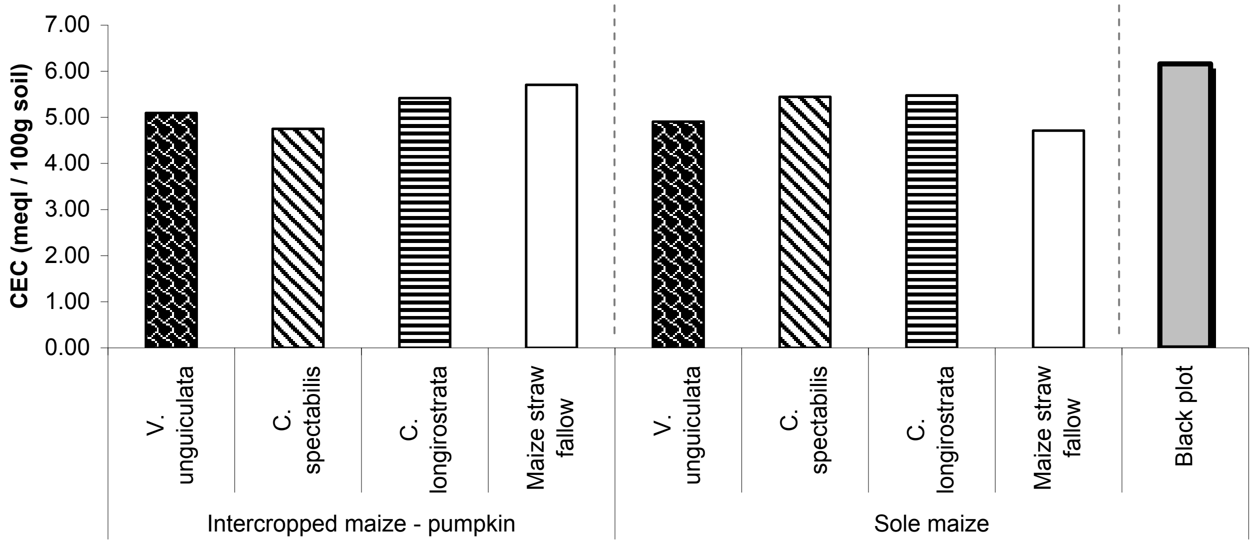
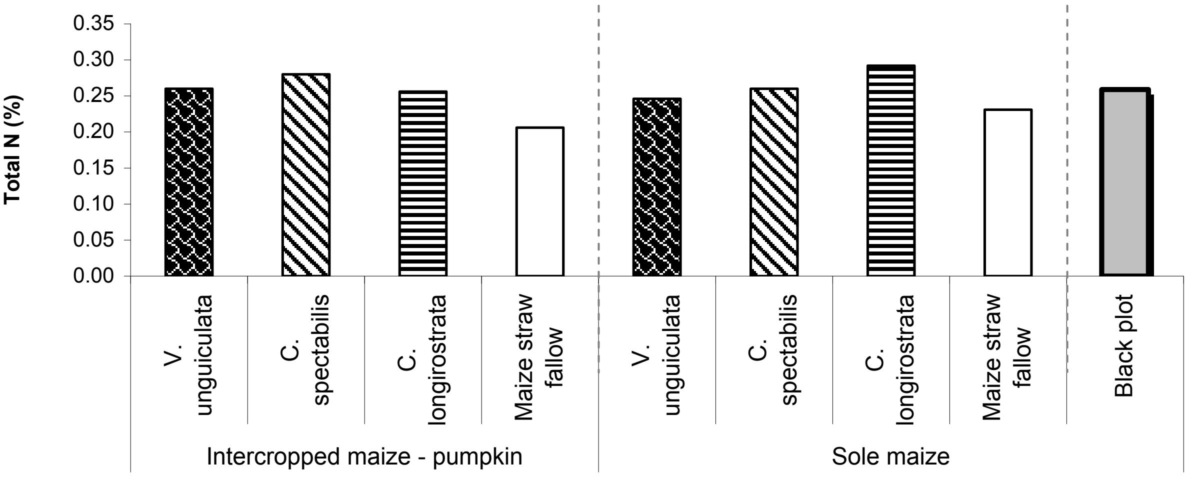


Figure 14: Effects of intercrops on the CEC at a soil depth of 0-10 cm the rambutan orchard

CEC is highest in the maize x pumpkin intercropped systems as compared to the maize/straw fallow (Fig. 14). However, the plot with *C. spectabilis* and *C. longirostrata* obtains similar results in both systems. The Ca and Mg contents are closely related the CEC, being the main contributors. High CEC of black plot is due to the lower Ca and Mg uptake by only one crop (Rambutan).

In the rambutan orchard, the total nitrogen (N) has a similar pattern to the total organic carbon. The plots with leguminous rotation present the highest nitrogen content (Fig. 15). The Chipilin (*Crotalaria* spp) plots contribute strongly to the nitrogen content in both systems. Biological N fixation and biomass incorporation are the determining factors for total N content in the soils of the leguminous plots. These results support the hypothesis that legume crops incorporate N in the production system by N fixation (Vandermeer, 1989; NAS, 1979). Contrary to the mango orchard, legumes were actively nodulating in the rambutan orchard.

The maize/straw fallow plots report the lowest N content. Again, the black plot produces higher N than the maize straw fallow plots (Fig. 15). Effects of the leguminous rotation on the soil N in intercropped maize x pumpkin and sole maize are very similar. It demonstrates that the intercropped maize x pumpkin does not the soil N level. Nevertheless, the magnitude of biological N fixation of legumes is highly variable and depends on several factors, such as plant species, inoculation, soil nitrate and water contents (Giller & Wilson, 1991). Similar results were found by Broughton (1977), where mixtures of crops containing *Pueraria* had an annual leaf litter return of 150 kg N ha^{-1} compared to only 44 kg N ha^{-1} for rubber stands. Those results demonstrate the importance of cover crops for the nutrient cycling in fruits plantation (Watson, 1989b)



Soil sampling 11-2006

Figure 15: Effects of intercrops on the soil N at a soil depth of 0-10 cm in rambutan orchard:

Soils contain naturally P-rich minerals, which are weathered over long periods and slowly made available to plants (Hyland *et al.,* 2005). One goal with crop management is to optimize crop P uptake. A typical corn silage crop will remove about 4.3 lbs of P_2O_5 per ton (35% dry matter).

In both intercrop and monoculture systems, the highest P amount is found in the plot with *C. longirostrata (68.30* mg/100g), followed by the plot with *C. spectabilis*. The P export through maize grain yield decreases P content in the plot with *V. unguiculata*. The leguminous scenarios dominated over the other plots. Nevertheless, the plot with maize/straw fallow (54.33 mg/100g) presents the lowest P values. The high biomass incorporation in the leguminous plots increases the P content. Moreover, legumes are known to extract soil P more efficiently. A clear example of the soil degradation by harvest nutrients output and low organic matter incorporation is demonstrated in the black and maize/straw fallow plots. Even with the maize x pumpkin intercrop system (Chapter 4.4.3), this scenario presented similar P content when compared to the sole maize system, even with the extra P removal through pumpkin yield. It indicates that the pumpkin cover induces interesting effects on the soil fertility and nutrient availability. According to Hyland *et al*. (2005), the temperatures between 65 and 105 ^{0}F favour P mineralization.

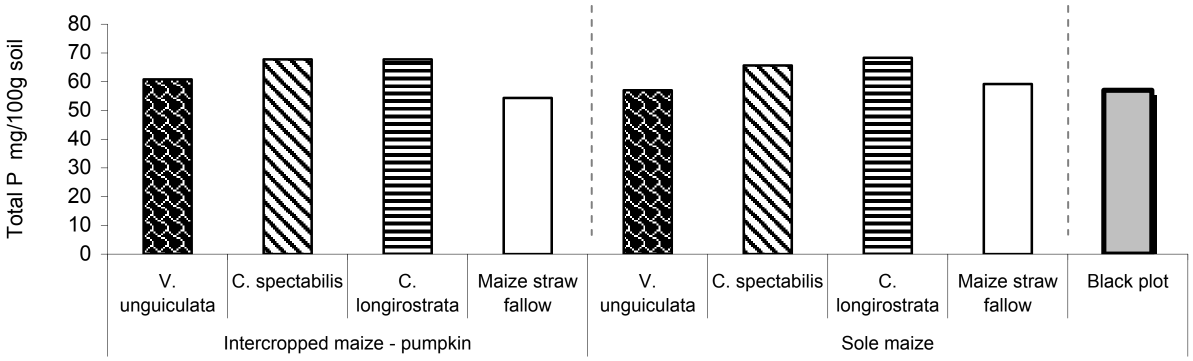


Figure 16: Effects of intercrops on the soil P at a depth of 0-10 cm in the rambutan orchard:

The leguminous scenarios show higher K content than the maize/straw fallow and black plots. In the maize x pumpkin intercropped system, the K content is higher than in the sole maize plots. In the intercropped system, the K content of the plot with *V. unguiculata* is two times higher than that in sole maize system. The highest K content is found in the plot with *V. unguiculata* (0.76 meq/100g) and the lowest K content (0.26 meq/100g) in the maize straw fallow plot (Tab. 8).

Table 8: Effects of intercropping systems on the soil parameters in the rambutan orchard

Intercrops	Rotation	Depth (cm)	Soil parameters in depth of 0-10 cm in the second sampling (11.2006)					
			pH	C/N	K (meq/100g)	Ca (meq/100g)	Mg (meq/100g)	Na (meq/100g)
Intercropped maize - pumpkin	*V. unguiculata*	0-10	5.16	10.25	0.76	3.77	0.79	0.07
	C. spectabilis	0-10	4.85	10.11	0.34	3.70	0.65	0.06
	C. longirostrata	0-10	5.01	10.46	0.54	4.01	0.79	0.08
	Maize straw fallow	0-10	5.20	10.50	0.26	4.41	0.95	0.09
Sole maize	*V. unguiculata*	0-10	4.94	9.91	0.33	3.62	0.89	0.07
	C. spectabilis	0-10	5.01	1.09	0.42	4.01	0.95	0.07
	C. longirostrata	0-10	4.82	9.90	0.32	4.25	0.83	0.08
	Maize straw fallow	0-10	4.86	10.19	0.26	3.70	0.67	0.08
Black plot		0-10	5.05	10.68	0.31	4.80	0.97	0.08

According to other authors, green manure cover crops have several advantages, among them, regulating soil surface temperatures, increasing soil organic matter, controlling soil erosion and contributing significantly to other essential nutrients like P, K, and Mg (Jeranyama *et al.,* 2000; Lehmann *et al.,* 2000; Vandermeer, 1999; Gachene *et al.,* 1997). Likewise, legume intercrops are included in cropping systems because they improve the soil fertility (Marroquín e*t al.,* 2007), suppress weeds (Pohlan, 1997; Exner and Cruse, 1993), fix biological N (Giller *et al*., 1994) and provide food for humans and for livestock (Wadington and Heisey, 1997).

4.1.2.2 Biological properties of the soil

Globally, each year, forest and savannas alone contribute about 42 Pg of C, while temperate grasslands, tundra, desert, cultivated and other ecosystem contribute only 18 Pg C to the total emissions of about 60 Pg C of respiration (both of vegetation and microbial decomposition of organic matter estimates vary from 60-75 Pg C) (Grace and Rayment, 2000).

Long-term effects of a management system on soil quality can be evaluated by using biological attributes such as total organic C and soil fauna and flora, as these characteristics are sensitive and respond to both natural and human induced changes (Gregorich *et al.,* 1997). The microbial biomass, being an agent of biological processes and pool of labile nutrients, is especially important in determining the quality and health of the soil (Fernandes *et al.,* 1997; Kennedy & Pependick, 1995). It is therefore, regarded as a good indicator of soil changes (Gregorich *et al.,* 1997). Intercrops are known to influence the biological properties of soils in a beneficial way (Belay *et al.,* 2001; Karlen *et al.,* 1994; Fyson & Oaks, 1990). Thereby, the current emphasis on low-chemical-input, sustainable systems has led to a renewed interest in adopting old farming practices such as intercrop, crop rotation, and use of manure as organic fertilizer.

Cover crop effects on soil microbiology can be observed in the rambutan intercropped orchard. The population of earthworms in the maize x pumpkin intercropped system is higher than in sole maize system (Fig. 17). The intercrops provoke a closer soil cover; therefore, the evaporation and soil temperature are decreased. Reverse cases are presented in the sole maize system and *V. unguiculata* plots. The complete absence of earthworms in all *V. unguiculata* plots is very interesting, but it was not possible to detect the cause. According to other authors, among various factors, land use, management practices, and environmental conditions, in particular soil temperature and moisture, are more important than the influence soil organisms (Frank *et al.,* 2006; Raich and Tufekcioglu, 2000)

Figure 17: Effects of intercropping systems on the earthworm in the rambutan orchard

The permanent soil covers through the successive planting of *Cucurbita maxima* and later of *C. spectabilis* or *C. longirostrata*, help producing high earthworm populations (Fig. 17). Likewise, the soil cover of *Ipomoea* spp weeds in the maize/straw fallow plot maintained soil humidity, which is necessary for reproduction of earthworm populations (26 ind. per m^{-2}). The high drought in the plots with sole maize may have decreased the earthworm populations (Fig. 17).

Soil respiration is related to many ecological processes, such as photosynthesis, root respiration, organic matter decomposition, and microbiological activity (Högberg *et al.*, 2001; Lomander *et al.*, 1998; Mallik and Hu, 1997; Sørensen, 1974).

The soil respiration in the rambutan orchard is very different from that in the mango orchard (Fig. 12). The CO_2 values in the maize- pumpkin intercropped system are similar to that in the sole maize system. The soil respiration in all plots had a slightly increasing tendency in the sole maize systems and a slow decrease over time in the maize- pumpkin intercropped system (Fig. 18). In the maize straw fallow plots, the soil respiration has a slightly increase in both systems over time. The soil respiration in the plots with chipilin species is very different, indicating that the biomass and the antagonisms of the *Crotalaria* sp. influence soil respiration. The *Crotalaria* spp during the growth produce plant – insect antagonism. For that reason, the insects do not visit the plants, but during the flowering period, a rich insect diversity has been recorded. In this case, chipilin species could also generate below-ground antagonism. According to Concilio (2006), soil respiration rate (SRR) response to disturbance varied with patch type, year, and treatment type. These processes are interrelated and affected by multiple biophysical factors in an ecosystem (Siyan *et al.*, 2005). Soil respiration is also associated with physical CO_2 diffusion processes affected by physical properties of soil and litter. Nevertheless, most research on soil respiration has focussed on closed forest systems (e.g. Giardiana and Ryan, 2000; Valentini *et al.*, 2000; Boone *et al.*, 1998; Bowden *et al.*, 1993) with little relevance for open tropical agro-ecosystems.

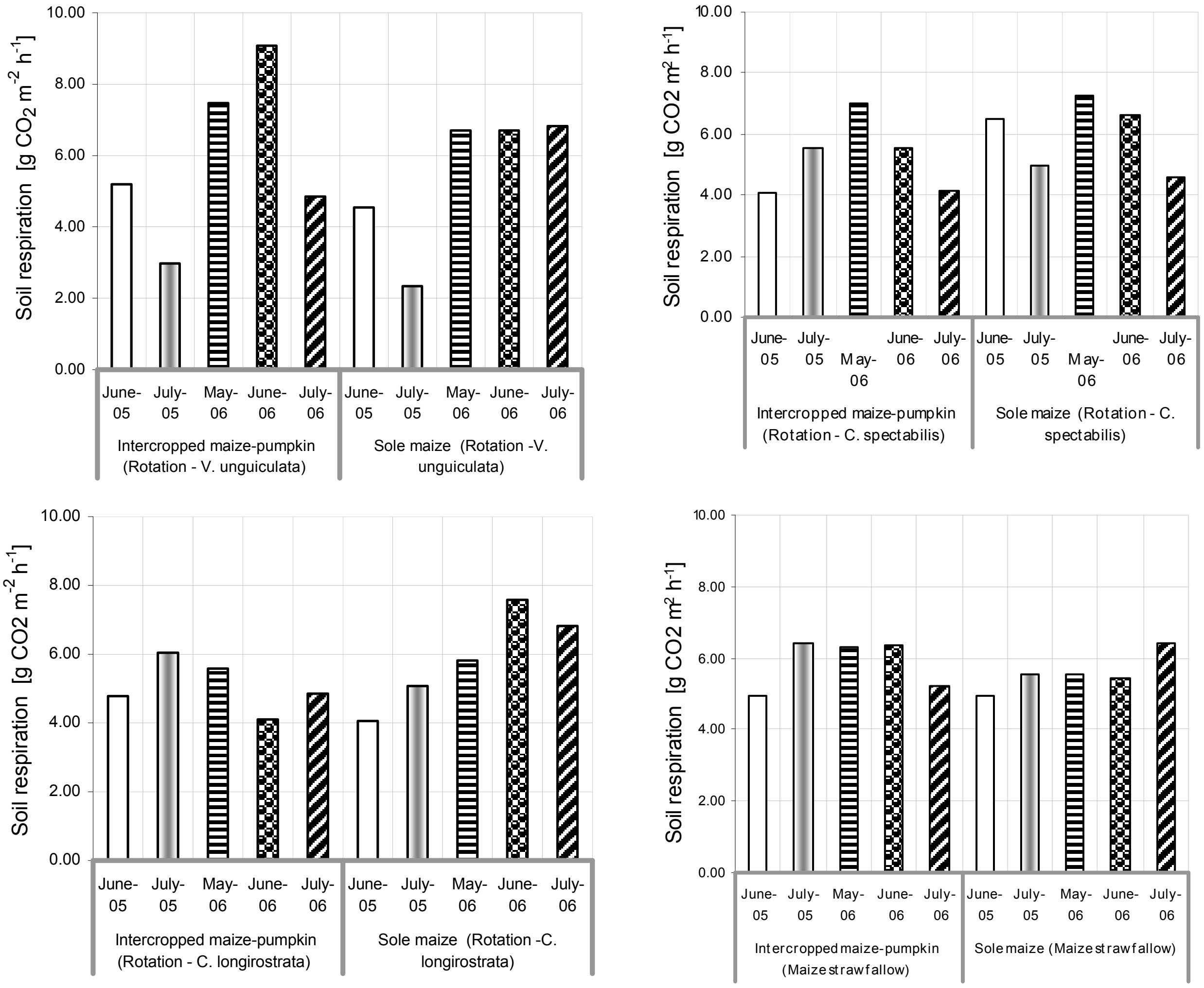


Figure 18: Effects of intercropping systems on the soil respiration in the rambutan orchard.

4.1.3 Conclusion

The maize x pumpkin intercropped system produces very dense soil cover. Such intercrops achieve over 50% of soil cover in the first two months. Soil humidity conservation is one of the principal effects of intercropped pumpkin. The intercropped system and the legume rotation produce interesting habitats for the micro-organism activities and increase the carbon sequestration. The lack of soil cover by the maize/straw fallow system provokes evaporation, soil temperature and soil erosion rise. The effects of legume species on the soil fertility demonstrate that there exists no marked difference among species on the soil fertility.

Response of intercropped system and legume succession is very different in both fruit orchards. Due to the higher ecological unbalance in the mango orchards, the maize x pumpkin intercropped system and legume rotation present better soil fertility response than the sole maize system. The soil fertility results in both fruit orchards demonstrate that the maize x pumpkin intercropped systems and legume rotation are an interesting alternative to improve soil fertility and the fruit orchard productivity.

The intercropped systems decrease both Ca and Mg in the soil. Therefore is necessary to correct the nutrient deficiencies. To maintain the orchard productivity it is important to focus research on both organic and mineral inputs, but with a responsibility for preserving natural resources.

4.2 Effects of intercropping systems on the weed population dynamics in fruit orchards

Plant diversity exists at different levels of integration in agro-ecosystems. It results from the interactions between plant genetic resources, biotic and abiotic environments, as well as from management practices (Almekinders *et al.*, 1995). Intuitively, diversified crop rotations could be associated with increased weed diversity compared with monocultures. However, this will depend largely on the type of crops included in the rotations and on the corresponding management (Légére *et al.*, 2005). Crop density and spatial arrangement are factors that affect crop and weed competition (Mohler, 2001). According to one current hypothesis, when weed seedlings are smaller that crop seedlings, as is usually the case, weed suppression by the crop should increase with crop spatial uniformity and density (Weiner *et al.*, 2001).

To develop weed control, modern agriculture requires the same approach of integrated management as used for insect control. Today, herbicides are used on most fields and are targeted against grass weeds as well as against dicotyledonous species. On average, today's herbicides control a larger spectrum of weeds than 25 years ago. Even so, weeds still represent an important constraint to crop production in the tropical region. For instance, smallholder farmers spend 50–70% of their total available farm labour on weed control and this control is usually carried out by machete - weeding (Chikoye *et al.*, 2002). In Central America, smallholder farmers (campesinos) are not only maintaining the machete - weeding, but they really know how to use some of the edible or medicinal plants among the weed community inside maize or bean crops. It is the major reason, why the "milpa" system (Chapter 2.3), maintains weed species richness. It demonstrates that the composition of weed communities depends on biotic and abiotic factors like management practices, seed banks, and availability of nutrients (Eiszner *et al.*, 1996; Pohlan, 1995).However, the concept of weed diversity in modern agriculture may be counter-productive when one considers that, generally, productivity is off - setting diversity and sustainability (Brummer, 1998; Hall, 1995).

From the practical point of view, the weed abundance and biomass structure are influenced by the weed management practices. Depends of the type of horticulture, conventional management or organic, exist on very abundant spectrum of weed management strategies. In the Soconusco it is very common to use chemical and mechanical methods with the effect of weed free mango orchards, which are only guarantees by complete open soils without any soil cover provoking soil erosion, nutrient displacement and destruction of the balance between flora and fauna. To complete this weed free situation, the mango farmers realize from two to four mechanical activities by weed slashing and/or tillage and additionally applying three or four times different total herbicides (like glyphosate or paraquat). The situation in the rambutan orchards is not so drastically. Here the farmers don't use the weed free strategy and try to manage only the natural soil cover with 1 to 2 mechanical operation and additionally 1 to 2 applications of herbicides (glyphosate or paraquat + 2,4 – D).

4.2.1 Weed biomass

Weed biomass capacity depends specially from the plant class and that is a result of interactions between biotic and abiotic factors. It is the reason, why the cover crops have never been as popular as they are today (Marroquín *et al.*, 2005; Baumann *et al.*, 2000). Therefore, the hypothesis that intercropped systems will produce greater changes in weed community structure than monocultures was postulated (see Introduction). It is concurrently predicted that species diversity of the weed community will be lower in the monocultures than in the intercropping. Results of a literature survey indicate that weed population density and biomass production may be markedly reduced using crop rotation (temporal diversification) and intercropping (spatial diversification) strategies (Pohlan *et al.*, 2006; Liebman and Robichaux, 1990). A decrease in row spacing often results in decreased weed biomass (Murphy *et al.*, 1996; Teich *et al.*, 1993;

Putnam *et al*., 1992; Andersson, 1986) and higher yields, but in some cases there is no effect on yield (Teich *et al*., 1993; Vander Vorst *et al*., 1983). Increasing crop density usually results in decreased weed biomass (Doll, 1997; Murphy *et al*., 1996; Blackshaw, 1993; Samuel & Guest, 1990; Randford *et al*., 1980)

Growers' experience has shown that changing tillage practices without increasing crop diversity within rotations has generally led to increased weed problems, especially in sole cropping systems (Eiszner *et al*., 1997; Gamboa y Pohlan, 1997; Liebman and Robichaux, 1990). In a study with sweet corn and pumpkin planted into cover crop residues of vetch, rye, crimson clover and ladino cover (*Trifolium repens*), the efficiency of land cover control was compared under no-tillage with or without glyphosate herbicide, and under bare ground conventional tillage (without cover crop) with glyphosate as well. Herbicides also affected weed biomass at four weeks (wk) after vegetable planting, with least biomass in herbicide-treated plots. Neither cover crop nor herbicide treatment significantly affected either weed biomass by 8 wk after planting or pumpkin fruit weight at harvest (Galloway and Weston, 1996)

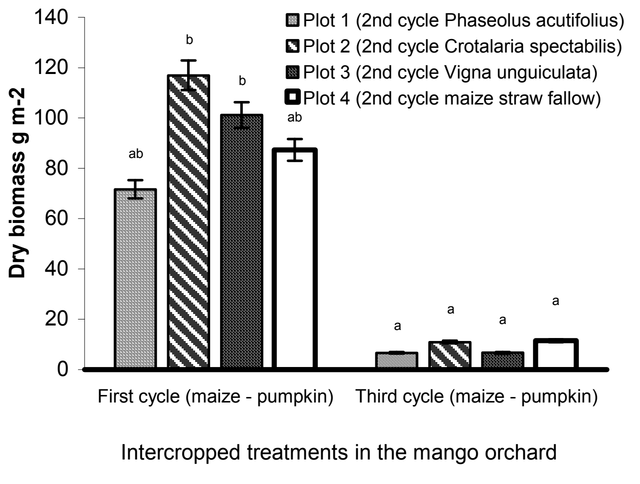
4.2.1.1 Dynamics of weed biomass in the mango orchard

Between 2005 and 2006, different crop successions intercropped in mango and rambutan orchards were analysed for their effects on biomass and composition of weed communities. Results show that weed biomass presents different patterns, which depend on the association (either sole maize or maize - pumpkin) and on the insertion of leguminous crops in the crop rotation, all this according to the surrounding fruit orchard. In the mango orchard (Cintalapa), the weed biomass in the maize x pumpkin combination decreases strongly in the third cycle down to 8.95 g m^{-2} from 94.26 g m^{-2} in the first cycle (Fig. 19).

At the beginning of the experiment the weed biomass in the maize x pumpkin intercropped plot 1 (2nd cycle *Phaseolus acutifolius*) was low at 71.63 g m^{-2} but higher in plot 2 (2nd cycle *Crotalaria spectabilis*) at 116.96 g m^{-2}. This weed biomass was equally low for all treatments during the third cycle (Fig. 19). This weed biomass suppression illustrates the advantage of intercropping leguminous crop during the second cycle. This weed control could be used in agriculture for diminishing herbicide.

Nevertheless, the biomass fall is owing to the decrease of *Rottboellia cochinchinensis* biomass production, presenting a weed biomass average of 74.25 g m^{-2} at the beginning (first cycle), contributing to 80 % of the total weed biomass production (Fig. 19). However, in the third cycle, *R. cochinchinensis* produced only an average biomass of 3.92 g m^{-2}, equivalent to 23.09 % of total weed biomass (Fig. 19). The difference in weed biomass between the leguminous treatments was only marginal for the plots 2 (2nd cycle *C. spectabilis*) and 3 (2nd cycle *Vigna unguiculata*) ($P = 0.05$).

The effects of maize growing without any companion crop in the third cycle, and the effects of the previous intercrop combinations can clearly be seen in figure 20. Now the weed biomass decreases in all treatments, with the exception of plot 2 (2nd cycle *C. spectabilis*), where weed biomass amounted up to 129 g m^{-2} in the third cycle (Fig. 20). The crop density and biomass of *C. spectabilis* can be considered as a soil fertility restorer particularly caused by changes of the field habitat i.e. increases in soil humidity, soil litter and soil fertility. Hence, *C. spectabilis* induced higher weed-crop competition, favouring the proliferation of a new species in the Soconusco like *Echinochloa colona* in the third cycle, reaching 25 % of total weed biomass, although the latter weed was absent in the first cycle. The increase of *Phyllanthus niruri* in the third cycle in plot 2, contributed strongly to the weed biomass increase of plot 2 in the third cycle. Clearly, *P. niruri* biomass increased from 2.70 g m^{-2} in the first cycle up to 51.77 g m^{-2} in the third cycle (Fig. 20).



* Weed Samplig 4 weeks after sowing

Figure 19: Effects of intercrops (2nd year) on the weed biomass in the intercropped system.

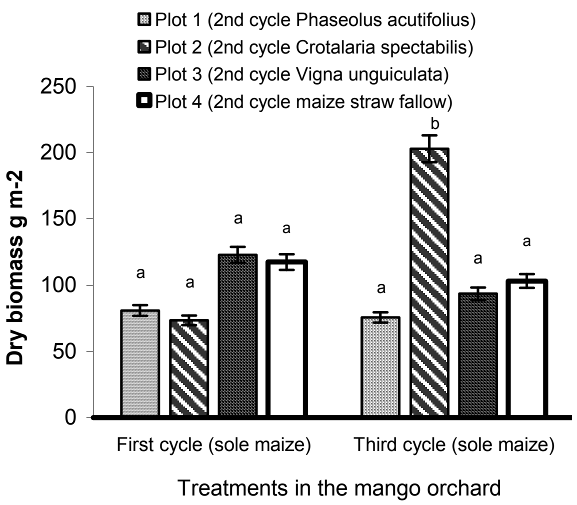


Figure 20: Effects of intercrops (2nd year) on the weed biomass in the sole maize system.

