Cacao and Neighbour Trees in Ecuador

How and Why Farmers Manage Trees for Shade and Other Purposes

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SUMMARY

We visited 21 cacao farms in Ecuador in March 1999 and spoke with farmers about how they managed cacao and other trees. We asked farmers about the value of these trees and their effect or role in cacao management and production. Farmers had a sophisticated system of shade management in which the other trees growing with cacao played many roles besides shade.

We suggest that 'shade tree' is an inappropriate description for trees growing in cacao farming systems in Ecuador and propose the term 'neighbour tree', which is used in this report.

Farmers did not identify shade as the most important function of other trees in cacao groves. Nor did farmers describe them as 'shade trees'. Farmers did say that shade had various effects on cacao production and that neighbour trees suppress weeds and control humidity. But the most important function of intercropped trees is to provide a product to the farmer or ecological service to cacao growing. The most common and important product of neighbour trees is fruit. Ecological services include: humidity and soil moisture control, regular supply of leaf litter and soil improvement through nitrogen fixation.

A stereotype of 'traditional' Ecuadorian cacao is that it is planted in the shade of natural forest trees. We did not see or learn of any cacao groves planted recently under natural forest trees. The most recent example we learned of was over 30 years ago. We saw many cacao 'agroforests' with timber and fruit trees, including highly valued exotic species, but most of these neighbour trees had either been planted, or were volunteer trees that the farmers managed. *Inga* species were the only trees deliberately planted by some farmers to shade cacao, though only for young plants. The *Inga* trees were usually removed after six to seven years, once the cacao was established. *Inga* also improves soil fertility, provides firewood and produces food from the large seedpods.

Citrus is the favourite fruit tree of Ecuadorian cacao farmers, planted on 19 of the 21 farms we saw. Other fruits include sapote (*Quarirabaea cordata*), mango, guava and avocado. Although fruit trees are usually grown next to cacao, both within the groves and on the edges, farmers never called fruit trees 'shade trees'. Fruit trees generally combined well with cacao though farmers said they provided fewer ecological services to cacao plants. They had been planted for produce and cash.

Farmers also plant a few timber trees, selecting volunteer seedlings and protecting them while the young cacao becomes established. Farmers and contract lumbermen fell timber trees occasionally, for timber and for sale. Timber trees are also valued for services to cacao production. Farmers prefer some species of timber trees, because when felled they do less damage to cacao trees.

Rapid biodiversity assessments if ants and nematodes in cacao groves showed that soil nematodes had the greater potential to provide useful information which would assist in developing improved management practices.

Sustainable cacao production depends on the effective incorporation of farmer knowledge. It helps researchers to identify the most important problems and, together with extension officers, provide the most appropriate solutions. Our study highlights a dichotomy between the value and role for neighbour trees as described by farmers and ascribed by researchers. Shade is not the most valuable feature according to farmers. A failure to recognize this will compromise advice given to farmers, despite the best intentions of researchers.

Further studies are needed to examine farmer knowledge of neighbour trees. This will help us to identify the best ways to help farmers sustain production of cacao while conserving important biodiversity and reducing environmental degradation.

Why shade?

Much of the cacao in Latin America is still grown in the shade of other trees, but cacao is increasingly grown in full sun. Environmentalists have emphasised the advantage of shaded cacao in maintaining a higher biodiversity of wild animals (including invertebrates) and as a habitat for birds. Ecologists and conservationists, relative newcomers to the field of cacao research, have encouraged the view that shaded cacao is potentially more sustainable. The trees produce longer, the need to seek new land (or fertiliser) is reduced and biodiversity is enhanced (Rice & Greenberg 2000).

We wanted to learn why some farmers preferred shade and others did not, prompted by the 1998 Panama conference on sustainable cacao. We wanted to explore the links between shade trees, cacao management and biodiversity, according to farmers.

We started our fieldwork in Ecuador by asking farmers about shade trees, in open-ended interviews in their cacao groves. We soon realised that their shade management was sophisticated and that the other trees growing with cacao played many roles besides shade, so we decided to call them '**neighbour trees**' instead of shade trees.

Cacao in Ecuador

Over a hundred years ago, Ecuador was the world's leading producer of cacao, before being devastated by disease, mismanagement and a growing production from other countries, especially in West Africa. Ecuador has never regained its previous dominance (see *Chronology* below), yet remains an important producer. Centuries of living with cacao has created an historical appeal for farmers, despite many problems, and cacao production still makes a major contribution to rural livelihoods.

Smallholders produce most cacao in Ecuador, yet they have received less support and study than larger producers. Smallholders[1] are widely scattered and use diverse management approaches, which creates difficulties for researchers and those attempting to improve cacao management and production.

Smallholders are occasionally stereotyped as inefficient, clinging to traditional practices and to old, aromatic cacao varieties grown under shade. Cacao in full sun produces more, especially with chemical fertiliser, and with irrigation to regulate moisture. The high-yielding hybrids of cacao rely on less shade. Lower-yielding, but high quality, aromatic cacao is more likely to be grown in shade.

Farmer knowledge

The present study responds to research needs identified at the Panama meeting. Ecuador was chosen as the site for the current study, because cacao production systems have evolved over hundreds of years, and there is a continuum from traditional to modern systems. Scientists know little about how farmers manage and perceive neighbour trees, and the value of these trees to farmers. This study describes farmer knowledge of these trees in relation to management of cacao.

[1] Average farm size from about 20 – 40 ha, depending on province. Average size of cacao stand 7 – 13 ha.

Chronology of cacao production in Ecuador: 16th to 20th century

1590 – 1689	1590 – Spanish colonists growing cacao and exporting. 1689: Jesuits planted 51 000 trees.
1780s +	98 310 cacao trees in Ecuador, from Machala to Babahoyo to Chone. 1796: Cacao being planted to exclusion of banana; governor orders land owners to plant 150 banana plants for every 10 000 cacao.
1800s	Cacao boom. Mass migration of Indians from highlands for labour. Cacao becomes the wealth of Ecuador. Guayaquil grows from 5000 in 1765 to 13 700 in 1804.
1820 – 1821	12 million cacao trees on 12 000 ha, producing 5489 tons. Land concentrated in the hands of a few hundred owners. 1821: Cacao production has risen to 6980 tons.
1840 – 1870s	Production stagnates around 5511 tons because of: yellow fever; political problems; economic crises in Europe; US Civil War.
1880s	Ecuador produces 45 360 tons per year, world's largest producer with 30% of market. 50 Ecuadorians and foreigners control agriculture, commerce and industry, many self-made, poor immigrants who made fortunes.
1890	Farmers start planting *Trinitario* (aromatic variety) with seeds imported from Trinidad. Inferior quality but could be grown on hills, further away from water. Little *nacional* was planted after 1900. Ecuador dominates cacao production as demand is stimulated through mass production of chocolate. Ecuador had trade surpluses 50% value of imports, and becomes a 'money machine'.
1890s	4827 farms, 58.6 million trees. Tenguel is the largest cacao farm with 3 million trees.
1900+	Cacao achieves record prices; Ecuador's economy depends on it. Brazil, Ghana and Nigeria production kicks in, price lowers, staying low throughout WW1. But trees planted during the earlier boom came into fruit in 1907 and production kept on increasing.
1914–1915	Cacao prices plummeted from $20 to $10 (per quintal; approx. 45 kgs). Ecuador produces only 6.8% of world supply. 60% of cacao in Ecuador was destroyed 1916–1931 by disease. Production declines from 48 955 t to 13 646t.
1919 – 1921	Large estates going broke, split up and sold to smallholders. Mass migration of agricultural labourers to Guayaquil. Tenguel farm produces 1361 t, by 1925 only 36 t. Farm sold to United Fruit. Planted clones from Trinidad and bananas. Clones not a long term solution, lived only 12–15 years.
1922 – 1938	Strikes, riots and looting in Guayaquil. 2000 people killed. Serious economic problems in Ecuador. 1936: Manabí starts to become an important cacao region. Price drops to historic low of $4 per quintal. Smallholder farmers buy and divide many large estates.
1940	New low production of 10 582 t; prices reached another low. But in 1947 disease in Africa helped increase price for Ecuador cacao.
1940s late	Complex but sophisticated system of named cacao bean types, categories defined on the basis of place of origin, colour of grain, harvest season etc. **Cacao quality types were ranked and sold at differential prices.** US confectioners were more interested in volume than quality and there is some suggestion that this contributed to superior grades being dumped into the bulk grades.
1950 – 1951	*Nacional* variety is only 30% of cacao grown in Ecuador. 91 m trees. Large haciendas have vanished. Little irrigation was used and yields low (206 kg/ha).
1963	Cacao was only 3.8% of value of Ecuador's agricultural production (bananas 24.9%). Price dropped again, to $8 per quintal.
1978	Yields were down to 0.25 t per ha, from 0.31 t per ha in 1971, due to disease. 11 companies exported $194 m of value-added cacao products (e.g. cacao paste) but companies collapsed when tax credits were removed in the early 1980s.
1990s	Largest estate is 200 ha, average holding <30 ha. Production back to 80 000 t. EU/CIRAD project aims to improve quality of cacao through technical improvements and better organisation of smallholders.

Source: Arosemena, G. (1991). *El Fruto de los Dioses: El Cacao en el Ecuador, desde la Colonia hasta el Ocaso de su Industria, 1600–1983.* Guayaquil, Ecuador, Editorial Graba. 855pp [2 vols].

Purpose of the study

The original project proposal used 'shade tree'. As we said above, we have substituted it with the term 'neighbour tree'[2].

AIM

> Identify constraints and opportunities for improving sustainable management of smallholder cacao in selected countries, with particular emphasis on the use of *shade* trees.

OBJECTIVES

1. Learn the importance and role of *shade* trees to farmers.
2. Evaluate the impact of *shade* trees on biodiversity.
3. Identify factors which influence the choice of cacao variety and management practices.
4. Assess the importance and impact of cacao pests in relation to *shade* trees.
5. Assess the health of *shade* trees and compare our assessment with farmer knowledge.

Field methods

The surveys were carried out over a period of three weeks in March 1999.

We improved our interview techniques and questions as we learned more about neighbour trees and cacao farms. We held regular team meetings to review progress and to compare what we did in the field with the aim and objectives of the project.

Most farmers were keen to speak to us and readily discussed their farms and cacao management, which were of great interest and concern to them. Our interviews were semi-structured. To find out why farmers decided to plant shade trees or not, we started by asking them to tell us about shade trees and how they farmed. We soon realised that farmers regularly mentioned certain key ideas (e.g. disease, weeds, irrigation). We adopted these farmer ideas into a checklist for the later interviews, to make sure that we covered all the major points that farmers considered important.

A general protocol or etiquette was prepared (by JB) for use in farmer interviews.

1. TELL THE FARMERS WHO YOU ARE AND WHAT YOU'RE STUDYING. They have the right to know, and the information may help reduce their anxiety, and get them onto the topic.
2. BE RESPECTFUL. Address farmers as you would a senior colleague.
3. ASK AS FEW QUESTIONS AS POSSIBLE, ESPECIALLY IN THE BEGINNING. People like to be listened to. Each question costs you rapport. Listen to the story they want to tell before breaking up their train of thought with questions.
4. IF A COLLEAGUE HAS BEEN INTERVIEWING A FARMER, DON'T COME IN AND START ASKING QUESTIONS. Those topics may have already been covered. Your question will probably be, at best, a non sequitur. Listen for a while and wait until the farmer comes to your topic, or until there is a long pause, and people are willing to have a new topic introduced.
5. NOT ASKING QUESTIONS ALLOWS FARMERS TO FEEL THAT YOU HAVE LISTENED TO THEM. They are then more likely to relax and answer a few questions later in the interview.
6. FOLLOW THE THREAD OF THE CONVERSATION. If you do ask questions, ask for clarifications: what do you mean? why did you do that?. Or, ask questions that follow on the topic: "You were telling us about weeds – how do you control them?"

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[2] Cacao requires shade during its early stages of growth. This may be provided by temporary ('baton-passing') plants or by mature trees. There is no absolute requirement for shade once the cacao tree is established, unless there is no irrigation, in which case shade trees preserve soil moisture.

7. TRY NOT TO PUT WORDS IN THE FARMER'S MOUTH. For example, point to a diseased pod and ask the farmer what it is. That is a better way of getting onto the topic of diseases than saying: "Do you have monilia?"

