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A CRITICAL ANALYSIS OF THE AGRONOMIC AND ECONOMIC SUSTAINABILITY OF ORGANIC COFFEE PRODUCTION

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SUMMARY

Organic coffee is one of several types of speciality coffees selling at a premium over mainstream coffees because of distinct origin and flavour, environment-friendly production or socio-economic concerns for the smallholder coffee growers. The demand for organic coffee in Western Europe, North America and Japan exceeds the present supply, which is still small (< 1% of annual world production). More than 85% of organic coffees come from Latin America and practically all is (washed) arabica coffee. The production of certified organic coffee follows the principles of organic farming developed in Europe and the United States out of concern for the perceived negative effects of conventional high-input agriculture on health and environment. It claims superior ecological sustainability in combination with sound economic viability. A rather complex and expensive system of certification has to be passed before such coffees can be sold as truly organic. Growers adhering to the strict rules of organic coffee production may to some extent share the concern of the health- and environment-conscious consumers, but they are motivated primarily by the economic benefits from the premium received for certified organic coffee. Nevertheless, there appears to be considerable injustice between the extreme preconditions demanded for 'organics' by the largely urban consumer of the industrialized world and the modest rewards received by the organic coffee growers for their strenuous efforts. From an agronomic point of view, there is also considerable ground for criticism on the principles of organic farming when applied to coffee. For instance, to sustain economically viable yield levels (1 t green coffee ha^{-1} $year^{-1}$) large additional amounts of composted organic matter will have to come from external sources to meet nutrient requirements (especially N and K). Most smallholders will be unable to acquire such quantities and have to face declining yields. Organic farming does not necessarily reduce incidence of diseases and pests below economically harmful thresholds, while the humid conditions of heavily shaded coffee may actually stimulate the outbreak of others. These and other aspects peculiar to the preconditions of organic coffee production are addressed in this review. It is concluded that the concept of organic farming in its strict sense, when applied to coffee, is not sustainable and also not serving the interests of the producer and consumer as much as the proponents would like us to believe. On the other hand, agronomically and economically sustainable coffee production is feasible by applying best practices of crop production and post-harvest processing.

INTRODUCTION

Organic coffee is one of several types of speciality coffees selling at a premium over mainstream coffees because of:

- distinct origin and flavour characteristics (e.g. Jamaican Blue Mountain, Guatemalan Antigua, Kenya AA)

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- environment-friendlier production systems (certified organic, shade-grown, bird-friendly)
- socio-economic concerns for the smallholder coffee growers (Fair Trade).

All speciality coffees together represent about 9–12% of annual world coffee production, most of it being of the first kind, based on origin and specific flavours. The growing demand for organic coffee (mainly in Western Europe, North America and Japan) exceeds the present supply, which is still less than 1% of annual world production (6.3 million t green coffee in 2003). More than 85% of the organic coffees are produced in Latin America and practically all are (washed) arabica coffees (ITC, 2002; Lewin *et al.*, 2004; Rice, 2001).

Crop yields have increased very significantly over the past century. For instance, average wheat yields in Northwest Europe are now regularly exceeding 8 t ha^{-1} against 2 t ha^{-1} at the beginning of the twentieth century when farmyard manure was still the main external source of plant nutrients (Austin *et al.*, 1989; Curtis *et al.*, 2002). Modern maize cultivars grown under intensive crop management practices may yield six times (6–9 t ha^{-1}) more than traditional varieties cultivated with low external inputs (Castleberry *et al.*, 1984). About 50% of these increases are generally attributed to the application of inorganic fertilizers and to the chemical control of diseases, pests and weeds; the other half to breeding for higher yields and improved harvest index, more efficient nutrient uptake and host resistance to diseases and pests (Austin *et al.*, 1989; Silvey, 1981). In the case of coffee, smallholder farms with no access to external inputs often produce less than 300 kg ha^{-1} $year^{-1}$ green coffee beans, while intensively managed plantations of arabica coffee at conventional spacing may yield annually 2 t ha^{-1} averaged over several years and robusta coffee plantations up to 3.5 t ha^{-1} Yields of 5 t ha^{-1} and higher have been obtained in some close-spaced and unshaded coffee blocks planted with compact-type arabica cultivars, e.g. in Brazil, Colombia and Kenya (Söndahl *et al.*, 2005).

Organically produced foods started to gain popularity some 30 years ago, especially with urban consumers in Northwest Europe, North America and Japan, out of concern for the perceived negative effects of conventional (high-input) crop production on the environment and human health. Organic agriculture is claimed to combine superior ecological sustainability with lower health risks and sound economic viability based on the following principles (IFOAM, 2000; Rice, 2001; Rice and McLean, 1999):

1. composted organic matter to improve soil quality (no inorganic fertilizers)
2. soil conservation (contour planting, terracing, cover crops, mulch, shade trees)
3. disease, pest and weed control by 'natural' methods only (no synthetic pesticides)
4. minimum use of fossil fuels in the production system
5. low environmental pollution during post-harvest handling.

Organic coffee production has to follow these practices, such as the regular application of composted organic matter, 'natural' methods of disease and pest control, and (leguminous) shade trees. IFOAM (International Federation of Organic Agriculture Movements) has formulated basic standards for organic coffees. Some

41 organizations (e.g. Naturland of Germany, ORCA in the USA, SKAL in the Netherlands) have been accredited to certify organic coffee. The procedures of registration, certification and regular inspection are rather cumbersome and expensive. All costs have to be borne by the coffee producers, while the extra premium for certified organic coffee is usually not more than 20% above mainstream coffee prices. Smallholder coffees, that are effectively produced without inorganic fertilizers and synthetic pesticides due to lack of financial resources and therefore organic by default, do not automatically qualify as organic. This is the case, for instance, with most of the arabica coffees in Ethiopia (Kufa and Shimber, 2001).

Some of the assumptions made in organic farming appear to lack scientific proof, such as those pertaining to soil quality improvement and plant nutrient management. Besides, in most conventional farming systems of Europe and North America many new practices, that include the integrated use of organic and inorganic fertilizers, have been adopted already (Kilham, 2002). Recently published reports of research projects in Northwest Europe and sub-Saharan Africa on the role of organic matter in sustainable field crop production have offered an opportunity to assess the validity of strictly applied practices of organic farming. Concepts of soil quality, soil organic matter (SOM) and plant nutrient uptake are presented in Box 1 for easy reference.

This has formed a useful basis for the evaluation of conventional and organic coffee production systems in respect of agronomic and economic sustainability. In the subsequent general discussion, all above-mentioned principles of organic farming will be addressed before reaching conclusions on the realities of organic coffee production.

ORGANIC FIELD CROP PRODUCTION IN EUROPE AND AFRICA

Organic versus conventional farming in Northwest Europe

Data from several projects comparing soil quality on organic and conventional farms in the UK were published in the journal *Soil Use and Management* (vol.18, 2002). The following summary of the main conclusions clearly indicates that the claimed superiority of organic farming, in respect of sustainability and environmental hazards, cannot be substantiated by experimental evidence.