Weed biomass differences between the treatments in the first cycle were not significant (P=0.05) (Fig. 20). Comparing the first and third cycles there were no significant differences except for treatment 2 (*C. spectabilis*) in the third cycle (Fig. 20). The weed biomass dynamics in mango orchard during four cycles (maize x pumpkin + leguminous crops) result not only from inserting leguminous crops in the rotation but also from intercropping pumpkin between the maize. This explains why weed biomass decreases strongly from first to third cycle in the intercropped maize x pumpkin (Fig. 19). The density and the cover of the maize - pumpkin intercrop are higher than in the sole maize culture, resulting in weed biomass decrease. A reduction in row spacing often results in decreased weed biomass (Murphy *et al.*, 1996; Teich *et al.*, 1993; Putnam *et al.*, 1992; Andersson, 1986).

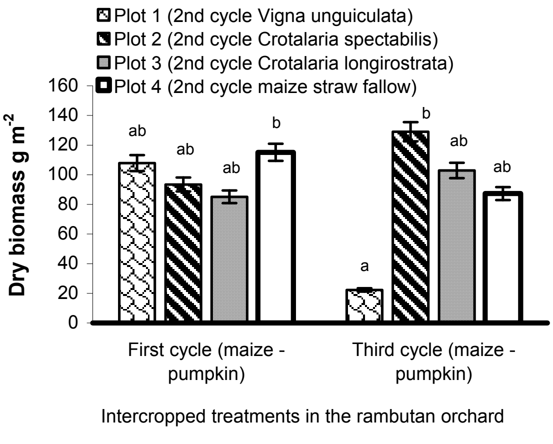
The weed biomass control is less in the maize-legume rotation without pumpkin intercrop than in the rotations including a pumpkin intercrop. However, the leguminous effects provoke changes in the habitat, eventually resulting in the proliferation of new species and stronger biomass production. Nevertheless, in some cases, these changes may even inhibit the development of some species. Increasing crop density and soil cover usually result in decreased weed biomass (Doll, 1997; Murphy *et al.*, 1996; Blackshaw, 1993; Samuel & Guest, 1990; Radford *et al.*, 1980).

Generally, it is possible to resume that the intercropping of different annual crops into the mango rows present on very usefully system of integrated weed management. These guarantees during the whole year soil cover, living conditions for many species of the fauna and flora and in this manner good reservoir for pollination insects, reduce the weed control activities in approximately 50 % and increase the land use factor.

4.2.1.2 Dynamics of weed biomass in the rambutan orchard

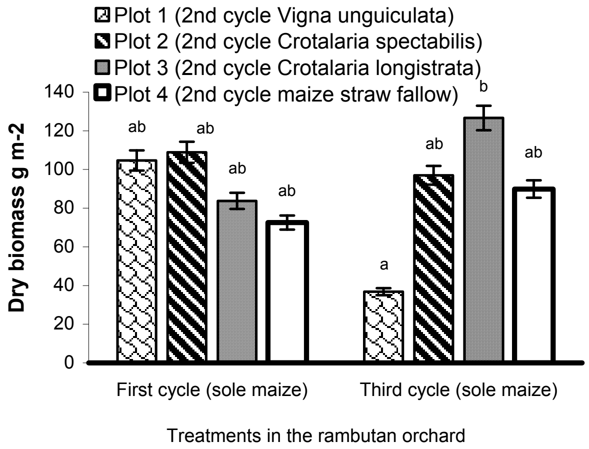
In the rambutan orchard in El Triunfo, the weed biomass changed slightly because of the leguminous rotation in the second cycle and of the long-term effect by the previous pumpkin crop (Fig. 21). The weed biomass behaves very differently in all maize x pumpkin intercropped treatments, where plots 1 and 4 present weed biomass decrease in the third cycle, whereas, treatments 2 and 3 increased. In the first cycle, the weed biomass was lower in the second (93.42 g m^{-2}) and third plots (85.12 g m^{-2}) (Fig. 21). In the third cycle, treatments 2 (102.89 g m^{-2}) and 3

(129.02 g m^{-2}) produced the higher weed biomass, whereas, treatment 1 (2nd cycle *Phaseolus acutifolius*) presented the lowest weed biomass (Fig. 21).



*Weed Sampling 4 weeks after sowing

Figure 21: Effects of intercrops (2nd year) on the weed biomass in the intercropped system.



*Weed Sampling 4 weeks after sowing

Figure 22: Effects of intercrops (2nd year) on the weed biomass in the sole maize system.

The weed biomass average in the first cycle was 100.37 g m^{-2}, and decreased to 85.38 g m^{-2} in the third cycle (Fig. 21). The proliferation of new species plays an important role on the weed biomass. The weed biomass of *Paspalum* spp comprised about 69 % of the total weed biomass in the first cycle. Nevertheless, in the third cycle biomass of *Paspalum* spp. decreased or was even absent in some treatments. The strong weed biomass decrease in maize x pumpkin intercropped plot 1 is due to the absence of *Paspalum* spp., whereas, in plot 2 two new species *(Crotalaria spectabilis* and *Leptochloa* spp.*),* comprising 8 and 33 % of the total biomass, proliferated. The same case is presented in plots 3 and 4, where proliferating new species (*Commelina diffusa, Leptochloa* spp.*, Ipomoea* spp. and *Cyperus* spp., contributing together over 40%, provoking the temporal absence of *Paspalum* spp. The weed biomass difference between maize x pumpkin intercropped treatments (leguminous in the 2nd cycle) and time effect (cycles) was only marginally significant (P= 0.05), where treatment 2 (2nd cycle C. *spectabilis*) presented significant higher weed biomass in the third cycle over treatment 1 (2nd cycle *Vigna unguiculata*). However, the weed biomass difference in the first cycle was not significant (P=0.05) (Fig. 3).

The leguminous effects on the weed biomass in the sole maize culture were similar to that of maize x pumpkin. The weed biomass decreased in the third cycle in the treatments with *V. unguiculata* and *C. spectabilis*, whereas, weed biomass increased in *Crotalaria longirostrata* and maize straw fallow plots (plots 3 and 4) (Fig. 22). The lowest weed biomass in the first cycle was in the plot 4 (maize straw fallow) and the highest weed biomass in plot 2 (*C. spectabilis*). During the third cycle, the weed biomass was higher in the treatment with *C. spectabilis* (plot 3), whereas, the lowest biomass was in the plot 1, *V. unguiculata* (Fig. 22). The difference of weed biomass between the treatments (leguminous in the 2nd cycle) and time effect (cycles) was only marginally significant (P= 0.05), whereas treatment 3 (2nd cycle *C. longirostrata*) presented significantly higher weed biomass in the third cycle over treatment 1 (2nd cycle *V. unguiculata*). However, the weed biomass difference in the first cycle was not significant (P=0.05).

The capacity of competitiveness of *Paspalum* spp. is the principal factor on the weed biomass during the first cycle. *Paspalum* spp. comprised about 67 % of the total weed biomass in the first cycle (Fig. 22). Nevertheless, *Paspalum* spp. was absent in the third cycle. The strong weed biomass decrease in plot 1 is due to *Paspalum* spp. being absent combined with the proliferation of two new species, however less aggressive than *Paspalum* spp. The new species

(Unknown and *Leptochloa* spp.) comprised respective 29 and 19 % of the total biomass. Similar case is presented in treatment 2, where *Paspalum* spp. was absent and *C. spectabilis* and Conchita azul proliferated, reaching 52 and 20 % of the total weed biomass (Fig. 22). The increase of weed biomass in plots 3 (*C. longirostrata*) and 4 (maize straw fallow) followed the same patterns as other treatments. Where the changes on the habitat, influenced the appearance of new species, *Leptochloa* spp. contributed for about 74 % of the total weed biomass in the plot 3, whereas *C. diffusa* reached 75.61 % of the total biomass in the treatment with maize straw fallow (plot 4)(Fig. 22).

The success of rotation and intercropped systems for weed suppression appear to be based on the use of crop sequences that create varying patterns of resource competition, allelopathic interferences, soil disturbance, and mechanical damage to provide an unstable and frequently inhospitable environment that prevents the proliferation of a particular weed species (Ugen *et al.*, 2002). Likewise, growers' experience has shown that changing tillage practices without increasing crop diversity within rotations has generally led to increased weed problems, especially in sole cropping systems (Oleszek *et al.*, 2001; Liebman and Robichaux, 1990).

4.2.2 Dynamics of weed species richness, evenness and diversity in the mango orchard

Pantil & Taillie (1979) view diversity as an "average" property of a community. It is a concept that ignores the total abundance of a community, the individual species abundances, as well as the identity of the species constituting the community. Weed diversity is strongly related to the ecosystem stability and may even beget overall biodiversity (Palmer & Maurer, 1997). Again, it confirms that the success of rotation systems for weed suppression appears to be based on the use of appropriate crop sequences (Ugen *et al.*, 2002).

Cover crops used as mulch have proven valuable in weed suppression. Mulch may function as a physical barrier to weeds, and suppress weeds through allelopathic interference. Moreover, mulch suppresses weeds by altering the quantity and quality of light reaching the soil surface, and by affecting soil temperature, moisture and mineral content of the soil (Blomgren and Mishanec, 2000). Herbicides play an important role in forming specific weed diversity in cropping systems. Herbicides may affect species richness differently owing to their selectivity patterns (Tomkins & Grant, 1997). Nutrient resources, be it organic or mineral, have little overall effect on weed diversity and communities' dynamics compared with other cropping practices (Stevenson *et al.*, 1997; McCloskey *et al.*, 1996). However, reducing nutrient input would affect plant diversity of farmland ecosystems (Wilson *et al.,* 2003).

4.2.2.1 Weed species richness

During the field research (2005–2006), a weed sampling was carried out in each crop cycle. Diversity, abundance and biomass of weeds were analysed in the 4th week after sowing (WAS) in each crop cycle. In this study, the weed species richness is defined as the number of weed species per m^{-2}. When averaged over the four cycles (2 years), a total of 72 species were found across all treatments. Fifty-nine species were determined in the plots with intercropped maize x pumpkin and 51 species in the plots with sole maize. From above 72 species, thirty-eight species were recorded in both treatments (plots with intercropped maize x pumpkin and plots with sole maize). Twenty-one species were recorded once only in the maize x pumpkin intercropped plots, whereas, thirteen species were found once only in the plots with sole maize. The weed richness in the maize x pumpkin intercropped plots was more diverse than the plots with sole maize (Fig. 23).

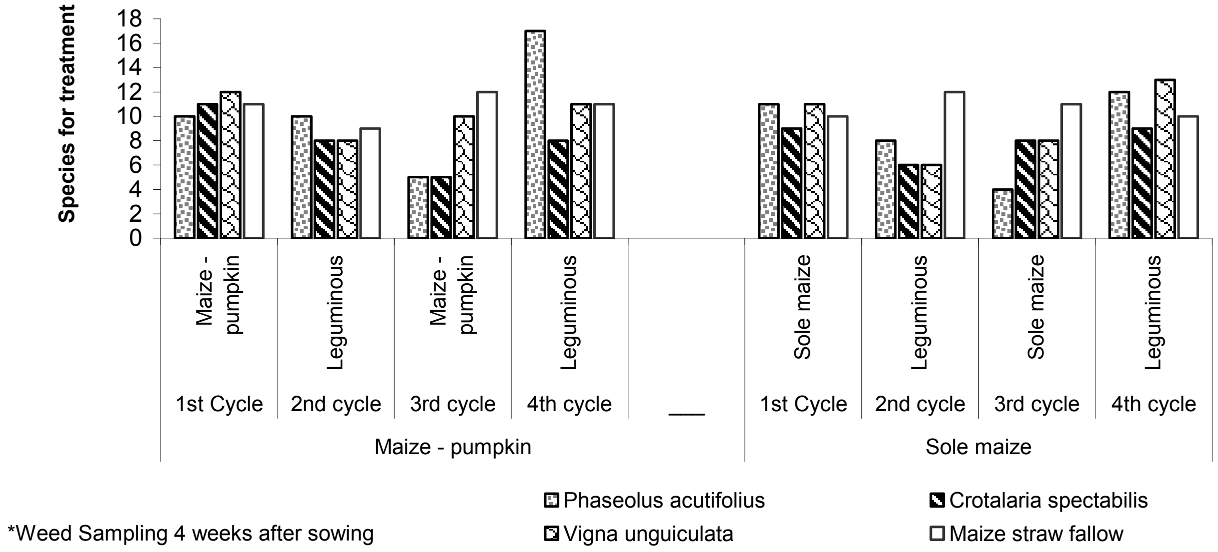


Figure 23: Effects of intercropping and legume crops on weed richness in the mango orchard.

During the period of four cycles, 32 species were found in plot 1 with intercropped maize x pumpkin (*P. acutifolius*) and only 22 species in plot 1 with sole maize (*P. acutifolius*). Similar patterns follow all leguminous treatments (Fig. 23), whereby twenty-five species were recorded in plot 2 with intercropped maize x pumpkin, against twenty-one species in plot 2 with sole maize (*C. spectabilis)* (Fig. 23). In the maize x pumpkin intercropped plot 3, thirty species were found, whereas, twenty-six species were recorded in plot 3 with sole maize (*V. unguiculata*). The dynamics of weed diversity in plot 4 are very different to that of the leguminous treatments, as only thirty species were recorded in both treatments (intercropped maize x pumpkin and sole maize) (Fig. 23).

The results of this study are within the range of those reported by other authors, where weed communities in winter wheat, were affected more by input level than by crop rotation (including spring/summer row crops in addition to winter wheat). Indeed, weed communities appeared to be more diverse in low input systems than in either intermediate or high input systems (Bárberi *et al.,* 1997). The first cycle begins (maize crops) with a weed diversity at 11 species on average in both systems (intercropped maize x pumpkin and sole maize). Weed diversity was reduced in the second cycle (rotation with leguminous crops), whereas, in the third cycle (maize crops) the weed diversity does change, increasing in some treatments, but decreasing in other treatments. Eventually, the weed diversity increases in the fourth cycle (leguminous crops). Similar tendencies are reported in maize-soybean-winter wheat cropping systems (including monocultures as well as two- and three-way combinations of these annual row crops) where weed species richness and evenness were less affected by crop rotation than by field management (Doucet *et al*., 1999).

4.2.2.2 Weed species evenness

The weed homogeneity was determined by Shannon´s E index. When averaged over all plots in the first cycle, E index ranged in the maize x pumpkin intercropped treatments from 0.57 in plot 1 to 0.71 in plot 3 (Fig. 24). In the second cycle plots 1 and 3 with intercropped maize x pumpkin the E index increased, whereas in plot 4 (maize straw fallow) the E index strongly decreased. In the fourth cycle, all maize x pumpkin intercropped treatments increased to 0.91 in plot 2 (*C. spectabilis*) (Fig. 24). It demonstrates that, during the fourth cycle, the maize-legume rotations change the habitats and affect weed abundance.

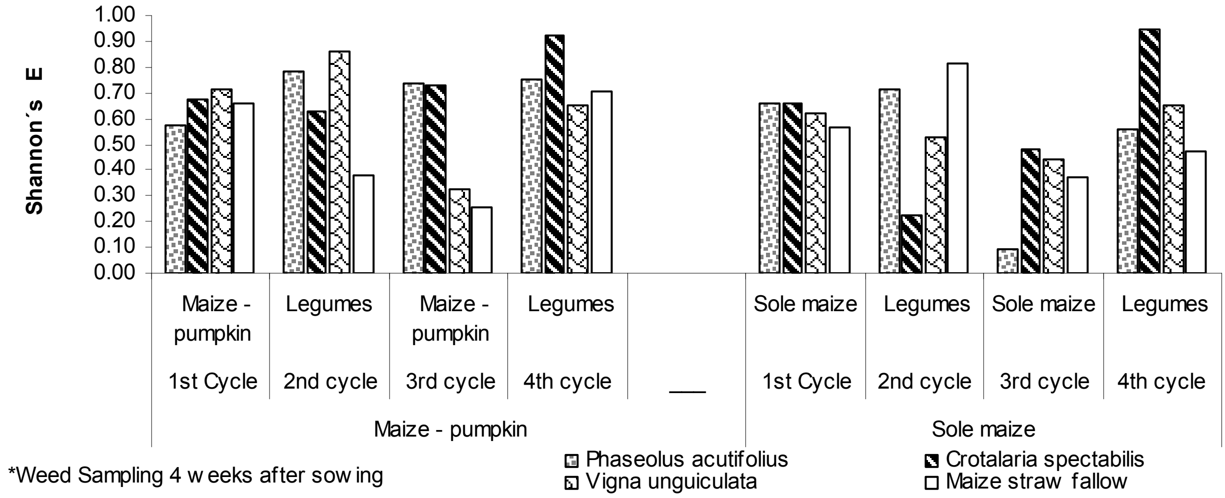
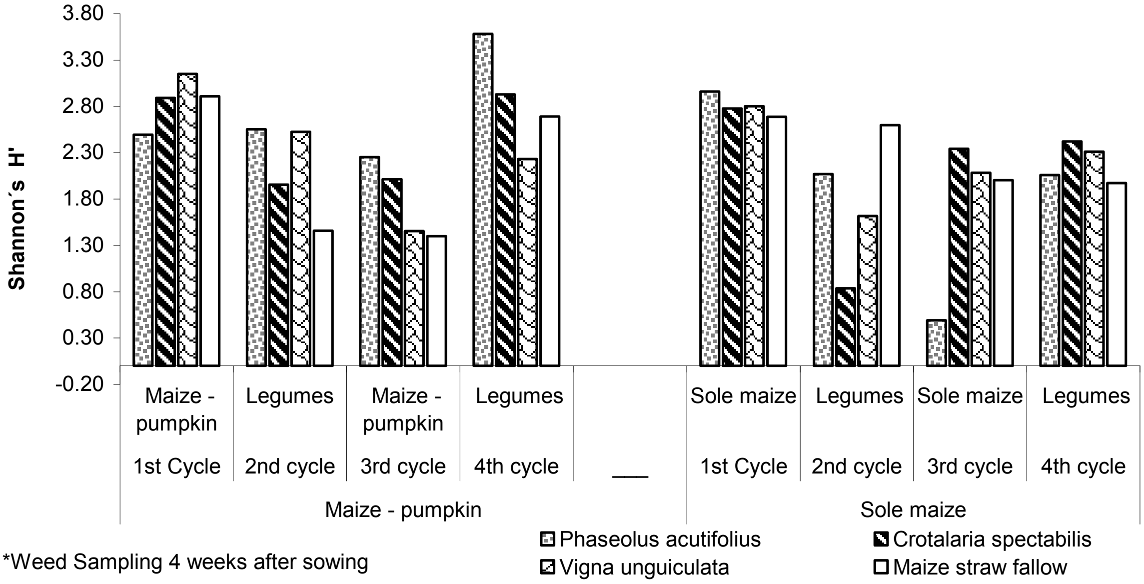


Figure 24: Effects of intercropping and legume crops on Shannon´s E index in mango orchard.

In the sole maize plots, the Shannon´s E index tends to go down in the plots 2 and 3 during the second and third cycles, with the exception of plots 1 and 4 (maize straw fallow) in the second cycle. Therefore, during the fourth cycle plots 2 and 3 present increased "E" indices, whereas, plots one and four show a decrease. Although, the index E tendency is similar in both variants (intercropped maize x pumpkin and sole maize), the actual E index in the intercropped maize x pumpkin was much higher than in sole maize, during the second, third and fourth cycles. It demonstrates that the intercropped maize x pumpkin plus the rotation with *P. acutifolius* or *C. spectabilis* change total weed abundance. Such effects of rotation would be an alternative for crops facing concomitant weed resistance problem, such as *R. cochinchinensis* in the mango orchard.

4.2.2.3 Weed species diversity

Weed diversity, as captured by Shannon´s H´ index was on average greater in intercropped maize x pumpkin that in sole maize (Fig. 25). H´ values ranged from 1.39 to 3.50 in the maize x pumpkin intercropped plots, but only from 0.50 to 2.90 in the sole maize plots. The H´ values tend to decrease in the second and third cycles, but in the fourth cycle, all maize pumpkin intercropped treatments presented an increased H´ value (Fig. 25). This tendency is similar in both intercropped maize x pumpkin and sole maize treatments. The associated effects (intercropping maize x pumpkin and rotation with leguminous crops) produced very strong effects on the weed species diversity, where plot 1 (*P. acutifolius*) with intercropped maize x pumpkin in the fourth cycle, both produced a richer diversity and a better homogeneity of weed abundance. Likewise, the intercropped maize x pumpkin in plot 2 presented a similar H´ value to that of plot 1, but plot 2 had reduced weed richness in the fourth cycle (Fig. 25). The intercropped maize x pumpkin plots 3 and 4 are similar for the diversity and dominance variables.



*Weed Sampling 4 weeks after sowing

Figure 25: Effects of intercrops and leguminous on Shannon´s H´ index in mango orchard.

In the plots with sole maize (Fig. 25), all treatments follow the same patterns as in the maize x pumpkin intercropped plots. The maize x pumpkin intercrop combined with legume rotation produces stronger effects on the weed dynamics than the combination of sole maize with subsequent leguminous crops in rotation. However, in plot 4 with sole maize (maize straw fallow) there exists a weed dominance problem together with poor diversity and richness of weeds. It demonstrates that the dynamics of weed diversity are very sensitive to agro-climatic change of the habitat. Other authors contend that weed diversity in no-tillage crop fields is higher than in tilled crop fields but lower than in 8 year-old fields (not cropped), whether the latter is fertilized or not (Gamboa, 1994; Odum *et al.,* 1994).

Our results are able to give the recommendation for the rambutan farmers, to develop intercropping with different annual crops like on system of integrated weed management. These are very important for the balance of fauna and flora and especially for the maintenance of the Meliponeaceae bee species, which are the most important pollination insects in rambutan orchards of Centro America. Otherwise, this practice can reduce weed control activities in approximately 25 % and increase the land use factor.

4.2.3 Dynamics of weed species richness, evenness and diversity in rambutan orchard

4.2.3.1 Weed species richness

In the rambutan orchard, eighty-three weed species are recorded, whereby the maize x pumpkin intercropped treatment has higher number of weed species than the sole maize treatment. When averaged over the four cycles, sixty-nine weed species are found in all maize x pumpkin intercropped plots, seventeen species higher than in the plots with sole maize (52 species). The first cycle starts (maize crops) with different weed richness in all plots, where the maize x pumpkin intercropped plots 1 and 4 present higher diversity (Fig. 26). Nevertheless, in the second cycle the intercropped plots 2 and 3 have increased diversity richness. In the third cycle though, the maize x pumpkin intercropped plots 1, 2 and 3 augment to 10, 15 and 10 species m^{-2} respectively, whereas, the plot 4 decrease the diversity from 15 to 12 species per m^{-2} (Fig. 26). During the fourth cycle the last intercropped plot 4 diminishes from 13 (first cycle) to 9 species m^{-2} (fourth cycle) (Fig. 26). When averaged over all intercropped plots during the four cycles, the number of species per m^{-2} is of 9 species m^{-2}, where the maize x pumpkin intercropped plot 2 (*C. spectabilis*) improves the weed diversity from 4 (first cycle) to 13 species m^{-2} (fourth cycle)

Similar tendencies are recorded in plots 1 and 3 (Fig. 26). In the plots with sole maize, the weed diversity richness is poorer that in the maize x pumpkin intercropped treatment.

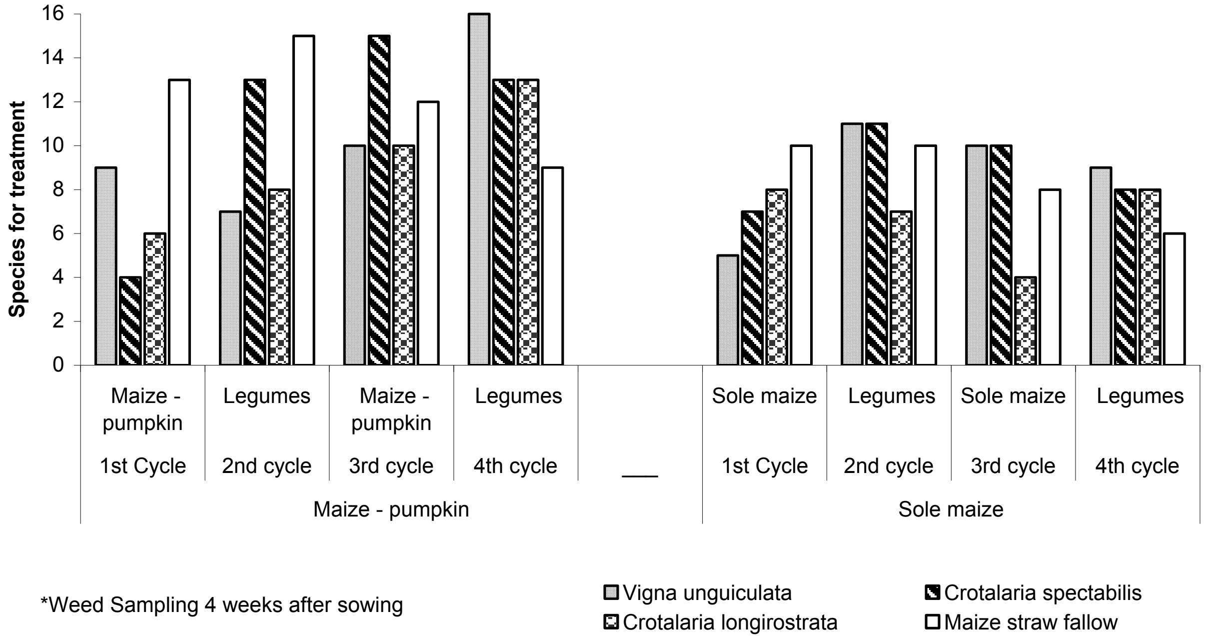


Figure 26: Effects of intercropping and legume crops on weed richness in rambutan orchard.

The weed diversity richness fluctuates from four (plot 2) to 13 species m^{-2} (plot 4) in the first cycle, whereas, in the second cycle all treatments with sole maize produce a weed species increase, ranging from 7 (plot 1) to 15 species m^{-2} (plot 4). Nevertheless, in the third cycle the four treatments with sole maize have reduced numbers of weed species. The decreasing patterns follow a downward trend up to the fourth cycle, where the three sole maize treatments plus leguminous crops (plots 1, 2 and 3) offer the higher weed diversity, with 3 species over the plots with maize straw fallow. Nevertheless, the dynamics of weed diversity in sole maize and leguminous rotation plots (plots 1, 2 and 3) tend to increase the weed species over time, whereas plot 4 (maize straw fallow) tends to decrease the weed diversity and richness (Fig. 26). Once more, these results demonstrate that weed species richness and evenness are less affected by crop rotation than by cropping management (Doucet *et al*., 1999).

4.2.3.2 Weed species evenness

The dynamics of weed abundance is captured as Shannon´s E, where the values E ranged from 0 to 1. For the maize x pumpkin intercropped plots the E indexes were higher in the fourth cycle. In plot 2 with maize x pumpkin intercrop the Shannon´s E index was augmented from 0.08 (first cycle) to 0.82 (four cycle) and from 0.31 to 0.82 in plot 3 (*Crotalaria longirostrata*). The same tendencies present plot 1 (*Vigna unguiculata*). Nevertheless, in the maize x pumpkin intercrop plot 4 (maize straw fallow) the Shannon´s E has decreased from 0.57 to 0.48 (Fig. 27). The weed homogeneities in plots with sole maize present similar patterns as the maize x pumpkin intercropped plots. However, the intensities in the sole maize plots are less. For that reason, the sole maize plot 1 diminishes from 0.34 to 0.79 and from 0.56 to 0.78 in the plot 3 with sole maize. The E index tendencies in the plot 4 (traditional maize straw fallow) suffer opposing patterns, where the evenness E index decrease from 0.62 to 0.34 (Fig. 27).