8. DON'T INTERRUPT A FARMER WHO IS SPEAKING. Do not mistake a short pause as a chance to leap in.

It took several days to establish a protocol for interviewing farmers. The first interviews were less focussed than later ones. Extension agents were invaluable in introducing us to farmers but we were not always able to control extensionists' more enthusiastic and well-meaning urges to tell us what they knew about cacao farming, or to speak for the farmer[3].

We began by asking direct questions about shade, using our research knowledge to pursue particular lines of enquiry about the effect of ‘shade’ on disease impact and cacao production. After the first week of interviews, JS remarked that very few farmers had actually used the term ‘shade tree’. We stopped asking about shade trees and instead began discussions with general questions on cacao management. This was much more productive.

All interviewees were male, though women joined some of the discussions. We usually avoided questions about land size and other economic details, because these are sensitive topics which can be threatening to farmers.

Methods used for the biodiversity studies are given separately in Annexes 5 and 6.

Study sites, farmer cameos

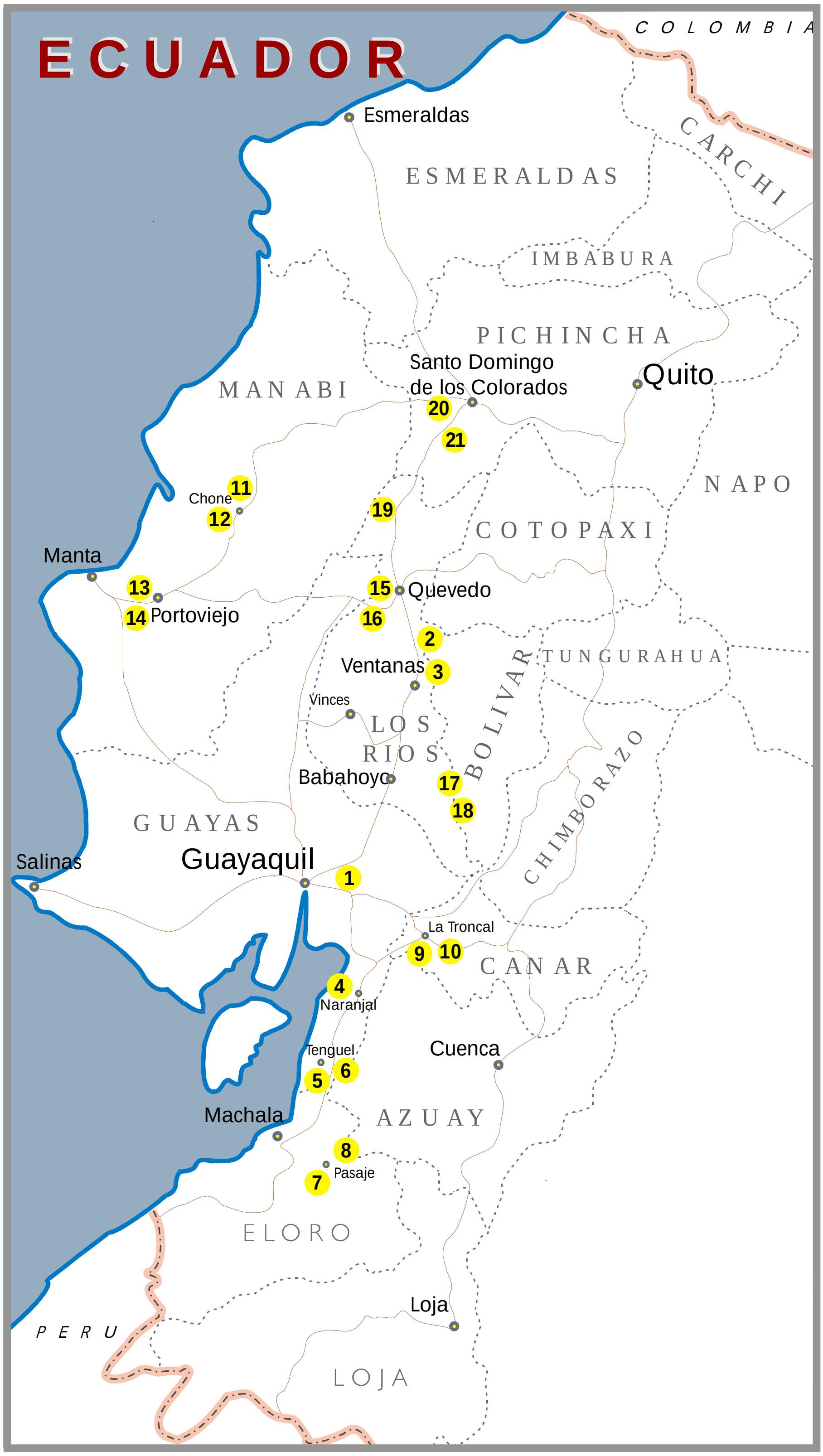
We visited 21 farms (Fig 1 and Annex 1). Each community visit took an average of half a day and included about two farms. We wanted to visit farms known to the chairmen of the local cacao growers' associations, introduced to us through the CIRAD / EU project, but this was not always possible. Some interviews were organised spontaneously in the field. We visited a varied group of farms (Annex 1).

Each farm was given a unique code. ECF1 stands for ECUADOR CACAO FARM number one. Farms were numbered in order of visit. We have omitted the findings from ECF6 and ECF15 because of incomplete data.

Three brief descriptions of farms and the interviews that took place (farmer cameos) are given in Annex 4.

[3] Since then, the authors have formalised concepts and methods for incorporating extensionists in research on farmers’ knowledge (Boa, Bentley & Stonehouse 2001, in press).

Figure 1: Location of study farms



RESULTS

Our results are presented mostly in the form of farmer statements. These are not verbatim quotes, because of the informal nature of our visits, but they are accurate accounts of what farmers said to us. Tables are grouped together on page 16.

Cacao varieties

The oldest cacao farm we saw was in Chone. Sergio Garcia (ECF11) said that his farm had produced cacao continuously for 200 years. Most farmers expressed a strong commitment to growing cacao. Further information may be available through reports produced by a CIRAD/EU project ECU–B7–3010/93/176. We did not seek out abandoned cacao farms, a feature commented on by several people during preparatory work for our surveys. (EB came across one example close to Vinces in early 1999). It would be useful in any future survey on farmer knowledge to include a few examples.

Many farmers were still in favour of growing *nacional* hybrids[4] (Table 1). They suspected that CCN51 would not remain productive for as long and whilst many growers are replanting with CCN51, farmers still value traditional varieties.

We expected to find distinct groups of farms with *nacional* and those growing CCN51, but we found several who had both (Annex 1). Those who were planting new cacao were selecting both *nacional* and CCN51. Some were replacing existing groves while others were determined to grow only *nacional*. Alfonso Mieles (ECF13) showed a particular commitment to *nacional*, even though his farm borders a demonstration plot of CCN51.

Agronomists often see traditional cacao systems as unproductive. One stereotype is that farmers with traditional varieties are sloppy about weeds; we could find no evidence for this. Farmers with *nacional* and related hybrids were all actively managing their orchards (Table 2). In the Southeast, around Naranjal and Tenguel, we found farmers who had moved in and out of cacao, usually to or from banana. They all had access to irrigation.

Neighbour trees: their role and value to farmers

When we first asked farmers if a tree growing above the cocoa was 'shade' he would give a simple answer ('yes', in one instance). Later investigations yielded a more diverse series of opinions and views and revealed a more complex series of interactions with cocoa (Table 3). Not all were positive and suggested different degrees of association of trees with cocoa and reasons for planting the trees.

When it came to describing interactions between cacao and other trees, farmers tended not distinguish the precise role of a particular tree. (Further information on how farmers view the suitability of individual trees for growing with cacao is given in Annex 2.) There was little or no evidence that shade was the principal function of these trees. This is discussed more fully below.

[4] Farmers used *nacional* to describe 'traditional' varieties, but even these are probably hybrids. Specialists think that little pure *nacional* remains in Ecuador. *Nacional* is used in this report for all the traditional, aromatic varieties, e.g. *venezolana, nacional, trinitario* and their hybrids.

It is important to distinguish between shade for young cacao and established cacao. This distinction was not always clear from our early interviews. There is an absolute requirement for shade during the establishment phase and we recorded a number of different plant successions:

1. Banana, cassava, then *Inga edulis* and papaya
2. Banana, papaya and coconut
3. Bananas and *Inga edulis*
4. Maize and *Inga edulis*
5. Maize and plantains
6. Maize, *Inga edulis*, citrus orange

The maize and cassava were harvested first. Bananas and plantains 'naturally died' according to one farmer, but many cacao groves maintain (or at least tolerate) these plants alongside cacao. We were unable to find any young cacao grown under the shade of existing forest trees and farmers explained that such sites were cleared completely in advance of planting cacao. The most recent example of this was over 30 years ago.

The management of *Inga edulis* is carefully planned. Farmers plant it with young cacao, which needs shade. After a few years, once the shade is no longer required, farmers kill the *guabo* (*Inga*) by debarking, and wait for the tree to gradually shed its foliage and dead branches, reducing the damage to cacao when the main trunk is felled. Guabo is the only major example of a tree we saw which really is a shade tree – though growers value it just as much for increasing soil fertility through nitrogen fixation and leaf litter.

A full list of neighbour (*shade*) trees is given in Annex 2. We identified four major roles for neighbour trees (besides producing fruit and timber): shade, soil improvement (nitrogen fixation and leaf litter), moisture or humidity control. The ability to regulate humidity within the cacao crop is partly a function of shade and crown architecture of neighbour trees. (Table 5). Most farmers referred to the moisture or humidity control as a general feature of all neighbour trees; no individual species were singled out (Table 6). The same was true for leaf litter on the whole, though *cedro* and *laurel* were particularly noted as being good. One observed that cacao 'self-fertilises' the soil while another said that cacao gave more to fruit trees grown in association than vice-versa, referring to nutrients from leaf litter.

We have omitted some neighbour trees said to be 'good for shade' at the beginning of our survey (Table 5). When the topic of shade was referred to more obliquely in later interviews, the same tree species were not mentioned. They included:

> *Artocarpus altilis* [*fruto de pan*, breadfruit]; *Hevea brasiliensis* [*caucho*, rubber]; *Psidium guajaba* [*guayava*, guava]; *Pseudobombax guayasense* [*beldaco*]; *Tectona grandis* [*teca*, teak]

Farmers had different opinions on the shade function of citrus varieties, which may reflect different canopy shapes and architecture – some citrus crowns were very ragged, a combination of poor management and disease. To the farmer, shade was inseparable from the way it influenced issues such as humidity, water loss, cacao pest impact and growth of ground weeds. Neighbour trees were described individually for the products they provided and, we suspect, these products were given a higher value than the ecological services also provided to cacao. Only *guabo* was singled out as being more effective in suppression of ground weeds. Some neighbour trees were more susceptible to parasitic plants, such as mango (Table 5). Farmers said the air weeds spilled on to the cacao.

Trees such as avocado and bamboo, two commonly occurring plants on cacao farms, were not generally grown in close proximity or direct association with cacao. The majority of these trees **did** provide useful products to farmers (Annex 3).

Pests and disease of cacao and neighbour trees

We asked farmers about cacao diseases and the health of neighbour trees (Table 6). Farmers were very familiar with cacao pests and diseases but less so with diseases of citrus, such as tristeza. *Moniliophthora* was the most serious disease affecting cacao, followed by witches' broom. *Mal de machete* was of little or no importance, according to farmers. Only one farmer mentioned possible black pod (*Phytophthora*) disease – *gato prieto*. We did not investigate the amount of losses due to diseases on different cacao varieties but farmers reported different degrees of loss. There was no clear view on the effect that shade had on disease development and we felt it would be useful to explore this topic further.

Farmers talked frequently about insect pests, particularly those that bite or sting. There was no evidence that any of these were damaging on cacao, though farmers were sometimes eager to control them. Farmers did not mention links between insects on cacao and insects on neighbour trees.

We asked about the health of neighbour trees but this topic evoked few responses. Several neighbour tree species had been badly affected by flooding, and many citrus trees had thin crowns and dieback. Farmers were concerned about the death of neighbour trees but were less concerned about dieback and other common non-specific symptoms. These were rarely serious in our opinion.