- On organic farms, yields are usually 20–40% lower compared to those on conventional farms. Nitrogen is regarded as one of the key factors limiting productivity. Organic farming systems have the potential to supply large amounts of N to growing crops through the incorporation of crop residues, manures and composts. However, optimum levels of available N are seldom achieved in practice and there is poor synchronization of N availability and crop demand (Berry *et al.*, 2002).
- Composting of manures and plant residues, as is recommended in organic farming for human health and plant sanitary reasons, causes a significant reduction in available N, due to volatilization and transformation into stable organic forms (Berry *et al.*, 2002).

Box 1. Soil quality and plant nutrient uptake

Soil quality concerns the combination of physical, chemical and biological properties within a particular environment that together provide a medium for plant growth and biological activity, regulate water flow and storage in the environment and serve as a buffer in the formation and destruction of environmentally hazardous compounds (Stockdale *et al.*, 2002). ***Soil fertility*** refers to the supply of nutrients and other components of soil quality that enable abundant growth of crop plants.

Soil organic matter (SOM) consists of (1) a large stable fraction (humus), which is completely amorphous and intimately combined with the mineral portion of the soil, colloidal in character and has properties of water and cation adsorption even better than clay minerals, and (2) a much smaller (< 20%) decomposable (labile or light) fraction of active organic matter, which in combination with the microbial biomass effects nutrient cycling (mineralization) and a better soil structure (increased aggregate stability by fungal hyphae and extracellular polysaccharides). A soil of optimal structure and biological activity requires, therefore, frequent input of fresh organic matter residues to replenish the light fraction of SOM (Shepherd *et al.*, 2002).

Plant nutrients are taken up by the root system from the soil solution as simple inorganic ions: nitrogen (N) mostly as NO_3-sometimes NH_4+, phosphorus (P) as H_2PO_4-, sulphur (S) as $SO_4=$, potassium as K+, calcium as Ca++, etc. (Halfacre & Bardon, 1979). The nutrients held in the soil solution form only a very small proportion of the total soil reserve (< 1% for nitrogen and < 0.01% for K). The SOM contains most of the N reserves and a considerable proportion of P and S; about 98% of all K and quantities of other cations are fixed in primary and clay minerals; 50–70% of the P reserves are strongly adsorbed or held in insoluble inorganic forms. Most of the cationic forms of nutrients present in the soil are adsorbed on the surfaces of clay minerals and SOM; these are exchangeable with cations in the soil solution. The soil ***cation exchange capacity (CEC)*** depends, therefore, on the amount and type of clay plus SOM content (Stockdale *et al.*, 2002).

- Nitrate leaching per hectare was found to be similar for organic and conventional farms. However, organic farms leached more N per kg of wheat grain produced, since yields were 40% lower (Stopes *et al.*, 2002).
- The soil microbial mass, which plays a critical role in nutrient cycling (source of readily available nutrients) and in promoting soil aggregation, was found to be similar for organically and conventionally managed soils. One of the prime determinative factors of the soil microbial status is the type and amount of organic material that regularly enters the soil ecosystem. Apparently, the lower external input of organic matter in conventional farms is supplemented by larger amounts

of root exudates and crop residues (roots and stubble) added to the soil from the more productive crop (Shannon *et al.*, 2002).

- Management of plant nutrient availability on organic farms depends largely on chemical and biological processes of SOM, while on conventional farms these soil processes are partly bypassed when readily available nutrients are added through applications of inorganic fertilizers. For example, about 50% of N uptake by a crop on conventional farms is derived from inorganic fertilizers in the year of application with the remainder from mineralization of SOM. There is also no evidence that the fundamental nutrient cycling processes in organically managed soils differ significantly from those in conventionally managed soils (Stockdale *et al.*, 2002).

Sustaining crop production in sub-Saharan Africa

Substantial increases in agricultural production are required in sub-Saharan Africa to feed a rapidly expanding population. However, the technologies of soil fertility improvement leading to the 'green revolution' of the 1970s in cereal crop production of Asia and Latin America have had little impact in sub-Saharan Africa, where mean annual application of inorganic fertilizers is still only 9 kg ha^{-1} (nutrients) against a world average of 90 kg ha^{-1} (Dudal, 2002). Progressive degradation of soil quality over the past 30 years, mainly caused by lack of external inputs and inadequate soil management practices, has seriously affected agricultural productivity of some 200 million ha in the moist savanna and humid forest zones of West and Central Africa (Keatinge *et al.*, 2001). For instance, average maize grain yields in some areas have declined from 3 t ha^{-1} to about 0.7 t ha^{-1} (Vanlauwe *et al.*, 2002). Soil organic matter is often down to 0.9% or less and nutrient outputs are much greater than inputs. Annual soil nutrient depletion as a result of harvested product and erosion has been estimated at 22 kg N, 3 kg P and 15 kg K ha^{-1} (Smaling *et al.*, 1997, 2002). Extensive research to address these problems, initiated some 20 years ago by the IITA (International Institute of Tropical Agriculture, Nigeria) in collaboration with national and international research organizations, has indicated the potential of reversing these negative trends in soil quality by following an integrated soil fertility management (ISFM) approach (Vanlauwe, 2004). The results have been reported in three books published in 2001–2004, two of these being proceedings of workshops held in Cotonou (Benin) and Minneapolis (USA) towards the end of 2000. The main observations and conclusions have been summarized below and confirm unambiguously the essential role of organic matter in rehabilitating soil quality, but also the need for additional plant nutrients from inorganic sources to attain socio-economically acceptable yield levels.

- Cropping systems based on organic matter as the only source of plant nutrients, such as advocated by LEISA (low external input and sustainable agriculture) are incapable of producing the yield increases required to meet local food demands. For instance, in the moist savanna zone of West Africa, maize grain yields of 1500 kg ha^{-1} were obtained against 750 kg ha^{-1} for control plots without organic matter. With combined inputs of organic matter and an optimum amount of inorganic fertilizer (N and P in particular) sustainable yield levels of 3–4 t ha^{-1} maize grain could be achieved (Vanlauwe *et al.*, 2001; Vanlauwe, 2004).