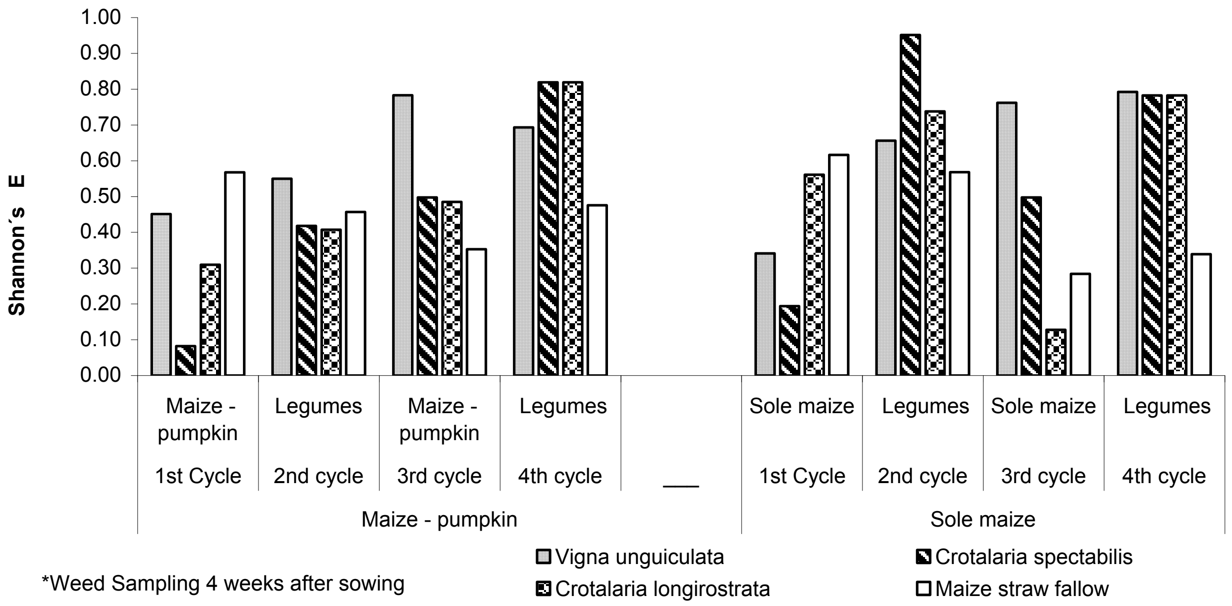
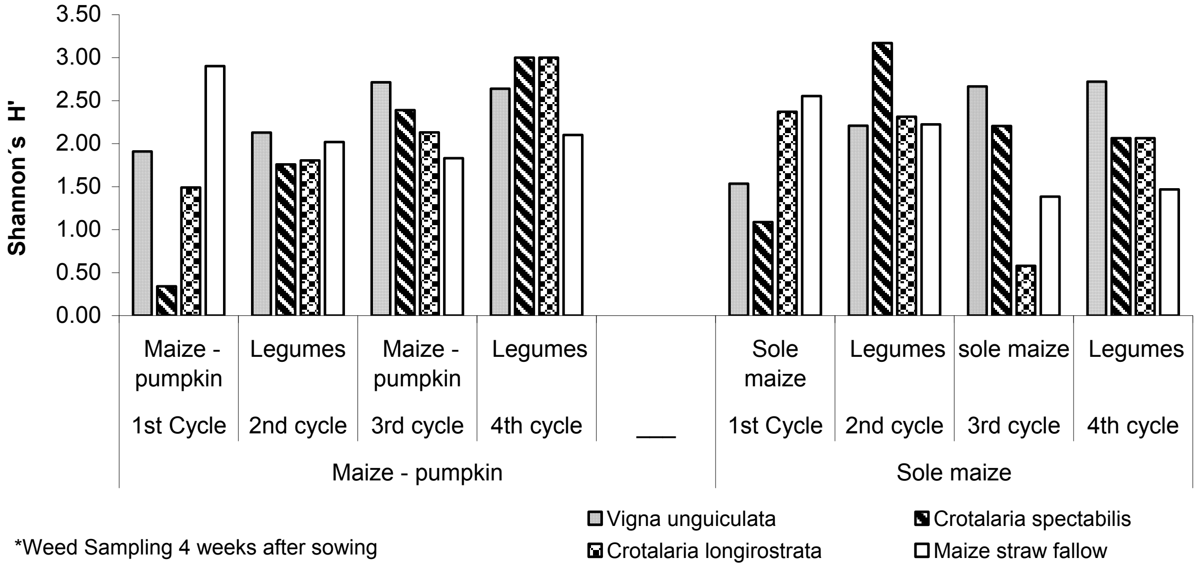


Figure 27: Effects of intercrops and leguminous on Shannon´s E index in rambutan orchard.

The Shannon´s E indices indicate that the effects of the leguminous crops on weed homogeneity in the intercropped maize x pumpkin are higher than in the plots with sole maize leading to a better weed homogeneity during 4 cycles as illustrated by plots 2 in intercropped maize x pumpkin. Although, all plots in treatment "sole maize" follow the increase tendency of evenness E, however the effect of leguminous cover crops on the weed homogeneity is here milder than in the plots with intercropped maize x pumpkin.

4.2.3.3 Weed species diversity

The Shannon´s H´ index fluctuate in this study from 0.50 to 3.00, where the diversity index increases in all plots with intercropped maize x pumpkin. In plot 2 (*C. spectabilis*) the H´ index increases steeply from 0.34 to 3.00. Same patterns occurred in plots 1 (from 1.91 to 2.64) and plot 3 (from 1.46 to 3.00). To the contrary, plot 4 with intercropped maize x pumpkin, is characterised by a Shannon H´ index decreasing from 2.90 to 2.10. The effect of leguminous cover crops on the weed diversity strongly increases after the third cycle. For this reason, plots 1, 2 and 3 (leguminous treatments) with intercropped maize x pumpkin present a higher diversity and a better homogeneity in the fourth cycle. The opposite is found in plot 4 (without leguminous crops), where poor diversity and slow weed homogeneity can be noticed, resulting in a strong dominance of few species in such habitat (Fig. 28). The Shannon´s H indices range from 1.09 to 2.72 in all plots with sole maize. Plot 1 offers the better Shannon´s H´ index (from 1.54 to 2.72). Similar results are recorded in plots 2 (1.09 to 3.17) and 3 (2.06 to 2.31). Nevertheless, the sole maize plot 4 diminishes from 2.55 to 1.47 (Fig. 28).



*Weed Sampling 4 weeks after sowing

Figure 28: Effects of intercrops and legume on Shannon´s H´ index in rambutan orchard.

The results of Shannon´s index demonstrate, that the intercropped maize x pumpkin with leguminous rotation improves weed diversity and its homogeneity, particularly when combined with either *C. spectabilis* or *C. longirostrata* rotation, and hence can be considered as the better production systems among the tested intercropping options. However, in the sole maize plots, the production system maize in rotation with *V. unguiculata* obtains the better diversity and homogeneity in the evaluated treatments. Indeed, the sole maize plot 4 (maize straw fallow) reduces the diversity and the homogeneity in both treatments (intercropped maize x pumpkin and sole maize), indicating that only few weeds present an abundance and biomass dominance during the four cycles.

Diversity indices measured in this study are within the range of those reported for various cropping systems in diverse geographical areas (Derksen *et al.*, 1995; Clements *et al.*, 1994; Shaltout & El Fahar, 1991). The Shannon´s H´ values reported in the literature for weed communities generally are < 2. In comparison, H´ plant communities in other sites may range between 2.0 and 4.0 in grasslands, 2.0 to 3.0 in deciduous forest, and potentially > 7 in the Pacific forest (Altessor *et al.*, 1998; Barbour *et al.*, 1987). Low plant diversity appears to be typical of arable land and intensively managed grassland (Wilson *et al.*, 2003), and is likely to be the result of periodic disturbances of various kinds, including selection of crop species and their associated management practices, tillage frequency and intensity and pesticide use.

The weed results of this study present similar tendencies to research reported elsewhere, where weed communities are more diversified and stable in cereal-forage rotations than in cereal monocultures (Stevenson *et al.*, 1997), whereas rotation of annual cereal and oilseed crops have little overall effect on weed diversity (Légére & Derksen, 2000). A well-planned crop rotation system can help producers avoid many of the problems associated with weeds, particularly with perennial weeds (Eiszner *et al.*, 1997; Tabachnik and Fidell, 1996; Pohlan, 1995; Liebman and Elizabeth, 1993; Daspehov, 1967)

4.2.4. Conclusion

The maize x pumpkin intercrops reduce the weed biomass and hence change the weed population for the next cropping cycles. Pumpkin cover decreased more the weed biomass than by crop rotation. The intercropped maize x pumpkin with leguminous rotation improves weed diversity and its homogeneity, particularly when combined with either *C. spectabilis* or *C. longirostrata* rotation. The competitiveness of *Paspalum* spp. in the rambutan orchard and

Rottboellia cochinchinensis in mango orchard was reduced with the maize - pumpkin – system and legume rotation integration. In maize straw fallow and black plot, the dominance of one or two weed species generates the weed biomass problems. The smallholder farmers spend 50–70% of their total available farm labour on weed control and weeds can provoke in some cases yield loss up to 100%. The maize x pumpkin intercropped system and the legume succession can not only reduce the weed control cost and labour, but it can offer foods like flower pumpkin, fruit and some parts of the plant as well.

4.3 Influence of legume crops on the entomology dynamics in the fruit orchards

Most of the Soconusco farmers that maintain an outstanding agricultural biodiversity are below poverty line and face periodical attacks by insects on the production systems. The application of costly and toxic insecticides has been promoted as the almost exclusive control measure of insect pests during recent decades. Consequently, pest insects have developed insecticide resistance, and native beneficial insect populations have been adversely affected (Morse and Buhler, 1997). There is a need for adoption (or re-adoption) of pest management strategies that are cheaper, more sustainable and environmentally sound. The use of mixed cropping systems is a traditional agricultural practice (Morlon *et al*., 1982) that may help alleviating the above mentioned situation. Weeds may function as repellent plants in the field and constitute a reservoir of natural enemies against insect pests (Nentwig *et al*., 1998; Altieri and Letourneau, 1982; Altieri and Whitcomb, 1979).

The value of native beneficial insects in fruit orchards is widely recognized and promoted by scientists and farmers. Nevertheless, research on potentially beneficial species, inhabiting local agroecosystems was largely abandoned in the tropical regions in 20th Century, due to the pervasive utilization of pesticide technologies. However, entomological studies are still focused on the effects of insecticides on the population dynamics of pests and on subsequent yield responses. An agricultural pest can be defined as a living organism that can damage a crop and thus compete with humans for food. Earlier it was hypothesized that lower levels of herbivores in diverse agroecosystems were a result of higher levels of natural enemies "enemies hypothesis" (Root, 1973). Thus, the conservation of natural enemies by the direct enhancement of vegetation diversity has been a subject of intense study for many years (Root, 1973 and Andow, 1999).

The intercropping advantages conveying a utilization efficiency of water, nutrients, cropping area and eventually, a higher productivity of cultivated plants is generally accepted. At the same time, intercropping may reduce occurrence of weeds, diseases, and insects (Baumann *et al*., 2000; Wiech, 1993; Lamberts, 1980). These advantage effects are attributed partially to allelopathic interactions between cultivated plants and other organisms living in the field (Oleszek *et al*., 2001).

This study investigates effects of the legume-intercropped crops (*Crotalaria* spp. *Vigna unguiculata* and *Phaseolus acutifolius)* on the insect population dynamics inside the fruit orchards of mango and rambutan as related to bloom and fruit-set.

4.3.1 Influence of legume crops on the entomology dynamics in the mango orchard

In the Soconusco the mango flowering period is present from November to February. Indeed, the insects were sampled at the end of December 2006. Beneficial insects are attracted to legume crops and to the maize straw fallow. Those insects observed in legume crops and maize straw fallow include important arthropod predators, parasite wasps, and pollinators representing 19 families (Tab. A-13). The most commonly occurring beneficial insects observed in the treatment with *C. spectabilis* are fruit flies and wasps, stinkbugs and whiteflies. In the rotation scenario with *V. unguiculata,* the insect diversity is represented by fruit flies, whiteflies, and wasps. Likewise, fruit flies, wasps, and mosquitoes occupy the high population in the treatment with *P.*

acutifolius. Once more, fruit flies, mosquitoes and butterflies dominate the rotation with maize straw fallow (Tab. A-13).

The arthropod diversity in the mango study is higher in the legumes crops that in the maize straw fallow. The highest insect diversity is found in the treatment with *V. unguiculata* (15 species), followed by *P. acutifolius* (13 species), and *C. spectabilis* (11 species) (Fig. 29). The poor vegetation cover and the very few attractive flowers in the field with maize straw fallow are attracting few arthropods. For that reason, the maize straw fallow rotation offers only 8 species and 23 individuals per bag (Fig. 29), whereas weed vegetation after the harvest of *V. unguiculata* and *P. acutifolius* offers attractive scenarios for the herbivoral insects.

The insect dominance in this study expresses the ecological imbalance of the mango orchards in the Soconusco region. The fruit flies species account for more than 60% of the total sampled individuals. In fields with *P. acutifolius, V. unguiculata,* and maize straw fallow they account for 79, 66 and 64%, respectively. To the contrary, dominance dynamics are found in the scenario with *C. spectabilis*, where fruit fly accounted for 46 % and wasps for 30 % of the insect population. It demonstrates that the allelopathic effects of *C. spectabilis* during plant growth play an important role on the insect population. According to Zago *et al*. (2002), Crotalaria is used as a green manure crop, particularly where rotation for control of nematodes is important. Nevertheless, at flowering, this plant contributes to the aesthetics of wild lands and gardens, and attracts insects where it is planted (Parrota, 2001).

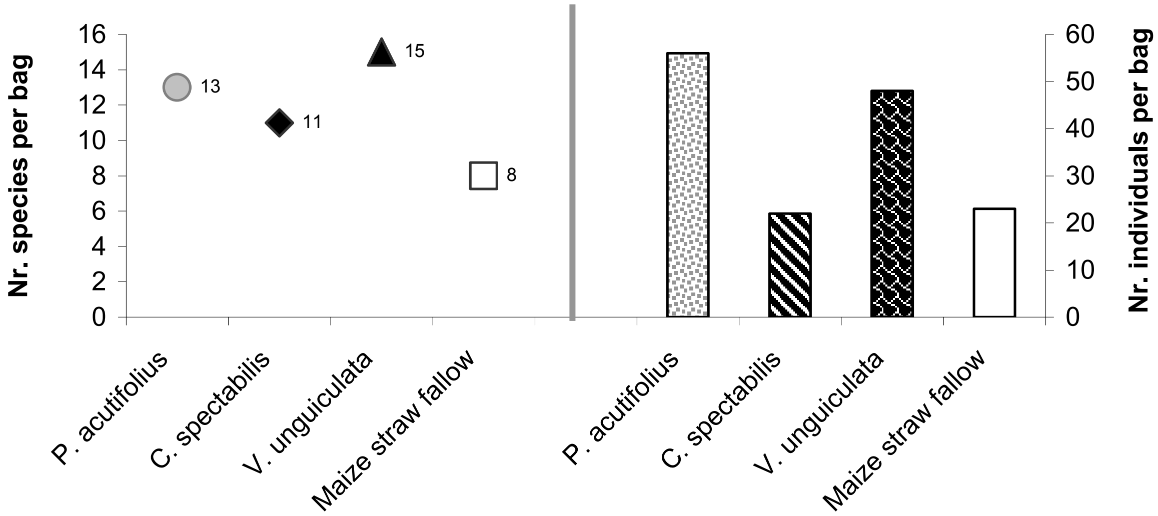


Figure 29: Effects of the legume crops on the entomology dynamics in the mango orchard.

Crotalaria spp. is also grown as a fodder plant. This has largely been abandoned because of the toxin alkaloids (principally monocrotaline) it contains (Burkill, 1995). Likewise, in herbal medicine, extracts of the whole plant are used to treat impetigo and scabies (Jain and De Filipps, 1991), as an antiseptic for cuts, and to treat intestinal worms (Parrotta, 2001). On the other site, the yellow and abundant attractive flowers of *Crotalaria spectabilis* that coincide with mango flowering period is an interesting alternative to alleviate the ecological imbalance and to improve the pollination of the mango flowers.

4.3.2 Influence of legume crops on the entomology dynamics in the rambutan orchard

Only few pests have been reported on rambutan orchard in the Soconusco region. Very poor of insects infest rambutan but none are regarded as serious, most are controlled with minimal spraying programmes (Vanderlinden, 2003). Sporadically, wasps are found attacking rambutan. They cause damage to the fruit and excoriations in the trunks and branches of the trees, but until now without significant economic consequences (Pérez & Pohlan, 1999). Until now, there are no problems with Mediterranean flies, which is a great advantage for the rambutan production. The Mediterranean fruit fly only attacks the fruit where the pericarp has been broken by other means and the pulp is exposed (Nakasone & Paul, 1998; Pérez, 1994). Likewise, Pérez (1996) confirms in earlier work, that the fruit fly complex is not found infesting the rambutan. Research from Borgman (1999) confirms that the rambutan fruit is not susceptible to infestation of *Anastrepha* spp. that are dispersed in the Soconusco, Chiapas.

Thanks to few pests and diseases in rambutan crops the chemical technology remains at low levels. The current management in the rambutan production systems has until now preserved a friendly and agro-ecological agroecosystem. Considerable evidence has emerged over the past twenty years to suggest that pest populations are much greater in monoculture than in policulture (i.e. with intercropping). There is considerable evidence of reduced population of insect pest in policultures (Andow 1991; Altieri, 1994; Altieri and Letourneau, 1999). Several studies have also shown that crop diversity strongly affects the population dynamics of some specialized herbivores (Bach, 1979).

Insects were sampled firstly on March 2007 in four randomly bags (40 * 60 cm) for each intercropped legume and four randomly bags in a traditional rambutan crop of eight meters distant. During the flowering period of rambutan (March – May) insects were sampled within the legume rows and in a traditional rambutan crop 8 m distant from legume crops. The most commonly occurring arthropods observed in the intercropped legume systems and in the rambutan monoculture were wasps, mosquitoes, horseflies, stinkbugs, and flies. Those arthropods represent 18 families (Tab. A-14). These results confirm results of insect diversity in rambutan orchards found by Vanderlinden (2003)

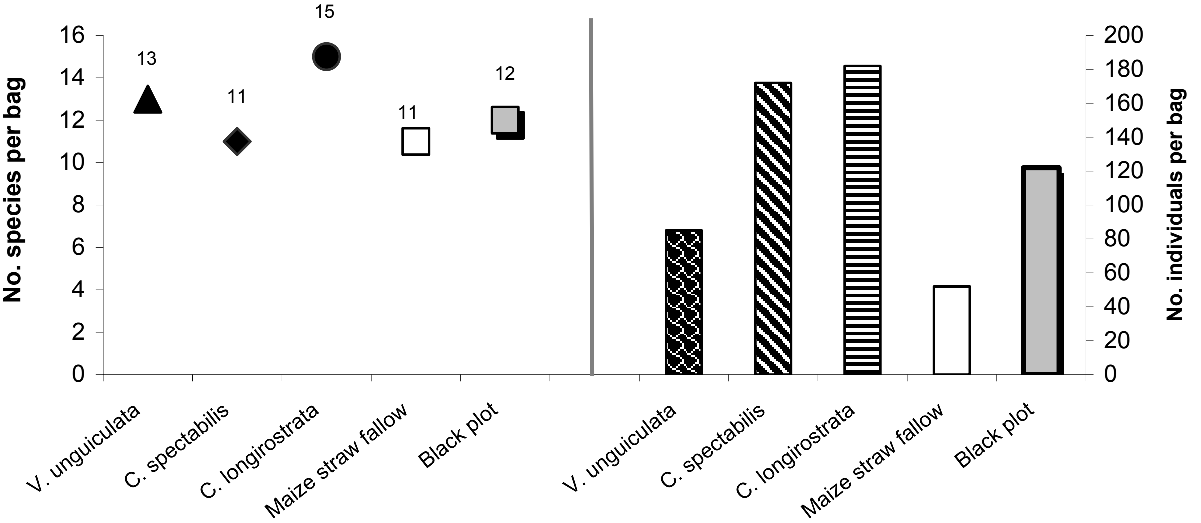


Figure 30: Effects of legume crops on the entomology dynamics in the rambutan orchard.

The insect abundance in the intercrops and the monocultures is represented by *Tabanus* spp., *Aedes* spp. and *Musca* spp.; which together achieve over 60% of the total abundance (Fig. 30 and Tab. A-14). Nevertheless, the *C. longirostrata* and *V. unguiculata* fields offer the highest diversity (13 and 15 species per bag). Eleven species are detected in the treatments with *C. spectabilis* and maize straw fallow (Fig. 30 and Tab. A-14). The vegetation of *Crotalaria* spp. and *V. unguiculata* offers habitat and food resources to the arthropods. For that advantage, the intercrops in Rambutan orchards enhance the diversity and structure of insects. Likewise, Pickett & Bugg (1998) report that farm management in view of increasing the presence of beneficial insects implies the establishment of food and habitat required by these species. Indeed, Jones and Guillet (2005) confirm that intercropped sunflower in organic systems attract beneficial insects and play an important role as a refuge for beneficial insects.

The difference of insect abundance between the evaluated systems was due to the dominance of mosquitoes and horseflies. In the chipilin plots (*C. spectabilis* and *C. longirostrata*), horsefly accounted for 46 (80 ind.) and 42 % (78 ind.) of the total abundance; likewise mosquitoes accounted for 32 (56 ind.) and 33% (61 ind) of the total population. However, in the fields with *V. unguiculata* and maize straw fallow, both insects accounted only for 45 and 22 % of total abundance.

On the other side, the attractive yellow flowers of chipilin contribute to attracting insects to the legume fields. Helenius (1998) reports that insect predators and parasitoids of crop pests can be influenced to take up residence within cropping systems by providing habitat for them. Nevertheless, by integrating one more crop in the rambutan orchard one changes insect diversity. These results support the hypothesis that crop diversification (by adding species) enhances abundance and structure of herbivorous insect's communities (Altieri, 1999). However, Koricheva (2000) remarks that plant diversity effects on the abundance of invertebrates are mostly indirect and mediated by changes in plant biomass and cover.

4.3.3 Conclusion

The diversity and structure of insects depend principally on the food resources and the required habitat. *Crotalaria longirostrata, C. spectabilis* and *Vigna unguiculata* are not only proven food resources, but also their flowers attract arthropods as well. In the field with *Crotalaria spectabilis*, the attractive and exuberant yellow flowers are the principal factor that attracts the insect population. The legume intercrops inside the fruit orchards enhance the diversity and abundance of the arthropods. Our results support the hypothesis that fields intercropped with *C. longirostrata* and *C. spectabilis* rows incorporated into the fruit orchard, exhibit greater insect densities. The flowering periods of *Crotalaria longirostrata* and *C. spectabilis* coincide with the mango and rambutan blooms. The bloom characteristics of chipilin can be an interesting alternative to improve the pollination quality and alleviate the ecological unbalance in the fruit orchards.

4.4 Productivity comparisons of different intercropping systems in fruit orchards

Mixed culture and different intercropping systems with leguminous and cereals is an old practice in tropical agriculture that dates back to ancient civilizations. The main objective of intercropping has been to maximise use of resources such as space, light, and nutrients (Li *et al*., 2003a; Franke, 1995; Morris and Garrity, 1993; Willey, 1990), as well as to improve crop quality and quantity (Mpairwe *et al*., 2002; Izaurralde *et al*., 1990; Nel, 1975) and soil fertility (Szott, 1987). Other benefits include water quality control through minimal use of inorganic nitrogen fertilisers that pollute the environment (Crew and Peoples, 2004). The current trend in global agriculture is to search for highly productive, sustainable and environmentally friendly cropping systems (Crew and Peoples, 2004). This has resulted into renewed interest in intercropping systems research (Vandermeer, 1989).

When two crops are planted together, interspecific competition or facilitation between plants may occur (Zhang *et al*., 2003; Vandermeer, 1989). For example, studies have reported that mixtures of cereals and leguminous produce higher grain yields than either crop grown alone (Dapaah *et al*., 2003; Mpairwe *et al*., 2002; Rao and Mathuva, 2000; Skovgärd and Päts, 1999; Watiki *et al*., 1993; Tariah and Wahua, 1985). In such crop mixtures, the yield increases were not only due to improved nitrogen nutrition of the cereal component, but also to other unknown causes where complementary plays a central role (Connolly *et al*., 2001; Nel, 1975). Nevertheless, opposite results were also found, where (maize-beans and maize x pumpkin intercrops) intercropping adversely affected the plant heights and circumferences of the component crops. In addition, the yield of the individual crop in each intercrop was depressed by intercropping compared with its sole yield. In maize-beans intercrop the maize yield was depressed by 15% and beans by 13% (Silwana and Lucas, 2002).

The Conservation Tillage is a system that has not received enough attention in the tropic. Such old system (conservation tillage) has been promoted as a productivity enhancing and resource conserving technology that benefits maize farmers. It enhances moisture use efficiency, prevents soil erosion (Scopel, 1994; Lal, 1989) and it results in higher and more stable maize yields, especially in areas where rainfall is low or scattered during the maize growing period. The same basic conservation principles are advocated by FAO under the concept "Conservation Agriculture" (http://www.fao.org/ag/ca/index.html).

In the Soconusco region, the maize system is based under the traditional management, called: Milpa or RTQ (**R**oza (weed slashing with machete) – **T**umba (Tree logging) – **Q**uema (incineration). Where the fields are slashing manually, burned and then sown using a bradawl (macana). In other cases, weeds are controlled with herbicide applications (Glyphosat or Paraquat), one week before sowing. Most farmers use local varieties and crop associations such as maize-bean or maize x pumpkin. Typically, the secondary crops are intercropped at irregular intervals between maize rows. This system has been maintained during centuries with very low yields (1.5 to 2.5 t ha^{-1}) and constant negative effects on the environmental resources. Results of a multivariate logistic model in Chiapas indicate, that the maize yields can be sorted out in three major classes: "good," "normal," and "poor" (respectively, 3.2, 2.3, and 1.5 t ha^{-1} on average) (Marroquín *et al.,* 2006; Marroquín and Pohlan, 2005; Erenstein, 1997).

4.4.1 Effects of intercropped systems on the maize productivity in the mango orchard

The complex interactions in legume/cereal cropping systems such as those used by traditional farmers have received little research attention in Mexico. In spite of agricultural intensification trends, intercropping remains a popular crop system among small-scale farmers in the tropics (Vandermeer, 1992; Gomez and Gomez, 1983; Ruthenberg, 1980). Farmers carry out intercropping because they see some advantages in the management of the intercrops. Some measures of disease control might be reinforced through intercropping (Messiaen, 1994). Competition between crops is reported to offer some solutions to weed control (Marroquín *et al*., 2007; Gamboa and Pohlan, 1997; Eiszner *et al.,* 1996; Schoonhoven and Voysest, 1993). In all agro-ecosystems, plant density is considered an important stress factor since, under such conditions the competition between different genotypes is very strong (Vafias *et al*., 2000b; Thomas *et al*., 1994; Fasoulas, 1993; Bonan, 1991; Tetio-Kagho and Gardner, 1988; Daynard and Muldoon, 1983). Spatial arrangement of crop components is one of the most important management factors that determine whether, an intercropping system can be advantageous or not (Dapaah *et al.,* 2003).

The results of mango orchard study demonstrate that the maize productivity in the first cycle was superior in the maize x pumpkin intercropped plots when compared with the sole maize plots (Tab. 9). Likewise, the average row number per maize ear (12.48) in the intercropped pumpkin plots is slightly better than in the sole maize plots (11.76 rows per ear) in the first year. Hence, the addition of a pumpkin intercrop did not reduce significantly maize yields, to the contrary. The maize x pumpkin intercropped plots 2 and 1 have the higher row numbers (13.16 and 13.26) whereas the sole maize plot 3 presents the lowest row number per maize ear (11.33) (Tab. 9). Average grain per row in the intercropped plots (28.31) was superior to that of the sole maize plots (26.85) (Tab. 9). The light, nutrient, and space competition in intercropped treatments appears to be stronger than in the sole maize treatments. However, the weight of 100 maize grains was not significantly different between treatments (intercropped plots 23.84 against 24.53 sole maize plots).

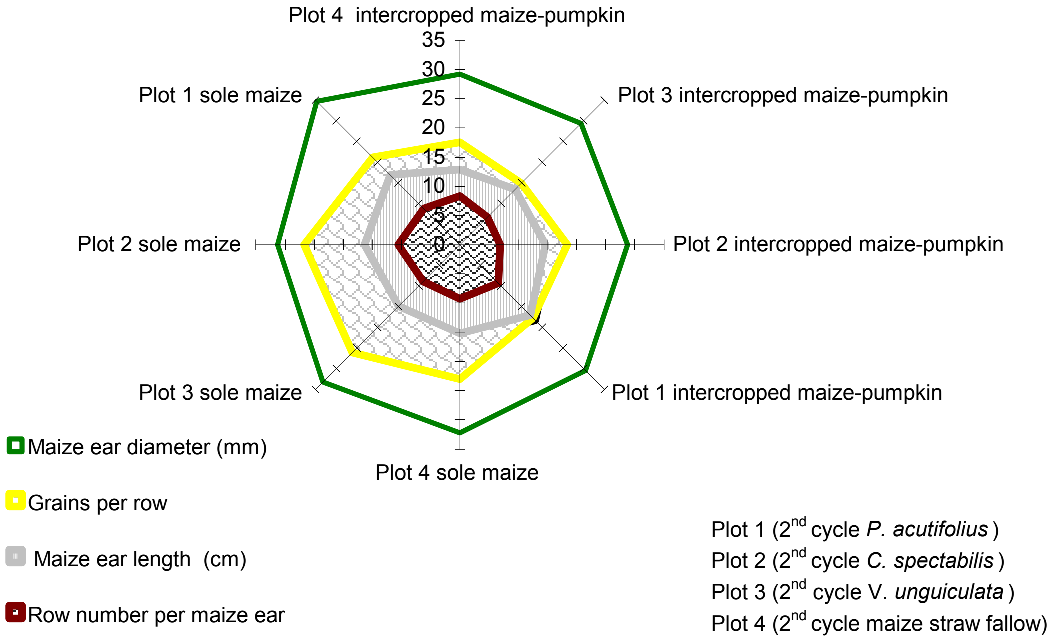
Table 9: Maize productivity in monoculture and intercropped maize in the mango orchard

Treatments (first cycle)	Yield parameters of maize at the first cycle (May-Aug/2005)			
	Yield (kg ha$^{-1)}$	Row number per maize ear	Grains per row	Weight of 100 grains (g)
Plot 4 (maize x pumpkin)	1729	12.16	25.86 ^{ab}	22.63 ^{a}
Plot 3 (maize x pumpkin)	1779	11.36	30.90 ^{bc}	22.73 ^{ab}
Plot 2 (maize x pumpkin)	2009	13.16	26.60 ^{ab}	26.36 ^{c}
Plot 1 (maize x pumpkin)	2145	13.26	29.90 ^{ab}	23.66 ^{ab}
Plot 4 (sole maize)	1722	11.86	24.20 ^{a}	24.36 ^{bc}
Plot 3 (sole maize)	1901	11.33	31.63 ^{c}	23.93 ^{ab}
Plot 2 (sole maize)	1858	11.86	26.43 ^{ab}	25.70 ^{bc}
Plot 1 (sole maize)	1851	12.00	25.16 ^{ab}	24.13 ^{bc}
$\overline{X}$ *Maize x pumpkin*	*1915*	*12.48a*	*28.31*	*23.84*
$\overline{X}$ *Sole maize*	*1833*	*11.76b*	*26.85*	*24.53*

Grains per row in the first year is significantly higher for sole maize plot 3 than for plot 4 (P=0.05). The sole maize plot 3 was significantly higher than all monoculture plots, but similar to intercropped plot 3. Nevertheless, the intercropped plot 2 presented higher 100 grain weight over all other plots, excepted for the sole maize plots 1, 2 and 4 (p=0.05) (Tab. 9).