Weeds

Farmers distinguish between two groups of weeds. There are the terrestrial weeds which compete for soil nutrients, which we called GROUND WEEDS, and there are epiphytic and parasitic plants that we call AIR WEEDS. Farmers are experts at removing air weeds. The farmers called parasitic plants '*hierba de pájaro,*' '*pajarito*', '*comida de pájaro*', '*solda*' and '*lentejilla*'. The epiphytes or bromeliads were called '*piñuela*', '*chupayo*' and '*lechuga*'. Farmers saw the parasitic plants as debilitating the cacao whilst the epiphytes filled up with water and weighed branches down. Much labour is spent removing air weeds.

Shade reduced the growth of ground weeds, though farmers did not always distinguish between the self-shading of cacao and that provided by neighbour trees. Some farmers saw neighbour trees as the source of the air weeds (Table 5).

Natural Forests and Planting Cacao

Environmentalists have expressed concern about the loss of natural vegetation due to expansion of cacao growing areas, particularly the loss of native forest (Rice & Greenberg 2000). None of the farmers we interviewed had recently cut down forested land. The most recent conversion of forest to cacao plantations we learnt about occurred more than 30 years ago (Annex 1) and most were much earlier. We asked widely about new plantings of cacao in areas of thinned forest (as in West Africa), but found none.

We talked with farmers about how they established cacao groves and how they decided which neighbour trees they wanted and which ones to encourage. Farmers said that land was completely cleared before they planted. In areas such as Tenguel, native forest has long since disappeared. This is true of other areas where cacao has been produced for more than three centuries. In other more recently established areas, all forest trees appear to have been removed prior to planting cacao.

Farmers explained how they encouraged volunteer timber species (Table 7). The timber trees seen today in cacao groves have been managed by farmers. We saw no cacao planted in the understory of natural forest, although there were a few wild trees on one farm (ECF3). Farmers think carefully about the mix and positioning of neighbour trees (particularly fruit trees) in relation to cacao. We saw many examples of mixed farms where (at first glance) the planting pattern of cacao and neighbour trees looked haphazard.

But on closer inspection, farmers showed us that the trees were planted in complex, thoughtful patterns (Table 7). For example, Griserio Pinos (ECF17) had a mature cacao grove on a steep, boulder-strewn slope. At first, the placement of the trees seemed as unordered as in a natural forest. But Mr Pinos said it was planted for 'the four winds' (*los cuatro vientos*) meaning that in order to allow maximum air flow in the grove, the trees were lined up in perfectly straight rows, up-hill, across slope, and diagonally from both of those directions. Once this was pointed out to us, we could see the lines of trees by eyeballing down the rows. The apparent disorderliness of the planting was merely a result of the broken terrain.

Marketing

We explored many topics with farmers, including prices. A selection of statements in Table 4 point to areas of interest and relevance to sustainable cacao.

Many farmers complained about low prices, and some blamed various conspiracies along the marketing chain designed to pay the farmer the lowest possible price. The main issue was that the fine flavour of *nacional* cacao and its hybrids does not attract a higher price than CCN51. A series of separate interviews with buyers and traders (carried out by JS) suggested that changes to the marketing chain made it less favourable or profitable to separate the fine flavour cacao and accord it a higher price. The issue of cacao price is outside the scope of the present study but needs to be investigated if traditional farms are to receive a fair price for their efforts, because neighbour trees are associated with aromatic, traditional varieties. Encouraging those varieties with better prices is the most effective way to encourage shade and neighbour trees.

On one occasion we were accompanied by a cacao researcher on a visit. The owner was not present. The researcher presented a very different picture of what farmers did (or did not do, according to him): they cut the weeds but ‘don’t bother to go back until harvest’; they do hardly any work; they don’t fertilise (the beneficial effects of tree litter were not mentioned); in some clearings farmers plant trees but mostly it’s natural forest. These were honestly held opinions and there may be some truth in them, but they suggested a caricature of smallholder farmers which was certainly different from our own experiences.

Biodiversity Assessments

We collected ants and took soil samples to analyse nematode diversity. The methods, results and preliminary conclusions of the ant study are presented in Annex 5, and in Annex 6 for the parallel nematode study. A short discussion of the important findings of these studies is presented below. For more details see the individual reports.

One aim of these studies was to identify a target group of organisms that could be easily studied in a short period of time (weeks rather than months), yet give useful results. We wanted to maximise the amount of useful information on biodiversity for a minimum period of collecting and monitoring populations. Biodiversity studies often involve lengthy monitoring whilst we wanted a quick and reliable scheme more appropriate to rapid appraisals of cacao farms.

Our conclusion is that the ant diversity study tells us little about biodiversity. Ant diversity was measured on cacao trees and not on neighbour trees. Farmers talked about insects a lot, often confusing the roles of different groups seen on cacao trees. Their interest usually centred on insects that irritated or stung people.

ANTS: The Shannon-Weaver index, one of several indices used to measure biodiversity, was used to compare diversity of ants with different aspects of cacao management. No relationship was found between either number or genera of ants or index and ‘traditional status’ (explained further in Annex 5), a broad indicator of management practices associated with the presence of neighbour trees. This differed from the findings of a previous study of ant biodiversity in coffee plantations, which showed that there was a significant and visible drop in ant species at the point where shade trees were eliminated and coffee planted in monoculture. Further details are in Annex 5. The value or benefit of ant diversity to sustainable cacao production in Ecuador is unclear and requires further study.

NEMATODES: We know a lot about the role of different feeding (trophic) groups of nematodes. They are a useful indicator of how soil is managed (Annex 6). The failure to use nematode biodiversity more frequently may be related to the much smaller number of specialists available to carry out studies, certainly when compared to entomology or other mammals that feature regularly in biodiversity assessments.

The study was unable to compare nematode biodiversity directly with 'traditional status' of cacao farms. However, our conclusion is that nematode biodiversity is more likely to satisfy criteria for speed, usefulness and relevance when it comes to assessing biodiversity. Similar methods and approaches are already being used in other studies of 'sustainable agriculture'. Further information on these studies is available from EB.

Only one farmer mentioned nematodes, a legacy of a banana disease, which an ever-helpful pesticide salesman had advised on. Farmers did not remark on nematode diversity or soil health, though this was explained briefly as we sought permission in each farm to take soil samples, an activity that the farmers viewed with more bemusement than keen interest.

GENERAL: When the issue of biodiversity was raised *en passant* during a meeting attended by over 15 chairmen of local cacao growers' associations, there was a murmur of recognition. Few insights were obtained when we pursued this topic with individual farmers. One farmer said: 'I went to college and studied agronomy and other matters. Do I think farmers think much about biodiversity? No.'

We collected plants (weeds) and fungi found growing around cacao trees and asked if they had any purpose. The responses were typically: 'they are weeds' and 'these fungi are inedible'. One farmer did link shade and biodiversity: 'The biodiversity is the same in or out of shade. The birds nest right in the cacao trees themselves, in the big ones. There are parrots there'.

CONCLUSIONS

Developing, implementing and sustaining smallholder cacao production requires understanding farmers and their economics, about which agricultural scientists still know little. We have documented farmer knowledge of cacao management and associated trees in a small sample of farms in Ecuador. Most of these farms were traditional, with low inputs and aromatic cacao varieties, but we also talked to farmers with more intensive production systems.

The aim of our study was to improve our understanding of the role of associated trees – which we have called *neighbour* rather than shade trees – and to assess their value to farmers. Our findings suggest that farmers and cacao scientists may have different ways of looking at trees grown in association with cacao. The farmers have a complex appraisal, combining the benefits or services provided by a tree to cacao and the value of the products which they obtain. The researchers and agronomists emphasise trees for shade whilst the farmers see the neighbour trees growing in a cacao grove as much more than shade. They provide of fruit, timber, control weeds, maintain soil fertility and soil humidity, but they also provide habitat for air weeds and influence the incidence of disease. Farmers can explain all of this in detail, for each tree species.

Cacao needs shade when young and establishing, but that shade is no longer essential – and can be removed – when the cacao trees mature. This fact seems to have confused agricultural ecologists, who have not noticed that many of the neighbour trees of cacao are not mainly for shade, or are not even for shade at all. Some neighbour trees, like citrus, are shorter than cacao and provide no shade whatsoever to cacao, yet they are still planted together.

Almost every farmer we spoke to in Ecuador eliminates ‘planned’ or ‘planted’ shade when it is no longer needed, after 2–5 years, sometimes replacing the original shade plants with fruit or other trees. Farmers occasionally use the word ‘shade’ (*sombra*) but it often comes low in a farmer's list of useful characteristics of a neighbour tree.

The high value that farmers give to most neighbour trees suggests that traditional cacao farmers are more concerned with intercropping in general than shade *per se* for cacao. A neighbour tree performs a service for cacao and is grown because cacao *can* be grown with other crops. Neighbour trees take advantage of cacao’s tolerance of other plants, while providing an additional product to farmers. Cacao production may be depressed by shade, but that loss is usually more than compensated for by the added income from the shade trees (including risk-protection by diversification).

Farmers rarely mention ‘shade’ as the main benefit of even tall *Inga* trees – fertilisation by leaf drop (and/or sometimes humidity regulation) come first. The functions of the so called ‘shade’ trees actually include.

- shade
- mulch and soil fertility enhancement
- humidity control
- wind protection – (little mentioned)
- soil protection – (although perhaps the value of this has been overstated)
- fruit (sale & home consumption)
- timber for construction (sale & home consumption)
- firewood (sale & home consumption)

Farmers manage these qualities over time, in a planned and sophisticated way, in a sort of relay cropping. For example, maize and manioc (cassava) may be planted with cacao seedlings, until the *Inga* grows tall enough to shade the cacao, and a few years later, when shade is not needed, the cacao may be intercropped with mango, coconut, citrus or other crops. As another twist: the cacao itself is sometimes a shade tree for coffee.

Farmers time the planting of each tree like an actor coming on stage to play a certain part. Each produces (a) services to cacao and (b) useful products when wanted, and then, when that service is no longer needed or that plant is no longer the best to provide it, it leaves the stage. Knowing what to plant and when, and when to remove it, requires a deep knowledge about each plant:

- usefulness of products
- mulch value
- shade value
- humidity control value
- phenology (when does it grow, when does it produce, when does it stop)
- edaphic requirements
- compatibility with neighbouring trees – for example one farmer said fruit trees go into cacao down every third alley between cacao trees, but papaya can go down every alley because it is spindly and so competes less with the cacao.
- ease of removal when the time comes to fell it
- economic risk management – one commodity may fetch a good price while another slumps. Having several crops spreads risk: at least one will almost always command a price. E.g. one farmer mixed cacao and papaya because papaya is typically worth more, but also fluctuates much more, and sometimes nobody will buy it at all. Cacao is less profitable on average, but always can be sold, even if the price is low.

The farmer balances these characteristics, as benefits in one area are often weaknesses in others. For example farmers generally understand that the cash value of woods is inversely proportional to the speed with which they grow.

All in all, this is an encouraging scenario – neighbour trees are neither forest relics nor wooden parasols. They are valued for many reasons. They offer insurance, mulch and water conservation, and they hedge against low cacao prices. Paradoxically therefore, hard times for cacao farming in general may encourage neighbour trees, since unshaded monocultures offer higher returns but may be riskier.

Current development-speak tends to lump sustainability and biodiversity together as ‘good things’ although in fact the link in ecological science between the two is largely unproven and hard to demonstrate. Farmers see the two entirely differently. Sustainability is something they understand well and value – they know they cannot move on to other land if they damage their current farm. Sustainability is a real and important concept of having a viable farm to leave to children and grandchildren. ‘Biodiversity’ on the other hand is something which has no use or point in terms of survival or prosperity, and so seems of little interest or importance.

Viewed in this way, another important point concerns the role of relic trees left over as shade when the forest is cleared for cultivation. The farmers who had cleared their own fields told us that they knew at the time that they were settling there permanently – they had come to stay, and always intended to leave the farms to their children. This in our view would argue against keeping relic trees, as opposed to replacing them with something more useful. People cutting forest for cacao in coastal Ecuador were probably not undertaking slash and burn. Their commitment to sustainable production on their current plots is clear. Paradoxically, therefore, the absence of forest relic trees may indicate a commitment to sustainability.

