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Global Research On Cocoa - *working with and for farmers*

The Issue of Seeing the Wood for the Trees

Agroforesters are familiar with the problem of trying to see the bigger picture, *and* the detail. Cocoa agroforestry is promoted as good for biodiversity, the environment and farmers, but how do you identify the system that best benefits all of these? And what are farmers seeking from agroforestry?

Eduardo Somarriba, an agroforester with CATIE (Centro Agronómico Tropical de Investigación y Enseñanza), Costa Rica shows the potential benefits of cocoa agroforestry by describing some of the work he has led in the Talamanca region of Costa Rica and in Panama on shade tree selection and management and its role in conserving biodiversity. He draws on this experience to identify key research priorities.

Historically cocoa cultivation has had both conflicting and synergistic relationships with forests and shade trees. In some cases it has contributed to deforestation, as in West Africa and Brazil's Atlantic Forest. In others it has helped reintroduce biodiversity in human dominated landscapes and protect natural forests. But the precise relationship between cocoa cultivation, loss/degradation of natural forest, and socioeconomic impact is largely unresearched. An article introduces work from Sulawesi indicating how shaded cocoa and certification could provide an economically sound mechanism for safeguarding forests in biodiversity 'hotspots'.

An article from India shows how cocoa can contribute to agroforestry where it is not the primary crop: it has become part of arecanut or coconut agroforestry systems, and farmers exploit its natural attribute as an understorey tree. This article also illustrates the implications of climate change on agroforestry and cocoa as more areas become marginal, with water management and drought becoming pressing concerns. Researchers have focused on breeding and crop physiology to produce cocoa varieties that meet the needs of farmers growing cocoa in a relatively dry – and probably drying environment. Looking beneath the canopy, an article from Brazil looks at soil and litter fauna in different cocoa agroforestry systems in Bahia; their role is crucial in carbon and nutrient cycling. Lastly, there are a few words about a new UK 'cocoa club'.

Cocoa and Shade Trees: Production, Diversification and Environmental Services

Cocoa is commonly cultivated by smallholders in association with trees that benefit the cocoa plant (through climate amelioration, soil protection and maintenance of fertility); provide products for home and farm use or for sale (timber, fruits, firewood, medicine, fibre or construction materials, honey, resins, etc.); and provide services to the household (cultural and aesthetic) and to society (soil, water and biodiversity conservation and carbon sequestration for mitigation of climate change). Diversified cocoa cultivation makes farm income larger and less variable and the business more resilient to perturbations such as falling cocoa prices.

In most cases, the botanical composition of the cocoa shade canopy is suboptimal for satisfying the needs of the smallholder farmer, shade levels are inadequate, and canopy cover is unevenly distributed over the plot. Most cocoa shade canopies have low species richness and simple vertical and horizontal structure to facilitate crop management. Poor agronomic practices such as pruning and thinning of shade trees are the norm, resulting in suboptimal yields of both cocoa and companion trees.

At CATIE we have developed a four-step protocol to help agronomists and farmers analyse and improve their cocoa shade canopies:

1. Determine what the farmers expect to obtain from their cocoa plantation i.e. what trees do they value on their farms and what goods and services do they want from them?
2. Determine what shade conditions would be the best for their cocoa plot. Characterise its shade canopy.
3. List and prioritise local (and potential) tree species that can be used in cocoa shade canopies. Provide details on the use of the species, and data on tree and crown characteristics relevant to shading.

Indigenous cocoa farmers in Talamanca, Costa Rica, intercrop cocoa and banana in micro-plots (<200 m^2). Timber trees (Cordia alliodora) *are selected from natural regeneration. This micro-plot is heavily shaded by secondary forest behind the plot. (E. Somarriba)*

4. Design and discuss with farmers interventions in cocoa shade canopies; improved shade canopies should optimally provide the goods and services demanded by both the household and global society.

Highlighting Shade

How much shade should there be in any given cocoa plantation? A set of key factors need to be evaluated at each cocoa plot to answer this question – and below we discuss the essential ones.

Self-shading

In the crown of a cocoa tree, upper leaves

In This Issue

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Cocoa and Biodiversity in Talamanca

The Talamanca region in southern Costa Rica is a critical area for biodiversity conservation along the Atlantic Mesoamerican Biological Corridor. It is also home to the Bribris and Cabecares, the two largest indigenous groups in the country, and is one of the most impoverished regions of Costa Rica. By selectively recruiting timber trees from natural regeneration, planting fruit and legume shade trees in canopy gaps, and removing excess plants in heavily shaded spots, indigenous cocoa farmers seek to satisfy the production and conservation goals of their households and of global society.

Cocoa is a traditional crop for these indigenous inhabitants of Talamanca, a component of their subsistence agricultural system. Commercial cocoa plantations were established and cocoa became the region's leading crop between 1940 and 1970, and as world cocoa prices soared in the late 1970s, the outlook seemed good. All this changed in 1979 with the arrival of frosty pod rot in Costa Rica. As the disease took hold, production dropped to nearly zero. In addition, world cocoa prices crashed in 1980 and remained low for nearly two decades. Many farmers abandoned cocoa and shifted to other crops. Others kept their plantations but with lax management and low yields.

Cocoa survived in Talamanca thanks to the efforts of the Talamanca Small-Farmers Association (APPTA), with the help of Asociación ANAI, The Organic Commodity Project, CATIE and others, and entered into the certified (and premium priced) cocoa market. In the early 1990s, following the Rio summit and the launch of the CBD (Convention on Biological Diversity), the importance of biodiversity began to be acknowledged at government and policy levels worldwide. Crucially for cocoa in Talamanca, a meeting in 1998[1] in Panama recognised the importance of shaded smallholder cocoa to the future of the world cocoa industry – and to biodiversity.