- The bulk of SOM is associated with clay-sized particles, which provide extra charges to the highly weathered soils with inherently low CEC so common in sub-Saharan Africa. Addition of organic matter may, therefore, be effective in enhancing the soil CEC. Organic matter of low quality (C: N ratio > 25) leads to more SOM formation than high quality organic matter. However, significant increases of CEC require very large quantities of organic matter to be incorporated into the soil (Merckx, 2002).
- There is nothing wrong with inorganic fertilizers when applied according to best practices. Inorganic fertilizers and organic matter are both sources of nitrate and phosphate ions to the plant. However, only organic matter provides carbon souces to the soil micro-organisms, which are essential for nutrient cycling of organic matter and soil aggregation. Inorganic fertilizers also increase SOM, as more crop residues will be returned at higher levels of crop production (Sanchez and Jama, 2002).
- Nutrients from inorganic sources are immediately available usually, while organic matter must first decompose to release N and other nutrients for uptake by crop plants, with the exception of K^+ and other dissolved ions which are readily leached from organic residues. Organic matter and manures are, therefore, more appropriate as basal inputs, whereas inorganic fertilizers offer flexibility in timing of application in relation to crop demands (Giller, 2002).
- The restoration of soil quality and enhanced crop production in Africa requires the strategic use of organic matter to enhance soil quality, together with the application of inorganic fertilizers in doses tailored to match market opportunities. Other essential factors of the integrated crop management system are: soil and water conservation measures, crop rotation, appropriate tillage (or no tillage) and improved seed (Dudal, 2002).

CONVENTIONAL COFFEE PRODUCTION

The following paragraphs focus on arabica coffee (*Coffea arabica*), mainly because almost all publications on this subject deal with this species. However, many of the observations and conclusions equally apply to robusta coffee (*Coffea canephora*).

Shade or no shade

The natural habitats of all *Coffea* species are the understorey of tropical forests in Africa. Many forms of *C. canephora* can be found in the equatorial lowland forests from Guinea to Uganda, but natural populations of *C. arabica* are restricted to the highland forests of southwestern Ethiopia (Berthaud and Charrier, 1988).

Arabica coffee is typically a shade-adapted species (Box 2) and most progenies from natural coffee plants, such as germplasm collections from Ethiopia, become severely stressed when grown without overhead shade and have low yields (Van der Vossen, 1985). However, practically all present cultivars are descendants of early

Box 2. Some physiological characteristics of arabica coffee

- The maximum net photosynthetic rate of unshaded leaves is low (7 μmol CO_2 m^{-2} s^{-1}) compared to that for leaves of other C-3 crops (15–25 μmol CO_2 m^{-2} s^{-1}).
- The saturation irradiances for leaf photosynthesis are 500 μE m^{-2} s^{-1} for unshaded leaves, only 20% of total irradiances at mid-day on sunny days in the tropics; these are even less, 300 μE m^{-2} s^{-1}, for shaded leaves.
- The net photosynthetic rates decrease markedly at leaf temperatures above 25 °C.
- The proportion of total plant dry-matter production allocated to leaves is 40–50 % (cf. 22% in the case of tea and 20% in oil palm).
- In contrast to most other woody perennials, there is no mechanism of early fruit shedding in coffee to prevent excessive crop load, possibly because there was no evolutionary advantage in the natural forest habitat, where floral initiation is low due to heavy shade. This may lead to excessive fruit set in full daylight and consequent overbearing die-back and biennial bearing, unless controlled by pruning and other crop management practices.

(Cannell, 1985)

coffee introductions from Ethiopia to Arabia (Yemen), where they were subjected to a relatively dry ecosystem without shade for a thousand years before being introduced in Asia and Latin America around 1700 AD and two centuries later in East Africa. They have retained the physiological attributes of shade-loving plants, but can tolerate drought and full sunlight much better because of a well developed root system, strong plant vigour and the ability to retain leaves longer under conditions of water stress (Van der Vossen and Browning, 1978).

Such coffee plants essentially become self-shading and produce high yields without shade and under intensive crop management, but even with overhead shade they generally yield much more than the forest coffees from Ethiopia.

In South America and East Africa coffee is mostly grown in pure stands without permanent shade, except at very high altitudes. Elsewhere (e.g. Central America, Indonesia, India, Cameroon), it is grown either in pure stands with shade trees or in association with perennial crops (coconut palms, rubber, clove, fruit trees), or in mixed gardens with food crops, bananas (e.g. northern Tanzania) and tree crops. In India and Indonesia, the stems of shade trees often serve to support the vines of black pepper and so provide an additional source of revenue to the coffee growers. In favourable ecosystems and with intensive crop management including high external inputs (fertilizers and pest/disease control) coffee will often produce much higher yields without than under shade. Without high inputs or under sub-optimal ecological conditions coffee usually shows better results under shade. Shade is provided by natural forest trees and/or planted trees of various leguminous (e.g.

Box 3. Effects of shade trees on coffee

Positive

- Reducing the extremes in high (low altitudes) and low (high altitudes) air and soil temperatures.
- Breaking the force of wind and heavy rainfall.
- Controlling erosion on steep slopes.
- Suppressing weeds.
- Producing annually 5–15 t (dry weight) organic matter per ha from litter and prunings.
- Recycling of nutrients otherwise not available to the coffee and reducing nutrient leaching.
- Preventing over-bearing and shoot dieback as a result of reduced light intensity.
- Providing additional revenue from the shade trees (timber, firewood and fruits) and support for secondary vine crops like black pepper and vanilla.
- Potentially reducing incidence of diseases (e.g. leaf rust) and pests (e.g. white stem borer).
- Improving cup quality, particularly in ecologically sub-optimal coffee zones (high temperatures).

Negative

- Progressively lower yields with increasing shade intensity, due to a reduction in flowering nodes, inflorescences per node and flowers per inflorescence.
- Competition for water between shade and coffee trees in seasonally dry regions.
- Damage of the coffee trees by falling branches from the shade trees and occasional tree felling.
- Additional labour costs for regularly pruning of over-head trees to avoid excessive shading.
- Potential increase of some diseases (e.g. South American leaf spot) and pests (e.g. coffee berry borer).

(Beer, 1987; Beer *et al.*, 1998; Guyot *et al.*, 1996; Muschler, 2001)

Inga, Albizzia, Gliricida, Erythrina, Leucaena) and other (e.g. *Grevillea, Casuarina*) species. In Central America, the density of shade trees varies from 156–204 trees ha^{-1} at lower altitude to 83–100 trees ha^{-1} at higher elevations. As a general recommendation, overhead shade should not reduce more than 50% of total irradiances (Söndahl *et al.*, 2005). Where rainfall is limiting and dry seasons are rather long, shade trees may adversely affect productivity due to severe competition for available soil moisture with the coffee. That is why in Brazil and Kenya most coffee is grown without shade. The main advantages and drawbacks of shade in coffee are listed in Box 3.

Table 1. Approximate nutrient uptake by arabica coffee producing 1 t green beans ha^{-1} $year^{-1}$.

	N (kg)	P (kg)	K (kg)
Green beans (1.0 t dry weight)	40	4	45
Pulp + parchment (1.25 t dry weight)	35	7	53
Vegetative growth	60	5	22
Total	135	16	120
Crop related output (see text)	*105*	*13*	*107*

References: Korikanthimath and Hosmani, 1998; Mitchell, 1988; Willson, 1985; Wrigley, 1988.