The maize yield results demonstrate that the intercropped maize x pumpkin does not affect the maize production. In the first cycle (Tab. 9), the yield was higher in the maize x pumpkin intercropped plots than in the sole maize plots. The maize x pumpkin intercropped plot 1 obtained the highest yield (2145 kg ha^{-1}) and the sole maize plot 4 the lowest yield (1722 kg ha^{-1}). The maize productivity indicates that when mixing a maize genotype with other species, response could take advantage of small agro-climatic changes. Others authors document that the yield of the individual crop in each intercrop (maize-bean and maize - pumpkin) is depressed by intercropping, when it is compared with its sole yield (Silwana and Lucas, 2002). In intercropping studies it has been demonstrated that, the maize grain yield is reduced by 20% in one out of four seasons in the first cycle on maize x pumpkin intercropping (Mashingaidze, 2004).

The maize productivity in third cycle is different from the first cycle, as the plots with sole maize present better yield parameters than the plots with maize - pumpkin (Fig. 31). In the sole maize plot 1 (2nd cycle *P. acutifolius*) all variables are superior i.e. the highest grain number per row (26.73), the highest row number per maize ear (10.56) and the largest maize ear weight (111.58). To the contrary, the maize x pumpkin intercropped plot 3 (2nd cycle *V. unguiculata*) obtains the lowest performances for grains per row (14.9), row number per maize ear (6.63) and maize ear weight (60.86) (Fig. 31). Analyzing over all plots in the third cycle, the sole maize plots present higher differences w.r.t. all intercropped plots for all productivity parameters (P=0.05) (Fig 31). Finally, the grain per row average in the sole maize plots (24.24) is higher than that of the intercropped plots (17.14). The clear effects of intercropping on maize productivity demonstrate figure 31, where the legume crops effects are stronger on the intercropped crops. Comparison between first and third cycle demonstrates, that all plots during the third cycle present a productivity decrease. The sole maize plot averages diminishes by about 2.61 grains per row and by 2.4 rows per maize ear in the third cycle. In the maize x pumpkin intercrop, the reduction is even critical, reaching 11 grains per row and 4.69 rows per maize ear.



Treatments (<u>third cycle</u>)	Maize ear length (cm)	Maize ear diameter (mm)	Maize ear weight (g)	Row number per maize ear	Grains per row
Plot 4 intercropped maize x pumpkin	12.87 ^{a}	29.18 ^{a}	59.91 ^{a}	8.33 ^{ab}	17.53 ^{ab}
Plot 3 intercropped maize x pumpkin	13.40 ^{a}	29.36 ^{ab}	60.86 ^{a}	6.63 ^{a}	14.90 ^{a}
Plot 2 intercropped maize x pumpkin	14.67 ^{ab}	28.78 ^{ab}	63.9 ^{ab}	6.90 ^{a}	18.43 ^{ab}
Plot 1 intercropped maize x pumpkin	17.06 ^{b}	30.45 ^{b}	64.45 ^{ab}	9.30 ^{bc}	17.73 ab
Plot 4 sole maize	15.19 ^{ab}	32.18 ^{b}	77.99 ^{ab}	9.23 ^{bc}	23.00 ^{bc}
Plot 3 sole maize	14.90 ^{ab}	33.27 ^{bc}	85.00 ^{b}	8.76 ^{b}	21.13 ^{bc}
Plot 2 sole maize	16.37 ^{b}	31.29 ^{b}	97.42 ^{bc}	8.90 ^{bc}	26.1 ^{bc}
Plot 1 sole maize	16.94 ^{b}	34.74 ^{c}	111.58 ^{c}	10.56 ^{c}	26.73 ^{c}
$\overline{X}$ *Maize x pumpkin*	*14.50*	*29.44*	*62.28*	*7.79*	*17.15*
$\overline{X}$ *Sole maize*	*15.85*	*32.87*	*93.00*	*9.36*	*24.24*

Figure 31: Maize yield parameters in monoculture and intercropped maize in mango orchard.

Cucurbita maxima is a plant that quickly develops a very good soil cover and provokes a strong competition for space and light. This is the case of intercropped plots, where the pumpkin competes severely with maize growth, achieving a plant height of 1.86 m in the intercrops versus 2.54 for the sole maize. On the other hand, the legume biomass has beneficial effects on soil fertility, humidity, and microbiology. These effects together provoked different response patterns of the maize genotypes. It demonstrates the sensibility of the maize genotypes to the environmental change. Other studies have demonstrated that maize grain yield decreases with an increase in maize density from 30,000, 36,000, and 42,000 plants ha^{-1}, whereas weed growth decreases with increasing maize density (Mashingaidze, 2004). Other authors found that, when crops of mustard (*Sinapis alba* L.), pea (*Pisum sativum* L.), and lentil (*Lens culinaris* Medik.) precede winter wheat, wheat yield is sometimes higher after pea and lentil, but not always. Moreover, response to N fertilizer is greatest following mustard (Guy and Gareau, 1998).

In the third cycle, maize yield decreases in all intercropped treatments, whereby intercrop plot 1 (2nd cycle *P. acutifolius*) even decreases from 2145 to 1463 kg ha^{-1}. Similar tendency is noticeable in all intercropped plots in the third cycle (Fig. 32). Within the intercrops, the differences between treatments in the third cycle are only marginally significant, whereby highest performance is recorded for the fourth treatment (2nd maize straw fallow). To the contrary, no differences are recorded between plot treatments for the sole maize plots (P=0.05).

In the third cycle, the average maize yield in the sole maize plots (1831 kg ha^{-1}) is higher than in the intercropped plots (1262 kg ha^{-1}) (Fig. 32).

In full-input studies Vafias *et al*., (2006) have found a significant interaction between genetic materials and plant densities, meaning that different materials respond in a different way under density stress. Yields of cereals are generally similar between the tillage treatments, but when problems occur with weed control, rodent feeding or with plant densities; the no-till (NT) treatment usually endures a more negative impact. Most varieties and environments do not show an interaction with tillage, but in some cases, certain varieties perform better (Guy and Wu, 2003). The same results were found in this study, where the competition between pumpkin-maize decreases maize yield.

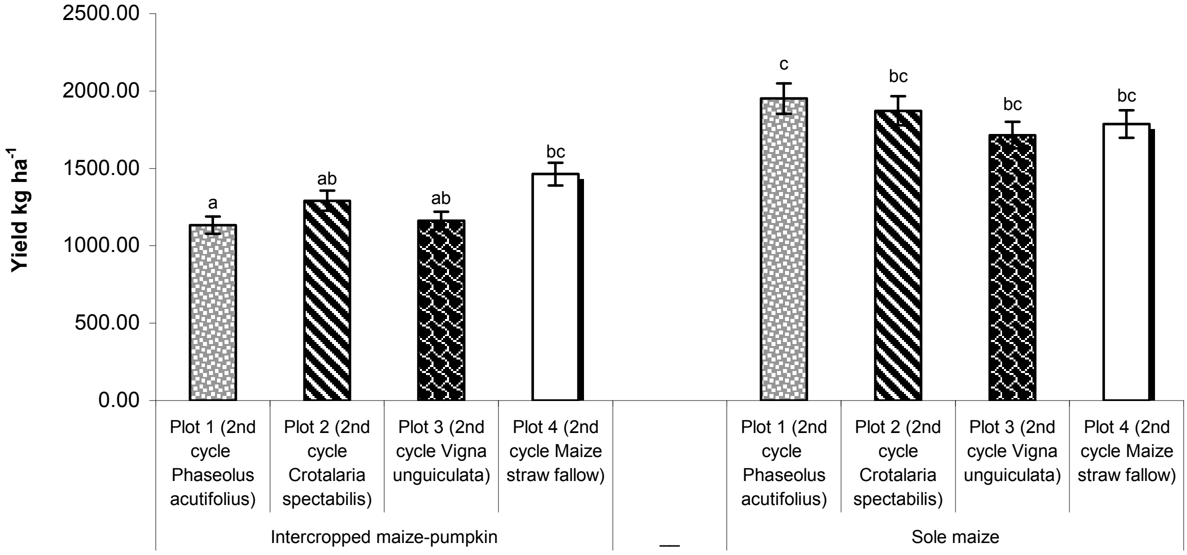


Figure 32: Effects of different intercropping systems on the maize yield (3rd cycle).

In the third cycle, the pumpkin biomass production (1130 kg ha^{-1}) is higher than in the first cycle (128 kg ha^{-1}). The vegetative growth of pumpkin provokes a strong space and light competition with maize crop, resulting in poor maize yield. This is a reason enough for many farmers to prefer monocultures instead of crop mixtures (Fasoulas, 1988). Although the *Crotalaria spectabilis* biomass is high in the second cycle (11004 kg ha^{-1}), the effects of this biomass are not reflected on the maize yield (2nd cycle *C. spectabilis*).

4.4.2 Effects of intercropping systems on the maize productivity in rambutan orchard

In Mexico, the rambutan fruit is not well-known, but it has a great potential for its establishment and development in the Soconusco, Chiapas, owing to the good agro-ecological conditions for the production of this fruit. Currently there are already some small plantations with a good adaptation and a rewarding yield (Vanderlinden, 2003*)*. In the Soconusco, the small-scale rambutan farmers maintain the plantation under a monoculture system, leaving inter-rows unused by weeding either chemically or mechanically. However, the inter-row space in young rambutan orchard can be exploited with annual crops. The intercropped models might be integrated in such fruits orchards to improve the fruit productivity and the farmer's income, achieving better ecosystem stability. For example, experiments in Colombia with maize-beans (*Phaseolus vulgaris* L.) (Francis & Sanders, 1978) and in India with sorghum (*Sorghum bic*olor L.) - pigeon pea (*Cajanus cajan* L.) (Rao & Willey, 1980) suggest that cereal-legume intercrops are more stable than sole crops. This concept of Eberhart & Russell (1966) is internationally well accepted and can be applied to these systems to develop stable cropping (Thiaw *et al*., 1993). In a similar study, Wahua (1985) found that intercropping reduces morphological parameters like the number of branches of melon, number of leaves and leaf area per plant. Likewise, intercropping reduces both height and circumference of maize and bean. However, when weeding is not carried out, the maize and bean grow taller due to competition for light between crops and weeds (Silwana and Lucas, 2002).

The rambutan orchard studies show that maize productivity is similar in both treatments (maize x pumpkin intercropped plots and sole maize plots). The row number per maize average in the first cycle is 12.27 for the intercropped plots, whereas, the sole maize plots produces 11.89 rows per maize ear (Tab. 10). A similar case is presented for the variables grains per row and weight of 100 maize grains, where the maize x pumpkin intercrops produce higher results than the sole maize plots. The grain per row average is non-significant, whereby plot 2 is definitely superior in both treatments (intercropping and sole maize). The maize x pumpkin intercrop 1 offers a higher 100 grain weight as compared to that of the sole maize plot 4 (19.20g – Tab. 10).

Table 10: Maize productivity in monoculture and intercropped maize in rambutan orchard

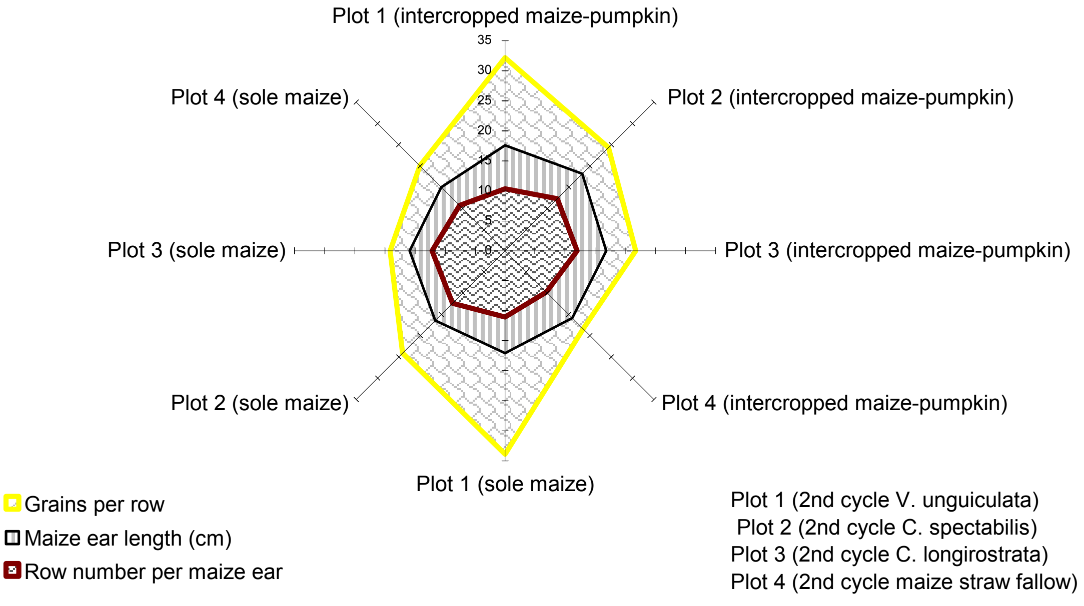
Treatments (first cycle)	Yield parameters of maize at the first cycle (May-Aug/2005			
	Yield (kg ha^{-1})	Row number per maize ear	Grains per row	Weight of 100 grains (g)
Plot 1 (intercropped maize x pumpkin)	2210	13.16	24.10 ^{a}	24.23 ^{c}
Plot 2 (intercropped maize x pumpkin)	1826	11.30	32.06 ^{b}	23.03 ^{bc}
Plot 3 (intercropped maize x pumpkin)	2059	11.40	24.06 ^{a}	23.96 ^{bc}
Plot 4 (intercropped maize x pumpkin)	2034	13.23	24.26 ^{a}	21.26 ^{b}
Plot 1 (sole maize)	1834	12.53	24.66 ^{a}	19.43 ^{a}
Plot 2 (sole maize)	1859	11.66	32.63 ^{b}	22.76 ^{bc}
Plot 3 (sole maize)	2059	11.66	24.20 ^{a}	22.63 ^{bc}
Plot 4 (sole maize)	1609	11.70	22.33 ^{a}	19.20 ^{a}
$\overline{X}$ *Maize x pumpkin*	*2032*	*12.27*	*26.12*	*23.12*
$\overline{X}$ *Sole maize*	*1841*	*11.89*	*25.96*	*21.01*

In the intercropped treatment, plot 2 has a superior number of grains per row (32.06). Equally, the sole maize plot 2 is higher (32.63) than all sole maize plots. The opposite case was presented with the sole maize plot 4 (22.33), showing a lower number of grains per row. Nevertheless, the difference between plots 1, 3, and 4 in both treatments is not significant (Tab. 10). The maize yield is similar in both treatments, although the maize –pumpkin intercropped plot 1 (2210 kg ha^{-1}) presents the highest yield and the sole maize plot 4 the lowest yield (1609 kg ha^{-1}). Nevertheless, the average difference between plots is not significant indicating that pumpkin does not affect maize yield significantly.

The maize productivity in the third cycle other time is similar in both treatments. The intercropped plot 2 shows the highest row number (12.24), whereas, the intercropped plot 4 presents the lowest value of row number (9.76) and grains per row (18.40). In both treatments, plot 4 produces the lowest values in productivity and plots 1 and 2 produce the best productivity parameters.

Difference between treatments is highly significant in both treatments, where plot 2 produces better than plots 3 and 4 for maize ear length and row number parameters (Fig. 33). However, plot 1 shows higher significance in both treatments on all plots for grains per row (Fig. 33). It demonstrates that the biomass of the *C. spectabilis* and *V. unguiculata* produces strong effects on soil fertility, eventually improving maize productivity. Figure 33 shows clearly, that the plots with legumes produce higher maize productivity than the control plot. Other authors report that planting maize with sugar bean (*Phaseolus lunatus*) or groundnut is a disadvantage to the grain legumes, but beneficial to maize. Intercropping groundnut with maize would be advantageous to the small-scale farmer in terms of increased maize yields, higher combined crop yields per ha, and increased weed suppression (Thwala *et al*., 2004). Likewise, Guy and Wu, (2003) found, that when maize was combined over varieties and conservation tillage (CT), CT produces 5 370 kg ha^{-1} and No Tillage is slightly lower at 5 170 k ha^{-1}. However, in other studies the yield of intercropped maize decreased with increasing number of soybean rows across all environments. Excessive soybean population density due to high number of rows resulted in decreased yield of maize (Dapaah *et al.,* 2003). Likewise Quainoo *et al*. (2000) obtained similar results in maize or sorghum intercropped with soybean. In contrast, Monhta & De (1980) found that the yields of maize or sorghum were not affected by intercropping with soybeans when arranged in either single or double rows.

However, the maize productivity in intercropped maize x pumpkin is slightly lower than sole maize systems. Indeed, light and space competition between maize and pumpkin is the factor for diminishing maize productivity. The high plant density per area provokes more competition among plant species. The climbing growth habitat and the quick soil cover of the pumpkin are the factors that impede on maize growth and lower productivity in this study. In other researches, the maize grain yield decreases with an increase in maize density and/or weed growth in a semi-arid location in Zimbabwe (Mashingaidze, 2004).



Treatments (third cycle)	Maize ear length (cm)	Row number per maize ear	Grains per row
Plot 1 (intercropped maize x pumpkin)	17.58 ^{bc}	10.34 ^{ab}	32.16 ^{c}
Plot 2 (intercropped maize x pumpkin)	18.16 ^{c}	12.24 ^{c}	24.32 ^{b}
Plot 3 (intercropped maize x pumpkin)	16.85 ^{ab}	12.00 ^{bc}	21.76 ^{ab}
Plot 4 (intercropped maize x pumpkin)	15.80 ^{ab}	9.76 ^{a}	18.40 ^{a}
Plot 1 (sole maize)	17.05 ^{bc}	11.02 ^{ab}	33.90 ^{c}
Plot 2 (sole maize)	16.47 ^{ab}	12.34 ^{c}	24.06 ^{ab}
Plot 3 (sole maize)	15.88 ^{ab}	12.14 ^{bc}	19.12 ^{ab}
Plot 4 (sole maize)	15.00 ^{a}	10.68 ^{ab}	20.04 ^{ab}
$\overline{X}$ *Maize x pumpkin*	*17.10*	*11.09*	*24.16*
$\overline{X}$ *Sole maize*	*16.10*	*11.55*	*24.28*

Figure 33: Maize yield parameters in intercropped maize in the rambutan orchard.

Nowadays, the leguminous crops play an important roll on soil fertility conservation. It is the reason, why the maize-beans intercrops are still widely practiced by many farmers. Figure 34 demonstrates how the legumes improve maize yield. Indeed, *Vigna unguiculata* and *Crotalaria spectabilis* (2^{nd} cycle) produce biomass yield increases in the third cycle. It is the reason, why plot 1 and 2 produce higher yield in both treatments during the third cycle. To the contrary, plot 4 (control) presents the lowest yield in both treatments (1617 and 1726 kg h^{-1}). Only plot 1 (intercropped maize x pumpkin and sole maize) produces significantly higher in both treatments over the other 3 plots (P=0.05). In studies of mixed ratios (bean and maize sole crop and 2 lines maize + l line bean, 2 lines bean + 1 line maize and 2 lines maize + 2 lines bean), Vahdettin *et al.* (2006) reported non-significant differences between cropping systems, except for maize grain yield. Here the highest grain yield was found in sole cropping systems for both crops.

The figures 32 and 34 (Maize yield in mango and rambutan orchard) show, how the maize genotype (Tuxpeño) responds differently to the agro-climatic conditions. Likewise, pumpkin presents different patterns of response to agro-climatic change, presenting a better growth and productivity in the mango orchard (clay soil) than in the rambutan orchard (silt soil). However, in other studies the yield of intercropped maize decreased with increasing number of soybean rows across all environments.

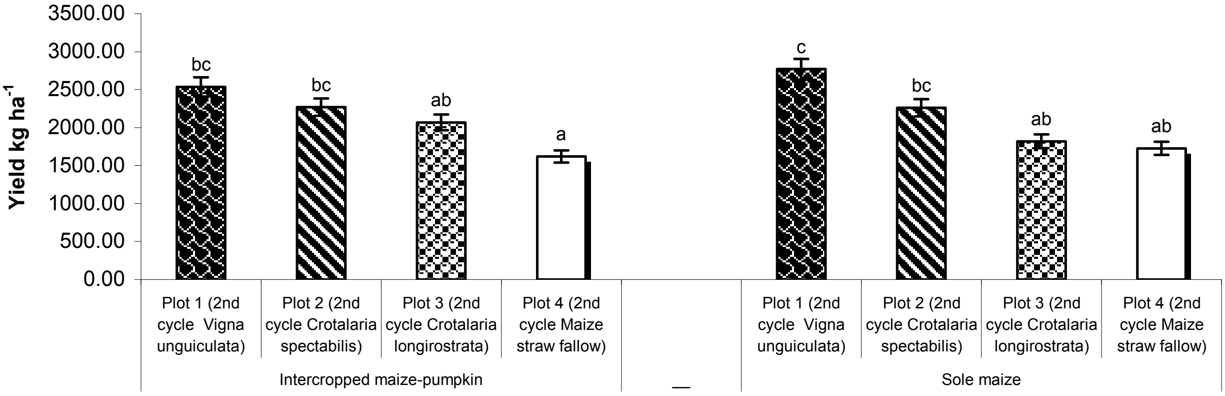


Figure 34: Effects of intercropping systems on maize yield (3^{rd} cycle) in the rambutan orchard.

4.4.3 Effects of maize x pumpkin intercropping on the pumpkin yield in fruit orchards

Based on differences in phenological characteristics of species in mixtures, the interactions among them may lead to an increased capture of a limiting growth resources (Silwana and Lucas, 2002; Ofori and Stern, 1986; Horwith, 1984; Mead and Willey, 1980; Willey, 1979; Willey and Osiru, 1972) and then accrue higher total yield than the cumulative production of those species if they were grown separately on an equivalent land area (Dapaah *et al*., 2003; Olufemi *et al*., 2001; Rao and Mathuva, 2000). Since the pre-hispanic cultures, the pumpkin (Spanish “Calabaza”) has been cultivated under maize x pumpkin mixed systems. Moreover, the researchers have given little importance to such maize culture. Normally the existing literature refers to *Cucurbita moshata* or *Cucurbita pepo*, rarely to *Cucurbita maxima*.

One of the main objectives of this study was determining the effect of pumpkin on the dynamics of weed communities inside fruit orchards. Nevertheless, the pumpkin productivity was very attractive to supplement the economic income of the maize and fruit farmers. This study demonstrates the importance of pumpkin on the productivity of whole fruit agro-ecosystem. The pumpkin productivity in mango orchards was higher in the plots, which has in the 2° cycle prevous legume cover crops than without leguminous. Very important for the commercial aspects were the higher number of fruits per area, especially harvest in the plots with *P. acutifolius* (Fig. 35).

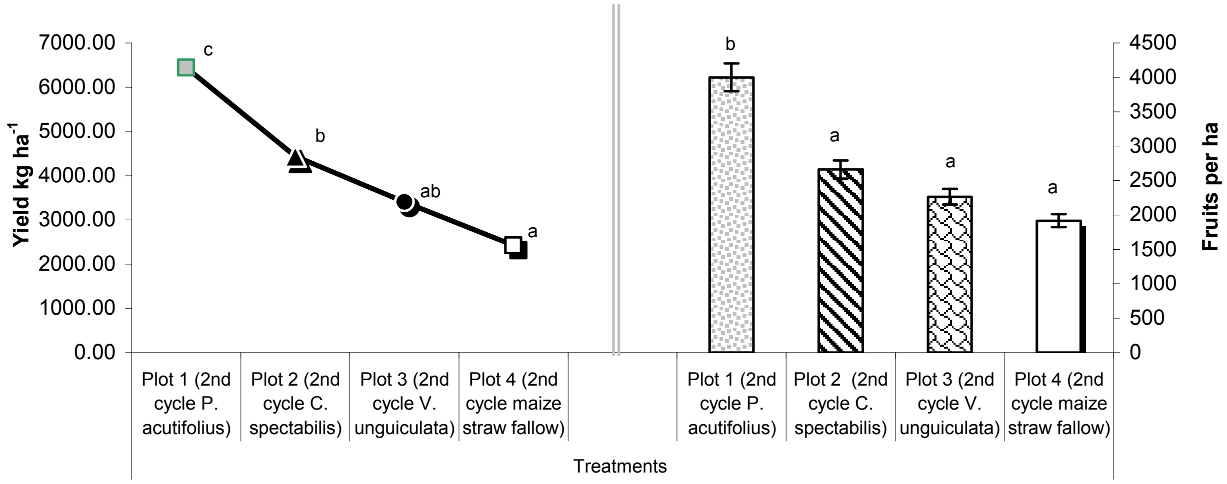


Figure 35: Effects of intercropping on the pumpkin yield in the mango orchard.

The plot 1 after *P. acutifolius* rotation (2nd cycle) produces the major number of fruits (4001 fruits ha^{-1}) and pumpkin yield (6447 kg ha^{-1}). In second place is the plot 2 (2nd cycle *C. spectabilis*) with 2662 fruits per ha and 4438 kg ha^{-1}. The control plot 4 (2nd cycle maize straw fallow) presents the lowest yield (2426 kg ha^{-1}) and lowest number of fruits per area (1917) though. The biomass production and their incorporation into the soil and the better ecological balance of legume crops enhanced productivity increase. It is the reason, why plots 1 and 2 performed better than plots 3 and 4. Both for yield and fruit number, plot 1 (*P. acutifolius*) presents higher significant differences on the other plots (P=0.05). In the rambutan orchard, the tendency of pumpkin productivity was similar to that in the mango orchard. In rambutan orchard the legume crops rotation produced positive effects on the yield and number of pumpkin fruits, culminating in plot 2 with the highest yield (5364 kg ha^{-1}) and the major number of fruits (2893 ha^{-1}). At the opposite, plot 4 (2nd cycle maize straw fallow) presents lowest pumpkin productivity (1309 kg ha^{-1} and 752 fruits per ha). Plot 2 produces significantly better than plot 3.

In both research places, the legume crops present strong effects on the pumpkin yield. The traditional maize x pumpkin system maintains similar productivity, and keeps a similar productivity in spite of the leguminous cover crops. Likewise, studies demonstrate, that there exists a quadratic effect of plant population growth upon yield (fruits per acre), with maximum yield occurring at 908 plants per acre of pumpkin (Cushman *et al*., 2001). Mashingaidze (2004) found than maize x pumpkin and maize-bean intercropping reduce weed biomass by 50-66% when established at a extremely high density of 12 300 pumpkin plants ha^{-1}, equivalent to 33% of the maize density (37 000 plants ha^{-1}), and 222 000 bean plants ha^{-1}. Pumpkin densities lower than 33% of the maize density failed to reduce weed biomass more than that achieved by sole maize. Thus, mixed culture systems between cereals and leguminous or cereals and cucurbitaceae might help to understand a complex series of inter- and intra-specific interactions (Marroquín *et al*, 2006a; Li *et al*., 2003b; Evans *et al*., 2001; Giller and Cadisch, 1995; Izaurralde *et al*., 1990) induced by modifications of light, water, nutrients, enzymes and weed abundance. More studies are needed to quantify such interactions in different cereal-legume-cucurbitaceae mixtures.

