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Selection of native trees for intercropping with coffee in the Atlantic Rainforest biome

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Abstract A challenge in establishing agroforestry systems is ensuring that farmers are interested in the tree species, and are aware of how to adequately manage these species. This challenge was tackled in the Atlantic Rainforest biome (Brazil), where a participatory trial with agroforestry coffee systems was carried out, followed by a participatory systematisation of the farmers experiences. Our objective was to identify the main tree species used by farmers as well as their criteria for selecting or rejecting tree species. Furthermore, we aimed to present a specific inventory of trees of the Leguminosae family. In order to collect the data, we reviewed the bibliography of the participatory trial, visited and interviewed the farmers and organised workshops with them. The main farmers' criteria for selecting tree species were compatibility with coffee, amount of biomass, production and the labour needed for tree management. The farmers listed 85 tree species; we recorded 28 tree species of the Leguminosae family. Most trees were either native to the biome or exotic fruit trees. In order to design and manage complex agroforestry systems, family farmers need sufficient knowledge and autonomy, which can be reinforced when a participatory methodology is used for developing on-farm agroforestry systems. In the case presented, the farmers learned how to manage, reclaim and conserve their land. The diversification of production, especially with fruit, contributes to food security and to a low cost/benefit ratio of agroforestry systems. The investigated agroforestry systems showed potential to restore the degraded landscape of the Atlantic Rainforest biome.

Keywords Participatory trial · Agroforestry systems · Agroecological management · Family farmers

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Introduction

The merit of agroforestry systems in reducing land degradation is widely accepted. This is especially

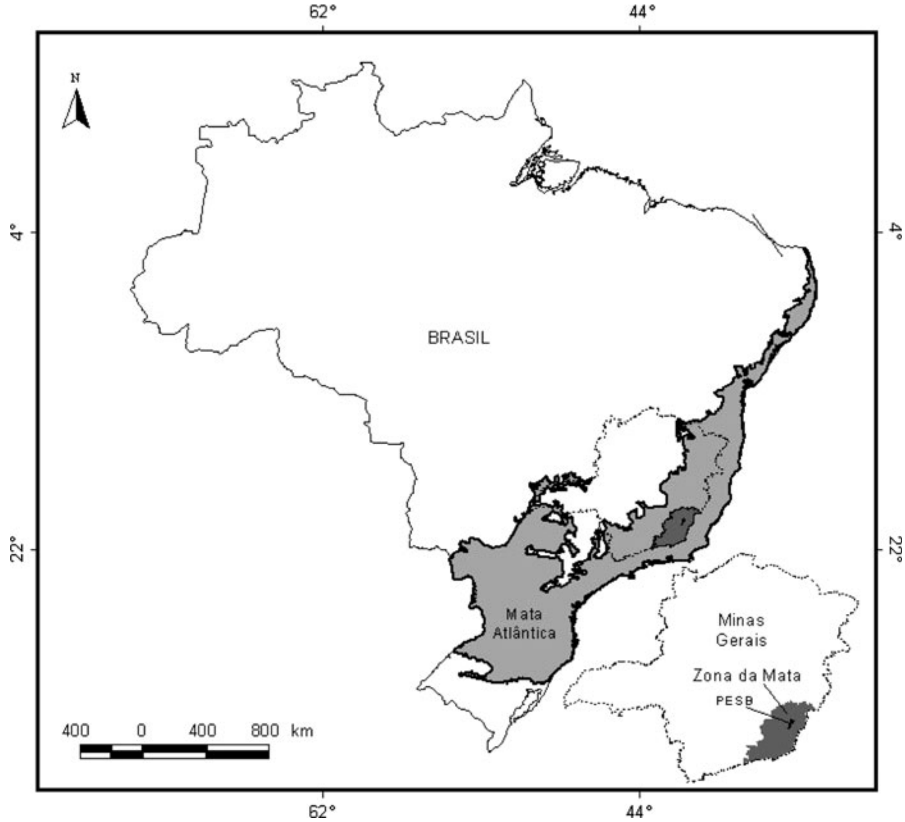

Fig. 1 The Zona da Mata region, Minas Gerais State, Brazil (*PESB* Serra do Brigadeiro State Park)

important in the Atlantic Rainforest biome in Brazil (Fig. 1), one of the most endangered and fragmented habitats in the tropics (Myers et al. 2000). For instance, in the basin of the Rio Doce, approximately 1 million hectare of forest remains, covering less than 15% of the total basin most of which is fragmented (Vandermeer and Perfecto 2007). The agricultural systems bordering these fragments are based on green revolution technologies and include full-sun coffee (*Coffea arabica*) or pasture, both of which probably impede inter-fragment migration of most organisms (Vandermeer and Perfecto 2007). In contrast, agroforestry systems could be used as buffer zones among tropical rainforest fragments and as migration corridors by interconnecting forest fragments (Vandermeer and Perfecto 2007; Harvey et al. 2008; McGinty et al. 2008).