Plant nutrient flows in shaded and unshaded coffee

Crop related nutrient outputs. Coffee makes higher demands on soil quality and more nutrients are removed annually by the harvested products in comparison to other tree crops like cocoa and tea (Anonymous, 1989; Van Dierendonk, 1959). Estimates of nutrients taken up by one hectare of arabica coffee (1300 trees ha^{-1}) in 6 t of fresh berries (yielding 1 t green coffee beans and 1.25 t dry pulp and parchment) and in vegetative growth (roots, stems, branches and leaves) are presented in Table 1. N and K are the two dominant nutrients, K being more important in fruit development and N for vegetative growth. The demand for P is much lower, but it is essential for root, flower bud and fruit development. Ca, Mg and other major and micronutrients, although often essential for a balanced nutrition of the coffee plant, may be left out in this discussion of nutrient flows since the required quantities are usually small to minimal in coffee (Mitchell, 1988; Willson, 1985).

Evidently, the nutrients taken up in the green beans are permanently removed from the coffee field, but in many cases, those contained in the pulp and parchment are lost as well. Smallholders often sell the harvested berries to private or co-operative factories for wet processing and even on larger coffee farms, which have their own processing facilities, the pulp is not always composted and returned to the field. In coffee-curing plants, the parchment hulled from the green beans usually serves as fuel for the boilers. In the case of dry-processed (natural) coffee, the fruit waste is often also left unused. Some of the nutrients taken up for vegetative growth are returned to the soil in leaf fall, prunings and dying feeder roots. However, a substantial amount (assumed here to be 50% for N and 40% for P and K) remains stored for several years in the permanent framework of roots, stems and branches (Mitchell, 1988; Wrigley, 1988) and will eventually be taken out of the field when the production cycle changes by stumping or replanting. The annual nutrient uptake and export from the field by the crop will increase in proportion to the higher production levels and the nutrient demand for vegetative growth should also be higher at the closer spacings (3000–7000 trees ha^{-1}) applied in much of present-day arabica coffee production.

Nutrient outputs due to non-crop factors. In addition to crop-related outputs, nutrients are lost from the coffee agro-ecosystem by leaching (N and K), denitrification and NH_3-volatilization. On sloping land with inadequate measures of soil conservation, erosion (run off during heavy rainfall) may cause considerable loss of N and other nutrients. Estimates of the magnitude of such nutrient depletion by non-crop factors are unavailable except for N caused by leaching. In closely spaced (7000 trees ha^{-1}) and heavily fertilized (300 kg N ha^{-1} $year^{-1}$) coffee plantations in Costa Rica, Babbar and Zak (1995) found annual losses of N to be 9 kg ha^{-1} from the top 0.6–1.0 m of soil under shaded against 24 kg in unshaded coffee. Even the latter value is low compared to the 50–100 kg N ha^{-1} lost annually by leaching in other tropical agro-ecosystems (Beer *et al.*, 1998). The nutrient outputs for all non-crop factors taken together are here tentatively set at 20 kg N, 2 kg P and 15 kg K ha^{-1} in shaded and twice as much in unshaded coffee, independent of yield levels.

Nutrient inputs from shade trees. The litter from shade trees may contribute annually 5–15 t (dry weight) organic matter to one hectare of coffee depending on the climate, soil quality and external inputs of fertilizers (Beer, 1988; Bornemisza, 1982). In India, 10 t litter from mixed shade trees in regularly fertilized coffee was reported to contain 40–60 kg N, 10–14 kg P and 35–50 kg K (Naidu, 2000). Where the leguminous tree *Erithryna variegata* (dadap) was part of the overhead shade, it even contained 95 kg N. Higher inputs of nutrients from shade tree litter, N in particular, have been reported in Costa Rica, but a large proportion of these must come from soil reserves and the high doses of inorganic fertilizer applied each year to these coffee farms (Beer, 1988). The nutrients gradually released from the decomposing litter add to chemical fertility, but the large annual inputs to SOM by shade trees are even more important in regard to the physical and biological improvement of soil quality (Beer *et al.*, 1998). Inputs from shade litter to organic matter are presumed to be positively related to coffee yield levels, because shade trees will also benefit from higher soil quality and nutrient reserves. Nutrients released annually from the organic matter from shade tree litter are here assumed to be 40 kg N, 10 kg P and 35 kg K at coffee yields of 1 t ha^{-1} green beans, and proportionally lower or higher at other yield levels.

Mulches

In unshaded coffee, mulch from grasses, wheat straw and maize stover helps to control soil erosion and weeds, preserve soil moisture and is also an important source of organic matter and nutrients (Mitchell, 1988). For instance, the practice of applying annually large quantities (5–10 t ha^{-1}) of mulch cut from elephant (or napier) grass (*Pennisetum purpureum*) on a plantation coffee in Kenya adds large amounts of plant nutrients to the soil, K in particular. According to the nutrient content data of various mulches and manures provided by Njoroge (2001) 10 t of mulch from elephant grass would contain 150 kg N, 26 kg P and 350 kg K, but from natural grasses or maize stover 140–200 kg N, 13–15 kg P and 88–160 kg K. However, smallholder coffee farmers in Kenya usually have no access to such large quantities and instead prefer to feed whatever is available to their livestock. Mulching of unshaded coffee is not much practised in most other coffee producing countries. Here again, it is fairly realistic to assume that more mulch is being applied where yields are higher: 10 t mulch applied

Table 2. Estimated annual nutrient flows and balance in shaded coffee (ha^{-1}).

Yield of green beans (t ha^{-1} year^{-1})	Nutrient output/input	N (kg)	P (kg)	K (kg)
0.5	Out (crop)	53	7	54
	(non-crop)	20	2	15
	In (shade litter)	20	6	20
	Balance	− 53	− 3	− 49
1.0	Out (crop)	105	13	107
	(non-crop)	20	2	15
	In (shade litter)	40	12	40
	Balance	− 85	− 3	− 82
2.0	Out (crop)	210	26	214
	(non-crop)	20	2	15
	In (shade litter)	80	24	80
	Balance	− 150	− 4	− 149

annually (nutrient input of 150 kg N, 26 kg P and 350 kg K) to coffee yielding 2 t ha^{-1} green beans and 5 t mulch at half the yield level.

Weeds

Weeds compete with coffee for moisture and plant nutrients, while some perennial grasses and sedges produce root exudates that are toxic to coffee. Weed control is particularly difficult (and expensive) in unshaded coffee. Control by herbicides has all the advantages of zero tillage, including no damage to superficial feeder roots of the coffee (Mitchell, 1988). The use of cover crops, although effective also in controlling weeds, is not common in unshaded arabica coffee because of excessive competition for moisture. In Colombia, selectively eliminating gramineous weeds by herbicides and occasional slashing back the broad-leaved 'arvenses' was found to be effective in promoting soil conservation with little loss of nutrients (Cadena and Baker, 2001).