Indigenous farmers in Talamanca grow cocoa under five basic shade canopy typologies:

1. Cocoa under mono-specific shade, either timber (e.g. laurel, *Cordia alliodora*) or nitrogen-fixing legume (e.g. guaba, *Inga*) species.
2. Cocoa under two-storey shade: a mixture of fruit (*Citrus*, *Nephelium lappaceum*, *Bactris gasipaes*), legume and timber species.
3. Cocoa intercropped with banana and fruit species under mono-specific shade (timber or legume).
4. Diversified home gardens with cocoa, fruit, timber and legume species.
5. Rustic cocoa (also known as 'cabruca'): cocoa planted under thinned natural forest.

Talamanca lies in one of Conservation International's designated 'biodiversity hotspots', and in the regional Talamanca-Caribbean Biological Corridor and the larger Mesoamerican Biological Corridor. The Talamanca mountain range contains the largest tracts of virgin rainforest in Costa Rica. Ninety percent of Costa Rica's known plant species are found in this area, 30% of which are endemic. The majority of Costa Rica's animal (mammal, bird, reptile, amphibian) species are also found here, including many endemics. However, what puts the area on the world stage is that the lowlands are an important route for migratory birds. Over the last 10 years, The Nature Conservancy, USA (TNC) has joined with Asociación ANAI and CATIE to investigate the role of shaded cocoa agrosystems in sustainable production and biodiversity conservation in the Talamanca Biological Corridor.

[1] http://nationalzoo.si.edu/conservationandscience/migratorybirds/research/cacao/principles.cfm

and branches cast shade on lower leaves. Furthermore, neighbouring cocoa trees cast shade on each other. The shade cast by upper leaves and branches plus the shade cast by neighbouring trees is called 'self-shading'. There is an inverse relationship between self-shading and the need for overstorey shade: if self-shading is high, then less overstorey shade is needed. If this happens, a smaller number of shade trees will be required and the farmer loses the capacity to produce goods (timber, fruit, etc.) and services (cultural, environmental) in the cocoa plot. Self-shading is determined by a combination of factors related to the form and size of the cocoa tree, and planting configurations and spacings – alone and in combinations. A key list is:

- Age of cocoa plants (young plants have small crowns, hence low self-shading; overstorey shade is needed).
- Pruning frequency and intensity of cocoa (infrequent and light pruning results in tall cocoa trees, crown overlap between neighbouring cocoa trees, and high self-shading).
- Grafted cocoa trees tend to be shorter and more open-crowned than trees from seed. Less self-shading is expected in well managed grafted-cocoa plantations than in similar plantations from seed.
- Close planting of cocoa will result in high self-shading. Triangular planting arrangements can 'pack' cocoa trees more densely in the plot than square or rectangular configurations. Self-shading is higher in more 'packed' planting configurations.

Temporal dynamics

In addition to the age-dependent changes in self-shading that occur as cocoa plants grow older and bigger, light requirements of the cocoa tree vary according to its annual cycle (leaf flushing; flowering, fruit development and filling; fruit maturation; radial growth of stem, branches and roots; quiescent phase). Light is needed at flowering and pod filling. For optimal cocoa performance, shade must be adjusted to the phenological rhythms of the cocoa plant by timely pruning or pollarding of the shade trees.

Site conditions

A range of site factors influences the amount of solar radiation reaching (or shading) the cocoa plot, including:

- The latitude, exposure and slope of the land where a cocoa plot is located determine the amount of solar radiation reaching it.
- High prevalence of cloud reduces solar radiation.
- The morphology of the surrounding land and the nature of the surrounding vegetation affect the 'lateral shade' cast on a cocoa plot
- Soil fertility has a role to play. In infertile soils farmers can grow cocoa with little shade only if they are ready to apply fertilisers (organic or not) to the soil. If they do not have the resources to do this – for instance, at times when cocoa prices are low – then they have to grow cocoa under shade. Shade reduces solar radiation and the demand of cocoa for soil nutrients. Some 95% of cocoa worldwide is produced without applying fertiliser to restore the nutrients removed in the harvested crop and lost through erosion and leaching.
- The rainfall regime is crucial for shade canopy design. In the context of cocoa agroforestry, it is important to be able to assess the minimum rainfall below which the introduction of trees to unshaded cocoa will result in poorer performance of the cocoa.

Canopy characteristics

The vertical and horizontal distribution of the canopy cover and its botanical composition affect the quantity and quality of shade. Tall trees cast 'lighter' shade than short ones. Tree species differ in the time of the year when they become leafless. Cocoa trees require a spatially homogene-

Cocoa–timber systems. Cordia alliodora *initially planted at 6x6 m spacing and thinned at year 5 to 170 trees/ha, Ojo de Agua, Changuinola, Panama. (E. Somarriba)*

Cocoa–timber systems. Terminalia ivorensis *initially planted at 6x6 m spacing. Thinning not required; heavy natural mortality due to die back and wind damage. Changuinola, Panama. (E. Somarriba)*

Timber Shade Trees in Talamanca

Research conducted by CATIE over 10 years in Talamanca and neighbouring Bocas del Toro in Panama looked at the agronomic and financial performance of cocoa plantations under various legume or timber shade tree species. We found that when each trees species is pruned and thinned to satisfy the needs of the cocoa crop, cocoa yields are similar under legume or timber shade. Timber species helped to reduce farmers' risks and increase farm income. In Talamanca and Bocas del Toro, we recommend planting *Cordia alliodora* on fertile well-drained soil, and *Tabebuia rosea* where drainage is poor. Assessments of damage to cocoa during timber harvest indicated this was not a major limitation and should not be a concern to farmers. From the biodiversity perspective, *Cedrela odorata* re-planting will help redress over-exploitation throughout its native range. What these three species also share are excellent timber properties.