NEXT STEPS

This is not the first study to show that farmers have a more complex understanding of the roles and values of other trees but it does confirm the need to explore this topic further. We highlight a number of points which have arisen from our brief study.

1. **Sustainable Cacao**
   Our hypothesis is that trees grown with cacao are not for shade alone. This needs to be tested further, examining the potential for introducing improved neighbour trees that combine more value to farmers with an enhanced contribution to cacao production.

2. **Conservation of Biodiversity**
   We need to promote neighbour trees that are useful to farmers and conserve biodiversity. Initiatives must consider carefully the importance of biodiversity to farmers since there are doubts about the priority of this issue in general cacao management.

3. **Cacao Prices to Farmers**
   Farmers receive scant price premium for high-quality, aromatic cacao from cacao, yet those are the varieties most often grown with neighbour trees. Paying a higher price for better cacao could be a direct way of encouraging smallholders to grow more trees with cacao, and to keep antique *nacional* cacao trees (which farmers recognise are nesting sites for some birds). This notion needs to be confirmed by market studies.

4. **Beyond Ecuador**
   We still have insufficient understanding of the role of neighbour trees in many countries. Further studies are required and the results integrated with other research and initiatives on sustainable cacao.

TABLES

Tables have been grouped together. Farms are numbered from ECF1 to ECF21 [ECF – Ecuador Cacao Farm] and these codes are used to indicate the source of farmer comments. Details of the farms are given in Annex 1. Our comments are shown in [square brackets].

Air weed is a term we gave to both parasitic and epiphytic plants associated with cacao.

Table 1: Farmer Choice of Cacao Variety

FARM	FARMER STATEMENT [our comment]
ECF3	My father and I are fond of *nacional*, the original variety of the country. We don't want to see it die out, and the flavour is superior to that of CCN51, although the prices of the two are now pretty much the same. We hope that in the future the price of *nacional* will rise because of its better flavour. Nobody can understand why there is no price differential already, as the superiority of *nacional*'s flavour is universally acknowledged.
ECF8	*Nacional* is recommended here. The root mat strength is important on these steep and broken slopes with thin and fragile soils. *Nacional* roots much better than CCN51.
ECF9	We apply fertiliser to a young plant of CCN51 so it will produce more. But us old-timers say, what happens to this plant if we make it produce a lot while it is young? The old plants of *nacional* are still alive. With shade, they live to be 100 years old. CCN51 is only 10–12 years old and we do not know how long it will live. A cacao plant will have to live 20–30 years to be profitable because it takes so much to establish it. Anything less is not worth while.
ECF10	I think CCN51 could live for more than 50 years [This would appear highly unlikely]
ECF18	My farm (*nacional*) is 40 years old and could be good for another 40 years.
ECF20	CCN51 lasts productively for 15–20 years. After this it loses its strength and has to be replaced. Yes, *nacional* will yield for 40 years but CCN51 produces more.

Table 2: Management Practices on Study Farms

FARM	CACAO VARIETY	IRRIGATION	FERTILISER	WEED CONTROL	PEST MANAGEMENT
ECF2	*Nacional* *ca. 10 ha.*	No	No	Air weeds: removed when cacao price is high.	No pesticides. Manual control
ECF3	*Nacional* *ca. 10 ha.*	No	Yes, urea	Air weeds: remove by hand. Ground weeds: controlled by shade.	No pesticides. Manual control. Suggested that urea application helps reduce disease impact.
ECF4	*Nacional* *ca. 10 ha.*	Yes	Yes	Air weeds: remove by hand. Ground weeds: controlled by shade	No information
ECF9	Venezolana + CCN51 *15 ha total*	Yes, intensive.	No – 'too expensive'	Applies cocktail of 3 herbicides, every 2 months. Air weeds: removed during cacao harvest.	Applies malathion twice a year against ant.
ECF10	CCN51 *35ha*	Yes, 'essential'.	Yes, including foliar fertilizer	Intensive. 'CCN51 needs more herbicides.' One application will last 6 months if dry when sprayed.	Removes leaf cutters with gasoline. They also spray against the 'cochinella and guasons'. Spray against 'sandwich maker' only when damaging; we don't want to kill pollinators'.
ECF11	Trinitario, Venezolana, *Nacional* *10 – 20 ha*	Yes, 2–4 times a year.	No, can't afford	Controls ground weeds with machete. Too costly to spray. Air weeds have to be cleaned by hand	No pesticides used on cacao. Applied to coconut insect pest.
ECF12	*Nacional* + Trinitario *50 ha* CCN51: *1 ha*	Yes. Owns pump.	Yes, urea very occasionally	Hand weeds four times a year. They 'clean' cacao during first year, later every two years.	Gets rid of the leaf cutters. Doesn't control termites, 'nobody worries about them'.
ECF16	*Nacional* complex *ca. 10–15 ha*	No, can't afford.	Yes, urea occasionally	Cuts air weeds by hand. Has few ground weeds. Uses 'liquid, gramoxone or aminapá'.	Removes diseased material by hand. Used to spray against witches broom. Uses malathion or DDT against termites.
ECF17	*Nacional* + Venezolana *15 ha*	No	No	Air weeds: if not removed trees won't yield for a year Ground weeds: hand removed 3–4 times a year.	Use lacquer to reduce risk of mal de machete. Asked for chemicals to control Monilia. Cuts out WB.
ECF18	*Nacional* *30 ha*	No	No	All weeds removed by hand. Air weed removal is 'biggest task around here'.	Manual control. Witches broom said to be declining as a result of successful removal.
ECF19	*Nacional* *10 ha*	No	No	Where shade is heavy, weed one a year by hand; twice a year in younger groves. No herbicides used.	No pesticides. Some neighbours use for young cacao but he's not sure why.
ECF21	CCN51 *30 ha*	No	Liberal; soil fert 3x pa; foliar also	Weeding requires much labour. Use machete and herbicide, 3 times a year.	Uses insecticides and fungicides

Table 3: Influence of Neighbour Trees on Management of Cacao

FARM	EFFECT OF NEIGHBOUR TREE	FARMER STATEMENT [our comment]
ECF9	NEUTRAL	When pests increase we do not think this is because the shade in our cacao has been removed to give full-sun production. Mandarin, orange and sapote combine well with the cacao and do not harm it. They are not shade. Mango is shade but it takes a long time (to grow).
ECF10	NEUTRAL	There is no relationship between the amount of shade or full sun in groves and pest problems, or the way in which we manage the cacao.
	POSITIVE	Trees are often put in rows down the edges of the main cacao plots. The main purpose these other trees is, in order of importance, fertilisation of the soil, to provide us with products and also for humidity control. For shade? This is not really worth a mention.
	POSITIVE, MOSTLY	Guabo does give fruit – here, try some. It produces wood for firewood. We take the guabo out after 3 years, because they have grown so fast they overshadow the cacao. The other trees are left longer. [Guabo = *Inga edulis*, a fast growing tree which fixes nitrogen.].
ECF11	POSITIVE	Why do I have all these trees together with cacao? Soil improvement is important. You can't overfeed the soil.
ECF13	POSITIVE	Rotting down of my other (shade) tree leaves for fertiliser is important. Coconut takes longer than most others – a frond will take up to year to rot down, less if wet. Whereas banana leaves are pretty much rotted down in 2 months.
ECF16	POSITIVE, MOSTLY	We plant laurel and other timber trees here and there. We also plant caucho but it dries up the earth. The guabo, especially guabo de bejuco, keeps the earth new. We removed one mango tree because it made too much shade. [Guabo = *Inga* spp. Caucho = rubber. Laurel = *Cordia alliodora*.]
ECF19	NEUTRAL	See how the breadfruit and citrus and the cacao are so close together, yet all give fruit? They don't interfere with each other.
	NEGATIVE	Fruit trees receive more from the cacao than they give back in leaf fertiliser.
	POSITIVE	I believe my farm is shaded. [This was not the first farmer to be confused when asked about the shade cast by other trees on cacao.] I am not sure what different management practices I would need to use if my cacao was in full sun but I expect I would need chemical fertilisers most. I do not use them at the moment. I say that shade in *nacional* improves production because there are fewer pests and diseases, particularly monilia. One of my neighbours disagrees and says that ventilation and air movement are important. Of course, you can have too much shade, but you also got the benefit from other trees growing with cacao. Yes, it is possible that cacao tolerates other trees, and that these give an opportunity to increase production. However, I still believe that cacao benefits from other trees and that shade is one of these benefits. I cannot say whether shade is more important than the other benefits.

Table 4: Growing and Producing Cacao

TOPIC	FARM	FARMER STATEMENT [our comment]
Air weeds	ECF17 & ECF12	It is only after cleaning off the [air] weeds that the tree sprouts new leaves, becomes pretty and a year later loads itself with fruit. We prune the branches of cacao and at the same time we prune off the [air] weed. We prune branches because they extend too far. Because of their weight and because of their great years they stretch too far and too low and take up too much space.
Cattle	ECF19	I used to have eight cows but about five years ago they were all stolen. I still feel bitter about this. I have never considered going back to cattle. Yes, (fruits) are much more difficult to steal. Even if they are stolen you still have the trees. When the cows are stolen all you have is grass.
Costs	ECF9	I am very angry about the high costs for chemical inputs and the low farmgate price for cacao. My inputs for cacao cost money because the dollar went up. But the price of cacao did not go up
El Niño	ECF12 & ECF20	The cacao was almost destroyed by El Niño. During the flood many trees died from the top down. The flood lasted one day. I lost nearly all the 800 CCN51 in one grove. The cacao is generating little income because of the after–effects of El Niño. It was very wet and there was practically no yield. This has made us rethink our plans. Plans for expansion are now on hold. Yield is increasing but quality is poor.
Extension	ECF11	*Extensionist*: I cannot keep on coming out if you do not have an association. *Farmer*: Why should farmers produce quality cacao if it does not enjoy a higher price? *Ext*: I always come very early in the morning. *F*: This is what matters least.
Price	ECF12	I plant cacao because you can always sell it. No matter how low the price gets, at least you can always get something for it. But not papaya. There are times when you cannot even give papaya away.

Table 5: Role of Named Neighbour Trees in Relation to Cacao

SCIENTIFIC NAME	LOCAL NAME	REPORTED ROLE [our comment]
Cedrela odorata	Cedro	SOIL IMPROVEMENT: • good fertiliser
Ceiba ?pentandra	Ceibo (bototillo)	SHADE: • removed – no good for shade [possibly gives too much?)
Citrus sp.	Cítrico	SHADE: • provides little shade • not grown for shade • (mandarins) are not for shade • citrus is not shade; it sucks the soil and gives nothing back • (mandarin and orange) are not shade
Cordia ?alliodora	Laurel	SHADE: • yes, it provides shade • affects cacao little as shade [seen as a positive service by one farmer] SOIL IMPROVEMENT: • feeds cacao with its leaves
Inga edulis	Guabo bejuco	SHADE: • yes; best shade SOIL IMPROVEMENT: • especially keeps the soil new
Inga edulis	Guabo	SHADE: • most important • good for young cacao • bad for shade & takes the 'sap from the earth. [may refer to another *Inga* sp. • best one for [young] shade, but removed after 3 yrs because they provide too much shade • no good for shade because it falls apart and damage the cacao • if planted too close to cacao it shades it [Santo Domingo – cloudy region with lower light levels] WEEDS: • throws out lots of stuff which prevents the weeds growing SOIL IMPROVEMENT: • improves the soil; is a great fertiliser; feeds the soil; keeps the earth new
Inga spectabilis	Guabo de machete	SHADE: • gives shade; no good for shade WEEDS: • air weeds (parasitic plants) grow on it and can kill. [Guabo was not specifically mentioned as a source of the air weeds found on cacao.]
Maclura tinctora	Moral fino	SHADE: • not good
Mango indifera	Mango	SHADE: • also grown for shade • provides shade by takes long time to establish WEEDS: • air weeds [parasitic plants] 'spill off' on to cacao
Quarirabaea cordata	Sapote	SHADE: • not for shade
Schizolobium parahybum	Pachaco	SHADE: • too high and thin to provide shade • gives some shade [seen as a neutral service]
Triplaris cummingiana	Fernán Sánchez	SHADE: • provides shade.

Bulleted lists are used to distinguish comments made by different farmers.