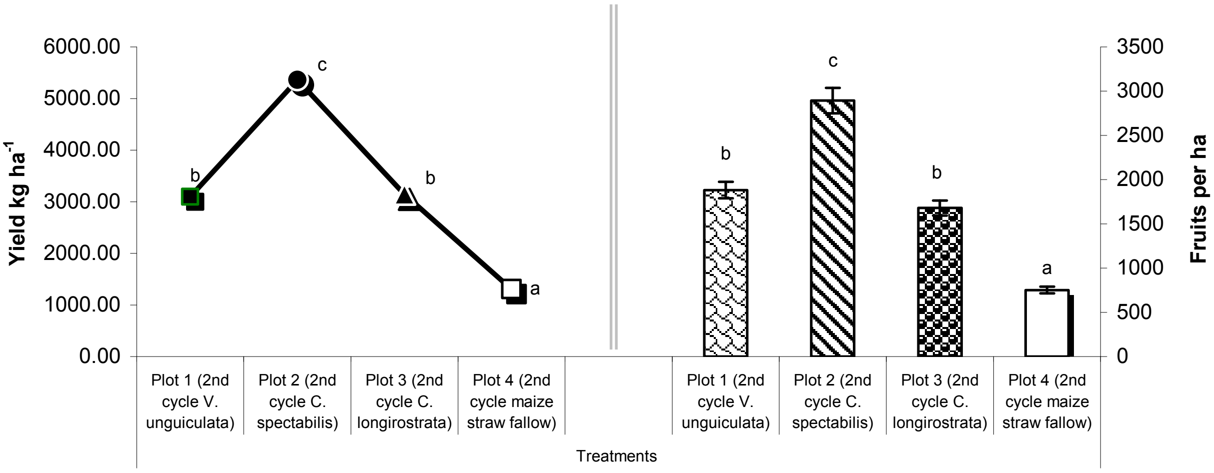


Figure 36: Effects of intercropping on the pumpkin yield (3rd cycle) in the rambutan orchard.

The traditional fruit orchards in the Soconusco present a strong ecological instability, caused by the management of the monoculture system. The damages of pests and diseases are beyond the economic threshold and it is difficult for establishing new crops in these fruit orchards. These micro-environmental problems are reflected on the pumpkin growth in the first cycle, where pumpkin biomass reaches only 0.12 t ha^{-1} in the mango orchard. Nevertheless, the integration of intercropped maize-leguminous during the second cycle induces several effects during the subsequent cycles of the rotation systems. These give more ecological stability and better growth of pumpkin in the third cycle, achieving a vegetative biomass production of 1.13 t ha^{-1} (without fruits). It is the fundamental reason, why plots with previous leguminous cover crops offered higher productivity subsequently (Fig. 35 and 36).

4.4.4. Effects of previous intercrops on the cowpea productivity

Cowpea (*Vigna unguiculata* L. Walp.), an annual legume, is also commonly referred to as southern pea, black-eye pea, crowder pea, lubia, niebe, coupe or frijole. Cowpea originated in Africa and is widely grown in Africa, Latin America, Southeast Asia, and in the southern United States (Davis *et al*., 2001). Cowpea is grown for both grain and fodder exhibiting wide range of variability. The addition of even a small amount of cowpea improves the nutritional balance of the diet and enhances protein quality. Cowpea is equally important as a nutritious fodder for livestock (Sheela Mary and Gopalan, 2006). The nutritive value of cowpea grain, leaves, and haulms is very high. The crude protein content is 5 and 23% in the fresh and dry leaves, respectively (Aravindhan and Das, 1995). In Africa, *Vigna unguiculata* is considered the second most important grain legume (Purseglove, 1974). For that reason cowpea is one of the important food legumes and a valuable component of the traditional cowpea -sorghum and pearl millet intercropping systems (Davis *et al*., 2001). In Uganda, the crop is grown predominantly in the northern and north - eastern parts of the country, i.e., in Tororo, Pallisa, Kumi, Soroti, Lira, Nebbi and Arua (Sabiti *et al*., 1994). However, the few cowpea varieties grown in the African countries are landraces with low yield potential (Adipala *et al*., 1997). Worldwide cowpea production has increased dramatically in the last 25 years. Nevertheless, the cowpea yield is very low in tropical countries. In Africa, the average cowpea yield in farmer fields ranges from 0.2 - 0.5 t ha^{-1} (Ndiaye, 2007). Likewise, United States production of dry cowpea has declined from 3/4 million acres to a few thousand over the same period (Davis *et al.,* 2001). Average yield data for cowpea grown in Texas, 1978 and 1979 respectively, showed significant variability, ranging from 625 and 1400 lb/acre for green cowpeas and 570 and 1000 lb/acre for dry seed (Davis *et* *al*., 2001). Among small farmers in the semi-arid tropics and tropical areas, annual cotton is commonly intercropped with food crops, such as cowpea and maize (Beltrão *et al*., 1986; Morgado & Rao, 1985; Zaffaroni & Azevedo, 1982; Barreiro Neto *et al*., 1981). Such intercrops are important sources not only of seed yield but also of biomass, which may be used as forage for animals. When the component crops (legume-cereal) are present in approximately equal densities, the more aggressive crop, usually the cereal (Willey & Osiru, 1972), often determines production. Yield is a result of complex traits, and it is difficult from correlations alone to determine which traits or factors contribute more to grain yield. Yield information from warmer climates, where one crop has been grown successfully, does not necessarily indicate a performance level that might be realized in other regions (Willey & Osiru, 1972).

On the other hand, Cowpea diseases constitute the most important constraint to profitable cowpea production in all agro-ecological zones, where it is cultivated. Among the fungal diseases, brown blotch (*Trichoderma viride*) is the most devastating one with yield losses of about 46% in Northern Nigeria (Alabi, 1994), reaching 75% though in wet years in the same area (Emechebe and Shoyinka, 1985). In the forest ecological zones, the yield loss could be as high as 85% (Shoyinka *et al*., 1997). Likewise, charcoal rot (*Macrophomina phaseolina*) causes on average a yield loss of 10%, which is equivalent to 30 000 t cowpea - an estimated value of US$ 146 million for Niger and Senegal alone (Ndiaye, 2007). Solarisation, addition of organic matter, maintenance of high soil moisture, fumigation and use of bio-control agents have shown to be potential methods for control of cowpea disease pathogens (Davis *et al.,* 2001).

Cowpea yield information from Mexico is very weak, even where the cowpea crop has been grown successfully. In the Soconusco, Chiapas, the cowpea crop is relatively new, where the farmers confound it with *Phaseolus* spp. beans. The bean confusion expresses also the possibility of cowpea to thrive in the Soconusco region. The agro-ecological conditions in such area might be an appropriated habitat to diminish the abiotic and biotic effects like pest and disease damage, as well as water stress. For example in West Africa, the most limiting factors for crop growth are water and nutrient stresses. Water stress also reduces leaf production and promotes senescence and abscission (Karamanos, 1980). Consequently, seed production, which is positively correlated with leaf area (Rawson and Turner, 1982), may also be reduced by water stress. For that reason, in Africa the average cowpea yields in farmers fields are low (Ndiaye, 2007).

Mango orchard

Results of the present study demonstrate good adaptation of cowpea as a cover crop option on residual moisture in the Soconusco area. The dry grain yield is higher in the plot with previous intercropping systems than in sole maize (Tab. 11). The cowpea yield in plot with previous intercropped maize x pumpkin is 222 kg ha^{-1} higher than the sole maize treatment (Fig. 37). The yield difference between intercropped plots and sole maize plots is significantly higher (Table 11). Dry grain yield is clearly correlated with the other plant traits i.e. yield components (plant population, pod number per plant, seed number per plant). The previously intercropped plot dominates with 1.96 pods more per plant on the previously sole maize plot. The intercropped plot has a similar tendency in seed number per pod, having about 0.34 seeds more per pod than the sole maize plot. It confirms the Path coefficient analysis, developed by Wright (1921, 1923) and which determines the significance of correlations between yield components and assigns relative importance to yield relations (McGiffens *et al*., 1994). Likewise, the highly positive correlation between number of seeds per pod and pod length indicates that with longer pods more space is provided for seeds (Sabiti *et al*., 1994). Other studies suggest that 100 - seed weight was indirectly influenced by the positive effects of seeds per pod, plant height and branch number (Nakawuka and Adipala, 1999). According to Jackai (1995), the highest contributors to seed yield appear to be branch number, pod number, and seeds per pod, although earlier research showed, that seed size is a primary determinant of yield in cowpea (Obisesan, 1985; Imrie and Bray, 1983).

Table 11: Effects of previous intercrops on the cowpea productivity in mango orchard

Treatments (third cycle)	Yield parameters of cowpea in the second year (fourth cycle)				
	Yield (t ha $^{-1}$)	Plant number per m ^{2}	Pod number per plant	Seed number per pod	Cowpea pod length (cm)
Plots 3 (Previous intercropped maize – pumpkin)	1570 ^{b}	8.80 ^{b}	14.40	13.00	17.92
Plot 3 (previous sole maize crop)	1348 ^{a}	6.90 ^{a}	12.44	13.34	18.50

P=0.05

The high productivity of the plot with previous intercropped maize –pumpkin is attributed to better soil humidity and availability of soil nutrients (Fig. 37). The pumpkin cover provokes increase of field capacity, which in turn enhances microbiological activities and soil mineralization. For that reason the plot with previous intercropped maize – pumpkin shows higher productivity. The water stress in the previous sole maize plots provokes productivity loss of the subsequent cowpea. Studies in the Sahelian region indicated also that on sandy soil substantial increase of cowpea yield could be achieved by soil amendment with six tons of compost ha $^{-1}$. An even greater yield increase is achieved by soil amendment with six t of compost and 50 kg NPK ha $^{-1}$ or 3 t ha $^{-1}$ of compost augmented by a bio-agent as *Clonostachys rosea (*Ndiaye, 2007).

Population density (number of plants per m ^{2}) is the most important crop parameter to analyze crop adaptation and ecological equilibrium. Plant density of cowpea after the sole maize plot is lower, expressing the deleterious effects of diseases and pests resulting from poor agro-ecological buffering. The cowpea population in the plot previously intercropped with maize – pumpkin is higher than when preceded by sole maize. The intercropped plot has about 1.9 plants per m ^{2} more than the sole maize plots. Likewise, field observations confirm higher presence of aphid population in the sole maize plot conveying a higher associated streak virus damage. Cowpea yield losses due to virus infection have been variously estimated between 10 to 100% (Raheja *et al*, 1974; Shoyinka, 1974). Out of more than 20 viruses reported on cowpea from different parts of the world (Brunt *et al*., 1990; Thottappilly and Rossel, 1985), nine are known to infect the crop naturally in Nigeria (Taiwo, 2003; Taiwo and Shoyinka, 1988)

Rambutan orchard

Estimates of the amount of N fixed biologically by cowpea range from 73 to 354 kg N/ha per year (FAO, 1984), some of which may be available to succeeding crops. Those characteristics can be approached in the fruit orchards like rambutan or mango. Cowpea offers an extra economic income for the farmers. For example, it is particularly important in West Africa with over 9.3 million t of annual production (Ortiz, 1998).

Under the rambutan orchard conditions, cowpea produces similar yield as in the mango orchard. The cowpea dry grain yield in the plot with previous intercropped maize – pumpkin is superior to the sole maize plot. The intercropped plot achieves a grain yield of 1479 kg ha $^{-1}$ versus 999 kg ha $^{-1}$ in the sole maize plot (Tab. 12). Likewise, pod number per plant in the plot with previous intercropped maize x pumpkin is higher than in the sole maize plot. The maize – pumpkin intercropped plot shows 1.1 pods more than in the sole maize plot. The pod number difference between treatments is not significant. However, the yield difference between both treatments is significantly higher for the maize – pumpkin intercropped plot. The seed per pod and pod length traits are similar in both treatments. Nevertheless, the plant density in the maize x pumpkin plot is higher than in the previous sole maize plot (Tab. 12). The grain yield in this study presents a positive correlation between pods per plant, seeds per pod and plant density. The cowpea productivity difference of the maize–pumpkin intercrop also produces a higher grain yield than that of the sole maize plot.

Table 12: Effects of previous intercrops on the cowpea productivity in rambutan orchard

Treatments (third cycle)	Yield parameters of cowpea in the second year (fourth cycle)				
	Yield (kg ha^{-1})	Plant number per m^2	Pod number per plant	Seed number per pod	Cowpea pod length (cm)
Plot 3 (previous intercropped maize – pumpkin)	1479 ^{b}	6.30 ^{b}	11.30	13.90	18.34
Plot 3 (previous sole maize crop)	999 ^{a}	4.10 ^{a}	10.20	13.90	18.56

P=0.05

The results of this study indicate that the agro-ecological conditions previously intercropped with maize - pumpkin offer a better habitat for the cowpea crop (Fig. 37). The lower soil humidity in the sole maize plot is the limiting factor, hence reducing mineralization and incorporation of biomass. Fortunatly in the Soconusco parasitic weed like Striga are not present, which under other site in Africa, have been reported yield losses associated with weed infestation (*Striga* spp.) to range from a few kg ha^{-1} to total crop failure cowpea (Atokple *et al.,* 1993; Obilana 1987). Older studies affirm that cover crops may fulfil several purposes in production systems (Bunting & Milsum, 1928).

Figure 37: Intercropped maize x pumpkin (left) and cowpea (right) in the mango orchard.

4.4.5 Conclusion

The maize x pumpkin intercropping rotation system affects the productivity of maize, only when the pumpkin plants manage climbing on the young maize plants at a very early growth stage. The intercropped maize –pumpkin can reduce up to 31% the maize yield. Likewise, the yield parameters are affected by intercropped maize x pumpkin. Pumpkin plants can repress also the maize plant growth and stem diameter.

In the first cycle, the pumpkin crops achieve less growth than in the third cycle, because the effects of intercrops on maize yield in the 3 cycle are stronger. The previous intercrops with leguminous crops in the maize fields can increase maize yield up to 41%. Thus, the legume treatments (scenarios) convey higher maize yield than the maize straw fallow.

The pumpkin yield is higher in the fields with previous leguminous rotation that in the maize straw fallow field. The integration of legume successions (scenarios) after the first cycle improves the ecological condition so that the third cycle pumpkin achieves a better growth, as much as 100% higher than for maize straw fallow treatments. The maize – pumpkin previous crop offers better condition for the subsequent cowpea growth scenario. The soil humidity and nutrient availability in the previous intercropped treatments result in a 48% cowpea grain increase when compared with maize monoculture.

Intercropped maize – pumpkin systems and legume crops like *V. unguiculata and Crotalaria longirostrata* and *C. spectabilis* are the scenario models that offer various possibilities to improve the economic income to the fruit farmer of the Soconusco, Chiapas.

4.5. Biomass production of the integrated crops in the fruit orchards

The value of legumes in crop rotations has long been recognized, but its use as green manure in cropping systems has declined due to the availability of low-cost synthetic N fertilizers (Badaruddin, 1990). Nowadays, soil fertility decline is one of the major constraints of production and food security in the tropical region. Earlier on, farmers attempted to integrate green manure legumes in the maize systems, but due to very high opportunity costs of land and labour to grow extra leguminous cover crops at the expense of food crops it was not successful (Amede and Kirkby, 2004; Fischler *et al*., 1999). On the other side, the fallow period required to replenish the soil productivity has been shortened. The primary function of soil productivity and fertility restoration through fallow is less effective, since intensive cropping is now more common (Ayoola and Makinde, 2007). Soil fertility breaks down due to continuous cropping with little or no external inputs and removal of crop residues. Eventually, soil productivity becomes unsustainable. The problem can be alleviated by inclusion of legumes in crop rotations and retention of their crop residues.

The intercropping system, especially with leguminous crops offers an interesting potential of biomass production. It is dependent on intercropped species and agro-ecological conditions. Differences among species were found in studies of grass biomass production. Indian grass, switch grass, and little bluestem were more productive on average (661.5 g m^{-2}) than big bluestem or side-oats grama, which averaged 424.1 g m^{-2}. However, there were no significant differences in productivity among the top three species (Wilsey, 2007). In other studies, vetch biomass yield was reduced by intercropping with maize according to year, regardless of varieties (Amede *et al*., 2005). Others authors suggest, than high and sustained crop yield can be obtained with judicious and balanced NPK fertilization in combination with organic matter amendments (Bayu *et al*., 2006; Makinde *et al*., 2001; Palm *et a*l., 1997; Kang and Balasubramanian, 1990). Likewise, intercropping provides a fast and good ground cover and allows the roots to exploit soil nutrients at various depths (Steiner, 1991). Hairy vetch, grown as a winter cover crop supplies from 50 to 120 kg N ha^{-1} to a subsequent tomato crop (Sainju *et al*., 2002; Yaffa *et al*., 2000; Teasdale and Andul-Baki, 1998). Equally, studies in Ohio demonstrated that field pea–rye mixtures produce more than 4 t h^{-1} biomass and enhance the productivity of the subsequent tomato crop, provided moisture is adequate (Akemo *et al*., 2000).

4.5.1 Biomass production of the integrated crops in the mango orchard

Intercropping trees with cover crops is a well-known strategy in several cash-crop production systems in the tropics. Through the permanent soil cover, erosion risk and therefore soil nutrient and organic matter losses can be decreased whereas soil structure can be improved (Lal *et al*., 1991). Nowadays, farmers are willing to integrate non-food legumes under maize only if the intercrop does not affect maize yield (Amede and Kirkby, 2004). Nevertheless, non-food legumes were tested in legume – maize screening trials, including *Mucuna, Canavalia, Crotalaria* and *Dolichos lablab*. Here, the minimum dry biomass to be incorporated for better productivity of maize was estimated at 5 t ha^{-1} (Lehmann *et al.*, 2000).

The biomass production depends of the species potential, the rainfall and soil nutrient availability. Therefore, the biomass production may vary considerably among years. In the present study, biomass production without grains, differ significantly between species. Unexpectedly, the sole maize system produces higher biomass than the intercropped system during the two last cycles (3 & 4). The overall yearly biomass mean for the legume treatments (plots 1, 2 and 3) in the sole maize system is 6892 kg ha^{-1} versus 5890 kg ha^{-1} for the maize–pumpkin intercropped system (Fig. 38 and 39). When comparing both rotation systems, the average maize biomass in the sole maize plots (2968 kg ha^{-1}) is higher than for maize – pumpkin (1915 kg ha^{-1})(Fig. 38 and 39). Similar differences are observed for the maize straw fallow rotation, which shows 2352 kg ha^{-1} in the sole maize system and only 1915 kg ha^{-1} in the maize x pumpkin intercropped system. Yield depressions have also been reported in many cassava based cropping systems (Ambe, *et. al.,* 1988; Ikeorgu, 1984).

In the mango orchard study, biomass differences among rotations resulted also from the additional leguminous intercropping scenarios. Biomass production of *C. spectabilis* alone is 4712 kg ha^{-1} and dominates over the singular legumes in the maize – pumpkin rotation. Likewise, the same system with C. *spectabilis* presents the highest total combined biomass (8636 kg ha^{-1})) in this study (Fig. 39). The biomass production of *C. spectabilis* demonstrates the adaptation and potential of this plant to improve the ecological stability of the fruit orchards in the Soconusco.

Vigna unguiculata (plot 3) in maize –pumpkin intercropped scenario has a biomass mean of 1571 kg ha^{-1} versus 3293 kg ha^{-1} in the sole maize rotation system (Fig. 38 and 39). Pumpkin (Calabaza) as a cover plant in the third cycle improves soil humidity, resulting in adequate agro-ecological conditions for the subsequent growth of *C. spectabilis.* To the contrary, pumpkin cover suppresses weed proliferation in the third cycle, but eventually the soil modification contributed to the increase of weed biomass in the fourth cycle (Fig. 38).

The total biomass production in the scenario with *P. acutifolius* (Fríjol Escumite) previously cropped before in the sole maize treatment is 6278 kg ha^{-1} and only 5068 kg ha^{-1} in the maize – pumpkin scenario (Fig. 38 and 39). *P. acutifolius* responds differently as compared to *C. spectabilis*. Field observations confirm that the virus damage, strong rainfall, and soil humidity limited the growth of Escumite bean crop and can cause total yield loss. For that reason the biomass of *P. acutifolius* in the sole maize scenario (1995 kg ha^{-1}) is higher than in the maize –pumpkin scenario (908 kg ha^{-1}).

The rotations with maize straw fallow, obtain the lowest biomass production in both systems (sole maize and intercropped maize – pumpkin) (Fig. 38 and 39). It demonstrates that both traditional rotations tend to degrade soil fertility and its productivity over time. In rotation with sole maize system, the maize biomass occupies 53% of the total biomass versus 55% for the maize – pumpkin rotation. These results indicate that the biomass production in the scenarios with maize straw fallow are mainly dependent on the maize biomass. In consequence, low soil fertility can been attributed to the low inherent soil management, and to the loss of nutrients through erosion and crop harvests (Gachene *et al.,* 1997; Palm *et al.,* 1997; Pfeiffer, 1990). On the other side, intensive monoculture aggravates soil degradation (Sharma and Mittra, 1991).

Reverse tendencies are recorded in the rotations with leguminous crops, where the escumite beans (*P. acutifolius*) and cowpeas (*V. unguiculata)* contribute for only 20% of the total biomass , whereas the *C. spectabilis* crop accounts for more than 50% of the total biomass of systems. Other authors also reaffirm the value of legumes in crop rotation, as potential suppliers of N and organic matter to succeeding maize crops (Hartwig and Ammon, 2002). For example, the fertilizer N-value of alfalfa to the following maize has been reported as high as 180 kg N ha^{-1} (Baldock *et al*., 1980). Different winter legumes used as cover crops were also reported to reduce N-fertilizer requirements of the following maize, sorghum, and cotton crops by 50 to 90 kg N ha^{-1} (Hargrove *et al*., 1986).

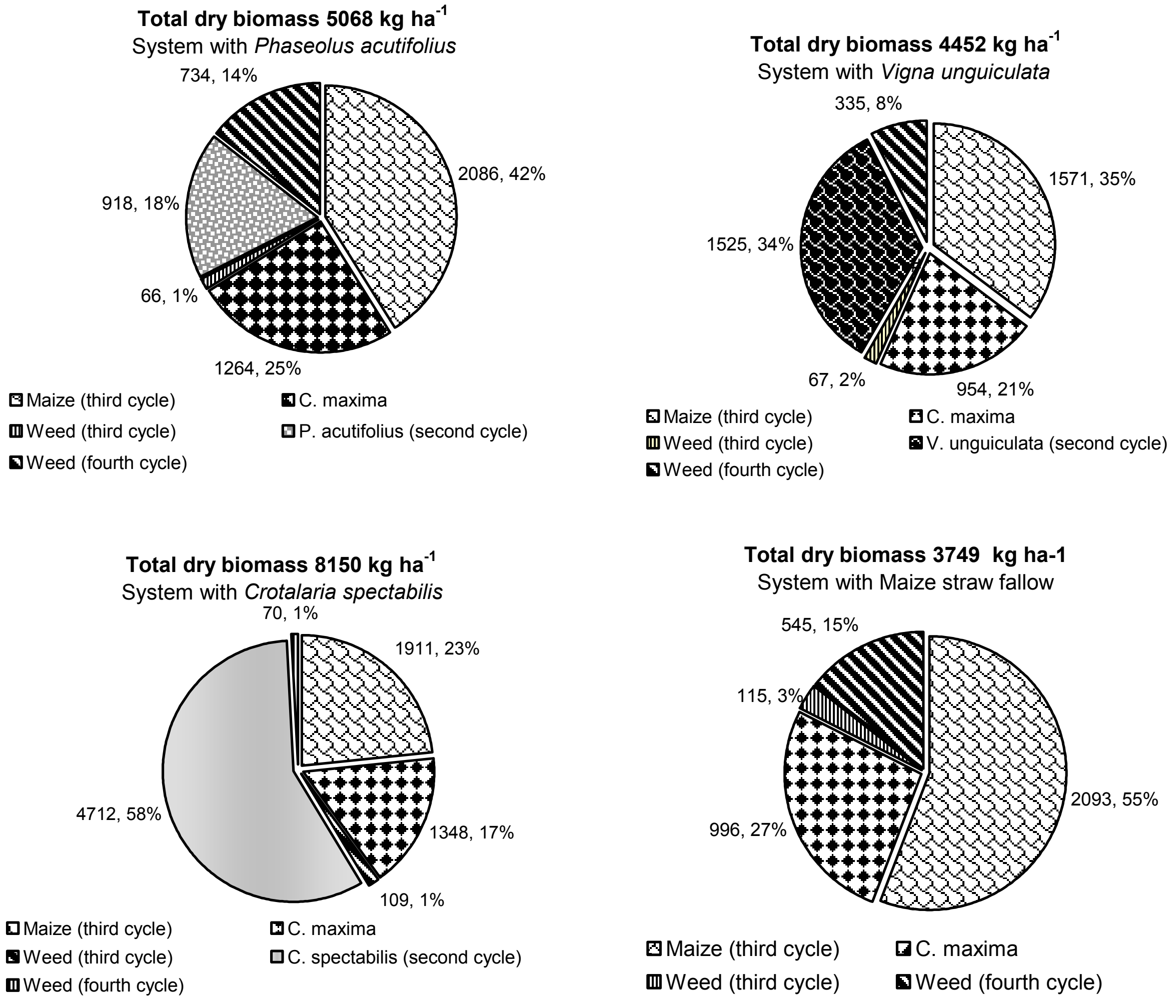


Figure 38: Biomass production of different intercropped system inside mango orchard.

Weed biomass accounts up to 15 % of the total biomass production in the evaluated systems. In the intercropped field with maize straw fallow, weeds contributed for 3 % (115 kg ha^{-1}) of the total biomass in the first cycle and 15 % (545 kg ha^{-1}) in the fourth cycle It is about 100 % higher than for both legume rotations in both cycles (1 and 8 %) (Fig. 38 and 39). In the sole maize system, the weed biomass difference among maize straw fallow rotation and the average legume treatments is higher than in the intercropped scenarios. Hence, weed achieves an aggressive growth in traditional maize systems, where long time maize monoculture and low soil fertility induce weed proliferation.

In the maize – pumpkin systems, the pumpkin plant inhibits maize growth, explaining why sole maize system produces high biomass. Here, maize plant height reaches 2.54 m. To the contrary, in the maize – pumpkin intercropped system, the maize plants grow only up to 1.86 m. It is a case, where intercropping is affected by adverse competition effects. Likewise, Watson (1989a) found, that the cover crop may also exert negative effects on tree performance.

Competition for nutrients can reduce crop yields. If a vine is used as a cover crop, intensive management is needed to prevent it from climbing the trees. Similar effects were found by Silwana and Lucas (2002) in maize-beans intercrops whereby yield of maize was depressed by 15% and that of beans by 13%.

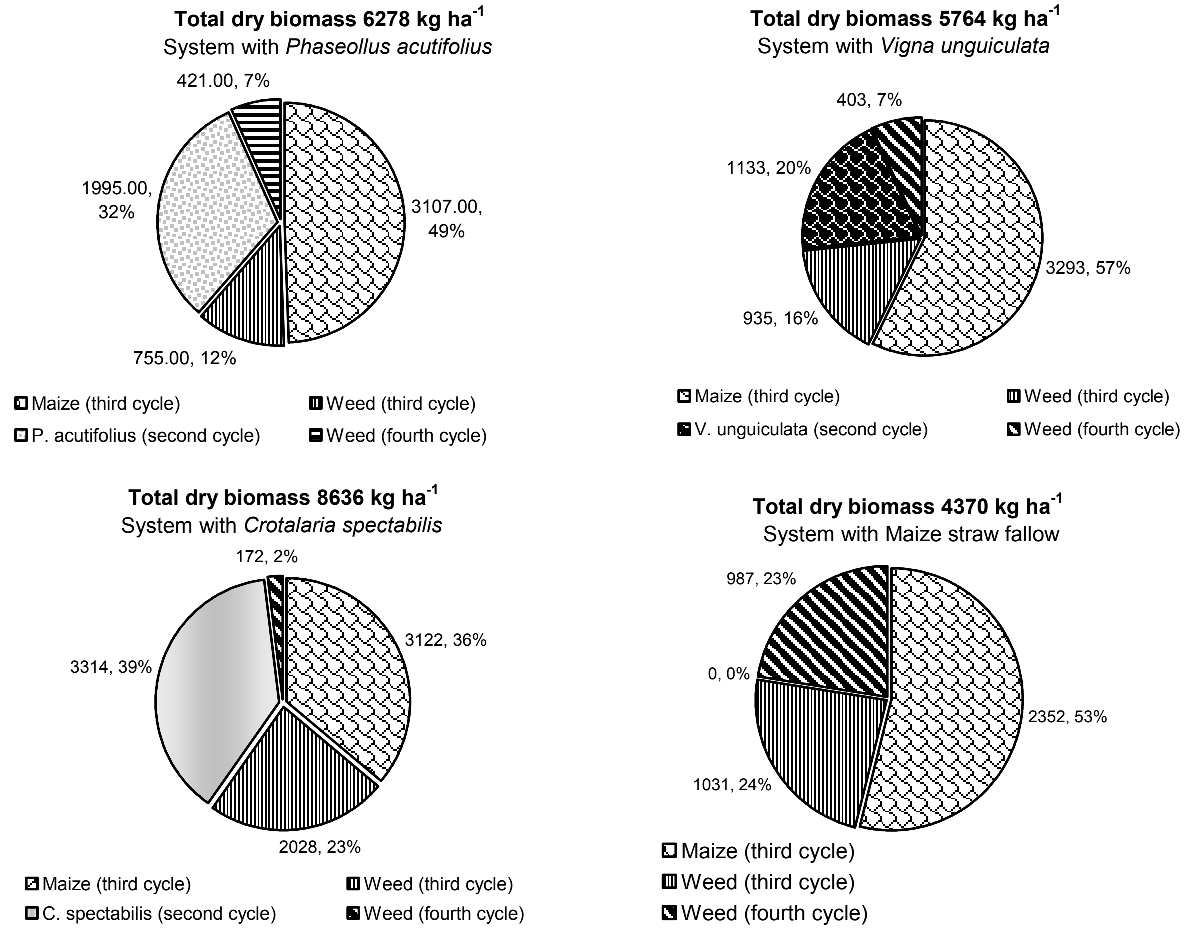


Figure 39: Biomass yield of different systems in sole maize cropping inside of mango orchard.