Cordia alliodora. Indigenous range from Mexico and the Antilles to Brazil and Bolivia. Occurs in humid or dry lowland forest (common in drier areas) ≤2000 m altitude. Tolerates annual rainfall as low as 750 mm; optimal growth at >2000 mm. Sensitive to soil conditions and nutrients, prefers well-drained soil free from seasonal waterlogging. A fast growing, light-demanding species, it readily colonises exposed fertile soil, growing to over 40 m in total tree height in humid zones. Narrow crown, high above ground, casts a light shade. Bole generally straight, cylindrical; often clear of branches for 50–70% of the total tree height. Easily established from seedlings, stumps, and even direct sowing. Self-prunes, coppices well. A renowned timber-producing species; lumber easy to work and finish.

Tabebuia rosea. Native range in tropical America, from Mexico to Colombia and Venezuela, and Guadeloupe. Medium- to large-sized deciduous tree up to 25 m high. Grows at ≤1200 m altitude with annual rainfall of 1250–2500 mm, and best in deep rich soil. Growth is fast especially when young. Natural seeding occurs and cuttings root quickly; established mostly by direct sowing and subsequent planting out. Withstands limited pruning but not pollarding. Tolerant to waterlogging. Yields excellent timber.

Cedrela odorata. Native to the West Indies, and from Mexico to Ecuador, Peru, French Guiana and Brazil (including Atlantic and Amazon rainforests of Brazil). Found in lowland or lower montane evergreen and semi-deciduous rainforest ≤1900 m altitude with annual rainfall of 1000–3700 mm. Light demanding, intolerant of waterlogging/flooding. Best in very fertile soils and with perfect drainage and thus good soil aeration. Tolerates periods of drought. Fast growing, up to 40 m high. Straight cylindrical bole, branchless for 25 m in closed forest stand, but short stemmed and branched when grown in the open. Natural regeneration good. One of the world's most important timber species, over-exploited; now in the IUCN 'Red List' of threatened species (although, ironically, invasive in some areas where it has been introduced).

Source: www.worldagroforestrycentre.org/Sites/TreeDBS/aft/botanicSearch.asp

ous shade cover over the plot. Many cocoa plantations have patches with either excessive or nonexistent shade.

Planning for Productivity and Biodiversity

Cocoa cultivation offers the unique opportunity to combine economically viable production with the conservation of soil, water and biodiversity and the provision of other environmental services to society (see Box: Cocoa, CO_2 and Climate Change, p. 7). Farmers can simultaneously enhance cocoa productivity and conserve biodiversity in cocoa plots by following the next seven steps (also see Box: Cocoa and Biodiversity in Talamanca):

Manipulating shade

This entails taking out or pruning trees where there is too much shade, and filling gaps by encouraging natural regeneration of selected species or by planting others. Tree species are selected based on fruit quality (e.g. rambután, *Nephelium lappaceum* or pejibaye, *Bactris gasipaes*), timber (see Box: Timber Shade Trees in Talamanca), forage or habitat value for domestic (pigs and chickens) and wild animals (fruit is a special enticement), or to restore highly degraded populations due to over-exploitation (e.g. *Cedrela odorata* in Talamanca), etc.

Pruning

Cocoa trees are lightly and infrequently pruned on most farms. Pruning is one of the most labour demanding management practices in cocoa cultivation. Annual cocoa pruning is recommended to ensure proper ventilation within the crown and illumination of main branches and stems to stimulate cocoa flowering and fruit setting; proper pruning also helps to maintain low levels of self-shading.

Short, grafted cocoa

Short cocoa trees are required for inexpensive and effective management of fungal diseases such as frosty pod (*Moniliophthora roreri*), black pod (*Phytophthora palmivora*) and witches' broom (*M. perniciosa*). For instance, controlling frosty pod requires the frequent inspection of cocoa pods by the farmers to allow early detection and discarding of infected pods before they sporulate, disperse and infect new healthy pods. Inspection of (nearly) all cocoa pods is possible only on short cocoa trees.

Encourage local participation in conservation

Cocoa households exploit a wide variety of plants and animals (mammals and birds, e.g. partridge) and their products from their cocoa farms. It is unclear which uses of biodiversity are sustainable and this needs investigating. The first stage is to help households get to know the biodiversity in their farms, evaluate the impacts of their activities on it, and adjust what they do to conserve these biological resources. Biodiversity conservation is affected by the way in which producers establish and manage cocoa farms and the intensity with which they hunt and make use of useful plants. So a balance may need to be struck, e.g. they may need to hunt less frequently, or restore threatened plant populations.

Manage beneficial and damaging populations

Biodiversity can have negative effects on farm productivity, and management may be needed, e.g. squirrels (*Sciurus* spp.) consume cocoa and various fruits; some birds consume grain destined for family subsistence consumption and animal feed; coatis (*Nasua narica*) damage bananas/plantains; rodents cause important post-harvest losses; some wild predators take chickens. Other populations represent an economic opportunity, e.g. laurel, *Cordia alliodora*, regenerates profusely and with better management could be produced in Talamanca as a sustainable timber product. On the other hand, *Cedrela odorata* has been overexploited through most of its native range; fortunately, *C. odorata* is easily and cheaply propagated and good germplasm is available. Some over-hunted animal species, such as *Pecari tajacu* (collared peccary), *Agouti paca* (paca, agouti) and deer – *Mazama americana* (red brocket) and *Odocoileus virginianus* (white-tailed deer), need to be protected until their populations recover before hunting resumes.