Estimates of nutrient balances

The information on nutrient outputs and inputs, as described above, presumably only covers a few of several factors determining nutrient flows in various coffee agro-ecosystems. Nevertheless, it offers an opportunity of getting a global idea of the annual nutrient balance for shaded and unshaded coffee at different levels of production. The data presented in Tables 2 and 3 are, therefore, intended as an illustration of scale rather than precise measurement. The nutrient output from the crop is calculated from the data presented in Table 1, taking yield levels into account. The non-crop outputs are most likely a gross under-estimation of actual losses in some eco-systems, but exact data are lacking.

In shaded coffee, the nutrient balance is negative for the three major plant nutrients at low to high levels of production. Sustained coffee production will, therefore, require correction of this negative balance by regular application of inorganic fertilizers and/or large amounts of nutrient-rich composts.

Table 3. Estimated annual nutrient flows and balance in unshaded coffee (ha^{-1}).

Yield of green beans ($t\ ha^{-1}\ year^{-1}$)	Nutrient output/input	N (kg)	P (kg)	K (kg)
1.0	Out (crop)	105	13	107
	(non-crop)	40	4	30
	In (5 t mulch)	75	13	175
	Balance	*– 70*	*– 4*	*38*
2.0	Out (crop)	210	26	214
	(non-crop)	40	4	30
	In (10 t mulch)	150	26	350
	Balance	– 100	–4	106

Table 4. Nutrient content of organic manures and residues.

Type	% of dry matter N	P	K	Ratio C/N	Reference
Coffee pulp, fresh (India)	2.4	0.5	4.2		Korikanth. and Hosmani, 1998
Coffee pulp, composted (India)	2.0	0.2	2.5		Naidu, 2000
Coffee pulp, composted (Mexico)	3.8	0.4		10	Sanchez *et al.*, 1999
Coffee pulp, fresh (Kenya)	3.7	0.4	6.5		Njoroge, 2001
Cattle manure (India)	0.4	0.2	0.2		Korikanth. and Hosmani, 1998
Cattle (Boma) manure (Kenya	1.3	0.6	1.4		Njoroge, 2001
Cattle manure (Europe ?)	2.0	0.8	1.8		Anon., 1989
Poultry manure (Mexico)	3.4	0.4		9	Sanchez *et al.*, 1999
Poultry manure (Kenya)	3.5	1.4	1.3		Njoroge, 2001
Sugarcane filter cake (Kenya)	1.3	1.1	0.6		Njoroge, 2001
Sugarcane filter cake (Mexico)	1.0			45	Sanchez *et al.*, 1999
Guano, Peru (average values)	12.0	5.0	2.5		De Geus, 1973
Fish meal	10.0	2.6	0.0		Follett *et al.*, 1982
Hoof and horn meal	12.0	0.9	0.0		Follett *et al.*, 1982

In the shaded coffee of India, growers are advised to apply fertilizers at the following annual rates, taking into account nutrient balances and fertilizer-use efficiencies, in 3 or 4 split applications (Naidu, 2000):

500 kg green beans ha^{-1}: 100 kg N, 40 kg P and 85 kg K
1000 kg green beans ha^{-1}: 150 kg N, 60 kg P and 124 kg K
2000 kg green beans ha^{-1}: 250 kg N, 80 kg P and 210 kg K

Recycling of nutrients taken up by the fruit waste (pulp and parchment) helps to reduce the negative balance, but the fruit waste requires composting before application to the coffee field, with consequent loss of part of the nutrients during the process. Composted coffee fruit waste was found to contain about 2% N, 0.2% P and 2.5% K (Naidu, 2000; Table 4). At a yield of 500 kg ha^{-1} green beans the quantity of composted fruit waste (625 kg dry weight) would recycle 12.5 kg N, 1.3 kg P and 15.6 kg K. This will be proportionally more at higher yield levels, but for each situation it appears that 3–4 times the amount of compost from fruit waste produced by the coffee field will be needed for sustained coffee production.

The nutrient balance in unshaded and mulched coffee, e.g. in Kenya, is highly negative for N in particular, but positive for K, as a consequence of the high K-content of the mulch. Yield responses to mulch application and also to N fertilizers (and P applied as foliar spray) are often considerable, but generally insignificant to K fertilizers (Oruko, 1977). Without mulch or other sources of organic matter, significant yield responses to N, P and K fertilizers are common, but such coffee production systems may not be sustainable in the long term because of a gradual decline in soil quality to be expected for most soil types.

ORGANIC COFFEE PRODUCTION

Organic fertilizers

Coffee fruit waste (pulp) requires proper composting before it can be applied safely to the soil under coffee trees (Korikanthimath and Hosmani, 1998). Other organic residues may be added to the coffee fruit waste to improve the final chemical and physical properties of the compost. Table 4 presents data on the nutrient contents, and for a few also the C/N ratio, of the ingredients for composts and mulches commonly applied in conventional as well as in organic coffee farming. There is large variation in N and K contents between coffee pulp from different coffee regions. Cattle manure has nutrient contents generally inferior to coffee pulp and the data from India indicate that some cattle manures can be chemically of very low quality indeed. Guano is an organic fertilizer of almost unique Peruvian origin and regularly applied to coffee plantations in that country (Krug and De Poerck, 1968; Toxopeus, 2003).

Finca Irlanda, in the southern Mexican state of Chiapas, is reputedly one of the first coffee plantations exclusively producing certified organic coffee, since the late 1960s, on 270 ha of moderately shaded and fairly closely planted (3300 trees ha^{-1}) coffee (Pülschen and Lutzeyer, 1993; Nigh, 1997; Wallengren, 1999). The plantation produces annually an average of 1500 t ripe berries, which after (wet) processing yield about 250 t (0.93 t ha^{-1}) green coffee and 810 t wet (315 t dry) fruit waste. Compost is prepared from a mixture of the coffee fruit waste (40%) and prunings (10%), cattle manure (20%), sugarcane trash (10%), hoof and horn and fish meal (5%), dolomitic limestone (5%), ground rock phosphate (5%) and some clay. This yields annually about 1000 t of compost for application to the coffee trees at 3.7 t ha^{-1} or 1.1 kg $tree^{-1}$ (Pülschen and Lutzeyer, 1993). No published data are available on the nutrient content of this compost, but a rough estimate can be made based on the data presented in Table 4. The 3.7 t of compost may thus supply 60–75 kg N, 8–10 kg P and 75–85 kg K ha^{-1} of coffee. According to Table 2, shaded coffee yielding an average 0.93 t green coffee ha^{-1} $year^{-1}$ will require annually an input of 78 kg N, 2 kg P and 75 kg K to maintain the nutrient balance required to sustain this medium level of coffee production. So, it appears that Finca Irlanda is capable of just doing that based on a compost with 50% fruit and tree waste from the coffee farm itself and the other half consisting of external sources of organic matter and 'natural' fertilizers.