4.5.2 Biomass production of the integrated crops in the rambutan orchard

During the first 8 years, the rambutan orchard provide enough space for intercropping, even if they are fully grown as they do not cover much area. It is possible to grow a vegetable - fruit mixed system. Field crops, such as fodders and vegetables could also be grown together with rambutan. The biomass inclusion maintains a stable ecological and economic production system. Apart from the nutrient aspect, a large problem of many cover crops is that they climb and eventually damage the trees seriously (Wilson *et al.*, 1982). Climbing effects can only be controlled by frequent cutting, which is very labour intensive. Therefore, farmer's adoption of legume cover crops is often limited. This dilemma may be solved by selecting legume species, which do not climb vigorously.

In the rambutan orchard study, the maize – pumpkin intercropped system produces higher average biomass (8276 kg ha^{-1}) than the sole maize system (6307 kg ha^{-1}) (Fig. 40 and 41). In the intercropped system, the overall average biomass of 3336 kg t ha^{-1} is close to that of the sole maize plots 3788 kg ha^{-1}. When comparing the leguminous plots and the maize straw fallow plot in the intercropped systems (Fig. 40), the average biomass of the legume plots (9273 kg ha^{-1}) is over 75% higher than that of maize straw fallow (5282 kg ha^{-1}). Similar results are found in the sole maize arrangement, where the average biomass of the legume treatments (6706 kg ha^{-1}) is higher than that of the maize straw fallow treatment (5109 kg ha^{-1}).

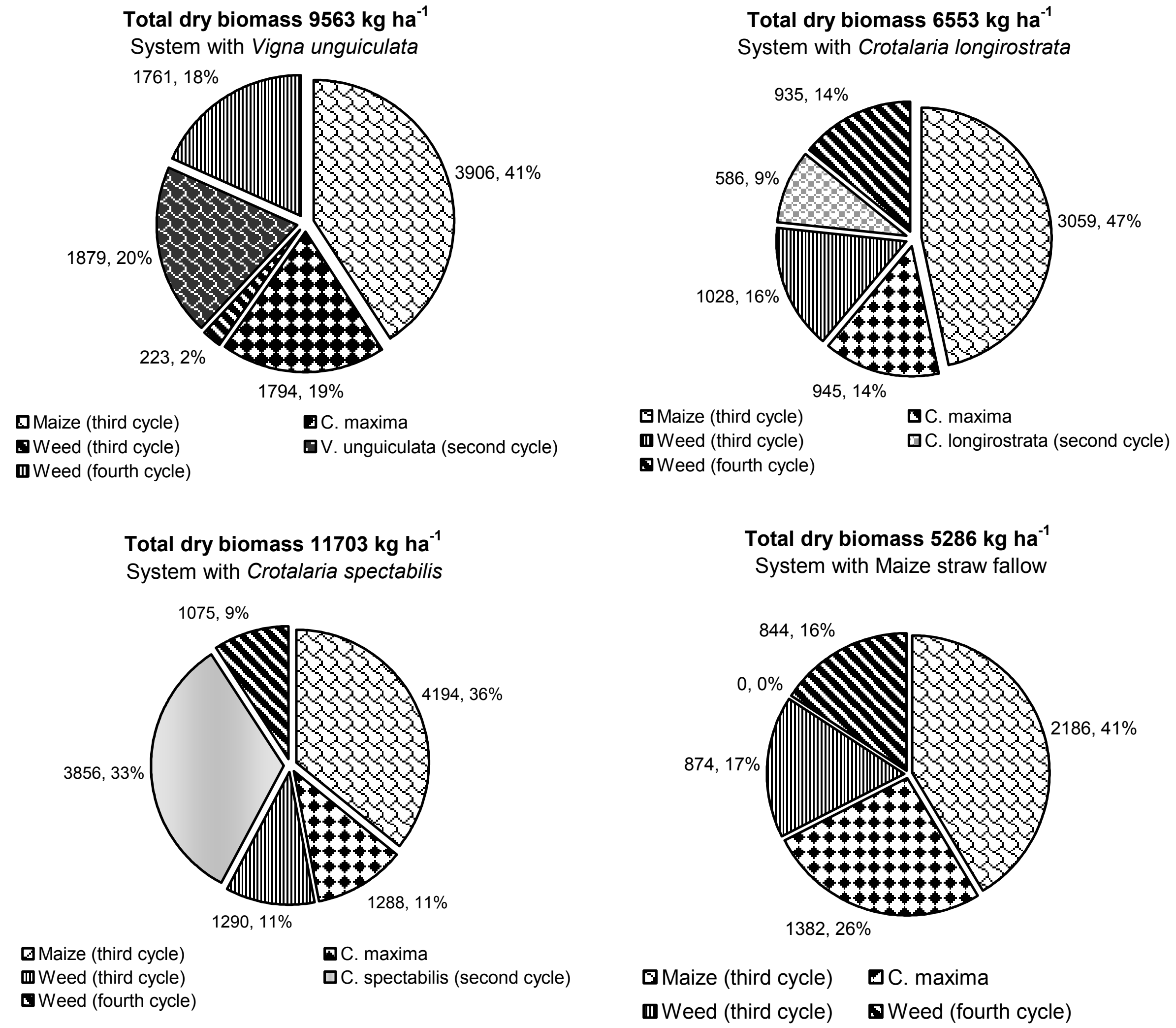


Figure 40: Biomass yield of different intercropped system inside of rambutan orchard.

The legume plots present high significant differences with the maize straw fallow plot. The same tendency is recorded for maize biomass in the legume plots compared with the performances of the maize straw fallow plot. In the sole maize system, the maize overall average biomass of the legume treatments is about 1155 kg ha^{-1} higher that the maize biomass of the maize straw fallow field. These results demonstrate that the leguminous crops (second cycle) after maize crops (first cycle) influence total biomass of the subsequent crops. Similar results are reported by Bogale *et al.,* (2001), where a significant increase in maize yield is obtained when leguminous crops are preceding as sole crops in rotations. Increases are less consistent in simultaneous and relay intercropping systems. Likewise, the incorporated residues of alfalfa and red clover are reported to contribute for 65 to 71% of their total N content to the succeeding maize (Hesterman *et al.,* 1987).

The total biomass of the rotations with *C. spectabilis* is the highest in this study. In the maize intercropped system, *C. spectabilis* achieved 3856 kg ha^{-1}; accounting for 33 % of the total biomass of the system (Fig. 40). In the sole maize system, the *C. spectabilis* scenario yields a biomass of 1569 kg ha^{-1}, contributing to 21% of the total biomass (Fig. 41).

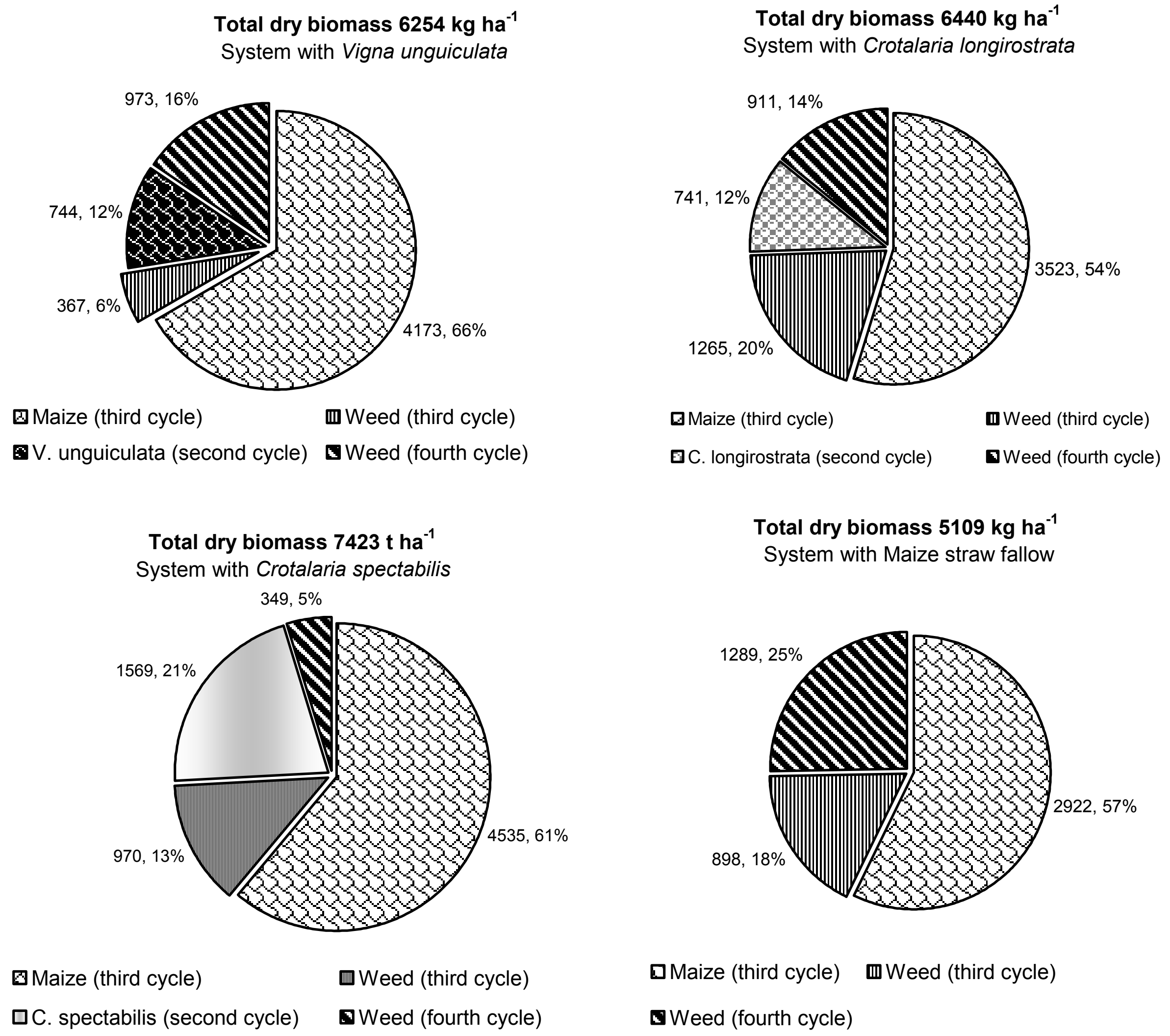


Figure 41: Biomass yield of intercrops in sole maize cropping inside of rambutan orchard.

The scenarios with *C. longirostrata* presented opposite results. In the maize –pumpkin intercropped system with *C. longirostrata* has been recorded a biomass of 586 kg ha^{-1} versus 741 kg ha^{-1} in the sole maize system. Hence, total biomass of the rotation systems depend on biomass yield capacity of the intercropped legume species. It also demonstrates that the plant structure and agro-ecological requirements between both legume species are very different. In a study using green manure - cover crop on maize yield, *Mucuna* produced the highest biomass (18.0 t ha-1) while *Vicia* gave the lowest (9.2 t ha^{-1}) (Gachene *et al*., 2000). On the other side, when sole crops produce higher yields of biomass than the intercrops, it is due to the competition for water, nutrient, and light (Fischler, 1997). Reports of other authors reaffirm the biomass yield capacity of the legume species. In Uganda, Fischler (1997) recorded 10.7 t dry matter (DM) ha^{-1} for sole cropped *Crotalaria*, while Siriri (1999) recorded values of 18 t DM ha^{-1} of sole cropped *V. benghalensis*. In Honduras, close to 20 t DM ha^{-1} of *Mucuna* was recorded (Buckles *et al*., 1998). Uutility of legume green manure in fruits demonstrate also the investigation in pitahaya orchards in Nicaragua (Salazar, 1994.).

In the fourth cycle, the average weed biomass of the legumes in the intercropped rotation system maize - pumpkin (1257 kg ha^{-1}) is significantly higher than in the sole maize rotation (744 kg kg ha^{-1}). The profuse rainfall in rambutan orchard intercropped with pumpkin cover induced changes on the availability of nutrients and water. For that reason, the intercropped system produces higher total biomass than the sole maize system (Fig. 40 and 41). According to other authors, before 1945, cover crops were relay cropped, overseeded, interseeded or double cropped into a main crop to provide and conserve nitrogen, increase organic matter, reduce soil erosion, and reduce weed and pest pressures (Hartwig and Ammon, 2002). Cover crops may also promote vesicular-arbuscular mycorrhizae, which will suppress weeds by plant species favouring strong mycorrhizal development, such as wheat (Jordan *et al*., 1996). Nevertheless, with the advent of herbicides and synthetic fertilizers, the use of cover crops has been greatly reduced (Hartwig and Ammon, 2002).

4.5.3 Conclusion

The average biomass yield of the legume scenarios in rotations with the systems maize – pumpkin and sole maize are higher than that of the maize straw - fallow rotation systems. Integration of legume crops inside the fruit orchard increases biomass yield over 75% in the whole system.

The biomass production of the maize straw fallow rotation systems result by the maize and weed biomass. Maize biomass accounts for less than 50 % of the total biomass in the legume rotation with *V. unguiculata, Crotalaria* spp. *and Phaseolus* spp. Nevertheless, the maize biomass contributes for more than 50 % of the total biomass in the systems with legumes.

Crotalaria spectabilis produces up to 6417 kg ha^{-1} of biomass. It represents a biomass increase of 121 %, when compared with the traditional maize systems. The maize – pumpkin intercrops produce an average biomass surplus of 1970 kg ha^{-1} in the rambutan orchard, whereas a deficit of 908 kg ha^{-1} is recorded in the mango orchard.

Intercropping pumpkin and legume cover crops like *Crotalaria* spp and *V. unguiculata* in fruit orchards can be an attractive alternative to improve organic matter, soil fertility, and ecological stability in the fruit agroecosystems in the Soconusco.

4.6 Influence of intercropped systems on the productivity of the fruit agro-ecosystems

Tropical fruits are grown on more than 60.000 ha in the Soconusco, Chiapas, and represent for the farmer the economically most important crops (mango, banana, papaya, and rambutan). They are traditionally cultivated with monoculture models and high chemical inputs. Due to the intensive technology implanted in the fruit agroecosystems of the Soconusco, intercropping is poorly developed in the fruit orchards. Nevertheless, intercropping trees with cover crops is a well-known strategy in several cash-crop production systems in the tropics. In Asia, cover crops are frequently planted inside oil palm plantations (Broughton, 1976), as well as with coconut (Aldaba, 1995) and to a lesser extent with rubber tree (Watson, 1989a). Cover crops are also used in coffee growing, for example in Cameroon (Bouharmont, 1978), Kenya (Bradshaw & Lanini, 1995; Njoroge & Kimemia, 1993) and Mexico (Pohlan, 2006). Cover crops may fulfil several purposes in tree production systems, which have long been recognized (Bunting & Milsum, 1928). If a pumpkin crop is used as a cover crop, intensive management is needed to prevent the invasive climbing on the trees.

Apart from tree nutrition, the cross-pollination plays an important role on the fruit quality and yield. In the case of mango and rambutan, such pollination can be improved with the attraction of insect pollinators. Nowadays, research focusing on the insect population dynamics in fruit intercropped systems, is insufficient. The pollination activities of insects have been thoroughly documented, but the influence of insects on the quality and the yield of fruits is unfortunately poorly explored. For example, the “baby mango” (Spanish “Mango niño”) which is frequently observed in cv “Ataulfo” in the Soconusco, Chiapas, still remains an unsolved problem of nutrition and/or of pollination.

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4.6.1 Influence of intercropped systems on the yield parameters of mango fruit

At flowering, the mango tree is covered with many pyramid-shaped panicles of red or pink flowers. These panicles, containing more than 1000 whitish or reddish – yellow flowers, combine hermaphroditic and male flowers in different proportions, differing from one variety to another. The pollen grains, which are bluish, are more or less conglomerated. They are carried by insects for pollination, rather that by wind (Parfonry, 2001).

On the other side, plants need water and nutrients to grow and to produce. Most of the water and nutrients that a plant needs is taken up from the soil. If there is a lack of water and nutrients, crops do not grow well resulting in poor quality and marginal yields. According to Ryan *et al.* (2001), the tree major factors contributing to plant nutrition are:

1. The amount of nutrients in the soil;
2. The soil ability to supply the nutrients to plants; and
3. Environmental factors that affect nutrient availability and their absorption.

The mango yields vary considerably. Mango is very prone to the phenomenon of alternation, particularly in extensive cultivation. An average of 20 – 30 t ha^{-1} can be used as a basis for productive varieties and for intensive cultivation. In extensive cultivation without irrigation, yields can range from 5 -15 t ha^{-1} (Parfonry, 2001, Chaves *et al.*, 2001).

In the Soconusco, the mango-growing extends actually over 23.000 hectares and is characterized by high diversity home gardens on the one hand, and by export orientated planting of mangoes on the other hand (Vanderlinden *et al.*, 2004; Pohlan *et al.*, 2000). Mango yield is influenced by eco-physiological conditions, variety, and cropping methods and otherwise by tree density and yield parameters like number of panicles per tree, number of fruits per panicle and fruit weight. In the Soconusco, more than 90 % of mango areas are planted with cv. “Ataulfo”, producing yearly approximately 6 -12 t ha^{-1} in the last 10 years (SEFIPLAN, 2005).

The temporary inundation, caused by the hurricane Stan in October 2005, provoked an untypical wind distribution during January 2007, causing the total loss of fruit harvest in the Soconusco, Chiapas. For that reason, the yield parameters analyses of mango corresponding to the cycle November 2006- April 2007 were removed from this study. For this situation, it was only possible to analize the mango yield parameters corresponding to the first fruit cycle (November 2005 - February 2006).

The mango yield parameters in Cintalapa are strongly influenced by the type of intercropped system. The number of fruits per panicle was the highest from start to end of fruit development in rotation plots intercropped with *Crotalaria spectabilis* and *Phaseolus acutifolius* “Escumite” (Fig. 42). Similar effects are observed for number of panicles per tree (Fig. 43). Once more, the plots with *Crotalaria spectabilis* and *Phaseolus* Escumite have significantly higher values in number of panicles. Additionally, only 115 panicles per tree are found in the black plot rotation (traditional system), which was treated with two applications of KNO_3 as flowering stimulation, but this treatment don’t result more panicles and lower fruit yield than the legume treatments with *Crotalaria spectabilis* and *Phaseolus* Escumite (Fig. 43 and 44).

The significantly highest mango yields in the scenarios with *Phaseolus* Escumite (9671 kg ha $^{-1}$) and *Crotalaria spectabilis* (7861 kg ha^{-1}) demonstrate the importance of pollinator insects and biomass incorporation on the fruit yields (Fig. 44). It is to be hoped, that these results can encourage the farmers to change their traditional management of fruit systems. Better nutrient balance of P and N content as well as soil respiration and higher pollinator population will increase mango yields. These effects confirm results of the legume-intercropped rotation (Fig. 44).

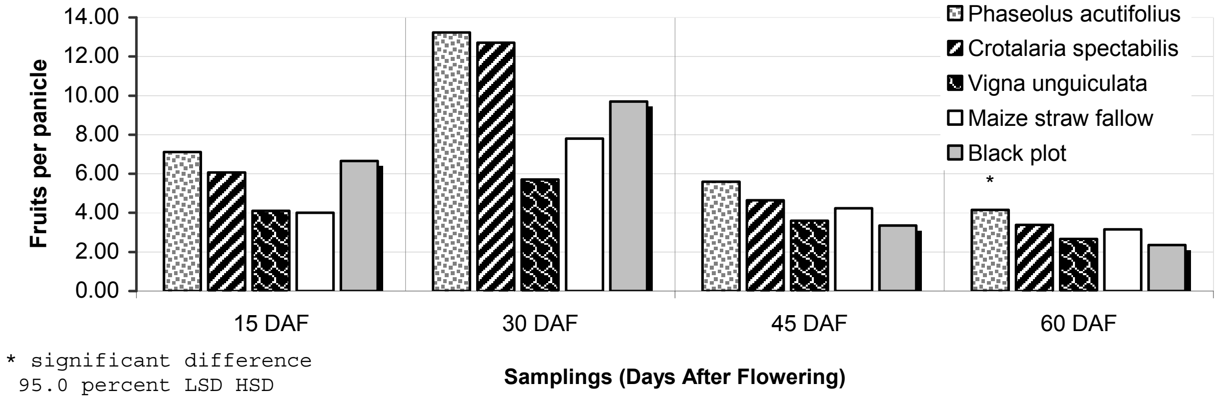
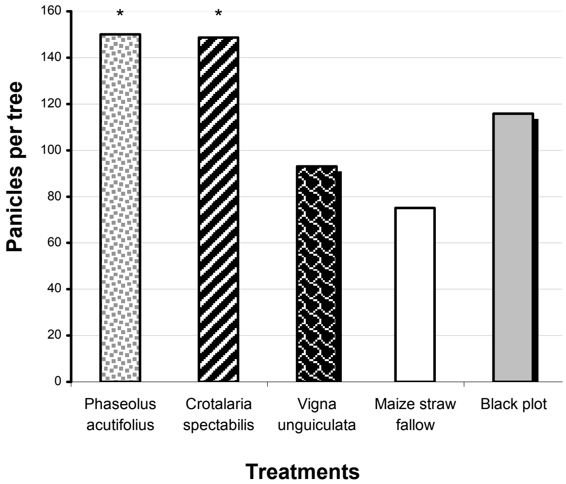


Figure 42: Effects of the intercropping and legume crops on the mango fruits per panicle.

The dynamics of fruits per panicle in the field are very interesting in the traditional black plot system, where fruits per panicle decrease over time. At the beginning of the flowering period, such system starts with high fruit numbers but eventually only three fruits will sufficient growth at the end. It shows that the trees present a higher abortion rate due to unbalanced nutrition and unfavourable soil humidity conditions.



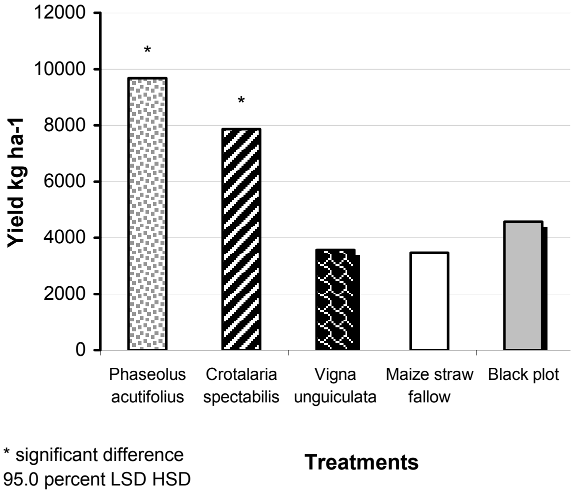


Figure 43: Effects of the intercropping and legume crops on the mango panicles per tree.

Figure 44: Effects of the intercropping and legume crops on the mango yield.

4.6.2 Influence of intercropped systems on the yield parameters of rambutan fruit

In the Soconusco, Chiapas, the commercial rambutan productions were initiated in the 90ties and encompass 500 ha at present. Current rambutan growing combines living soil cover management with integrated pest practices. Cover crops also reduce orchard maintenance cost and prevent weed growth; they may also rescue fruit trees from pest infestation. Expieriences to intercrop legumes in Rambutan exist f.e. in Thailand with *Centrosema pubescens*, *Phaseolus* spp., *Pueraria phaseoloides*, *Crotalaria*, *Vigna* and *Canavalia* spp. (Almeyda *et al*., 1979). Diverse studies have demonstrated that it is possible to find fruit flies of the *Anastrepha* complex in the rambutan orchards, but these fruit flies never attacked the rambutan fruits (Pérez Romero and Pohlan, 2005).

Besides N deficiency, Rambutan commonly also suffers from deficiencies of zinc, iron, boron, and sometimes manganese. Foliar sprays or soil applications via soil drenching or fertirrigation can correct deficiencies. Foliar applications are timed to coincide with the appearance of new vegetative flushes (Lim & Diczbalis, 1998a). Studies in Malaysia showed that a hectare of rambutan (70-80 trees/ha) yielding 6720 kg of fruit removes 13.4 kg nitrogen (N), 1.8 kg phosphorus (P), 10.2 kg potassium (K), 4.84 kg calcium (Ca) and 2.47 kg magnesium (Mg). More than 50% of the phosphorus, calcium and magnesium are in the fruit pericarp and 20-40% in the aril (Nakasone & Paull, 1998). Time and doses of application need to correspond to the differing needs at various phonological stages of the growth cycle as related to local agro-ecological conditions. Critical periods for application are before flowering and fruit set, during fruit set and development, and immediately after harvest (Nakasone & Paull, 1998).

On the other hand, rambutan trees are normally classified into three types: male trees producing only staminate flowers (40-60% of a seedling population), trees with hermaphrodite flowers that are functionally female and trees with hermaphrodite flowers some of which are functionally female and others functionally male. The last type is more desirable and most commercial cultivars behave hermaphroditically and are self fertile, with 0.05 to 0.9% of the flowers functionally males. Although apomixis may occur in some cultivars, research has shown that the pollination is entomological, whereby bees and other insects are attracted to the nectar and the colour of the flowers (Erickson & Atmowidjojo, 2001; Fraire, 1995). Initial fruit set may approach 25%, but a high level of abortion contributes to a much lower level of production at harvest (Erickson & Atmowidjojo, 2001).

There is no formal published standard quality for international trade in fresh rambutan, although export markets have similar importer preferences. The Chanthaburi Horticultural Research Centre set up quality standardization for two commercial varieties of Thai rambutan (Rongrien and Seechompoo) in 1992. The draft standard that was developed for these varieties could be categorized into Extra, Class Class II and I. Only the highest-quality fruit should be exported. Adoption of the standard by all parties concerned could bring about fair market system, faith, and promotion of sale (Hiranpradit *et al*., 1992).

Following are general quality standards obtained through published technical articles and interviews with rambutan producers in the Soconusco:

- export markets require the rambutan to be fresh in appearance, clean, practically free from insects, diseases and blemishes;
- the rind should be bright in colour, uniform and true to type, with fresh spinterns;
- the fruits should weight at least 30 g (less than 33 fruits per kg), with a flesh recovery ratio of more than 45%;
- the aril must be firm, sufficiently developed, with minimum 18% soluble solids It should be thick and have not an off-flavour due to over maturity or fermentation;
- the aril should separate easily from the seed, which should be small. In some rambutan cultivars, the hard testa comes away with the aril, which makes these cultivars less desirable;
- shape, smell and taste must be typical of the nature of the produce (Lim & Diczbalis, 1998a; Hiranpradit *et al*., 1992; Medlicott, 1995).

4.6.2.1 Yield parameters of rambutan fruits in the first cycle (2006)

As an alternative to the establishment of cover crops in new orchards, the alleyways may be cropped, for the first few years, with a range of annual food crops. This has the advantage of producing a profitable yield before the rambutan trees come into bearing and, at this early stage in the growth of the orchard, food crops such as beans, leafy crops, and root crops will not compete with young rambutan trees (Tindall, 1994). In some areas, rambutan is grown as an intercrop with coffee and Cocoa and, in the Philippines, rambutan has been successfull under mature coconut trees (Coronel, 1983). In Mexico, *Nephelium* has also given good results when intercropped with coffee (Pérez, 2000a).

The rambutan trees in El Triunfo are now 6 years old and give the fourth commercial harvest. Experiences from other rambutan plantations in the Soconusco, show that yields generally vary widely at this age, depending on the management and agro-ecological conditions. In the first cycle, the Rambutan scenarios with *Crotalaria spectabilis* have a significant positive influence on the number of panicles per tree (98 and 74 panicles) and the number of fruits per panicle (18 and 13) (Fig. 45 and 46). In these scenarios, visual observations recorded a very effective protection against wind and a high activity of different wasps and honeybees (*Melipona* spp and *Apis* spp). Results of Erickson & Atmowidjojo (2001) confirm the beneficial effects of the wasps on the rambutan pollination.