Marketing and certification

Managing cocoa to benefit biodiversity needs to be exploited in order to facilitate access to certified niche markets (for wood, fruit, cocoa). Schemes are needed to reward farmers for conserving biodiversity or adopting practices that aid conservation on their farms.

Future Needs: a Call for Action

Cocoa agroforestry has much to contribute to sustainable cocoa production by seven million cocoa households worldwide. Farmers need the knowledge and skills to manipulate cocoa shade canopies to optimally satisfy their needs. To consolidate cocoa agroforestry science and technology, we need to develop in (at least) four fields:

1. Advance research to improve understanding of: (a) ecological interactions between shade canopies and the cocoa crop – nutrient cycles; light–fertility–yield interactions; micro-environment and pathogens; water–shade–yields; and soil, water and biodiversity conservation; (b) cocoa production systems: cocoa as part of the household livelihood strategy, shade canopy typologies, farm economics (profitability, risk and stability); and (c) the human component: the household life cycle, the family group, community ties, producer associations, technology dissemination and adoption, aversions and preferences regarding the use of trees on the farm, etc.
2. Understand the legal and policy framework that encourages or discourages households from fully realising the benefits derived from cocoa agroforestry. For instance, we should evaluate (a) the forestry and environmental legislation that deters tree planting and utilisation on farms; (b) sanitary barriers – for fruits, especially; (c) limitations on germplasm rights for useful native fruit and timber species (and facilitate exchange between cocoa growing regions); and (d) the impact of global trends, conventions, trade agreements, technology bottlenecks, climate change, etc.
3. Identify and discuss ideas to better integrate the timber and fruit industry with cocoa households and the value chain.
4. Synthesise successful strategies for the implementation of cocoa agroforestry development projects, draw lessons from failures and derive recommendations for new cocoa projects, both on-going and future.

Further Reading

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Trade-offs between Cocoa Intensification and Biodiversity

Countries that still possess rainforest are under pressure to preserve it because of the projected impact of its loss on biodiversity and ecosystem functioning, including carbon sequestration. However, growing populations living on the fringes of these forests need more agricultural production for subsistence and income-generation. Intensification, so one argument runs, maximises productivity and so spares land. How this compares with more extensive, wildlife friendly farming, as found in shaded cocoa, has been poorly documented. A multidisciplinary study of ecological losses and socioeconomic tradeoffs in cocoa agroforestry systems in Sulawesi that seeks to redress this[1] is outlined here.

Agriculture is Central Sulawesi's largest sector in terms of employment and output, with cocoa a key crop. The Lore Lindu National Park in Central Sulawesi is one of the core areas for protecting the Wallacea biodiversity hotspot. This study, conducted on the Park fringes, evaluated the effects of land use strategies in cocoa agroforestry in terms of species richness and related ecosystem functions; it also looked at economic drivers of agroforestry expansion. The study focused on management, not landscape effects, by selecting sites with differing levels of intensification all close to natural forest. A gradient of increased intensification was drawn up using percent canopy cover as an indicator of forest tree loss. As the study area included no unshaded plantations, socioeconomic data was collected from these elsewhere, and other ecological studies were used for comparison.

The last 20 years have seen a 230% increase in cocoa production in the area. Satellite images indicate how 15% of the study region was deforested and converted to intensive agriculture between 1972 and 2003, and agroforestry areas supporting cocoa and coffee under shade expanded from 57.2 km^2 in 1983 to 133.4 km^2 in 2002. Intensification of cocoa was triggered by increased farmgate prices, but also because transmigrants transferred their knowledge of this style of agriculture to the indigenous population, triggering a shift from a food-first rice-based system to a cash crop-first strategy based on cocoa (which provides twice the revenue), thus increasing pressure for land. A trend for decreased shade in cocoa of harvesting age (from 80% to about 30%) along with more fertiliser and pesticides, represents intensification over this period.

Conversion of rainforest to extensive cocoa agroforests with high shading levels has little effect on overall species richness, but species richness of forest-dwelling species is reduced by some 60%. It is reasonable to infer that rare forest species are likely to be adversely affected, underlining the limitations of agroforestry for conserving forest biodiversity. As cocoa agroforestry becomes more intensively managed and shade is reduced further, to around 40-50%, add-on ecological changes are small. Although this study did not look at unshaded cocoa, other studies have found that this harbours significantly fewer species, so another steep decline presumably occurs when shade is completely removed.

There are, however, functional impacts of shifts in species richness in shaded agroforests: reductions in plant mass and carbon storage by 75%; increased soil surface temperatures and reduced relative humidity of air; and fewer soil arthropods and thus lower soil decomposition rates – although soil fertility did not vary in this study. Other studies have equated complete removal of shade with more pest outbreaks, erosion and pollination disruption.

Socioeconomic survey data indicate that a doubling of income accompanies reduction in shade from >80% to 35–50%, with the relatively limited losses in ecological terms indicated above. In contrast, conversion from forest in the first place, or the complete removal of canopy, causes disproportionately large ecological losses. Thus a 'middle way', of thinning of high shade cover to create more open agroforests, rather than either clearing natural forest to bring more land into production or clearing shade completely to farm more intensively, appears the best ecological option.