Table 6: Effect of Neighbour Trees and Shade on Pest Impact

PEST	FARMER STATEMENT [our comment]
DISEASE IMPACT	FULL SUN REDUCES / SHADE INCREASES With full sun (no shade) there is less disease. Too much shade and rain leads to more Monilia. Cacao diseases are worse when cacao is grown with other trees. SHADE REDUCES With *nacional*, shade reduces pest impact, particularly Monilia. Too much shade is bad since air movement is reduced. Shade reduces witches broom. NO RELATION There is no relation between the amount of shade or sun and pest impact. Increase in pest not associated with move from shade to full sun.
WEED CONTROL	SHADE BENEFICIAL Shade controls weeds. Shade removes weeds. CACAO SELF-SHADING Older cacao shades out its own weeds and less (neighbour tree) shade is needed. When cacao canopy closes weeds are eliminated. CCN51 needs more herbicide protection than traditional varieties. [because there is less self-shading compared to *nacional* varieties] NO EFFECT OF SHADE Air weeds (bromeliads) are the same whether shade or full sun.

Table 7: Clearing Land for Cacao and Establishing Neighbour Trees

FARM	FARMER STATEMENT [our comment]
ECF2	The farmers I know in this region have sown their (neighbour) trees. They are not left behind when the forest is cleared.
ECF3	There has not been high forest hear for 35 years but there are still many native trees – they plant themselves.
ECF8	The farmers that I know leave very few native trees standing [when they plant cacao]. They use some laurels left over from the forest clearing.
ECF17	My farm was completely cleared of trees originally. The big trees you see here, which are now 40 years old, were originally volunteers.
ECF18	I cut down all trees on my farm,. I encouraged volunteer trees such as laurel, like my neighbour [ECF17]. Above my farm is still natural forest. It is a bit dangerous because of snakes but it is exploited for bush meat. The natural forests are now largely stable I have lately cut down all the mature trees in my plot. They originally started as volunteers. I still have a guayacón of 27 years which will be very valuable. I am leaving this for my children to cut down in 30–35 years time. [we suspect more practical reasons of time and effort were the reason the timber trees were still there]
ECF19	Here is my piece of forest. This 12 year old bantano was cut down ten years ago and has grown again. (It is now about 60 cm in diameter.) I made a table with the wood. Bantano is not worth as much as laurel on the market. The spacing of my sapote and avocado trees is different from cacao. They are 12 m apart whilst the cacao is 4 m. That is why the fruit trees do not appear in a precise line – unless you ignore the lines of cacao and look more carefully! Do I have to plan for fruit trees when planting my cacao? No. The fruit trees can be fitted in to any cacao tree spacing. [ask the farmer if there is a pattern – it may not be obvious]

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Annex 1: Study Farms

Cacao Variety, Area and History of Land Use

FARM	FARMER, PLACE	CACAO VARIETY, AREA	HISTORY OF USE
ECF1	VÍCTOR HARO *'El Deseo', El Milagro*	*Nacional* *Ca. 2 ha.*	Forest was cut down and rice planted first before the present small grove was created. The owner's family came originally from Daule and he has lived here for about 50 years.
ECF2	SEGUNDO GUARALLA *Asociación Pasaje, near La Unión and El Sapotal Viejo, Ventanas*	*Nacional* *Ca. 10 ha.*	Although there were nearby patches of natural forest the cacao trees appeared to have been planted some time ago, maybe as much as 20 – 30 years ago. The owner came originally from Manabí around 30 years ago.
ECF3	NÉSTOR MAQUILÓN *El Rosario, Ventanas*	*Nacional* *Ca. 10 ha.*	This was high forest until 35 years ago, around the time that the present owner arrived. He had come from Guayaquil but his family was originally from Mexico.
ECF4	COLÓN RODRÍGUEZ *Cooperativa 6 de Julio. Cantón Naranjal*	*Nacional* *Ca. 10 ha.*	Grove was 40 years old. Not clear when the present owner arrived. The land was probably in bananas previously.
ECF5	MILTON SUAZO *Recinto Israel, Parroquia Tenguel*	CCN51 *1 ha.*	The CCN51 grove was previously bananas and mixed fruit and is only 5 years old. Also had *nacional* on another plot, but we did not see it.
ECF7	AUGUSTO DUTA *El Progreso, near Machala*	Venezolana *Ca. 5 ha*	Previously natural forest – the stumps of the original trees could still be seen. This grove is 20 years old.
ECF8	JOSÉ CHACHA *Cadena, near Pasaje*	*Nacional*, Trinitario *Ca. 10 ha*	This area was settled 80 years ago. The grove is 35 years old and was bought soon after it had been established by another grower.
ECF9	TOMÁS OLMEDO *near La Troncal*	Venezolana and CCN51 *15 ha total*	Rice grown after forest was removed. Cacao planted 15–20 years ago, after his family had settled here. Planted a new stand (CCN51?) 6 years ago, another last year. Originally from El Milagro.
ECF10	GUILLERMO FERREIRA *near La Troncal*	CCN51 *35ha*	Owns 3–4 groves. Land was parcelled out 40 years ago and appears to have been unimproved pasture at the time. These groves were not established until 8 years ago. Farmer has lived here for about 40 years.
ECF11	SERGIO GARCÍA *Recinto El Mosquito. Parroquia Santa Rita. Cantón Chone*	*Trinitario, Venezolana, Nacional* *10 – 20 ha*	Owns 4 groves, all close to each other. Planted first grove 80 years ago, replacing cacao that was 200 years old. One grove was only planted 10 years ago. Another planted 20 years ago, previously pasture. Farmer and his family have lived here for many years.
ECF12	EMIGDIO GARCÍA *Sitio Garrapata. Parroquia Santa Rita. Cantón Chone*	*Nacional* *1 ha – relic* *Nacional* and Trinitario *50 ha* CCN51: *1 ha*	Son of ECF11. Oldest (relic) grove was established 80 years ago; the most recent, 30 years ago. The relic grove was previously bananas, other land was pasture. The more recent land planted to CCN51 was previously bananas.
ECF13	ALFONSO MIELES *Sitio Arreaga. Cantón Portoviejo*	*Nacional* *6.5 ha*	Only one year old. Originally 'scrub' infested with *algarrobo* (?*Prosopis*) then arable land and annual crops. Farmer has lived here for 10 years.

FARM	FARMER, PLACE	CACAO VARIETY, AREA	HISTORY OF USE
ECF14	MAURO JUILLEM *Recinto Playa Prieta. Cantón Portoviejo*	*Nacional* *5 ha*	Abandoned farm bought 15 years ago. Previously king grass and slowly converting to dairy, sugar cane, lemons and cacao. Planted 8 years ago.
ECF16	ALADICO CONTRERAS *near INIAP Pichilingue, Quevedo*	*Nacional* complex *Ca. 10–15 ha*	High forest more than 30 years ago. First planted to bananas which then failed. Followed by maize, soya and rice for around five years. Has been cacao for 25 years, about the same time the farmer arrived.
ECF17	GRISERIO PIÑOS *Sitio Bermejal. Parroquia Tambo*	*Nacional* mostly, some Venezolana *15 ha*	Was forest more than 30 years ago, then sugar cane followed by bananas. He has owned for 30 years, after the cacao was planted. Came originally from Chillanes, Bolívar.
ECF18	LIVER MICHILENA *Sitio Bermejal. Parroquia Tambo*	*Nacional* *30 ha*	Cleared forest about 28 years ago and went straight to cacao.
ECF19	ANTONIO HEREDIA *via Santo Domingo km 40, Recinto Río Manso*	*Nacional* *10 ha*	Was previously banana. Bought 35 years ago when it had already been planted to cacao. Some groves planted more recently – three and 12 years ago.
ECF20	ALBERTO CALACAZÓN *Comuna Chihuilpe, Parroquia Santo Domingo*	*Nacional* *5 ha* 'Clones' *3 ha*	Owns two plots. The *nacional* is only five years old. Unclear about previous land use though no evidence that natural forest has been cleared recently in order to plant cacao.
ECF21	JORGE DIEZ *Farm 'San Antonio', Santo Domingo via Quevedo KM 38*	CCN51 *30 ha*	Probably pasture before it was planted with cacao. This was said to be the largest cacao farm in Ecuador, owned by the army. Cacao was planted in 1994.

Annex 2: Neighbour trees

Suitability for Growing with Cacao

The scientific names of neighbour trees used in this report have been derived from the local names given to us by farmers. The following list of local names and scientific names comes from F. VALVERDE, *Plantas Utiles del Litoral Ecuatoriana* [PULE] and Gentry (1998). The authors' interpretation of local names might differ from that used by farmers in our study.

The suitability of different trees is according to farmer observations recorded during our surveys. Blank cells indicate that no opinions were offered.

LOCAL NAME (# OF FARMS)	SCIENTIFIC NAME	GENERAL NOTES	SUITABILITY FOR GROWING WITH CACAO
Aguacate / Palto (5)	*Persea americana*	Avocado	Foliage denser at the time of cacao flowering and fruiting.
Amargo (2)	*Simarouba amara*		
Balsa (2)	*Ochroma pyramidale*		
Caucho (2)	*Castilla elastica*	Caucho also = *Ficus elastica*	Dries up the earth.
Cauje (2)	*Pouteria caimito*		
Cítrico (19)	*Citrus* sp.	Includes mandarins (4) and tangerines (1); some farms had more than one citrus variety.	Can grow well with cacao and both fruit. Mandarin combines well with cacao.
Fernán Sánchez (6)	*Triplaris cummingiana*		
Fruto de pan (5)	*Artocarpus altilis*	Bread fruit	Makes too much leaf litter and cacao gets clogged up. Can grow well with cacao and other fruit trees
Guabo (6)	*Inga edulis*	[The most common shade tree used by farmers.]	During droughts is more rooted and dries out soil further. People don't use guabo around here (Chone). Guabo is least valuable as a product tree though some use for firewood.
Guabo bejuco (6)	*Inga edulis*	= Guaba de bejuco	
Guabo de machete (5)	*Inga spectabilis*	= Guaba vaina de machete	
Guaya / Guayacán / Guayacón (5)	*Tabebuia* sp.	Guaya interpreted as a contraction of guayacán	
Laurel (11)	*Cordia ?alliodora*	Laurel de puna=*Cordia alliodora,* laurel fino=*C. micrantha*	Blows over in wind and destroys cacao. Causes least damage [of timer trees] when felled. Affects cacao very little. Does not cast too much of a shadow (i.e. good because it doesn't shade cacao)
Mamey (3)	*Mammea americana* or *Calocarpum mammosum*	Mamey cartagena=*Mammea americana;* mamey colorado=*Calocarpum mammosum*	

LOCAL NAME (# OF FARMS)	SCIENTIFIC NAME	GENERAL NOTES	SUITABILITY FOR GROWING WITH CACAO
Mango (7)	*Mango indifera*		Drought tolerant, withstands flooding. When it gets too big is falls apart and damages the cacao. Big tree can destroy 3–4 cacao trees. Foliage denser at the time of cacao flowering and fruiting.
Pachaco (6)	*Schizolobium parahybum*		More damaging than either laurel or Fernán Sánchez when felled.
Sapote (7)	*Quarirabaea cordata*		(Compared to mango) less tolerant of drought and flooding. Combines well with cacao and does not impede flowering or fruiting.
Teca (3)	*Tectona grandis*	Teak	

1. The following tree species were recorded from only one farm:

Badeia [*Passiflora quadrangularis*]; Bantano [*Pithecellobium macradenium*]; Beldaco [*Pseudobombax guayasense]*; Cadi [*Phytalephas* sp.]; Caña de guadua [*Guadua angustifolia];* Canelón [*Swartzia littlei];* Canuto [*Cercopia* sp.?]; Cedro [*Cedrela odorata];* Cadi; Ceibo (bototillo) [*Ceiba ?pentandra (*poss*. C. trichistandra)*]*;* Cereza [*Bunchosia* sp.]; Guachapelí [*Albizzia guachapele];* Guanábana [*Annona muricata*]; Guayacón blanco [*Tabebuia* sp. ?]; Guayava [*Psidium guajaba];* Guabo colorado [*Inga* sp. ?*];* Guabo mico [*Inga vera];* Matopalo [*Ficus* sp.]; Moral fino [*Maclura tinctora];* Yuca de ratón [*Gliricidia sepium*]

No scientific name equivalent was found for these local names. All were recorded from one farm only.