Coffee fruit waste left to degrade naturally in heaps will require 6–8 months to turn into stable compost containing about 2% N. Sanchez *et al.* (1999) described methods of accelerated composting of coffee fruit waste in Mexico and found that a regularly aerated mixture of 40% coffee pulp, 30% sugarcane filter cake, 20% poultry litter and 10% wood chips (bulking agent) resulted in a high-quality compost within 50 days with the following characteristics: water 61%, pH 8.3, N 4.5% and P 2.5% (both on dry weight basis) and a C/N ratio of 7.2.

Kamala Bai *et al.* (2000) reported the results of annual applications of about 5 t compost ha^{-1} on soil quality and yield for 43 ha of arabica coffee grown organically under shade in the Karnataka State of south India. The compost was prepared by mixing slurry from a biogas unit (based on coffee fruit waste and cattle manure) with sheep and poultry manure and rock phosphate. Liming to improve soil pH was carried out every 4–5 years. The average yield over nine years (1989–1998) was 1.18 t ha^{-1} green coffee, against a mean of 1.32 t ha^{-1} before conversion to organic coffee production in 1989. No data on the nutrient content of the compost have been given, but from the yield level it appears that the compost contributed at least 104 kg N, 5 kg P and 101 kg K (cf. Tables 2) to a balanced nutrient supply. The soil was in an optimal condition with pH 6.1, organic matter content of 5.9% in the top 20 cm and all the major nutrients above threshold values for adequate soil fertility in coffee. Here again, it should be realized that the applied compost included a considerable amount of ingredients from outside the coffee farm.

Agrochemicals

The rejection of most agrochemicals, on account of supposedly excessive use of non-renewable (fossil) energy resources during manufacturing or unacceptable environmental and health risks (Rice, 2001), severely restricts the application of fertilizers and pesticides in organic coffee production.

The use of all types of inorganic N-fertilizers is prohibited according to IFOAM (2000) standards and other inorganic fertilizers are strongly discouraged, except when derived directly from natural deposits. However, claims about excessive use of energy in the manufacturing of inorganic fertilizers are not supported by the facts (Box 4).

The organic farming approach presumes lower yield losses due to diseases and pests in 'natural' agro-ecosystems. For coffee, that would be achieved by appropriate management of soil fertility, shade trees, crop sanitation (timely removal of disease-affected and pest-infested leaves, berries or branches) and a balance between pests and natural enemies (biological control). Synthetic pesticides will never be permitted, but a number of naturally derived products have been approved for disease and pest control in organic coffee production, including Bordeaux mixture, neem oil and leaf extracts, nicotine, rotenone and pyrethrum. (Naidu and Raghuramulu, 2000). With all herbicides banned, manual weeding is usually a considerable cost factor in organic coffee production.

Box 4. Facts about inorganic fertilizers and energy use

Fertilizers
Consumption in 2001: 140 million t; 60% N, 24% P_2O_5, 16% K_2O.
Manufacturing **N:** atmospheric nitrogen is fixed by a special process to produce ammonia, which is subsequently converted to urea with a hydrocarbon source of energy (natural gas). **P, K** and other plant nutrients are mined from natural deposits. The ores are further processed to make them more soluble and concentrated for better plant uptake.
Total energy use by the fertilizer industry in 2001: 1.9% of world energy consumption.

Energy
World energy consumption in 2001: 7000 Mtoe = 293 EJ, of which 80% from fossil fuels (oil, gas, coal).
(toe = tonne of oil equivalent; EJ = Exa Joules)
Energy use per capita in 2001 (GJ):

North America	335	Colombia	28
Japan	205	Guatemala	26
EU	180	India	22
Brazil	45	Kenya	21
Indonesia	29	Peru	19

(IEA, 2003; IFA, 2002)

Economic viability of organic coffee production

Publications on the economics of organic coffee production have so far been few. The results of two case studies comparing the profitability of organic with conventional coffee production in similar agro-ecosystems are summarized in Table 5. Both studies

Table 5. Profitability of organic versus conventional coffee production (1).

Arabica coffee under shade		Organic		Conventional	
Mexico (1990)		*a*	*b*	*a*	*b*
Yield of green coffee	kg ha^{-1}	900	900	1250	1250
Farm gate price	\$ kg^{-1}	*1.55*	*2.75*	*1.20*	*2.50*
Gross income	\$ ha^{-1}	1395	2475	1500	3125
Production costs	\$ ha^{-1}	1482	1482	1392	1392
Net income	\$ ha^{-1}	*− 87*	993	108	1733
Costa Rica (1998)					
Yield of green coffee	kg ha^{-1}	1100	1100	1400	1400
Farm gate price	\$ kg^{-1}	*2.64*	*3.21*	*2.18*	*2.92*
Gross income	\$ ha^{-1}	2904	3531	3052	4088
Production costs	\$ ha^{-1}	1470	1470	1403	1403
Net income	\$ ha^{-1}	1434	2061	1649	2685

a: at current farm gate prices in 1990 and 1998.
b: at assumed farm gate prices, related to high world market prices in 1997.

concern arabica coffee grown under shade, the Mexican study using data on yields and production costs taken from Finca Irlanda estate and a nearby conventional coffee plantation (Pülschen and Lutzeyer, 1991). In Costa Rica, 10 pairs of smallholder farms (< 7 ha per farm) in five different regions were selected, each pair including one organic and one conventional coffee plantation (Lyngbaek *et al.*, 2001). Production costs cover all field operations and post-harvest handling (wet processing and curing) up to the green bean stage.

ICO (International Coffee Organization) average indicator prices for mild arabica on the world market were in 1990 about 90 cts per lb ($\$1.98\,kg^{-1}$) of green coffee and 140 cts per lb ($\$3.08\,kg^{-1}$) in 1998. Mean farm gate price in 1990 for conventionally grown coffee was according to the Mexican study $\$1.20\,kg^{-1}$ and in Costa Rica $\$2.18\,kg^{-1}$ in 1998, which were about 60% and 70% respectively of the world market prices. These farm gate prices were used to calculate gross income for the conventional and farm gate + 20% premium for that of organic coffee plantations ('a' columns in Table 5). As an indication of potential gross and net incomes in years with very high world market prices, calculations have also been made with farm gate prices being 60% and 70% respectively of the mean world market price in 1997 of 192 cts per lb ($4.18 per kg), adding 10% premium for organic coffee ('b' columns in Table 5). Premiums for organic coffee are usually lower during years of high coffee prices.