Without creation or extension of national parks, economic incentives are needed to slow cocoa intensification beyond this ecologically acceptable level. Data from cocoa farming households indicate a 40% difference between yields under low-shade agroforestry and unshaded plantations. Assuming a yield of 630 kg/ha/year, compensation to the tune of €0.34 /kg would be needed. This is within striking distance of premiums paid for organic fair trade cocoa in Mesoamerica. In addition, 'willingness-to-pay' studies with farmers indicate their preference for low-shade agroforestry systems over open plantations suggesting that low-shade agroforestry would be an acceptable compromise between economic forces and ecological needs.

[1] Steffan-Dewenter, I., Kessler, M., Barkman. J. *et al*. (30 co-authors) (2007) Tradeoffs between income, biodiversity, and ecosystem functioning during tropical rainforest conversion and agroforestry intensification. *Proceedings of the National Academy of Sciences, USA*, 104(12), 4973–78.

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CPCRI: Cocoa Breeding and Physiology in India

Cocoa was introduced to southern India during the 20th century mainly as a mixed-crop in coconut and arecanut gardens (see Box, Arecanut: Cocoa Shade Crop in India) as it was found that the climate within the gardens is conducive to cocoa growth. The commercial cultivation of cocoa started in India in 1970 and the area under cocoa reached 29,000 ha by 1980-81, mainly due to the attractive prices during that period. At present Kerala, Karnataka and Andhra Pradesh are the major cocoa growing states. Cocoa production in India during 2005 was 10,175 tonnes against the demand of 16,000 tonnes. Under the present trend, it is forecast that demand will increase to 22,000 tonnes in 2010 against projected production of 13,000 tonnes. However, the industry has a projection target of 30,000 tonnes by 2015.

Collection and Conservation

The cocoa improvement programme was started at the Central Plantation Crops Research Institute (CPCRI), Vittal in the early 1970s with a mandate for introduction, selection, hybridisation and evaluation of cocoa. The germplasm collection at CPCRI consists of 185 accessions gathered from various primary and secondary centres of origin. The main objectives of breeding are high yield, bean size of more than 1g, reduced shelling percentage, drought tolerance and resistance to black pod disease.

Breeding

The hybridisation programme was started at Vittal in 1980 with selected self incompatible, but cross compatible, parents with the specific objectives of a higher number of pods, high dry bean yields, greater fat content and drought tolerance. Four sets of hybrids were produced, planted and evaluated under progeny trials at Vittal from 1983 to 1991. A comparison of parents and hybrids in progeny trials indicated that more vigour is exhibited by the progenies than parents and showed positive and significant heterosis over their mid parental value.

- The parents in progeny trial I included Upper Amazon Collections/Imperial College Selections, Scavina series and Nanay series, i.e. Na 31, Na 33, SCA 6, ICS 6, ICS 95, IMC 67 and five hybrids. Progenies from Na 33 × ICS 89 excelled in dry bean yield, DBY (1.005 kg/ tree/ year).
- Progeny trial II had a total of 17 hybrids, their parents and a check line I-56. All showed significant differences with regard to bean yields. The progenies of hybrid I-56 × II-67 gave the maximum bean yield (1.481 kg DBY) followed by I-14 × I-56 (1.465 kg) and I-56 × III-35 (1.418 kg).
- Progeny trial III involved nine hybrids; four Malaysian hybrids and five bulk Forasteros. From a consistency point of view the progenies ICS 6 × SCA 6, ICS 6 × SCA 12 and IMC 67 × ICS 6 can be considered as high yielders with 1.145, 0.952 and 0.941 kg DBY, respectively. The Malaysian hybrid Amelonado × Na 33 also yielded over 1 kg DBY at 1.082 kg.
- Under progeny trial IV nine hybrids with their seven parents were evaluated and among them the crosses II-67 × NC 29/66 and II-67 × NC 42/94 registered the highest pod index (dry bean weight/pod) of 47.86 and 41.25 g, respectively. They were evaluated for biochemical components, which showed significant differences among hybrids and parents. These hybrids were evaluated and selected for water limited conditions and considered as drought tolerant.
- Eight high yielding trees of Nigerian origin (NC 102, NC 119, NC 73, NC 63, NC 13, NC 116, NC 53 and NC 8) were selected and multiplied clonally and further evaluated. Among them the clone NC 45/53 had the highest yield range of 0.930–1.726 kg DBY/tree/year and this clone is both self and cross compatible. Another clone, NC 38/119, was also selected as it showed the best stability indices.

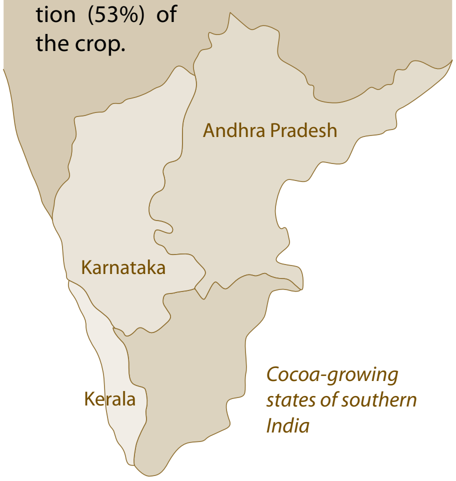
These hybridisation efforts resulted in development of varieties which are vigorous, early, heavy bearing and have standard bean characters, viz., I-56 × II-67, ICS 6 × SCA 6, II-67 × NC 29/66, II-67 × NC 42/94 and NC 45/53. These are suitable for cultivation in Kerala, Karnataka, Tamil Nadu, Goa, Maharashtra and the north-eastern states.