Scenarios with *V. unguiculata* and *C. longirostrata* present very similar yield parameters. Likewise, the traditional rambutan black plot rotation don't differ to the legume rotations and to the maize straw fallow in the number of panicles per tree (Fig. 45). The differences between *V. unguiculata*, C. *longirostrata* and traditional systems were only marginally significant for the variables panicles per tree and fruits per panicles (Tab. A-7 and A-8). However, the scenarios with *C. spectabilis* present highly superior performances for both systems (Tab. A-7 and A-8).

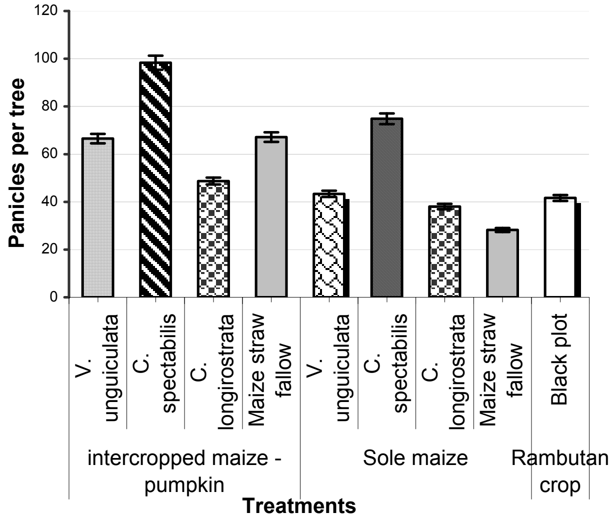


Figure 45: Effects of intercropping and legume crops on the panicle number per rambutan tree.

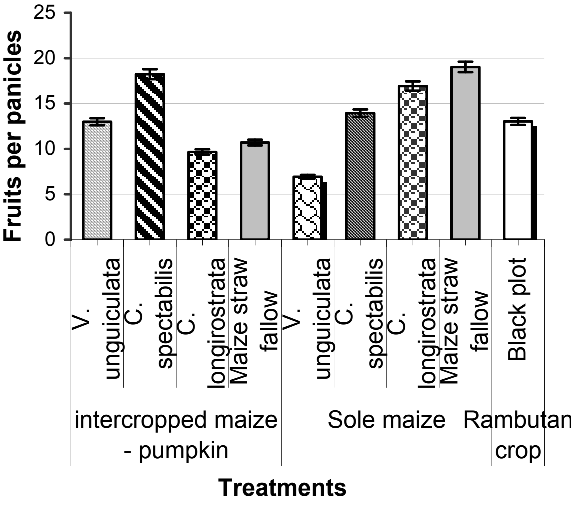


Figure 46: Effects of intercropping and legume crops on the rambutan fruits per panicle.

The rambutan yields demonstrate the same hierarchy as for the corresponding yield components. The significant highest yield with 6842 kg ha^{-1} characterizes the intercropped treatment with *Crotalaria spectabilis*, followed by the scenarios with *V. unguiculata* (Cowpea) at 4397 kg ha^{-1} and, finally with the sole maize – straw fallow rotation trailing at only 1841 kg ha^{-1} (Fig. 46). The average fruit yield in the sole maize rotation in (2878 kg ha^{-1}) is lower than in the maize – intercropped rotation (4138 kg ha^{-1}). Likewise, the average fruit yield from the legume scenarios is higher than the maize - straw fallow rotations and the traditional black plot system. The treatments with *C. spectabilis* and *V. unguiculata* present highly significant differences w.r.t. the other treatments (Fig. 47). These results give the conclusion, that the biomass incorporation and changes in the soil properties by cover crops contributed to improve rambutan fruit yield.

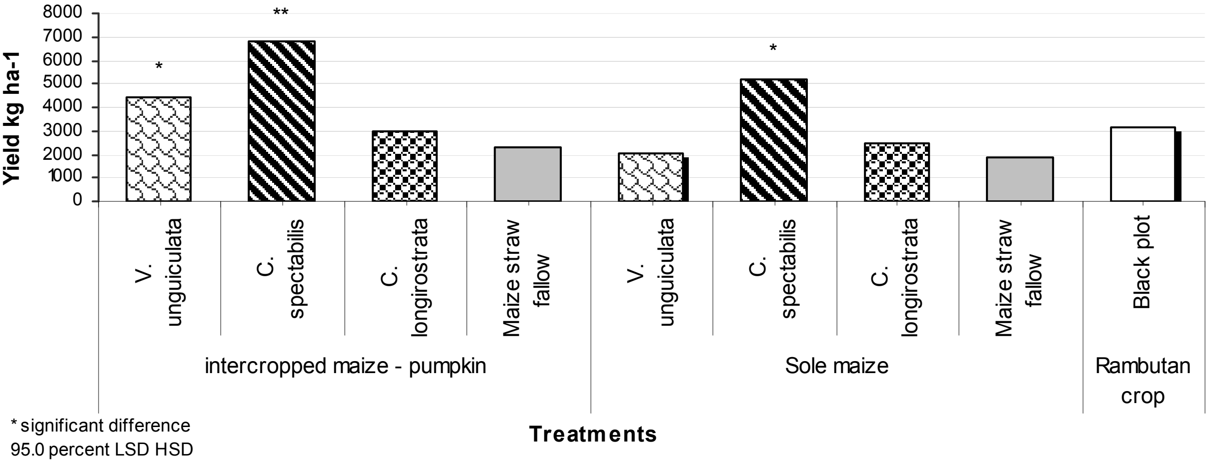


Figure 47: Effects of intercrops and legume crops on the rambutan yield (1st cycle).

4.6.2.2 Yield parameters of rambutan fruits in the second cycle (2007)

The rambutan yield parameters of the second cycle (2007) of our studies show a similar tendency as in the first cycle (2006). Once more, the treatment with *Crotalaria spectabilis* presents high significant values. *C. spectabilis* produces highest number of panicles per tree in both evaluated systems (93 and 86), followed by *V. unguiculata* (73 and 70) and *C. longirostrata* (59 panicles per tree) (Tab. 13). The worst performance is given by the maize/straw fallow rotation, achieving only 47 panicles per tree in the intercropped system and 42 panicles in the monoculture system (Tab. 13). The traditional black plot system produces 48 panicles per tree.

Fruits per panicle show a similar situation to that of panicles per tree, where the legume scenarios obtain a higher number of fruits per panicle than the maize - straw fallow and the black plots *C. spectabilis* and *C. longirostrata* offer the highest number of fruits per panicle (Tab. 12). Again, the maize/straw fallow scenario produces the lowest values of fruits per panicle in both systems (9 and 8 fruits). Nevertheless, the difference shown between the treatments are not statistically significant (Tab. 13). Range of fruits per panicle in our studies support the variability documented by other researchers, indicating that Rambutan fruits may be produced in large bunches, with 40 to 60 fruits per panicle, but most often only 12 to 13 fruits per panicle are retained up to maturity (Zee, 1993; Erickson and Atmowidjojo, 2001; Nakasone & Paull, 1998).

In the rambutan case, the yield is strongly dependent on panicles per tree and fruits per panicles. For that reason the treatment with *C. spectabilis* shows high significant differences as compared to maize/straw fallow rotation and to the scenario with *C. longirostrata* in the sole maize systems (Tab. 13). The difference between legume treatments and black plot is only marginally significant. When comparing both systems, maize x pumpkin intercropped systems produce a positive yield difference of 220 kg ha^{-1} (Fig. 48). The highest yield is obtained in the scenarios with *C. spectabilis* (6534 kg ha^{-1}), followed by *V. unguiculata* (5642 kg ha^{-1}), whereas, maize/straw fallow plots produce the lowest rambutan yield. Nitrogen and Potassium content in the legume scenarios in both rotation systems are important elements that influence rambutan yield.

Table 13: Effects of intercropping and legume rotation on the rambutan yield parameters

Intercrops	Leguminous rotation	Yield parameters of rambutan in the second cycle (Nov 2006 – May 2007)						
		Yield(kg tree)	Panicles per tree	Fruits per panicle	Fruit diameter (cm)	Fruit length (cm)	Fruit weight (gr)	Brix degree (%)
intercropped maize - pumpkin	*V. unguiculata*	5141.46 bc	73.33 bc	13.78	3.79 b	4.68 c	33.54 c	18.24 a
	C. spectabilis	5719.06 bc	91.33 c	16.31	3.30 a	4.20 a	28.95 ab	18.11 a
	C. longirostrata	4441.99 bc	59.16 bc	15.56	3.23 a	4.61 bc	32.14 bc	18.62 a
	Maize straw fallow	1940.04 a	47.5 bc	9.85	3.19 a	4.40 ab	26.71 a	18.95 a
Sole maize	*V. unguiculata*	5642.25 bc	70.66 bc	13.08	3.36 ab	4.40 ab	29.62 ab	18.22 a
	C. spectabilis	6534.54 c	86.33 bc	15.76	3.50 ab	4.38 ab	29.77 ab	18.09 a
	C. longirostrata	2294.01 ab	32.16 ab	14.50	3.30 a	4.51 bc	29.44 ab	17.88 a
	Maize straw fallow	1890.04 a	42.00 a	8.25	3.33 ab	4.44 bc	29.11 ab	18.83 a
Black plot		2840.22 bc	48.16 bc	13.20	3.31 a	4.19 a	27.73 a	18.57 a

The yield results indicate that the maize x pumpkin intercrop slightly reduces rambutan yield for the scenarios *V. unguiculata* and *C. spectabilis* but improves it in the case of the *C. longirostrata* scenario. Indeed, biomass incorporation, wind protection, soil humidity and insect dynamics are all factors that influence the final rambutan yield. The attractive yellow flower and plant height of *Crotalaria* spp. contribute to improve the pollination, as demonstrated by the number of fruits per panicles. Here, *C. spectabilis* and *C. longirostrata* present the highest numbers of fruits per panicle (Tab. 13).

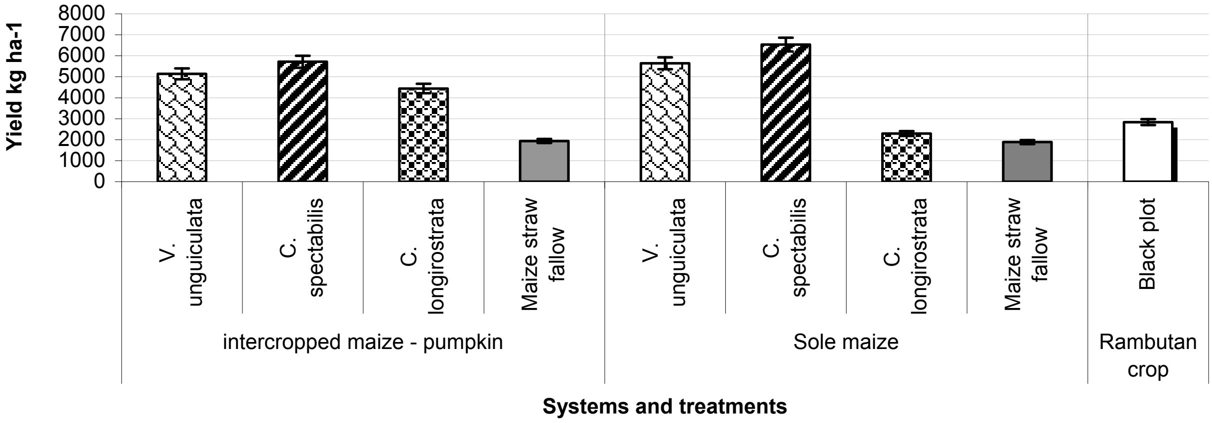


Figure 48: Effects of intercropping and legume crops on the rambutan yield (2nd cycle).

Results of fruit weight show a very different tendency to the above described variables. In sole maize system, all treatments show similar values of fruit weight, whereas in the maize x pumpkin intercropped system, the scenario with *V. unguiculata* produces the highest fruit weight (33.54 g). The lowest fruit weight is obtained in the maize straw fallow plot (26.71 g). Once more, the black plot maintains intermediate values around 27.73 g (Fig. 49). Thus, the scenarios with *V. unguiculata* and *C. longirostrata* present significantly higher differences over the maize/ straw fallow and black plots (Fig. 49).The general quality parameters establish that the fruits should weight at least 31 g (less that 33 fruits per kg) (Lim & Diczbalis, 1998b; Medictot, 1995). Likewise, Vanderlinden (2003) found fruit weight ranges from 23 to 30.3 g in the rambutan orchards in the Soconusco region.

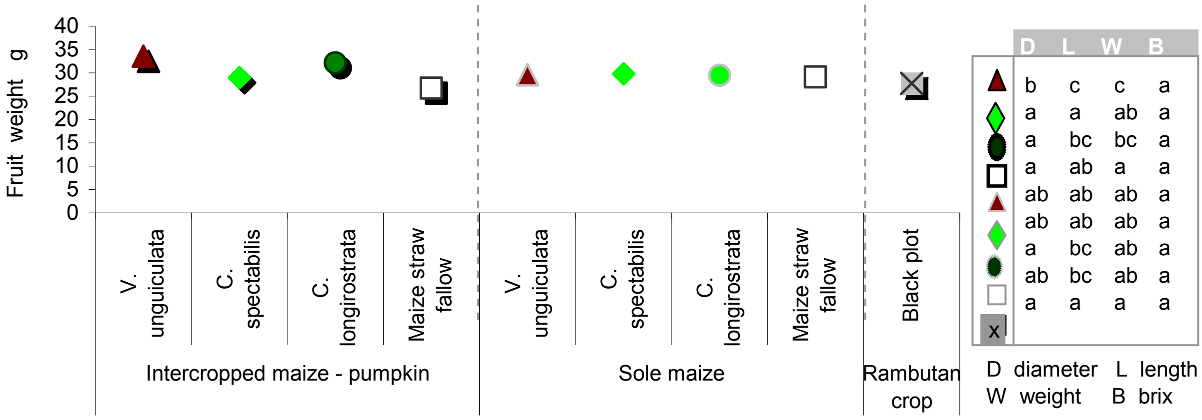


Figure 49: Effects intercropping and legume crops on rambutan quality parameters.

In the sole maize system all treatments maintain a similar quality. To the contrary, in the maize x pumpkin intercrop system only the *V. unguiculata* scenario produces a high significant difference over the other treatments for the variables length and weight of fruits. Diameter and °Brix of rambutan are not influenced by annual intercropping. Vanderlinden (2003) reports in studies realized in the Soconusco, Chiapas, that the length and the diameter of rambutan fruits ranged from 3.7 to 4.2 cm and from 3.1 to 3.40 cm, respectively.

Figure 50: Biomass and insects in the *Crotalaria* crop inside the rambutan orchard.

4.6.3 Conclusion

The integrated legume crops inside mango orchards produced unexplained effects on the number of mango fruits per panicle. Nevertheless, the fruit abortion is more present in the scenarios with maize/straw fallow, black plot and *V. unguiculata*. The legume intercrops as *P. acutifolius* and *C.*

longirostrata increase the number of panicles per tree and eventually, fruit yield. To the contrary, *V. unguiculata* scenario maintained the number of panicles very similary to that of the black and maize/straw fallow scenarios. The mango yield in the intercropping system with *C. longirostrata* and *P. acutifolius* was superior when compared to all other scenarios.

Maize x pumpkin intercrops induced rambutan fruit yield increases close to 220 kg ha^{-1}, when compared with the traditional system. Thus, the legume intercrops in rambutan orchards increase rambutan yield with 69 % on average. Nevertheless, the combination of sole maize with rambutan resulted in a rambutan yield decrease to 35%.

4.7 Eco-volume and Bio-volume of the intercropped fruit systems

Eco-Volume (V_{eco}) is the aboveground quantifiable space or volume limited by a uniform vegetation stand and its height, within which coexist wide interactions among biotic and abiotic components. Eco-volume is the product of the area occupied by a uniform type of vegetation and its eco-height (Torrico, 2006). Eco-volume of a plant community is defined as the soil surface multiplied by the average height (eco-height) of a given phytocenose or agricultural system. It is expressed as a volume in m^3. The V_{eco} of a single plant is defined, as the volume of a cylinder with basal area equals to the basal area of the canopy and the aboveground height at the highest point of the plant (Zhixin, 2007).

The importance of the eco-volume is its emphasis on the interrelationship between species living within the boundaries of a space or volume (area x eco-height). Each eco-volume encompasses a biological community (or biocoenosis defined by Mölbius, 1997) adapted to specific conditions in a give place (Tansley, 1935). Janssens *et al.* (2004) indicates that the eco-volume has an effect on precipitations (additional precipitations also coined as “eco-precipitations” are generated), as well as on regulation of the ecological functions like microclimate and water cycles. Eco-volume is also related with the landscape ecology concept proposed by Troll (1939).

The eco-volume is subject to either periodic or abrupt changes based on climatic cycles or due to man-made disruptions, like deforestation or extract of plant materials (Torrico, 2006). According to the same author, the forest systems have the highest values of eco-volume, varying between 4450 m^3 ha^{-1} for semi-arid forest in northeast Brazil up to 250000 m^3 ha^{-1} for primary mountain rain forest in the Atlantic region. The highest values of eco-volume in agricultural systems (average: 90000 m^3 ha^{-1}) correspond to agroforestry systems (coffee and cocoa), and ecological systems. The horticultural systems and grassland have reduced values averaging 24000 m^3 ha^{-1}.

4.7.1 Eco-volume dynamics in the fruit intercropped systems

The V_{eco} of the intercropped systems is the V_{eco} summed over all intercropped crops. The V_{eco} of the annual intercropped crops are added to the fruit crop eco-volume, which vary on time, space, and species. The introduction of intercrops inside the mango systems affects the eco-volume of the mango trees (Fig. 51). At the beginning of the second cycle (May 2006), all mango system offered an average V_{eco} of 10943 m^3 ha^{-1}. Their volume is increased from May 2006 to August 2006 in 26645m^3 ha^{-1} with the intercrops of maize in the systems with legume crops and maize/straw fallow. The maize system averaged of 15497 m^3 ha^{-1} of V_{eco}. The traditional system (mango without intercropping), offered an average V_{eco} of 11257 m^3 ha^{-1}. Due to the bending of maize plants in August (dobla), the scenarios with maize crops present a V_{eco} diminution of 29% (Fig. 51). From legume sowing in August 2006, V_{eco} in the legume scenarios increased slowly over time and eventually achieved maximal V_{eco} in October 2006 for the scenarios with *P. acutifolius* (25285 m^3 ha^{-1}) and *V. unguiculata* (22601 m^3 ha^{-1}). From October 2006, the V_{eco} in the scenarios with *V. unguiculata, P. acutifolius* and maize/straw fallow begin to decrease until

February 2007. Whilst, the *C. spectabilis* scenario adds 13298 m^3 ha^{-1} to the V$_{eco}$ of the mango x sole maize intercrop, *C. spectabilis* scenario produced highest V$_{eco}$ at 32400 m^3 ha^{-1} in December 2006. That volume is maintained up to February 2007. From January onwards, fruit set commences slowly in the mango orchard. For those reasons, all crops in the mango system are eliminated in February 2007, inducing a strong V$_{eco}$ decrease, especially in the scenario with maize + *C. spectabilis.* At the end of the second cycle (April 2007), V$_{eco}$ values are similar in all evaluated fields (average of 11671 m^3 ha^{-1}), due to vegetation removal and mango fruit management geared at better fruit quality and yield.

In addition*,* *P. acutifolius* contributed to the V$_{eco}$ with 3590 m^3 ha^{-1} and *V. unguiculata* crop with 4897 m^3 ha^{-1} (Fig. 51). Highest eco-volume values are achieved at the flowering periods due to the contribution of the annual intercrops after which eco-volume decreases steadily. Nevertheless, *C. spectabilis* scenario has a more persistent eco-volume in the mango system (Fig. 51).

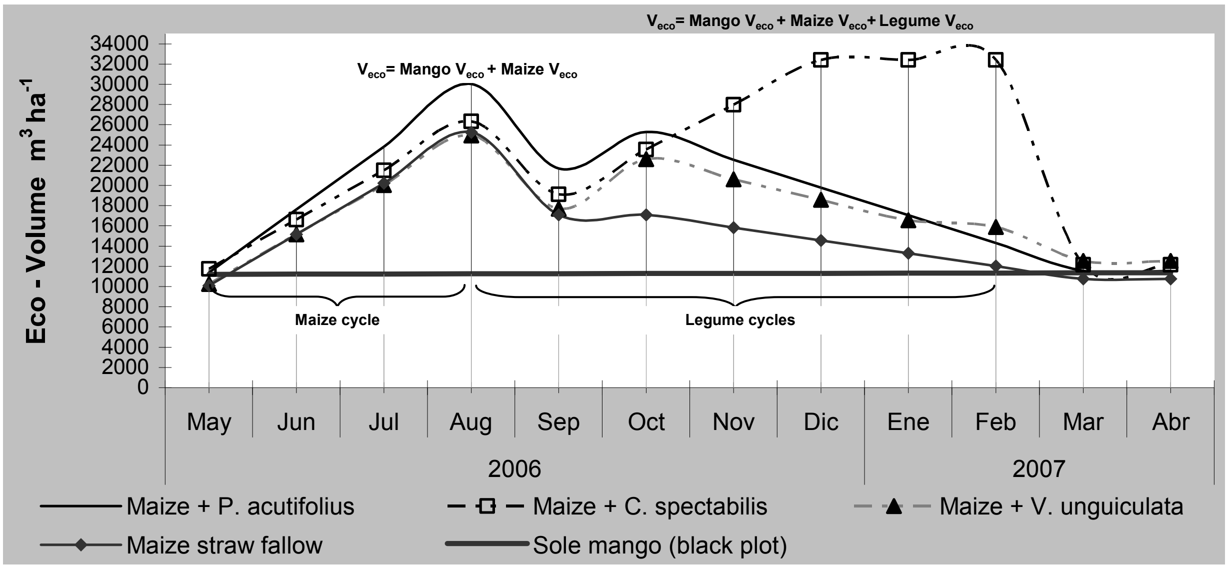


Figure 51: Eco-Volume dynamics in the mango intercropped systems.

The eco-volume dynamics of the rambutan-intercropped system indicate that the legume intercrops in rambutan orchard increase to two times the total V$_{eco}$ of the fruit system. At the start of the second cycle (May 2006) in the rambutan orchard, all systems offer an average V$_{eco}$ of 7882 m^3 ha^{-1}. This average V$_{eco}$ augments to 14561 m^3 ha^{-1} in August 2006 for the scenarios with maize, due to the contribution of the V$_{eco}$ of maize crop inside the rambutan system (Fig. 52). The scenarios with maize crops achieve an average V$_{eco}$ of 21994 m^3 ha^{-1} at the maize tasseling time, whereas the traditional system (rambutan without intercrops) obtain only 11242 m^3 ha^{-1}. Due to the maize plant bending (August 2006), the fields with maize intercropping present an eco-volume diminution of 33% (Fig. 52). Thus, the scenario with maize/straw fallow obtained its high V$_{eco}$ at the maize tasseling period (August 2006) after which V$_{eco}$ decreased slowly, eventually reaching its lowest eco-volume in March 2007.

In the periods with legume intercropping, the rambutan system attains the highest eco-volume values in November 2006 for *C. spectabilis* field (Fig. 52). In the legume cycles, the scenario with *V. unguiculata* obtains its highest V$_{eco}$ (14690 m^3 ha^{-1}) in October 2006. This legume crop added 6222 m^3 ha^{-1} to the rambutan system. On the other hand, the *C. longirostrata* crop adds a V$_{eco}$ 9289 m^3 ha^{-1} into the fruit system, enabling the total rotation system to reach a total V$_{eco}$ of 23753 m^3 ha^{-1} in November 2006. Finally, the scenario with *C. spectabilis* reached a total V$_{eco}$ of 31601 m^3 ha^{-1} in November. This legume crop integrated not less than 16821 m^3 ha^{-1}

to the rambutan system (Fig. 52). The results demonstrate that maize-legume intercrops with rambutan increase over 100% the eco-volume of the rambutan system during the intercropping cycles. From March 2007, the fruit set commences slowly in the rambutan plant. For those reasons V_{eco} decreased inside the rambutan system across all legume scenarios. At the end of the second fruit cycle (April 2007), V_{eco} in the intercropping systems (11729, 13492, 12598 and 12546 and m^3 ha^{-1}) are lower than that of the sole rambutan system (15990 m^3 ha^{-1}). Due to the principles of nutrient uptake, light, and space competition, the rambutan trees in the fields with annual crops (maize and legumes) presented a lower growth than in the sole rambutan system.

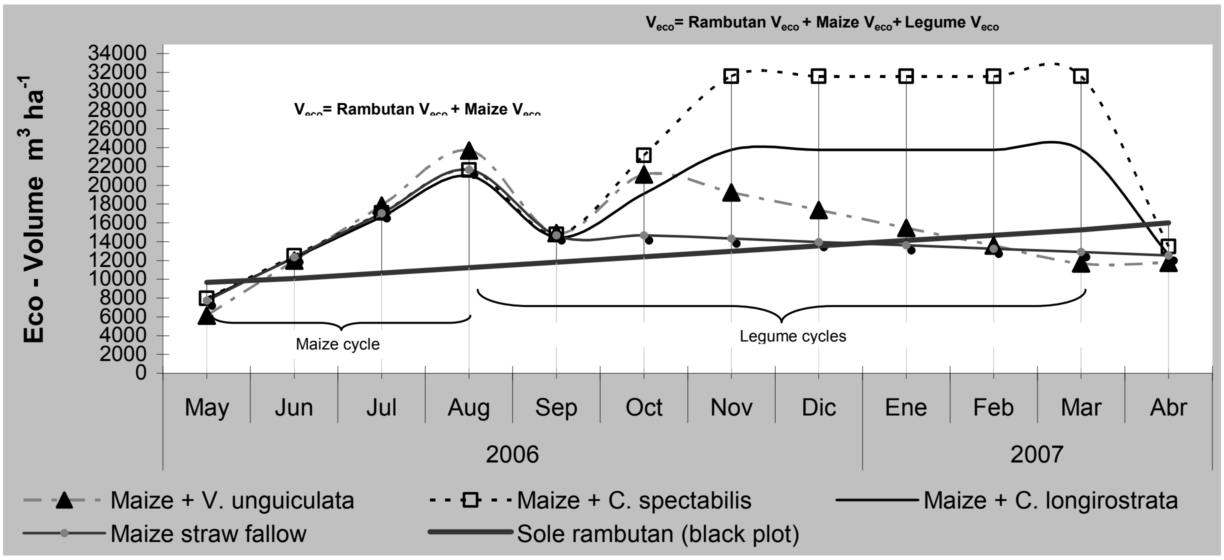


Figure 52: Eco-Volume dynamics in the rambutan intercropped systems.

4.7.2 Bio-volume dynamics in the fruit intercropped systems

Bio-volume (V_{bio}) is the total volume of the plants (trees, bushes, herbaceous, etc) taken by their corresponding biomass. Hence, bio-volume of a plant is its biomass divided by its corresponding specific weight. The concept is based on the hypothesis that the plants mainly compete for space (Kolnaar, 2006; Janssens *et al*., 2006; Diaz *et al*., 2004; Hansen, 1999; CIID, 1998). Bio-volume of the fruit systems can be estimated drawing on the principles of cylindrical figures.

Based on results of Torrico (2006), the natural systems offered the highest values of V_{bio} (1575 m^3 ha^{-1}) in the mature Atlantic rainforest of Eastern Brazil and to a lesser extent its fragments with 912 m^3 ha^{-1}. The ecological cropping of coffee in the Northeast Brazil has a great bio-volume value of 739 m^3 ha^{-1}. Other agricultural systems with very good V_{bio} are the cocoa agroforestry in Cameroon (396 m^3 ha^{-1}). The agricultural systems with less V_{bio} are the grass systems, horticultural systems and the Sylvopastoral system (13, 32 and 74 m^3 ha^{-1}, respectively)

The bio-volume (V_{bio}) in this study is reported as the V_{bio} of the fruit trees only per ha. It offers tools to determine the influence of intercropping systems on the bio-volume dynamics. Research in the mango system has started with an average mango tree V_{bio} of 17.33 m^3 ha^{-1} for the maize x pumpkin intercropped system and 11.39 m^3 ha^{-1} for the sole maize system. One year later (Oct. 2006), the mango V_{bio} in the intercropped system, augment to 22.48 m^3 and 19.40 m^3 ha^{-1} in the system with sole maize. At the end of the mango system studies (Feb. 2007), the intercropped system show 27.20 m^3 and 26.89 m^3 ha^{-1} for sole maize system. In the traditional mango system a volume of 32.23 m^3 ha^{-1} has been recorded. Thus, intercropping implementation inside a mango orchard affects the mango crop bio-volume. In the mango traditional system V_{bio} increased with 13 m^3 ha^{-1} in not more than 19 months. During the same period, the legumes and maize/straw fallow rotations obtained a V_{bio} increase of 15 m^3 ha^{-1} in the sole maize systems and of 10.40 m^3 for the legume scenarios in the maize x pumpkin intercropped system. The maize/straw fallow rotation in the intercropped system offers an increment of 9.33 m^3 ha^{-1}. These results indicate that the maize x pumpkin intercropped system reduces the bio-volume of the mango crops. The highest V_{bio} is obtained in the scenarios with sole maize or with legume intercrops and the lowest V_{bio} in the scenarios intercropped with maize x pumpkin and maize/straw fallow rotation.