Yields were on average 22–28% lower and production costs 5–7% higher in organic than in conventional coffee plantations. Especially the cost of labour was 20% higher on organic farms, due to additional manual work in weeding and preparation and application of compost. At the prevailing low prices for coffee in 1990, the conventional farm in Mexico just stayed above break-even point, while the organic farm had a slight negative net income despite the 20% premium received for its coffee. With the higher prices for 1998, both types of farms in Costa Rica had a positive net income, although some 13% lower in case of the organically produced coffee despite the 20% premium also received here. During years of very high world market prices, net incomes are substantial in all four cases, but now with organic farms trailing some 23–43% behind conventional farms. In actual fact, the differences should be larger, as the considerable costs for mandatory certification and inspection of organic coffee farms have not been included in these calculations. These have been estimated at $\$0.07–0.11\,kg^{-1}$ of green coffee (Rice and McLean, 1999).

A third study on the profitability of organic and conventional coffee is based on data provided by the ISMAM, which is a Maya coffee co-operative in the Chiapas state of Mexico exporting annually some 2500 t green coffee all produced organically (Nigh, 1997), and presented by E.D.E. Consulting (1997). Only yield data and production costs (including processing to green coffee) are being considered here. Without specification in the report, the much higher yield difference would implicate a comparison between organic coffee production under shade and conventional production without shade. Farm gate prices are taken as 60% of world market prices in 1997 for conventionally produced coffee ($\$2.50\,kg^{-1}$, just as in Table 5), but now the premium for organic coffee is put at 20% (as indicated in the E.D.E. Consulting

Table 6. Profitability of organic versus conventional coffee production (2).

Arabica coffee		Organic	Conventional
		Shade	*No shade*
Mexico/ISMAM (1997)			
Yield of green coffee	kg ha^{-1}	920	1610
Farm gate price	$ *kg*$^{-1}$	*3.00*	*2.50*
Gross income	$ ha^{-1}	2760	4025
Production costs	$ ha^{-1}	2010	2685
Net income	$ ha^{-1}	750	1340

report) resulting in a farm gate price of $3.00 kg^{-1} for organic coffee. The ISMAM data show higher production costs compared to the previous two case studies, particularly for unshaded coffee production. The net income for organic coffee farms is again considerably (44%) lower despite the extra premium (Table 6).

DISCUSSION

Maintaining soil quality

Coffee, like many other tropical tree crops, has a high potential for environment-friendly agricultural production especially when grown in a kind of agro-forestry system (Smith, 2000). However, the available data reviewed above show that, even in the most ideal agro-ecosystem, the coffee requires much higher levels of nutrient inputs and crop management to achieve environmental sustainability, than generally assumed by the proponents of organic agriculture (e.g. Van Elzakker, 2001).

While experimental evidence for differences in soil quality and uptake of plant nutrients between organic and conventional coffee farms is rather scarce, the recent results from field crop studies in Northwest Europe and sub-Saharan Africa on these issues contribute considerably to the present discussion. Briefly, the nutrient cycling processes in organically and conventionally managed soils are similar, organic matter is very important in maintaining soil quality, but additional inputs of inorganic fertilizers remain necessary for balanced plant nutrient flows and adequate yield levels. These conclusions appear to apply equally well to coffee.

The estimates presented in this review indicate negative nutrient balances (for N, P and K) in shaded coffee farms at low to high levels of production (Table 2), which require correction by external inputs of nutrients to avoid depletion of natural resources by nutrient mining. Composted coffee fruit waste returned to the field can only supply 25–30% of these additional nutrient requirements. The two organic coffee farms in Mexico and India, referred to in this review, had the means of acquiring nutrient-rich organic matter and manures to make up for the difference and so achieved nutrient balances enabling sustained moderate yields (0.9–1.1 t ha^{-1} $year^{-1}$ of green coffee). However, most smallholder coffee growers lack the resources to have regular access to considerable quantities of organic matter or manures and will see their already low coffee yields further decline, especially during the current period of very low world market prices. So, it appears that the larger coffee producers are in a better position to produce certified organic coffee than the resource-poor small farmers, who are actually the declared main target of the organic coffee movements.

Unshaded coffee is bound to develop negative nutrient balances, but the Kenyan example (Table 3) shows that high yields can be sustained indefinitely (> 50 years) by a combination of grass mulches, inorganic fertilizers (N and P, adequate K supply from the mulch) and other sound crop management practices, where climate (montane, equatorial) and soils (deep, volcanic origin) are favourable. On the other hand, 'organic' coffee production by smallholder farmers in the Buyenzi region of Burundi based exclusively on mulches, cut and carried from nearby fields, became unsustainable in the long term due to gradual depletion of plant nutrients (Metzler-Amieux and Dosso, 1998).

Agrochemicals

All inorganic fertilizers are made out of natural raw materials (Box 4) and provide plant nutrients in the form of simple inorganic ions identical to those released by mineralizing organic matter (Box 1). Prohibition of their use considerably reduces possibilities of applying methods of efficient nutrient management developed in coffee production (Mitchell, 1988), such as synchronizing nutrient availability with crop development and correction of diagnosed nutrient deficiencies by topdressing or foliar applications. The rejection of inorganic fertilizers on account of excessive use of fossil fuels during manufacturing is not supported by the facts, while also demands for minimal use of fossil fuels imposed on organic coffee production appear preposterous in view of the tremendous energy uses per capita in the main consuming countries (European Union, Japan and North America), which are 10–20 times higher than in most coffee producing countries (Box 4).

The hazards of indiscriminate use of chemical pesticides to the environment and the health of coffee farmers are real, but the consumers need not fear because the fruit and parchment skins are already minimizing chances of pesticides contaminating the bean in the field and any pesticide residues still present in the green bean will be destroyed during the roasting process. The successful development of new arabica cultivars with host resistance to coffee leaf rust (CLR) and berry disease (CBD) enables fungicide-free coffee production in areas, where recurrent severe outbreaks of these diseases would otherwise require frequent fungicide sprays to prevent heavy crop losses, e.g. in India, Colombia and East Africa (Van der Vossen, 2001). Host resistance to other diseases, such as the South American leaf spot (*Mycena citriclor*) on arabica in Central America and black rot (*Koleroga noxia*) in India on arabica and robusta coffee, are either not available or in an initial stage of development. Nematodes (mainly *Meloidogyne* spp. *and Pratylenchus* spp.) can cause considerable problems on arabica coffee in Central America, in particular, but also in Brazil, India and Indonesia. Much progress has been made in developing arabica cultivars with resistance to certain nematode species, as well as in utilizing nematode resistant robusta coffee as rootstock for arabica cultivars (Anzueto *et al.*, 2001; Bertrand *et al.*, 2000). Several hundred insect species have been identified as minor and important coffee pests. Among the most damaging and worldwide coffee pests are the coffee berry borer (*Hypothenemus hampei*), stem borers (e.g. *Xylotrechus quadripes*), scale insects (e.g. green scale, *Coccus viridis*) and leafminers (e.g. *Perileucoptera coffeella*). Integrated pest management (IPM) has proved to be much more effective in reducing damage to the coffee trees and crops than frequent routine applications of insecticides. Integrated pest management includes early warning systems (monitoring of insect populations) in combination with cultural (pruning and shading), biological (insect traps; introducing insects or micro-organisms parasitic to the pest) and chemical (carefully timed incidental applications with selective and non-persistent insecticides) methods of control (Bardner, 1985; Oduor and Simons, 2003). Complete banning of all synthetic insecticides, as advocated for organic coffee production, weakens IPM for some important pests. For instance, control of the coffee berry borer with bio-insecticides like neem formulations and sprays with *Beauveria bassiana* is ineffective (Baker *et al.*, 2001; Naidu *et al.*, 2001). Weed control by hoeing or blanket applications with herbicides may increase soil erosion. Mulch suppresses weeds and helps soil conservation, but is not always available in sufficient quantities, and cover crops often compete for soil moisture to the detriment of coffee production. Selective elimination of problem weeds by spot application of a selective herbicide, while allowing limited growth of the others to provide ground cover, promotes soil conservation without reducing yields (Cadena and Baker, 2001; PAN-UK, 1998).