In-vitro screening of the majority of the available germplasm against black pod disease using isolates of the prevailing three *Phytophthora* spp. (*P. palmivora*, *P. capsici*, *P. citrophthora*) has indicated a few good lines with a certain degree of tolerance, one of which is NC 51 (parentage being C44). This particular line has been utilised as a pollen donor in an inheritance study with the selected seven best lines (I-14, II-67, III-35, III-105, IV-20 and NC42/94), which are used as parents for breeding.

The softwood grafting method was

Arecanut Cocoa Shade in India

Arecanut (*Areca catechu*) or betel nut is an important commercial crop in India. The total production of arecanut in India is 0.416 million (4.16 lakh) tonnes cultivated in an area of 0.354 million (3.54 lakh) ha. It is cultivated in the states of Karnataka, Kerala, Assam, Tamil Nadu, Meghalaya and Maharashtra with Karnataka being the leading producer. The betel nut has a prominent role in social, religious and cultural life. It is popular for chewing, but is also used in ayurvedic and veterinary medicines. An estimated 10 million people depend on the arecanut industry for their livelihood in India, and the country ranks first in the world in both area (58%) and production (53%) of the crop.



Cocoa-growing states of southern India

standardised for clonal multiplication of selected accessions and high yielding hybrids for quality planting material production. Grafts are being supplied to the cocoa growers, demonstration farmers and developmental agencies regularly to the tune of 50,000 per year. F_1 hybrid pods are also being supplied from clonal orchards.

Physiology

The microclimate existing in coconut and arecanut gardens, which transmit approximately 30–50% (about 400 µmol/m^2/s) of light is very conducive to cocoa growth as the cocoa plant is shade tolerant. Trials indicated that light penetration from an arecanut canopy and hence cocoa yield were optimum with a 1:1 ratio of arecanut and cocoa at 3.3 × 3.3 m spacing. However, in existing arecanut gardens with 2.7 × 2.7 m tree spacing, planting cocoa at 2.7 × 5.4 m spacing is good because it causes least self-shading. The net photosynthetic rate (P_n) ranges from 1.6 to 7.0 µmol CO_2/m^2/s in cocoa leaves depending on season and accession. Cocoa has low P_n and net assimilation rates compared with many other tropical tree crops and is relatively tolerant of shade. This is mainly because cocoa has evolved as an understorey tree.

Growth and yield are influenced by a number of environmental factors, particularly rainfall, temperature and water stress. As a plantation crop, cocoa is very sensitive to drought. Water stress affects the most important physiological determinants of yield, canopy architecture, photosynthesis and partitioning of assimilates. In India the intensity of drought is more pronounced in the northern regions of Kerala and coastal Karnataka (dry spell extending up to 3–6 months). Cocoa plants are subjected to severe stress in the rainfed coconut gardens. However, the situation is better in arecanut gardens, which are irrigated. But even here non-availability of water towards the end of summer exposes cocoa to stress.

Efforts have therefore been made to identify drought tolerant characteristics in cocoa accessions. Research conducted during the last decade has shown that thick leaves, higher epicuticular wax content and efficient stomatal closure under drought to reduce transpirational water loss underlie better drought adaptation. The observed increases in stomatal resistance did not affect photosynthesis significantly and it was found that water use efficiency was enhanced in tolerant accession types. It has been possible to identify some drought tolerant accessions, viz. NC 23 (P3 × P), NC 29 (P6 × P4) and NC 42 (T 86/2). These are being used as parents along with high yielding trees in a breeding programme. Under situations where the dry periods are shorter, it is possible to introduce drought tolerant genotypes identified at this Regional Station. Nonetheless since even this drought adaptive strategy may fail in such areas with a longer dry season, it is necessary also to have an appropriate scheduling of irrigations. Studies to find out threshold levels of soil moisture for cocoa productivity and water economy through drip irrigation have been done. Water relations, soil moisture profiles and photosynthetic characters determined in relation to drip irrigation in cocoa showed stress effects at levels of 10 litres/day. Optimum responses were noticed at 20 litres/ day level with higher yields achieved.

Areca–cocoa mixed cropping system (CPCRI)

The cocoa plant requires a fairly large canopy and leaf area to sustain high productivity because of its very low P_n and net assimilation rate. When cultivated as an intercrop under palms, a maximum of two-storeys, i.e. two layers of cocoa branches, is maintained. The plants require a minimum of pruning, which is restricted to removing the highly shaded and non-fruiting branches. The main stem grows to 1–1.5 m high before the first jorquette is allowed to form. In cocoa, canopy area is an important determinant of yield. Pruning is essential for maintenance of optimum canopy shape. Maximum yields were obtained with a large canopy (16–20 m^2) at a tree spacing of 2.7 × 5.4 m. The average land equivalent ratio (LER), which is a measure of comparative yields in mixed crops compared with sole crop, ranged from 0.82 to 1.74, the maximum being achieved at 2.7 × 5.4 m tree spacing. (The higher the LER, the more efficient the system.) There were significant differences with regard to spacing and canopy treatments. There was significant interaction with bean yield on both a plant and an area basis. There was an increasing trend in yield with pruning treatments. Maximum yields were recorded with 2.7 × 2.7 m and 2.7 × 5.4 m tree spacing with large canopy on a per area basis. However, on a plant basis 2.7 × 5.4 m tree spacing with large canopy recorded the highest yield.