In the case of rambutan, the maize x pumpkin intercropped system affects the V_{bio} dynamics. The average V_{bio} at the end of the first fruit cycle (Oct. 2006) is 1.48 m^3 ha^{-1} for the intercropped system with pumpkin and 1.24 m^3 ha^{-1} for the sole maize system. At the end of this study (April 2007), the intercropped system with pumpkin presents an average eco-volume of 3.48 m^3 and 3.04 m^3 ha^{-1} for the sole maize system (Tab. 14). Nevertheless, the black plot offers the highest value with 4.05 m^3 ha^{-1} (Tab. 14). The integration of intercropped maize x pumpkin and legume rotation increase V_{bio} positively with 2.60 m^3 ha^{-1}, but on the other hand the black plot presented the highest value with 2.65 m^3 (Tab. 14).

Table 14: Effects of intercropping and legume crops on the Bio-Volume of rambutan trees

		Bio-Volume of the rambutan trees (m^3 ha^{-1})			
Intercrops	Legume rotations	V_{bio} (Oct - 2005)	V_{bio} (Oct - 2006)	V_{bio} (Apr - 2007)	V_{bio} increase (Oct- 05 to Apr - 07)
intercropped maize – pumpkin	Legumes	1.56	2.34	4.16	2.6
	Maize straw fallow	1.404	2.184	2.808	1.404
Sole maize	Legumes	1.092	1.56	3.12	2.028
	Maize straw fallow	1.404	1.716	2.964	1.56
Black plot	Sole rambutan	1.404	2.496	4.056	2.652

4.7.3 Conclusion

Intercropping can incorporate additionally up to V_{eco} 15497 m^3 ha^{-1} to the fruit systems. Their value represents over 100% of the V_{eco} values for traditional fruit orchards. The intercropping sequence maize - *Crotalaria* spp. can increase up to two times the total V_{eco} of the fruit orchards. The V_{eco} in the fruit orchards intercrops with maize and *Crotalaria* maintain a high V_{eco} until the end of the dry season (April). To the contrary, the scenarios associating fruit, maize and annual legume crop rotation (Maize straw fallow, *P. acutifolius* and *V. unguiculata*) maintain the V*eco* only until the end of the rainfall season (October). On the other hand, the V_{bio} of the fruit orchards is not affected by the intercropping system, when integrating intercrops like maize x pumpkin or legumes. Nevertheless, maize monoculture and maize/straw fallow rotations have a negative impact on the V_{bio} of the fruit orchards.

V Prospects of the intercropping systems in the tropical fruit orchards

The productivity and agro-ecological situation of the fruit orchards in the extreme south region of Mexico illustrates the results of an applied technology opposite to the demand management for the fruit production systems. Still with whole technology and enormous government inversion and other institutions, the pest damages are until now the cause of enormous economic loss and fruit orchard quarantined area. Likewise, the production systems of coffee, banana, papaya, and mango present technical and commercial problems in the Soconusco, Chiapas. Nevertheless, the expectations of the fresh exotic fruits on national and international marketing indicate, that exotic fruit demand will increase in the next decades, principally in the United State and Europe. Some of the exotic species that could take up important places on the national and international fruit markets are Mamey (*Mammea americana)*, Chicozapote (*Manilkara zapota)*, Guanabana (*Annona muricata)*, Rambutan (*Nephelium lappaceum*), Tamarindo (*Tamarindus indica),* Chincuya *(Annona purpurea)* Litchi (*Litchi chinensis*), Mangostan (*Garcinia mangostana*), Passion fruit (*Passiflora edulis*) and others.

To confront the growing fruit demand in the next decades there exists a need to made changes on the management of tropical orchards. These transformation strategies have to be geared towards sustainability. Incorporation of vegetable intercropping systems inside fruit orchards offers interesting advantages to improve the ecological balance and economic inputs of the fruit productions systems. The results of this study support the findings that legumes and pumpkin intercropped inside fruit orchards can be attractive answers to the problematic of the fruit agro-ecosystems in the Soconusco. The vegetables intercropped with fruit only do not improve the resources and economic inputs, but diversify the nutrition habits of the farmers as well. The fruit intercropped systems offers flexible prospects to the farmers in order to overcome the unwanted monocultures be it mango, coffee or any other fruit tree.

Increases of fruit and vegetable yields like pumpkin, cowpea and edible chipilin in the intercropped fruit models are the best results to alleviate the poverty and nutrition problems of the campesinos in the Soconusco. Likewise, the biomass production and enrichment of flora and fauna diversity in the fruits intercrops can lessen the alarming ecological problems due to the high pesticide use and intensive monoculture systems. Finally, the results of intercropped pumpkin in the fruit orchard demonstrate that such system is more profitable than any other fruit monoculture.

VI RECOMMENDATIONS

The traditional maize systems (Roza-Tumba and Quema) in the tropical region are not profitable. Due to the short time for the vegetation and soil fertility regeneration, they only provoke until now negative effects on the natural resources and genera major poverty. It was also confirmed in the Kyoto protocol. With that has demonstrate, that the tropical region like Soconusco, Chiapas, are not area for maize monoculture.

For that reason, it is necessary focus studies on the dynamics of intercropped fruit orchards and their contribution on the carbon sequestration, energetic balance, flora and fauna diversity, as well as alternatives to diminish the young migration. This situation is due to the lack of employments in the rural area, where employments source exist only at the harvest period.

To summarize the results we offer the following main recommendations:

- The soil erosion and the failing management of organic matter are the principal factors that depress the productivity of the fruit orchards. For that reason, it is urgent to integrate cover crops inside the fruit orchards.

- Due to the nutrient outputs by annual and fruit crop harvests, it is necessary to integrate plant nutrition studies to correct some nutrient deficiencies in the fruit intercropped systems.

- In monocultures, the flora and fauna diversities become severely eroded over time. Their contributions to the system productivity and ecological harmonisation have not received enough research attention. The integration of annual intercrops inside the fruit orchards and their effects on the biotic and abiotic factors are a research priority for the fruit sustainability.

- Finally, it is recommended to integrate intercropping in the fruit orchards in order to reduce the market price volatility of a single commodity and offer better food diversity and nutritional balances of the rural population of the Soconusco.

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VIII ANNEX AND COMPLEMENTARY DATA

Table A- 1: Effects of intercrops on the soil parameters in rambutan orchard (1st sampling)

Intercrops	Rotation	Depth (cm)	Soil parameters in the first soil sampling (05-2005)										
			pH (H2O)	C-E (µS/cm)	TOC %	N %	C/N	mg P/100g soil	mval Ca/ 100g soil	mval K/ 100g soil	mval Mg/ 100g soil	mval Na/ 100g soil	CEC (mval / 100g
Intercropped maize - pumpkin	*V. unguiculata*	10-30	5.21	147.40	2.42	0.274	8.83	52.86	3.42	0.36	1.50	0.10	5.39
	C. spectabilis	10-30	4.99	188.30	2.267	0.224	10.12	54.48	3.59	0.36	0.96	0.06	4.98
	C. longirostrata	10-30	5.20	125.70	2.116	0.215	9.84	53.94	5.43	0.38	1.18	0.08	7.08
	Maize straw fallow	10-30	5.04	169.70	2.696	0.256	10.53	56.10	4.60	0.38	1.06	0.08	6.12
Sole maize	*V. unguiculata*	10-30	5.07	153.70	2.44	0.25	9.76	50.71	4.35	0.42	1.16	0.07	6.00
	C. spectabilis	10-30	5.09	137.30	2.17	0.221	9.82	53.40	3.59	0.32	1.01	0.08	5.00
	C. longirostrata	10-30	5.18	131.70	2.274	0.23	9.89	51.78	4.43	0.36	1.09	0.07	5.94
	Maize straw fallow	10-30	5.22	125.20	1.97	0.196	10.05	49.63	4.26	0.29	1.06	0.10	5.71

Table A- 2: Effects of intercrops on the soil parameters in mango orchard (1st sampling)

Intercropping	Rotation	Depth (cm)	Soil parameters in the first soil sampling (05-2005)										
			pH (H2O)	C-E (µS/cm)	TOC %	N %	C/N	mg P/100g soil	mval Ca/ 100g soil	mval K/ 100g soil	mval Mg/ 100g soil	mval Na/ 100g soil	CEC (mval / 100g
Intercropped maize - pumpkin	*P. acutifolius*	10-30	5.77	124.70	2.415	0.23	10.41	80.37	6.43	0.60	1.70	0.07	8.81
	C. spectabilis	10-30	5.48	147.80	2.621	0.26	10.04	61.49	6.60	0.30	1.70	0.09	8.70
	V. unguiculata	10-30	5.79	136.90	2.21	0.19	11.39	58.26	6.43	0.49	1.73	0.10	8.76
	Maize straw fallow	10-30	5.40	118.90	2.885	0.28	10.05	58.26	5.93	0.37	1.55	0.07	7.92
Sole maize	*P. acutifolius*	10-30	5.39	147.40	2.471	0.23	10.38	69.59	5.35	0.27	1.28	0.10	7.00
	C. spectabilis	10-30	5.57	147.90	2.428	0.23	10.47	53.94	6.02	0.31	1.65	0.07	8.05
	V. unguiculata	10-30	5.53	166.10	2.12	0.29	7.21	67.97	6.77	0.45	1.90	0.07	9.19
	Maize straw fallow	10-30	5.19	125.90	2.728	0.27	10.10	57.18	4.60	0.31	1.26	0.09	6.26

Table A- 3: Effects of intercrops on the soil parameters in mango orchard (2^{nd} sampling)

Intercropping	Rotation	Depth (cm)	Soil parameters in the second soil sampling (11.2007)										
			pH (H2O)	C-E (µS/cm)	TOC %	N %	C/N	mg P/100g soil	mval Ca/ 100g soil	mval K/ 100g soil	mval Mg/ 100g soil	mval Na/ 100g soil	CEC (mval / 100g
Intercropped maize - pumpkin	*P. acutifolius*	0-10	5.31	73.00	3.39	0.26	13.00	66.69	6.85	0.36	1.31	0.09	8.62
	C. spectabilis	0-10	5.47	106.40	2.89	0.26	11.12	58.63	7.96	0.49	1.52	0.11	10.08
	V. unguiculata	0-10	5.76	69.40	2.73	0.24	11.26	60.78	7.01	0.59	1.58	0.08	9.27
	Maize straw fallow	0-10	5.56	60.10	3.06	0.27	11.25	57.01	4.96	0.39	1.05	0.09	6.49
Sole maize	*P. acutifolius*	0-10	5.78	77.40	3.08	0.26	12.02	66.15	9.69	0.37	1.98	0.08	12.12
	C. spectabilis	0-10	5.58	103.80	2.33	0.22	10.38	61.31	7.01	0.43	1.41	0.08	8.93
	V. unguiculata	0-10	5.85	52.20	2.68	0.24	11.22	63.46	6.85	0.46	1.72	0.09	9.13
	Maize straw fallow	0-10	5.52	61.20	3.16	0.28	11.29	52.72	5.35	0.45	1.19	0.08	7.07
Black plot		0-10	5.75	49.50	3.06	0.33	9.34	70.45	6.54	0.36	1.43	0.09	8.41
Intercropped maize - pumpkin	*P. acutifolius*	10-30	5.38	50.30	2.63	0.23	11.59	68.30	5.67	0.24	1.21	0.08	7.20
	C. spectabilis	10-30	5.59	64.20	2.91	0.22	13.36	58.63	6.70	0.26	1.47	0.07	8.50
	V. unguiculata	10-30	5.91	45.10	2.02	0.20	10.32	53.79	6.30	0.45	1.45	0.08	8.27
	Maize straw fallow	10-30	5.56	45.70	2.53	0.24	10.56	52.18	4.72	0.23	1.13	0.09	6.17
Sole maize	*P. acutifolius*	10-30	5.89	103.90	2.35	0.21	10.97	62.93	7.56	0.27	1.84	0.09	9.76
	C. spectabilis	10-30	5.74	66.10	2.12	0.20	10.74	54.87	6.85	0.29	1.31	0.09	8.54
	V. unguiculata	10-30	5.88	44.10	1.99	0.20	10.13	57.55	5.91	0.31	1.52	0.09	7.83
	Maize straw fallow	10-30	5.60	42.70	2.52	0.23	10.76	50.03	5.20	0.30	0.91	0.10	6.50
Black plot		10-30	5.77	45.10	2.51	0.23	10.71	55.94	5.35	0.28	1.25	0.09	6.97

Table A- 4: Effects of intercrops on the soil parameters in rambutan orchard (2nd sampling)

Intercropping	Rotation	Depth (cm)	Soil paarameters in the second soil sampling (11.2007)										
			pH (H2O)	C-E (µS/cm)	TOC %	N %	C/N	mg P/100g soil	mval Ca/ 100g soil	mval K/ 100g soil	mval Mg/ 100g soil	mval Na/ 100g soil	CEC (mval / 100g
Intercropped maize - pumpkin	*V. unguiculata*	0-10	5.16	97.50	2.67	0.26	10.25	60.78	3.77	0.46	0.79	0.07	5.10
	C. spectabilis	0-10	4.85	161.00	2.83	0.28	10.11	67.76	3.70	0.34	0.65	0.06	4.75
	C. longirostrata	0-10	5.01	132.60	2.68	0.26	10.46	67.76	4.01	0.54	0.79	0.08	5.42
	Maize straw fallow	0-10	5.20	99.90	2.16	0.21	10.50	54.33	4.41	0.26	0.95	0.09	5.71
Sole maize	*V. unguiculata*	0-10	4.94	127.00	2.44	0.25	9.91	57.01	3.62	0.33	0.89	0.07	4.91
	C. spectabilis	0-10	5.01	138.00	2.62	0.26	10.09	65.61	4.01	0.42	0.95	0.07	5.44
	C. longirostrata	0-10	4.82	169.60	2.89	0.29	9.90	68.30	4.25	0.32	0.83	0.08	5.48
	Maize straw fallow	0-10	4.86	120.40	2.35	0.23	10.19	59.16	3.70	0.26	0.67	0.08	4.71
Black plot		0-10	5.05	131.30	2.77	0.26	10.68	57.01	4.80	0.31	0.97	0.08	6.16
Intercropped maize - pumpkin	*V. unguiculata*	10-30	5.27	65.70	2.12	0.20	10.43	53.79	3.54	0.28	0.83	0.06	4.71
	C. spectabilis	10-30	5.12	98.40	2.17	0.21	10.15	55.40	3.46	0.29	0.69	0.06	4.51
	C. longirostrata	10-30	5.20	109.60	2.13	0.21	10.25	52.72	4.09	0.40	0.85	0.07	5.42
	Maize straw fallow	10-30	5.43	68.20	1.79	0.17	10.30	48.95	4.25	0.24	0.97	0.07	5.53
Sole maize	*V. unguiculata*	10-30	5.25	73.20	2.03	0.20	10.23	47.88	4.17	0.29	0.93	0.08	5.46
	C. spectabilis	10-30	5.19	104.10	1.96	0.20	9.82	54.33	3.14	0.48	0.81	0.06	4.49
	C. longirostrata	10-30	5.07	101.90	2.29	0.21	10.78	56.48	4.01	0.27	0.85	0.07	5.20
	Maize straw fallow	10-30	5.17	70.30	2.04	0.19	10.59	53.25	3.85	0.21	1.17	0.07	5.31
Black plot		10-30	5.22	81.80	2.25	0.22	10.30	48.42	4.33	0.27	0.87	0.08	5.55

Table A- 5: Differences between the first and second soil sampling in rambutan orchard

Intercrops	Rotation	Depth (cm)	Difference of soil parameter values between the first and second sampling										
			pH (H2O)	C-E (µS/cm)	TOC %	N %	C/N	mg P/100g soil	mval Ca/ 100g soil	mval K/ 100g soil	mval Mg/ 100g soil	mval Na/ 100g soil	CEC (mval / 100g
Intercropped maize - pumpkin	*V. unguiculata*	10-30	0.06	-81.70	-0.30	-0.07	1.60	0.93	0.12	-0.08	-0.67	-0.04	-0.67
	C. spectabilis	10-30	0.13	-89.90	-0.09	-0.01	0.03	0.92	-0.13	-0.07	-0.27	0.00	-0.47
	C. longirostrata	10-30	0.00	-16.10	0.01	-0.01	0.40	-1.23	-1.34	0.02	-0.33	-0.01	-1.66
	Maize straw fallow	10-30	0.39	-101.50	-0.90	-0.08	-0.23	-7.14	-0.35	-0.14	-0.09	-0.01	-0.59
Sole maize	*V. unguiculata*	10-30	0.18	-80.50	-0.41	-0.05	0.47	-2.83	-0.18	-0.13	-0.23	0.00	-0.54
	C. spectabilis	10-30	0.10	-33.20	-0.22	-0.02	0.01	0.93	-0.45	0.17	-0.20	-0.03	-0.51
	C. longirostrata	10-30	-0.11	-29.80	0.01	-0.02	0.90	4.69	-0.42	-0.09	-0.23	0.01	-0.74
	Maize straw fallow	10-30	-0.05	-54.90	0.07	0.00	0.54	3.63	-0.41	-0.07	0.11	-0.03	-0.40

NOTE: - DECREASE
+ INCREASE

Table A- 6: Differences between the first and second soil sampling in mango orchard

Intercrops	Rotation	Depth (cm)	Difference of soil parameters between the first and second sampling										
			pH (H2O)	C-E (µS/cm)	TOC %	N %	C/N	mg P/100g soil	mval Ca/ 100g soil	mval K/ 100g soil	mval Mg/ 100g soil	mval Na/ 100g soil	CEC (mval / 100g
Intercropped maize - pumpkin	*P. acutifolius*	10-30	-0.39	-74.40	0.22	-0.01	1.18	-12.07	-0.77	-0.36	-0.49	0.01	-1.61
	C. spectabilis	10-30	0.11	-83.60	0.29	-0.04	3.32	-2.87	0.09	-0.04	-0.24	-0.02	-0.20
	V. unguiculata	10-30	0.12	-91.80	-0.19	0.00	-1.07	-4.47	-0.13	-0.04	-0.28	-0.03	-0.48
	Maize straw fallow	10-30	0.16	-73.20	-0.36	-0.05	0.51	-6.08	-1.21	-0.14	-0.43	0.02	-1.75
Sole maize	*P. acutifolius*	10-30	0.50	-43.50	-0.12	-0.02	0.59	-6.66	2.22	-0.01	0.56	-0.01	2.76
	C. spectabilis	10-30	0.17	-81.80	-0.31	-0.04	0.28	0.92	0.84	-0.01	-0.35	0.01	0.49
	V. unguiculata	10-30	0.35	-122.00	-0.13	-0.10	2.92	-10.41	-0.86	-0.15	-0.37	0.02	-1.36
	Maize straw fallow	10-30	0.41	-83.20	-0.21	-0.04	0.65	-7.15	0.60	-0.02	-0.35	0.01	0.25

NOTE: - DECREASE
+ INCREASE

Table A- 7: Multiple range tests for rambutan panicles per tree by treatments (first cycle)

```
-----------------------------------------------------
Method: 95.0 percent LSD
Treatments                         Mean    Homogeneous Groups
-------------------------------------------------------------
Sole maize + Maize straw fallow      28.2105           X
Sole maize + C. longirostrata        38.0526           XX
Black plot                           41.6316           XX
Sole maize + V. unguiculata          43.3684           XX
Maize x pumpkin + C. longirostrata   48.7368            XX
Maize x pumpkin + V. unguiculata     66.5263             XX
Maize x pumpkin + Maize straw fallow 67.1579             XX
Sole maize + C. spectabilis          74.8421              X
Maize x pumpkin + C. spectabilis     98.3158               X
-----------------------------------------------------
```

Table A- 8: Multiple range tests for rambutan fruits per panicles by treatments (first cycle)

```
-----------------------------------------------------
Method: 95.0 percent LSD
Treatments                           Mean  Homogeneous Groups
--------------------------------------------------------------
Sole maize + V. unguiculata            6.93684         X
Maize x pumpkin + C. longirostrata     9.67895         XX
Maize x pumpkin + Maize straw fallow   10.7053         XX
Maize x pumpkin + V. unguiculata       13.0000          XX
Black plot                             13.0316          XX
Sole maize + C. spectabilis            13.9421          XXX
Sole maize + C. longirostrata          16.9368           XXX
Maize x pumpkin + C. spectabilis       18.2316            XX
Sole maize + Maize straw fallow        19.0368             X
-----------------------------------------------------
```

Table A- 9: Multiple range tests for rambutan fruit weight (gr) by treatments (first cycle)

```
-----------------------------------------------------
Method: 95.0 percent LSD
Treatments                          Mean    Homogeneous Groups
--------------------------------------------------------------
Sole maize + V. unguiculata        22.6632           X
Sole maize + C. longirostrata      24.3068           XX
Sole maize + Maize straw fallow    25.1632           XX
Maize x pumpkin + S. spectabilis     25.9158          X
Maize x pumpkin + C. longirostrata   26.2211          X
Maize x pumpkin + V. unguiculata     26.4947          XX
Black plot                         26.6316            XX
Sole maize + C. spectabilis        27.2984            XX
Maize x pumpkin + Maize straw fallow 29.2895           X
-----------------------------------------------------
```

Table A- 10: Multiple range tests for rambutan yield (kg ha-1) by treatments (first cycle)

```
--------------------------------------------------------------------------------
Method: 95.0 percent LSD
Treatments     Count                   Mean Homogeneous Groups
------------------------------------------------------------
Sole maize + Maize straw fallow      1841.63           X
Sole maize + V. unguiculata          2031.18           X
Maize x pumpkin + Maize straw fallow 2312.17           X
Sole maize + C. longirostrata        2447.37           X
Maize x pumpkin + C. longirostrata   3000.57           XX
Black plot                           3187.42           XX
Maize x pumpkin + V. unguiculata     4397.43            XX
Sole maize + C. Spectabilis          5194.08             XX
Maize x pumpkin + C. spectabilis     6842.64              X
-------------------------------------------------------------------------------------------
```

Table A- 11: Multiple range tests for rambutan fruit diameter (mm) (first cycle)

```
-------------------------------------------------------------
Method: 95.0 percent LSD
Treatments     Count                Mean   Homogeneous Groups
-------------------------------------------------------------
Sole maize + V. unguiculata           30.3958         X
Maize x pumpkin + C. longirostrata    31.1132         XX
Sole maize + Maize straw fallow       31.8221         XXX
Maize x pumpkin + Maize straw fallow  31.9268         XXX
Sole maize + C. spectabilis           32.0416         XXX
Maize x pumpkin + C. spectabilis      32.3768         XXXX
Sole maize + C. longirostrata         32.6716          XXX
Black plot                            33.3011           XX
Maize x pumpkin + V. unguiculata      34.3105            X
```

Table A- 12: Multiple range tests for rambutan fruit length (cm) (first cycle)

```
--------------------------------------------------------------------------------
Method: 95.0 percent LSD
Treatments     Count             Mean      Homogeneous Groups
-------------------------------------------------------------
Sole maize + V. unguiculata          40.0826         X
Maize x pumpkin + C. spectabilis     40.6484         XX
Sole maize + C. spectabilis          41.5889         XX
Sole maize + C. longirostrata        41.8116         XX
Black plot                           42.1274         XX
Maize x pumpkin + C. longirostrata   42.8268         XXX
Maize x pumpkin + V. unguiculata     43.4758          XX
Sole maize + Maize straw fallow      45.2679           X
Maize x pumpkin + Maize straw fallow 49.4242            X
----------------------------------------------------------------------------------------------------
```

Table A- 13: Insects diversity during the mango flowering period (12-2006)

Family	**Cientific name**	**Common Name (English)**	**Common Name (Spanish)**	**Intercrops in the Mango orchard (2nd cycle)**			
				P. acutifolius	*C. spectabilis*	*V. unguiculata*	Maize straw fallow
Theridiidae	*Argyrodes* spp	Spider	Araña negra	1	0	0	0
Vespidae	*Eumenes* spp	Wasp	Avispa cojon	0	1	0	0
Vespidae	*Eumenes* spp	Wasp	Avispa negra	1	1	1	1
Apidae	*Apis* spp	Domestic Honey Bee	Avispa de castilla	0	1	0	1
Mantidae	*Mantis* spp	Mantis	Caballo del diablo	1	0	1	1
Tettigoniidae	*Tettigonia* spp	Grasshopper	Chapulin	0	0	1	0
Cicadidae	*Cicada* spp	Annual Cicada	Chichara	1	1	0	0
Pentatomidae.	*Euschistus* spp	Stinkbug	Chiche cafe	0	0	1	0
Pentatomidae.	*Nezara viridula* spp	Green Stinkbug	Chinche verde	1	1	0	0
Coccinellidae	*Coccinela* spp	Ladybugs	Cochinilla	1	0	1	1
Apidae	*Melipona* spp	Wasp	Avispa enredapelo	0	0	1	0
Tettigoniidae	*Scudderia* spp	Katydid	Esperanza	1	1	1	1
Acrididae	*Anacridium* spp	Grasshopper	Grillo	1	0	1	0
Lampyridae	*Lampyris* spp	Lightning bug	Luciernaga	0	1	0	0
Noctuidae	*Spodoptera* spp	Butterfly	Mariposa cafe	1	1	0	0
Noctuidae	*Mythimna* spp	Butterfly	Mariposa blanca	0	1	0	1
Nymphalidae	*Heliconius* spp	Butterfly	Mariposa negra	1	0	0	1
Cicadellidae	*Empoasca* spp	Greenfly	Mosquita verde	0	0	1	0
Aleyrodidae	*Bemisia* spp	Whitefly	Mosquita blanca	0	1	1	0
Tephritidae	*Anastrepha* spp	Fruit fly	Mosquita negra	0	1	1	0
Xylocopinae	*Xylocopa* spp	Latter bees	Ronron	1	0	1	0
Culicidae	*Aedes* spp	*Mosquito*	Zancudo	1	0	1	1
Libellulidae	*Sympetrum* spp	Damselfly	Cigarrito	0	0	1	0
Tabanidae	*Tabanus* spp	Horse Fly	Tabano	1	0	1	0

Table A- 14: Insects diversity during rambutan flowering period (03-2007)

Family	Cientific name	Common name (English)	Common name (Spanish	**Intercrops in the Rambutan orchard (2nd cycle)**				
				V. unguiculata	*C. spectabilis*	*C. longirostrata*	Maize straw fallow	*Black plot*
Theridiidae	*Argyrodes* spp	Spider	Aranha	0	0	1	0	0
Halictidae	*Polistes* spp	Paper Wasp	Avispa carnicera	1	1	1	1	1
Apidae	*Melipona* spp	Wasp	Avispa enrredapelo	1	0	0	0	0
Vespidae	*Eumenes* spp	Wasp	Avispa negra	1	1	1	1	1
Vespidae	*Eumenes* spp	Wasp	Avispa sumbadora	0	0	1	0	0
Mantidae	*Mantis* spp	Mantis	Caballo del diablo	0	0	0	1	0
Cicadidae	*Cicada* spp	Annual Cicada	Chicharra	1	1	1	1	1
Pentatomidae.	*Nezara viridula*	Green Stink Bug	Chinche	1	1	1	1	1
Coccinellidae	*Coccinela* spp	Ladybugs	Cochinilla	1	0	0	0	1
Unknow			Desconocida	1	1	1	1	1
Tettigoniidae	*Scudderia* spp	Katydid	Esperanza	0	0	1	0	0
Acrididae	*Anacridium* spp	Grasshopper	Grillo	1	1	1	1	1
Formicidae	*Solenopsis* spp	Fire ant	Hormiga fuego	0	0	1	0	0
Noctuidae	*Spodoptera* spp	Butterfly	Mariposa cafe	0	0	1	1	1
Muscidae	*Musca* spp	Housefly	Mosca de casa	1	0	1	1	0
Muscidae	*Musca*	Fly	Mosquita negra	0	1	0	0	1
Aleyrodidae	*Bemisia* spp	Whitefly	Palomita blanca	1	1	0	0	0
Xylocopinae	*Xylocopa* spp	Latter bees	Ronron	1	1	1	1	1
Culicidae	*Aedes* spp	*Mosquito*	Zancudo	1	1	1	1	1
Tabanidae	*Tabanus* spp	Horse Fly	Tabano	1	1	1	0	1

ERKLÄRUNG

Ich versichere, dass ich diese Arbeit selbständig verfasst habe, keine anderen quellen und Hilfsmittel als die angegebenen benutzt und die Stellen der Arbeit, die anderen Werken dem Wortlaut oder dem Sinn nach entnommen sind, kenntlich gemacht habe.

Die Arbeit hat in gleicher oder ähnlicher Form keiner anderen Prüfungsbehörde vorgelegen.

Bonn, den 12 Mai 2008

____
Francisco Javier Marroquin Agreda