Post-harvest processing

About 40% of the world coffee are processed according to the wet method, including most of the organically produced coffees. These so-called washed coffees are generally of superior quality, although certain Ethiopian or Brazilian dry-processed arabicas are much sought after for their specific taste and flavour (ITC, 2002).

Dry-processed coffees may cause few environmental hazards, but conventional methods of wet processing, to convert the harvest of ripe berries into dry green coffee, require large volumes of water at the initial stages of depulping, fermentation and washing. Even with water recycling, the processing of 6 t harvested fruits will produce, in addition to 1.1 t parchment coffee and 2.7 t fruit pulp, 25 000 litres waste water, which require proper treatment in stabilization ponds before discharge to prevent severe pollution of river waters. The fruit pulp can either be returned to the coffee field after composting or fed into a biogas plant (Adams and Dougan, 1981; Wrigley, 1988). These data are derived from mechanized coffee factories, but also small-scale coffee farmers using traditional hand pulpers do face similar difficulties of discharging the pulp and large volumes of waste water without polluting the environment. Many years of engineering efforts by the coffee research institute Cenicafé in Colombia (Cadena and Baker, 2001) have come up with innovative coffee processing machinery, that reduces water consumption to 10% of that of conventional equipment with no increase in power use and even improves coffee quality. Another important step into the direction of sustainable coffee processing are solar drying units developed in Colombia (Cadena and Baker, 2001) and Indonesia (Mulato, 2004).

Traditional and modern cultivars of arabica coffee

There is a widespread belief with coffee roasters and traders, that traditional varieties of arabica coffee give a better cup quality than the new 'hybrid' varieties, because of introgression of disease resistance from robusta coffee (e.g. Illy, 2001).

Although Hibrido de Timor (progenitor for resistance to CLR) arose originally from a natural interspecific cross between *Coffea arabica* and *C. canephora*, the phenotype of this variety is truly arabica. The confirmed good cup quality of CLR-resistant Catimor lines in Costa Rica (Bertrand *et al.*, 2003) and in Colombia (Moreno *et al.*, 1995), as well as the CBD + CLR-resistant hybrid variety 'Ruiru II' in Kenya (Njoroge *et al.*, 1990) clearly demonstrates that introgression of robusta genes does not necessarily lead to a inferior beverage in arabica varieties. However, coffee quality is also strongly influenced by the agro-ecosystem (climate, soil, altitude and agronomic practices) in which the variety is grown (Söndahl *et al.*, 2005). Lack of inputs and poor crop management, as a result of the current low coffee prices, appear to be major factors for deteriorating quality of arabica coffees in several producing countries.

Organic proponents argue that the new varieties would also need more inputs and therefore be less suitable for organic coffee production. On the contrary, the compact plant stature and disease resistance of these modern cultivars allow closer spacing, resulting in almost complete ground coverage and better uptake of available soil nutrients by denser rooting. The efficiency rate of fertilizer applications is increased, as is demonstrated by higher yields per unit area for high-density coffee at similar rates of fertilizer application common for traditional coffee tree densities (Njoroge, 1991).

Economic sustainability

In Central American agro-ecosystems favourable to arabica coffee, organic coffee under shade produced 20–30% lower yields compared to shaded conventional and 40% lower than unshaded coffee (Tables 5 and 6). The premiums received for organic coffee are obviously insufficient to compensate for the lower yields, slightly higher production costs and fees for certification and inspection by IFOAM-accredited organizations. Net incomes for organic coffee farms were thus 25–50% lower than those of conventionally managed farms, but still fairly remunerative when coffee prices are high (in 1997 and 1998). However, in years of very low world market prices, as in 1990 and again during the current coffee crisis, organic coffee farms appear to end up in the red figures much sooner than conventional farms, despite the price premiums of some 20% for organic coffee.

The organic farming movement appears to offer little in economic and social sustainability to the millions of smallholder farmers elsewhere, who can produce only 200–400 kg ha^{-1} $year^{-1}$ green coffee under less favourable agro-ecological and socio-economic conditions. Coffee is often their only source of cash income, but this can no longer meet the basic needs of their families because of the persistent coffee crisis (IISD, 2003; Oxfam, 2002). The principles of organic farming may not increase yields substantially and the modest premium does not sufficiently compensate for the additional efforts required to meet the strict regulations for certified organic coffee.

CONCLUSIONS

The profusion of articles on organic coffee in journals, books and on the internet, contain plenty of market-promotional statements, meant above all for the urban consumers of the industrialized world, extolling its benefits for the natural environment, biological diversity and human health, but none provide hard evidence for its alleged environmental and socio-economic superiority over conventional coffee production. The present review has been an effort to fill this gap by assessing the principles and practices applied in organic coffee production against sound agronomic and agro-economic criteria. This has led to the conclusion that the following statement of outspoken proponents in the organic movement 'if it is not organic it is not sustainable' (cited in Chapman, 2001) does not apply to coffee. This review indicates that fully organic coffee is unsustainable, for smallholder coffee producers in particular. Consequently, there is a need to define what is necessary for the sustainable production of coffee, but it seems clear that some use of inorganic fertilizers is necessary if maintenance of smallholder livelihoods is to be one of the criteria of sustainability.

Ecologically sustainable coffee production is certainly possible by applying best practices of agronomy, crop protection and post-harvest processing. These include soil conservation measures with or without shade trees, applying organic and inorganic fertilizers to maintain optimum soil quality and crop nutrient levels, planting of disease resistant varieties and applying IPM to reduce crop losses due to biotic stress factors, and the use of novel processing equipment. However, full commitment of all stakeholders in the Coffee Sector is required in helping to restore economic and social sustainability of coffee production, which are so badly eroded by the latest coffee crisis (Baker 2004; IISD, 2003, 2004).

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