Net Primary Productivity and Carbon Sequestration

The cocoa–areca mixed crop not only gives sustainable production, but also serves as a good system for biomass production and carbon accumulation. Measurements of growth parameters for cocoa and areca were used to estimate biomass by regression equations. Based on these, it is possible to estimate dry biomass and total carbon content of areca and cocoa. The carbon content of areca and cocoa plant parts ranged from 39 to 42%. Further measurements of cocoa and arecanut biomass made include the total primary productivity of areca + cocoa, which was 26.57, 54.09 and 87.10 t/ha in the 5th, 8th

Cocoa, CO_2 and Climate Change

According to the Intergovernmental Panel on Climate Change (IPCC), increasing levels of greenhouse gases particularly carbon dioxide (CO_2) in the atmosphere are implicated as the primary cause of contemporary global warming. The IPCC identifies burning fossil fuels and deforestation as major factors in the rise in CO_2 levels, and recognises that this needs to be slowed (mitigated). Carbon sequestration, the removal and storage of carbon from atmospheric CO_2 in carbon sinks (e.g. forests) through physical or biological processes (e.g. photosynthesis) has thus assumed new importance.

While reducing carbon emissions is the ultimate goal, change will take time, so the Kyoto Protocol introduces the concept of carbon offsetting: CO_2 released by burning fossil fuels can be offset by planting trees to absorb CO_2 and sequester it. Some argue that sequestered and fossil carbon are not equivalent as the plant carbon will eventually be released back into the atmosphere through harvesting, natural decay or fire, and also point to the vast areas of trees that would need to be planted. Nonetheless, the notion has been greeted enthusiastically as a positive step.

Given that CO_2 producers are not necessarily in the best position to conduct offsetting activities, the Protocol introduced the notion of carbon trading; a mechanism for marketing carbon emissions as a commodity: countries emitting excess carbon can purchase carbon offsets from another country, to manage their carbon sinks. Originally conceived to operate at the country level, companies and even individuals in industrialised nations are being encouraged to consider their green (carbon) footprint and offset their energy use, with the ultimate aim of achieving carbon neutrality – no net CO_2 release. It can be argued that offsetting encourages people to continue their polluting ways instead of modifying their habits, but another very significant criticism is that the offset forestry schemes often ignore traditional forest dwellers and users.

However, where the local people are already practising agroforestry, they may be able to make monetary gains. In India it is being realised that cocoa mixed crop production systems are ideal for such carbon sequestration mechanisms.

and 15th years of growth respectively, and the carbon stock which was 10.96, 22.38 and 36.05 t/ha during the same periods of time. Thus, the development of cocoa based systems for carbon trading mechanisms that will enhance farmer incomes are being proposed – see Box: Cocoa, CO_2 and Climate Change).

Further information: www.cpcri.ernet.in

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Soil and Litter Fauna in Bahia Cocoa Systems

Soil fauna is a vital component of soils and serves as a potential indicator of soil quality. Adequate management of soil biological resources such as faunal communities is vital to the sustainability of perennial cropping systems like cocoa. Soil fauna plays a significant role in crop residue and litter decomposition and in soil functional properties, including carbon and nutrient cycling. Soil processes such as organic matter dynamics, and soil physical properties such as aggregation, structure, porosity and moisture, are known to be regulated by faunal activity. Management practices as well as climate, soil type and vegetation greatly affect faunal activity.

Agroforestry systems, owing to the large quantities of plant residues deposited on the soil, are characterised as systems that accumulate organic matter and are generally considered to have positive effects on biodiversity and its conservation. The work described in this article investigated how soil fauna fared under different cocoa agroforestry systems prevalent in the Brazilian state of Bahia, which themselves reflect the history of cocoa growing in this area.

Cabruca or cocoa forest was formed when the forest canopy trees were thinned and underplanted with cocoa trees. It became the conventional way of growing cocoa in Bahia and, as natural forest became fragmented and eventually disintegrated, the dominant forest type of the Bahia cocoa belt. But cabruca itself became degraded: the forest trees were retained at lower densities than in natural forests, and this together with management of the understorey meant too few forest saplings survived to replace original shade trees as they died. Farmers often planted exotics in their place, including leguminous *Erythrina* spp. Farmers have in some cases cleared forest all together and planted cocoa in rows, with shade provided by regularly-spaced plants such as banana and *Erythrina*. (See Figs 1 & 2.)

Fig. 1. Cocoa under natural forest – 'cabruca'

Fig. 2. Cocoa under Erythrina *shade*

Studies were undertaken in southern Bahia to characterise and compare the distribution of meso- and macro-fauna communities in the soil and litter of cocoa agroforestry systems and natural forest. Organisms were collected from soil and litter using Berlese–Tullgren funnel apparatus over 15-day periods in September 2003 (winter), February 2004 (summer) and August 2004 (winter). Sampling was conducted in five cocoa agroforestry systems:

- Cocoa (approximately 25 years old) under *Erythrina* shade, renewed 5 years before by grafting with witches' broom (*Crinipellis pernicious*) resistant genetic material (CRE).
- Cocoa (approximately 70 years old) under natural forest (cabruca), renewed as above (CRF).
- Old cocoa (approximately 25 years old) under *Erythrina* shade (OCE).
- Old cocoa (approximately 70 years old) under natural forest (OCF).
- A cocoa germplasm collection (CGC).

Samples were also collected from natural forest (NF) next to the agroforestry systems as a model of a self sustaining system. Small seasonal variations were observed in density and richness of soil and litter fauna (Fig. 3). There was little difference observed in functional groups between various agroforestry systems and natural forest. Functional groups with larger faunal density included microbial grazers (Collembola) and social insects (majority Formicidae).