Chontilla; Pechicho, Pijao; Porotá / Porotú , Quiceañera; Visola

2. There is some doubt as to whether the following are true neighbour trees. They were often not grown in direct association with cacao. They include [# farms]:

Carambola = *Averrhoa carambola* [2]; *Cocos nutifera* [2 +]; *Papaya carica* [2]; Poma rosa [*Syzygium jambos]*

Annex 3: Neighbour Trees

Products Used by Farmers

Local name	Scientific name	Fruit	Timber	Other uses; notes
Aguacate / Palto	*Persea americana*	Yes	–	
Amargo	*Simarouba amara*	–	Yes	Good wood, but limited market access.
Balsa	*Ochroma pyramidale*	–	Yes, sold.	
Bantano	Not known	–	Yes, domestic use.	
Beldaco	*Pseudobombax guayasense*	–	Yes, sold.	
Cadi	Not known	–	Yes, sold.	Palm. Leaves used for roofing.
Caña de guadua	*Guadua angustifolia*	–	–	Poles (*palanca*) for harvesting cacao
Canelón	*Swartzia littlei*	–	Yes	Medicinal. Bark infusions against rheumatism.
Canuto	*Cercopia* sp.?	–	–	Weed – may not have a service or product?
Caucho	*Hevea brasiliensis*		Yes, sold.	
Cauje	*Pouteria caimito*	Yes	–	
Cedro	*Cedrela odorata*		Yes, sold.	Market access was poor at ECF8
Chontilla	Not known	–	–	Produces wine–like liquor called *chicha*.
Cítrico	*Citrus* sp.	Yes, domestic use. and sold.	–	
Fernán Sánchez	*Triplaris cummingiana*	–	Yes, sold.	
Fruto de pan	*Artocarpus altilis*	–	–	Food for pigs.
Guabo	*'Inga laurina'*	–	–	Sold, not clear for what.
Guabo bejuco	*Inga edulis*	Yes	–	Firewood.
Guaya / Guayacán / Guayacón	*Tabebuia* sp. ?	–	Yes, sold.	
Guayacón blanco	*Tabebuia* sp. ?	–	Yes	
Guayava	*Psidium guajaba*	Yes	–	
Laurel	*Cordia ?alliodora*	–	Yes, sold.	
Mamey	*Mammea americana* or *Calocarpum mammosum*	Yes	–	
Mango	*Mango indifera*	Yes, domestic use. and sold.	–	
Pachaco	*Schizolobium parahybum*	–	Yes, sold	Good wood but limited market access.

Local name	Scientific name	Fruit	Timber	Other uses; notes
Papaya	*Papaya carica*	Yes, domestic use. and sold.	–	
Pechicho	*Vitex gigantea* ?	–	Yes	
Pijao	Not known	–	Yes	Used for roofing.
Poma rosa	*Syzygium jambos*	Yes	–	Yes, sold.
Sapote	*Quarirabaea cordata*	Yes, domestic use. and sold.	–	
Teca	*Tectona grandis*	–	Yes, sold	
Visola	Not known	–	–	For making traditional (Tsachila) houses
Yuquerratón (or yuca de ratón)	*Gliricidia sepium*	–	–	Living fence.

Annex 4: Farmer Cameos

Descriptions of Three Contrasting Farms

By Jeffery Bentley

Locations of the three farms are shown in Fig. 1.

The following accounts are written to give a ‘flavour’ of the visits, and are an attempt to personalise the results presented elsewhere in this report. Writing for natural scientists tends to adopt a more passive and neutral tone. At the same time, it is important to reflect the personal narratives which form the heart of any farmer survey, such as this one.

1. The Forest Farm of Néstor Maquilón

ECF 3: El Rosario, near Ventana, Ecuador

WE DROVE UP TO MR MAQUILÓN'S farm in the rolling hills of Ventana; he was on the roof of a new house, pounding in two-by-fours that had been hand-cut with a chain saw. The 65-year-old cacao farmer climbed down, shook our hands and said he'd love to teach us something about timber and cacao.

We said we didn't want to interrupt his work, but Mr Maquilón was excited to show us his farm. This is one of the few villages we saw in Ecuador where cacao is grown in the shade of timber trees.

Mr Maquilón (far left, photo) almost trotted, if one could trot through mud. He slipped into a grove that looked almost like a rain forest. He was eager to point out each kind of tree, teaching us their names and explaining that all of them were shade for cacao, but that they could all be sold for timber.

The trees plant themselves; the farmers notice when they sprout, and if the tree is in a convenient place, the farmers do not cut it down.

Some of these trees have other uses besides timber. Mr Maquilón used his machete to surgically remove a wedge of bark from the *canelón* tree. He asked us to smell it. It smelled like cinnamon. He said people boil the bark and then bathe in the infusion, to cure rheumatism.

A mature strangler fig, towering over the canopy, added to the illusion that this orchard was wild forest, although there has been no high forest at all left in this area for 35 years. Some of the timber is not native, and people plant it.

The guabo is particularly versatile. Local people use the wood for fuel, the plant for shade over cacao, and they eat the pulp that grows around the hard seeds of this tree-legume.

Like farmers elsewhere in Ecuador, Mr Maquilón also plants fruit trees. The most popular fruit is the banana. The fruits are gradually replacing the timber trees, since fruit can be eaten and sold, and is easier to harvest than timber. It's a real trick to fell a mature timber tree without bringing down neighbouring cacaos.

Many other trees and woody plants are grown in the gardens between people's homes and the groves, including a bamboo grown just for the poles used to make cacao-harvesting-tools.

About once a year, after the cacao has been harvested, Mr Maquilón climbs into his trees to pick off what we call ‘air weeds,’ the bromeliads and creepers that grow on the branches of cacao trees. Only the creepers are actual parasites, rooting into the wood of the cacao tree, but even the bromeliads take up space on the branch, and when they fill up with water, they weigh the branch down.

Air weeds thrive in the cool moist air below the shade trees. But Mr Maquilón depends on shade to keep his cacao from drying out during the dry season, because he does not have irrigation.

Some years, when there is too much rain and not enough cacao, Mr Maquilón decides that he will not make enough money from cacao to make it worthwhile to clean the air weeds off the trees, and he lets the air weeds grow for another year. During those years he is glad he has a little timber or fruit to sell.

Mr Maquilón uses a little urea to fertilise his cacao trees, which are traditional varieties. He uses few agrochemicals, but he is not self-consciously trying to be an ‘organic’ farmer. Like many cacao farmers in Ecuador, Mr Maquilón said he didn't need a lot of chemicals.

As we walked back from the grove, we passed 4 lumberjacks using ropes and a log ramp to wrestle logs out of the mud and onto the bed of a battered truck, whose cab had been completely rebuilt with boards.

Mr Maquilón walked quickly past the loggers, teasing them a little for muddying up this dirt road. This is a community of people who manage forest and cacao, and who deal with the loggers as equals. Hopefully, logging by a small firm on a private cacao farm is more sustainable than mining timber from tropical rain forest.

2. Becoming a Modern Farm; Tomás Olmedo

ECF 9: Near La Troncal, Ecuador

THIS FARM IS ON A BROAD PLAIN, which was cleared of forest at least 40 years ago, and planted in rice and bananas. Many of the woodland patches now growing near here have been planted because of cacao farming.

When we dropped in on Mr Olmedo, he was working in his groves. His son-in-law graciously offered to find him. We followed the young man through the cacao, until he told us to wait under a sapote tree, and help ourselves to the stringy orange fruits. Mr Olmedo soon appeared, carrying a backpack sprayer and a bucket full of herbicide bottles.

Mr Olmedo explained that he had two groves: an old one, 20 years old, of Venezolana, and a new orchard, 8 years old, of CCN-51. He explained that guabo is important for shade for CCN-51, but only for young trees. When the cacao is 5–6 years old, the farmers cut rings through the bark of the guabo tree. The tree dies, and the leaves fall off, but the tree falls apart slowly, a piece at a time, without the danger of dropping a timber bole on a cacao tree. The guabo also fertilises the soil, covering it with a leaf mulch and seedpods.

The Olmedo family raises some laurel trees for timber. They sawed some planks and left them to dry in the sun on simple racks, behind their house. They have a few individuals of many different fruit trees.

Of all these neighbour trees, the mango is one of the few that gives shade. Most of the other neighbour trees, like the citrus, grow at about the same height as the cacao, and are raised in the place of cacao, not as shade. There are more neighbour trees nearer the family's house, and in the old grove. The further one gets into the old grove, the fewer neighbour trees one sees. Mr Olmedo explains that cacao is the most important tree, and any tree that cannot be combined well with cacao has no place in the orchard.

This cacao grove is too sunny to have many air weeds. But the ground weeds do quite well, and the Olmedo spray a cocktail of 3 different herbicides on them every few months. The family could cut the weeds with machetes, but Mr Olmedo explains that a weeding job that would take 20 days by hand takes only 3 days with chemicals.

The Olmedos' cacao does not need shade, because they have irrigation. They belong to a 500-member irrigation scheme originally sponsored by the Ecuadorian government. Ditch water replaces shade, for preserving soil moisture during the dry season.

Mr Olmedo would like to apply chemical fertiliser, but cannot. He used to apply a little, but the fall of Ecuador's currency (the Sucre) drove fertiliser prices above what he could afford. He is angry about that, and wants the government to ensure that cacao prices keep pace with the prices of the things he has to buy. Like many farmers and agronomists we met, Mr Olmedo was unclear about how the market worked. There is a common notion that merchants are parasites and that prices are set by the whim of government.

Mr Olmedo said that he had serious problems with fungal diseases in cacao, especially monilia. Like all the farmers we talked to, he controls monilia by breaking off the damaged pods, to help prevent the build-up of disease. This practice is now widespread, thanks in part to the efforts of cacao extension programmes.

We asked Mr Olmedo about 'sustainability' and 'biodiversity.' Mr Olmedo said he had not heard of 'sostenibilidad' or 'biodiversidad,' so we explained the ideas to him. He was interested in sustainability. He had wondered if fertilising young trees would make them produce too much, and shorten their lives, adding that unless his new grove of CCN–51 lives for 20–30 years, "it won't be profitable." The notion of biodiversity was less interesting to him. "Both of my groves have many kinds of birds in them, and both groves have the same kinds of birds, even without the fruit trees. Parrots will nest right in the big cacao trees."

The whole time we talked to Mr Olmedo, his children and grandchildren chased each other around in the trees. Unlike people with office jobs, these farmers make no clear distinction between work and home. They work at home and their children play in the workspace. Farmers may or may not have sophisticated idea of biodiversity, but for them, the environment is home, and sustainability means making sure that their children and grandchildren will be able to keep farming. "Our way of life is cacao."

3. The 300 Year-Old Cacao Farm of Sergio García

ECF 11: Santa Rita, Chone, Ecuador

MR GARCÍA IS A THIN, WHITE-HAIRED MAN who raised 10 children in the house where he was born. He has 4 cacao groves, one of which his father planted 80 years ago, to replace a grove that may have been 200 years old. The younger orchards were planted in what had been pasture and corrals. Over the years, Mr García has invested in cacao, at the expense of cattle.

Mr García's two-storey house sits on a flat plain above the nearby river. This makes his farm easy to irrigate, but also flood-prone. He lost a lot of trees to the El Niño floods of 1998.

The farm is planted in traditional, aromatic varieties of cacao, and has few shade trees. Mr García plants papaya and bananas and coconut with young cacao. After 2 years he removes the papaya, because the papaya gets too tall to harvest by hand, and he doesn't like to harvest papaya with a pole. Mr García says that the bananas give fresh, cool shade to the young cacao, and that once the cacao is mature, and provides its own shade, the bananas lose themselves The coconut stays permanently, rising a bit above the cacao.

Mr García uses a complex grid system for planting his orchard. The coconuts are set out at 4m x 4m. The bananas are planted every 3m, in a row between the coconut. The cacao and citrus are planted in the same rows as the coconuts. Like other groves we saw, this one was set out with a mathematical precision. There is nothing sloppy or disorganised about the way these neighbour trees are planted with cacao.

One reason he favours light shade is that he notices that he has less monilia, less witches' broom, and less creeper (an air weed) when the cacao gets sun and air.

There are other neighbour trees that grow below the cacao, like the papaya, and a few coffee trees, scattered among the cacao. Mr García grows some other trees at the edge of the orchard. He has a new plot of passion fruit vines growing on wires, and a few carambola trees in the garden near his house.

Mr García is essentially an organic farmer, using little chemical fertiliser, and using a machete instead of herbicides. He would like to use them, but cannot afford to buy them. In the dry season he waters his orchards with well water, using a gasoline pump and a long hose. This year he is afraid that he will not have enough money to be able to afford to irrigate, because of his losses during El Niño.

Some of local knowledge appears strange to scientists, and requires more than a short visit to analyse it properly. For example while we were talking to Mr García, one of his neighbours came up and took him aside to ask him which was the appropriate stage of the moon in which to castrate pigs. A waxing crescent moon, for growth, Mr García told him, somewhat amazed that the man did not know that.

Like most of the farms we visited, this one had not been recently carved from the forest, but was a sort of forest planted by people, to replace bananas, rice, or in this case, pasture. We learned from Mr García's farm that a household can sustain cacao farming for generations, that traditional varieties can be grown in light shade, provided they have irrigation, and that some farmers would use more chemical fertiliser and more herbicides if prices were more favourable.

Annex 5: Ant Biodiversity

Ants as Indicators of Biological Diversity in Cacao in Ecuador

John Stonehouse [5]

Introduction

Biodiversity of animal life is difficult to assess quickly, as in the brief farm visits made during this study. For any reliable estimation, the animal sought must be as abundant and easy to catch as possible, to allow the collection of sufficiently large samples to allow meaningful inferences to be drawn. Insects represent the most visibly abundant group, and flightless insects are much more easily and reliably caught. Ants are the only group of grove-inhabiting visible animals which allow sufficient numbers to be caught or recorded.

There remain limitations to the use of ants as biodiversity indicators. In particular, abundance may fluctuate in time with differences in time of day, time of year, humidity, temperature and light levels, and time elapsed since the most recent application of pesticide or weeding.

This study in many ways resembles an earlier one (Vandermeer & Perfecto, 1998) in which the number of ant species attracted within a time limit to baits of tuna fish in coffee groves and natural forests in Mexico and Costa Rica were compared to a score for the degree of intensification and monoculture. This study found that a significant and visible drop in species number occurred at the point where shade tree species were eliminated and the coffee planted in monoculture, and concluded that shade trees were a significant contribution to ant species diversity.

Methods

Ants were gathered opportunistically in gaps in conversations with farmers. In each plot ants were collected from ten cacao trees, selected at random. All individuals found between 1 and 2m height up the trunk were collected. If none were found the trunk was searched for 30 seconds before being left for the next. A rough estimate of catching efficiency represented by this was made on one farm (ECF5) where after sampling from ten trees (garnering four ant species) a search was made of a further ten, which found one more species. The farmer examined the haul and gave his belief that one species with which he was familiar and knew to be present in the grove was still missing from the sample. This suggests that the catch from ten trees is a respectable fraction of those present.

Collections were made on fourteen plots on twelve farms (on two farms there were different plots considered by the farmer to differ in their degree of technification and these were sampled individually). Ants were collected with a brush into glass phials containing killing strips, then preserved in alcohol and subsequently mounted and identified to subfamily or genus level (Bolton, 1994).

The fourteen plots were awarded scores for 'traditional' versus 'technified' status. The score was the sum of three values:–

1. 0 for use of chemical fertiliser, 1 for no such use
2. 0 for use of chemical pesticides, 1 for no such use
3. 0 for absence of shade trees, 1 for 1 to 4 recorded species, 2 for 5 to 8 recorded species, and 3 for nine recorded species or more

[5] With the field assistance of Duncan Boa

Data were summarised to show, for each plot, the number of individuals found, the number of species found, and the Shannon-Weaver diversity index. This is calculated as the sum, across all species, of the fraction of the sample represented by each species, multiplied by its own natural logarithm. This negative value is then multiplied by -1 to obtain a positive with a higher score for a greater diversity. Any sample containing only one species always scores 0. This index has been criticised as unrealistic and devoid of meaning (Southwood 1978) but is widely used, giving as it does higher values for both the number and species present and for an even spread of individuals among them, with little domination by a few species.

Results

Overall, on the fourteen plots there were found 234 ants in sixteen genera. The smallest number of genera found in one plot was one, with a Shannon-Weaver diversity index of 0, the largest were five genera with a diversity index of 1.39.

Table 5.1: Fourteen farm plots listed by code number, the three values comprising the score for traditional status, the numbers of genera found and Shannon-Weaver indices.

Farm code	Fertiliser used	Pesticide used	Shade diversity	Traditional status score	# of ant genera	Shannon-Weaver index
5	yes	yes	0	0	4	1.15
7	no	yes	2	3	4	0.84
9 (new)	yes	yes	2	2	3	0.95
9 (old)	no	yes	2	3	2	0.4
10	yes	yes	3	3	1	1.05
11	no	no	2	4	2	0.69
12	no	no	1	3	4	1.14
14	no	no	0	2	2	0.18
16	no	no	3	4	2	0.67
17	no	no	2	4	1	0
19	no	no	3	5	1	0
20 (new)	no	no	0	2	4	1.39
20 (old)	no	no	1	3	5	1.39
21	yes	yes	0	0	1	0

In the event, in contrast to the finding of Vandermeer and Perfecto (1998) there is no apparent relationship between either number of genera or Shannon-Weaver index and the score for traditional status, as was shown by visual inspection of the plotted relationship and regression analysis, which found both relationships to be weak and insignificant and, contrary to expectation, negative.

An interesting finding was that diversity was surprisingly large between farms. Sixteen genera were found, but the largest number on any one farm was five. Similarly, the two genera most frequently found, the myrmicine *Crematogaster* (found on eight plots) and the ponerine *Ponera* (on seven plots) were found on barely half the plots. This implies that there is no 'standard ant fauna' for Ecuadorian cacao groves and, although the diversity of species on any individual farm may be low, that over the totality of farms may be much higher.

Regarding the ant types found, two individuals, from two different plots, belong to the subfamily attinae, the notorious leafcutter ants, endemic to the Americas, which are the dominant herbivores in many tropical American ecosystems, consuming more plant material than any other group, and are often devastating crop pests (Hölldobler & Wilson, 1990). Few farmers described these insects as pests or problems, apart from some mentions of possible damage to flowers. The small numbers found seem to support the general view of farmers that they are largely harmless.

All other ants found in significant numbers are from groups which are generalised predators and scavengers. The most widespread groups are from the subfamilies Ponerinae and Myrmecinae, generalised opportunistic foragers traditionally considered to be 'original' or 'primitive' ant forms established prior to the diversification of the group into more specialised lifestyles such as seed eating, leaf cutting or specialist predation (Richards & Davies, 1977). Apart from tending sap-sucking homoptera for their honeydew, which is not recorded as a significant problem in cacao, these insects are either harmless or beneficial, as chasing away general insect predators and, as has been recorded in Malaysia, flies which may carry and transmit monilia spores (Khoo & Ho, 1992). The manager of one particularly technified farm, a monoculture of CCN51 on which both fertilisers and pesticides are used, identified one ant as an attine, announcing it to be a pest which he sprayed, but he was mistaken. Such ants may, however, bite people and be a nuisance and obstacle to work on the crop; several farmers stated that ants could be a nuisance in this way (and in one case apparently fatal) but none used control methods for this reason.

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Table 5.2: Description of nominal ant species collected from Ecuador cocoa farms

Nominal species	Length mm.	Name & description
1	2.3	'Pointy-bottom'. black/grey, smooth, wasp abdomen, 2 spikes backwards from thorax, scorpion posture, club antennae – myrmecine Crematogaster?
2	8.S0	'V-neck' pair of spines rising from back of neck, dark red brown
3	9.0	Very dark brown, smoothish pillar-box pregaster. Ponerine Ponera?
4	2.5	Pale beige head & (eyeball/fried egg) abdomen, dark brown thorax & legs
5	7.0	Red-brown, attine?, 3 scale-enlarging segments to abdomen, 2 rows of spines on thorax
6	8.5	Dark red-brown, 6-spike forethorax, 2-spike hindthorax
7	1.0	'Tiny but spiny'. orange-brown, 2-bead pregaster, pair of rear-facing thorax spikes. Myrmecine
8	2.2	Black, small, 2-nodule beadle integrator, slim-clublike antennae, hairless
9	1.6	Orange-brown, pregasters like 2 beads, not spiny
10	2.2	Black, with zebra stripes from abdominal tergites
11	1.5	Smooth, long antennae; dark brown head, abdomen, 1st antenna, tibia, femur, beige rest
12	1.7	Knobbly; pregaster like 2 beads
13	1.0	Pear-shaped saggy bottom
14	0.3	Hopelessly small & bedraggled
15	1.2	Brown, smooth, single spike on hind thorax
16	1.8	Black, long antennae, big stiff hairs, no pregastral nodules

[Table 5.3 appears on the next page]

Table 5.4: Summary Ant Diversity data from 14 samples taken from Ecuador cacao farms

	ECF5	ECF7	ECF9 sample 1	ECF9 sample 2	ECF10	ECF11	ECF12
# ant 'species'	4	4	2	3	2	2	4
# ants (all spp.)	50	37	22	5	17	13	12

	ECF14	ECF16	ECF17	ECF19	ECF20 sample 1	ECF20 sample 2	ECF21
# ant 'species'	2	2	1	1	6	4	2
# ants (all spp.)	22	13	1	26	9	4	5

Table 5.3: Number of ants in 14 samples taken from Ecuador cacao farms by nominal species groupings.

Nominal ant species	ECF5	ECF7	ECF9 sample 1	ECF9 sample 2	ECF10	ECF11	ECF12	ECF14	ECF16	ECF17	ECF19	ECF20 sample 1	ECF20 sample 2	ECF21	Total # ants	Total # samples
1	11	5	19					21	5	1	26				**88**	7
2															**0**	0
3		4		1			5		8			4	1	5	**28**	7
4		27					5								**32**	2
5								1				1	1		**3**	3
6															**0**	0
7	18														**18**	1
8						6									**6**	1
9	20		3	3	10										**36**	4
10				1	7								1		**9**	3
11							1								**1**	1
12							1								**1**	1
13		1										1	1		**3**	3
14												1			**1**	1
15												1			**1**	1
16	1					7						1			**9**	3

Blank cells indicate no data.

Annex 6: Nematode Biodiversity

Biodiversity of Nematodes as Indicators of Soil Health

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Introduction

Considerable interest has been expressed in the last 10 years or so in the potential use of soil nematodes as bioindicators of soil health. In many ways they are well suited to such a task, being numerous and diverse with a wide range of trophic specialisms [6]. They are also easy to extract from the substrate. Their main drawback is the practical problem of ready identification to species level, but this obstacle has been largely circumvented by the use of trophic group categorisation – a procedure which can be performed relatively easily in most cases.

A plethora of indices has been proposed for assessing nematode diversity, some being weighted in favour of the rarer representatives whereas others have a numerical weighting. Species richness, absolute abundance, number of trophic groups, fungal feeder / bacterial feeder ratio, trophic diversity, the Shannon and the Simpson diversity indices, Bongers' maturity index and a plant parasitic index have all been utilized with varying degrees of concordance (see, for example, Bongers, 1990; Freckman and Ettema, 1993; Yeates *et al*., 1993 and Pankhurst, 1997). A number of these indices depend upon nematodes being categorised into one of five colonizer / persistor categories (the c-p ratio) based on their trophism. Such ratios may be plotted on a c-p triangle, thus allowing temporal fluctuations to be tracked and compared (de Goede, 1993). The major studies done so far attempt to correlate nematode diversity with soil health in the broadest sense and to assess the environmental disturbance on nematode communities caused, for example, by pollution from heavy metals or the effects of various agricultural operations, including the application of various agrochemicals.