The V index developed by Wardle[1,2] was used to quantify soil fauna responses

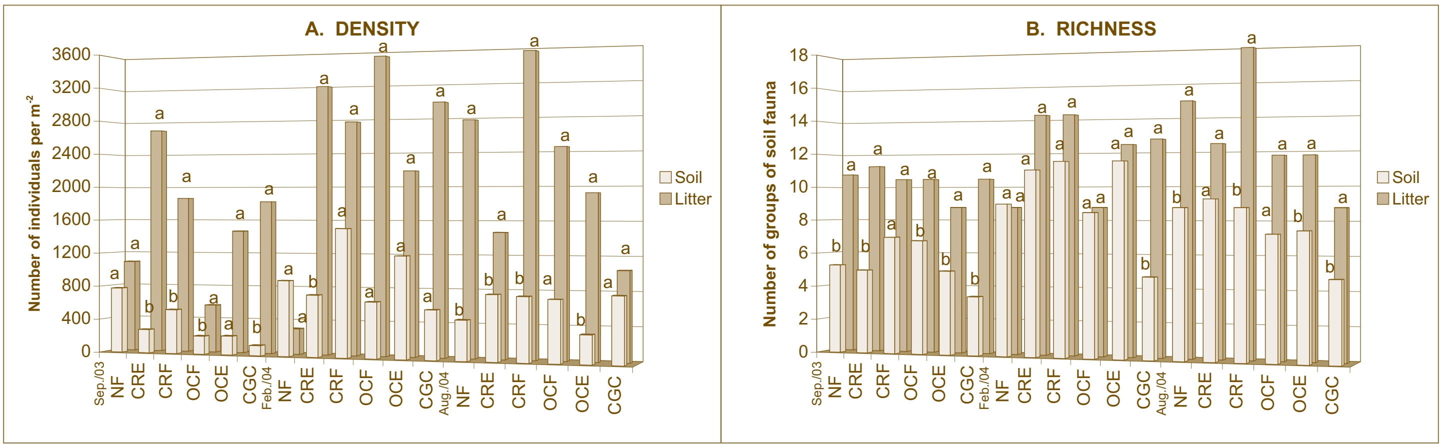

Fig. 3. Seasonal variations of (A) fauna density and (B) richness of fauna in soil and litter in cacao agroecosystems. Columns with same letter, for soil and litter, within each defined sampling date, are not significantly different at T test P = 0.05. NF: natural forest; CRE: renewed cocoa under Erythrina; CRF: renewed cocoa under forest; OCF: old cocoa under forest; OCE: old cocoa under Erythrina; CGC: cocoa germoplasm collection.

to agroforestry systems. This measures changes due to soil management in groups of soil fauna by comparing the relationship between faunal densities in areas with and without management. Results for each faunal group are expressed as a number between -1 (organisms occurring only under natural forest) and +1 (organisms occurring only under cocoa agroforestry systems), and this indicates whether populations were stimulated or inhibited by a particular management system.

Varying degrees of inhibition or stimulation of soil faunal growth were observed in all sites and at all sampling times, and this was influenced by season and soil components (soil and litter). In general, populations of more than 50% of the organism groups were stimulated within cocoa agroforestry systems. Inhibition of populations was more common in the dry season, while during the rains populations of about 50% of organism groups, mainly in litter, were highly stimulated. Populations of a few organisms were unaffected by the nature of the cocoa agroforestry system.

The results indicate that the cocoa agroforestry systems adopted in southern Bahia have beneficial effects on the soil and litter faunal communities. There was no clear influence of sampling time on soil faunal community structure and activities, but the development of a litter layer resulted in high abundance and diversity of soil fauna. Thus soil management as practised in the various cocoa agroecosystems was shown to conserve the soil fauna.

Collaborative research is underway between Universidade Estadual do Norte Fluminense (UENF), Campos, Rio de Janeiro; Almirante Cacao, Itajuipe, Bahia, Brazil; and USDA-ARS Beltsville MD, USA to further assess the dynamics of carbon and nutrient cycling in these various agroecosystems under cocoa.

[1] Wardle, D.A. (1995) Impacts of disturbance on detritus food webs in agro-ecosystems of contrasting tillage and weed management practices. *Advances in Ecological Research* 26, 105–182.

[2] Wardle, D.A. & Parkinson, D. (1991) Analysis of co-occurrence in a fungal community. *Mycological Research* 95, 504–507.

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UK *Cocoa Valley Club*

The Thames Valley Cocoa Club, whose inaugural meeting was held at IPARC, Silwood Park in March 2006, is a forum for exchanging ideas on selected cocoa subjects, and participation of PhD students is especially appreciated. The club now has a web page, which includes presentations made at the second annual meeting (Reading, May 2007): www.thamesvalleycocoa.org

Rob Lockwood's presentation sums up the club's aims: rather than being a 'talking shop' the idea is to identify gaps in lab–field–farmer implementation of techniques and develop research 'road maps' as live and updateable documents (via the web page).

The club's name reflects the concentration of active cocoa scientists (and chocolate production!) along the UK's M4 corridor and Thames estuary, but it is absolutely NOT an exclusive club: colleagues, from UK and overseas, are welcome to join us if they are 'in the area'. We aim to hold two meetings/year with the next provisionally slated for autumn 2007. If you are interested in participating, contact Roy Bateman (r.bateman@imperial.ac.uk) or Rob Lockwood (RandMLockwood@aol.com).

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