Soil factors influencing nematode diversity include nutritional enrichment or pollution of the ecosystem, as well as physical changes to the soil structure caused by agricultural operations. Nutrient enriched soils show a reduced biodiversity index as under such conditions the populations of short-lived r-strategists (bacterial feeding rhabditids) expand enormously relative to the other components (in this respect, it is also important to appreciate that impoverished soils may be extremely diverse as no one nematode group is able to achieve trophic dominance). Soil tillage, by breaking down the structure of the soil ecosystem, militates against larger, often predatory or omnivorous nematodes, which are slower to reproduce and may have a life cycle spanning several years (K-strategists). In general, agricultural operations also tend to favour an increase in the proportion of plant parasitic nematodes and a reduction in the diversity and abundance of their nematode predators. Thus, agricultural practices that do not discriminate against primarily K-strategist nematodes may be expected to show a more stable nematode community structure with long term implications for crop health and sustainability.

Materials and methods

Soil samples were collected from a number of cacao farms and extracted using a modified tray technique. Extracted nematodes were killed and fixed in dilute formalin. Due to the low numbers of nematodes recovered, total counts of each extract were done, the nematodes being categorized according to trophic group (plant parasitic nematodes were also identified to genus level).

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[6] 'Feeding groups'. These are explained in more detail at the end of this Annex.

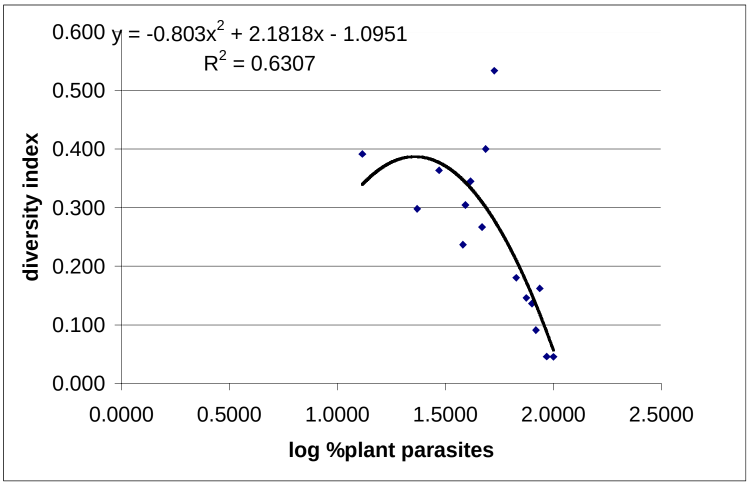

Fig 2: Diversity index of all plant nematodes in soil samples from selected Ecuador farms against proportion of plant parasitic nematodes.

Results

Considerable differences in diversity between the various farms were apparent (Table 1), although the relatively low numbers of nematodes recovered and the lack of replication inhibited statistical analysis. The main plant parasitic nematode genus was *Hemicriconemoides*, a common component of cacao soils. Other plant parasitic nematodes included *Xiphinema* (abundant in one site), *Helicotylenchus*, *Paratylenchus*, *Pratylenchus* and *Paratrichodorus*. An overall trend was observed whereby nematode diversity was inversely related to plant parasitic nematode abundance. The proportion of extreme r-strategists (bacterial feeding Rhabditida) was low overall, indicating a general lack of large quantities of bacteria breaking down organic matter. Omnivores/predators were relatively abundant at several sites, the nematode predators including juveniles of two genera of Mononchida and an actinolaimid (Dorylaimida). Most nematodes recovered, with the exception of the plant parasitic species, were juveniles. This may in part be a reflection of the extraction process employed (very few large nematodes were found in the samples) or a temporal effect (nematodes may migrate vertically in the soil profile to escape adverse conditions).

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Table 6.1: Analysis of soil samples for nematodes from Ecuador cacao farms

Cacao Farm #	ECF2	ECF3	ECF4	ECF5	ECF7	ECF9A	ECF9B	ECF10A	ECF10B	ECF11	ECF12	ECF16	ECF17	ECF19	ECF20	ECF21
Sample #	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
Tylenchida																
Tylenchus s.l.	2			5	6		2	2		1		2	3	2	3	4
Helicotylenchus	1	5			1	1		12	1		1	2	3	2	6	2
Hemicriconemoides			22	67	148	34	38		30	11	7	5	8	8		1
Paratylenchus		3			7		1						13			
Tylenchorhynchus		1							1							
Pratylenchus				1												
Meloidogyne														5	3	4
Total Tylenchida	**3**	**9**	**22**	**73**	**162**	**35**	**41**	**14**	**32**	**12**	**8**	**9**	**27**	**17**	**12**	**11**
Number of species	*2*	*3*	*1*	*3*	*4*	*2*	*3*	*2*	*3*	*2*	*2*	*3*	*5*	*5*	*3*	*4*
Aphelenchida																
Aphelenchoides	5	1			1			3				1	1			4
Aphelenchus				2		1	1	6	3	3	1	2		4	5	6
Total Aphelenchida	**5**	**1**	**0**	**2**	**1**	**1**	**1**	**9**	**3**	**3**	**1**	**3**	**1**	**4**	**5**	**10**
Number of species	*2*	*1*		*2*	*1*	*1*	*1*	*2*	*2*	*2*	*1*	*2*	*1*	*1*	*1*	*2*
Dorylaimida																
Xiphinema		2								24			2			1
omnivores	4	14		3	9	7	18	6	1	4	2		19	7	7	6
predators (actinolaims)	1											1				
Total Dorylaimida	**5**	**16**	**0**	**3**	**9**	**7**	**18**	**6**	**1**	**28**	**2**	**1**	**21**	**7**	**7**	**7**
Number of species	*3*	*5*		*2*	*3*	*3*	*6*	*3*	*1*	*3*	*2*		*8*	*4*	*5*	*6*
Cephalobida	7	11	0	8	2	1	0	0	1	5	1	4	15	3	4	10
Number of species	*3*	*3*	*0*	*3*	*2*	*1*	*0*	*0*	*1*	*3*	*1*	*2*	*2*	*1*	*3*	*2*
Rhabditida	0	1	0	0	0	0	0	0	0	0	0	5	0	1	0	3
Number of species	*0*	*1*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*1*	*0*	*1*	*0*	*1*
Mononchida	3	6	0	2	0	0	1	1	0	0	2	0	1	0	0	2
Number of species	*2*	*2*	*0*	*1*	*0*	*0*	*1*	*1*	*0*	*0*	*2*	*0*	*1*	*0*	*0*	*1*

Cacao Farm #	ECF2	ECF3	ECF4	ECF5	ECF7	ECF9A	ECF9B	ECF10A	ECF10B	ECF11	ECF12	ECF16	ECF17	ECF19	ECF20	ECF21
Areolaimida	0	1	0	0	0	0	0	0	0	0	0	1	6	0	1	0
Number of species	*0*	*1*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*1*	*2*	*0*	*1*	*0*
other microbivores	0	2	0	0	0	0	0	0	0	0	1	0	5	3	0	0
Number of species	*0*	*1*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*1*	*0*	*1*	*3*	*0*	*0*
Diplogasterida	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Number of species	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
Triplonchida																
Paratrichodorus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Number of species	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*1*
Number of species	**9**	**14**	**1**	**8**	**8**	**6**	**11**	**8**	**6**	**7**	**8**	**7**	**18**	**14**	**10**	**16**
Diversity Index	**0.391**	**0.298**	**0.045**	**0.091**	**0.046**	**0.136**	**0.180**	**0.267**	**0.162**	**0.146**	**0.533**	**0.304**	**0.237**	**0.400**	**0.345**	**0.364**
Number of plant species	**2**	**4**	**1**	**3**	**4**	**2**	**3**	**2**	**3**	**3**	**2**	**3**	**5**	**5**	**3**	**6**
% plant species	**22.2**	**28.6**	**100.0**	**37.5**	**50.0**	**33.3**	**27.3**	**25.0**	**50.0**	**42.9**	**25.0**	**42.9**	**27.8**	**35.7**	**30.0**	**37.5**
Grand total of nematodes	**23**	**47**	**22**	**88**	**174**	**44**	**61**	**30**	**37**	**48**	**15**	**23**	**76**	**35**	**29**	**44**
% Tylenchida	13.0	19.1	100.0	83.0	93.1	79.5	67.2	46.7	86.5	25.0	53.3	39.1	35.5	48.6	41.4	25.0
% Aphelenchida	21.7	2.1	0.0	2.3	0.6	2.3	1.6	30.0	8.1	6.3	6.7	13.0	1.3	11.4	17.2	22.7
% Dorylaimida	21.7	34.0	0.0	3.4	5.2	15.9	29.5	20.0	2.7	58.3	13.3	4.3	27.6	20.0	24.1	15.9
% Cephalobida	30.4	23.4	0.0	9.1	1.1	2.3	0.0	0.0	2.7	10.4	6.7	17.4	19.7	8.6	13.8	22.7
% Rhabditida	0.0	2.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	21.7	0.0	2.9	0.0	6.8
% Araeolaimida	0.0	2.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.3	7.9	0.0	3.4	0.0
% Diplogasterida	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
% Mononchida	13.0	12.8	0.0	2.3	0.0	0.0	1.6	3.3	0.0	0.0	13.3	0.0	1.3	0.0	0.0	4.5
% Triplonchida	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.3
% others (microbivores)	0.0	4.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.7	0.0	6.6	8.6	0.0	0.0
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Notes and Synopses of Nematode Trophic (feeding) Groups

1. TYLENCHIDA >Phytoparasites, usually of plant roots.

Tylenchus s.l.: Mostly root hair or fungal hyphae feeders. Ectoparasites restricted to browsing on epidermal cells. Unlikely to cause damage to plants because of the nature of their feeding damage.

Hemicriconemoides: Capable of feeding deep within woody roots because of the strength and length of their feeding stylet. The nematodes are ectoparasites as the body of the nematode remains in the soil and does not penetrate the root tissue. This genus is common under cacao and is often the dominant phytoparasitic species in the rhizosphere. The nematodes tend to do best in more open textured soils where movement is facilitated.

Helicotylenchus: Operate either as ectoparasites or semi-endoparasites of plant roots. Often present in large numbers and may damage certain crops, particularly those with softer roots that enable the nematode to penetrate the cortex and thus introduce secondary pathogens

Tylenchorhynchus: Another ectoparasite, but with a short stylet and thus capable of feeding only off the outer layers of the root. Unlikely to cause damage to woody roots

Paratylenchus: Minute ectoparasites but with long stylets and capable of feeding deeper within the root tissue. May cause problems to soft rooted plants when present in large numbers

Pratylenchus: Migratory endoparasites of plant roots, particularly of the softer rooted herbaceous plants. Capable of causing much damage, both directly and by facilitating invasion of the tissues by secondary organisms

Meloidogyne: Specialist endoparasites with a sedentary, obese female producing huge numbers of eggs. The soil stage is the infective juvenile. Often polyphagous, they may attack soft rooted plants or, occasionally trees such as coffee.

2. RHABDITIDA >Free-living bacterial feeders.

May exist in large numbers, particularly where there is abundant rotting organic matter and associated bacteria. Primarily r-strategists with a short life cycle.

3. CEPHALOBIDA >Bacterial feeders.

More specialist than rhabditids. Prefer to graze bacteria off soil particles, etc. May be abundant in soils, particularly drier or sandier soils and are extremely diverse.

4. ARAEOLAIMIDA >Bacterial feeders.

Similar to cephalobes in general respects, but often more abundant in wetter soils. Bacterial feeders.

5. DIPLOGASTERIDA >Bacterial feeders and predators of small soil organisms

6. DORYLAIMIDA >Fungal hyphae feeders, omnivores (algae, dead or live soil organisms), phytoparasites and obligate predators.

Diverse group. *Xiphinema* is a phytoparasite and feeds deep within roots by means of a very long protrusible stylet. Usually attacks woody plants. Actinolaimids are rather large and active species that prey on other soil nematodes and small invertebrates such as mites, tardigrades and rotifers. Most abundant in stable, well structured soils that enable these large nematodes to move freely through the pore structure. Often regarded as K-strategists, although smaller forms are more intermediate

7. MONONCHIDA >Predators on other soil organisms, including nematodes.

Mostly voracious, large and active nematodes. Usually rare in tilled agricultural soils as they require a stable soil environment with a good structure to facilitate movement in search of prey. K-strategists.

8. TRIPLONCHIDA >Phytoparasites.

9. APHELENCHIDA >Mostly fungivores

Feed on the contents of the hyphae. Some species also attack plants, but these are mostly restricted to the foliage and above ground parts of herbaceous forms.