Agroecologists recognise that agroforests mimic natural ecosystems. In doing so, agroforests increase the efficiency of use of sunlight, soil nutrients and rainfall, enhance biodiversity, promote soil quality, protect crops and increase productivity (Altieri and Nicholls 2000). The loss of soil quality is one of the main problems faced by family agriculture in the Zona da Mata (Fig. 1), partially located in the basin of the Rio Doce. This problem was pointed out in a Participatory Rural Appraisal (PRA) carried out in 1993 by the non-governmental organisation Centre of Alternative Technologies of Zona da Mata (CTA-ZM) in partnership with farmers' organisations (mainly unions and associations) and the Federal University of Viçosa (Cardoso et al. 2001).

In order to overcome this problem, the farmers proposed techniques like the use of green manure and the management of spontaneous herbaceous vegetation for soil cover. In turn, personnel from the NGO (CTA-ZM) and university proposed and carried out a participatory trial with agroforestry systems. Although the coffee crop has favourable characteristics for agroforestry, full-sun coffee systems are predominant in Brazil, including in our study region, and farmers usually lack experience with agroforestry coffee systems (Cardoso et al. 2001).

Farmer education and trial are more important for the development of agroforestry systems than for monoculture cropping systems (Douthwaite et al. 2003; Mercer 2004). Agroforestry systems are knowledge intensive and require the involvement of the farmer at all stages of their development (Mekoya et al. 2008). This learning process is only possible through diverse methodologies and a participatory trajectory, which formed the backbone of the trial carried out by CTA-ZM and partners in the Zona da Mata.

The trial was necessary to develop and adapt agroforestry systems technologies to local conditions in order to effectively increase the productivity of agroecosystems and simultaneously preserve the environment. The general objectives in developing agroforestry systems were to (i) revert soil degradation, (ii) produce diversified products and (iii) promote the use of native tree diversity. CTA-ZM and partners assisted the farmers in the design, implementation, monitoring, evaluation and re-design of the experiments in a continuous learning process (Cardoso et al. 2001).

When implementing agroforestry systems, the farmers were encouraged to use native trees from the Atlantic Rainforest. In order to contribute to nature conservation, it is important to incorporate regionally vulnerable or threatened species rather than focusing on exotic or domesticated species (Méndez et al. 2007). Indeed, many farmers prefer local instead of exotic species (Mekoya et al. 2008). However, it was unknown which native tree species were most suitable in meeting the above-mentioned objectives.

Understanding the criteria needed to select trees is important in designing sustainable agroforestry systems because tree species differ in terms of their intercropping suitability. Based on their experience, farmers often have valuable ideas about these criteria. However, such knowledge is rarely investigated or reported (Soto-Pinto et al. 2007). Thus, the objective of this paper is to present farmers' criteria for selecting or rejecting tree species for their agroforestry systems as well as to report the main tree species used by farmers in the Zona da Mata. Furthermore, we present a specific inventory of trees of the Leguminosae family in order to extend the farmers' information. Leguminosae are one of the major angiosperm tree families worldwide, providing food, timber and firewood and several environmental services like fixing nitrogen, a nutrient that limits production in tropical ecosystems. They are therefore important for the productivity of the agroecosystems and the economy and livelihood of farmers' families (Lewis and Owen 1989).

In order to analyse tree species used by farmers and their criteria for selecting or rejecting tree species, a participatory systematisation was carried out (Souza 2006) after 10 years of trial (Franco 1995; Guijt 1999; Carvalho and Ferreira-Neto 2000; Franco 2000; Cardoso et al. 2001). The farmers involved in the participatory systematisation were among those who started the agroforestry trial. Here, systematisation is understood as systematic organisation; the act of organising something according to a system (Oxford Advanced Learner′s Compass dictionary) or a rationale (www.wordreference.com). We gathered, organised and synthesised the knowledge and experience acquired by the farmers throughout the trial period. We used a participatory approach, in which farmers were involved in a process of reflection and analysis.

Materials and methods

The study site

The Zona da Mata has a tropical highland climate with an average temperature of 18°C, average precipitation of 1,500 mm year^{-1}, and 2–4 dry months per year. The area is hilly, with slopes ranging from 20 to 45% and altitudes from 200 to 1,800 m (Golfari 1975). Oxisols are the main type of soils; they are deep and well-drained, but acidic and poor in nutrient availability. The combination of deep soils with hilly slopes has led to the formation of several springs and streams. Brazilian law protects and restricts the agricultural use of the areas on hilltops, steep areas, stream margins and areas surrounding springs (Brasil, 1965). In the Zona da Mata, this includes most of the landscape (Freitas et al. 2004). Although protected, the farmers continue to use these areas, not always in ways that conserve the landscape and biodiversity.

This region has a long history of soil degradation. Land cover has passed through a cycle that started in the mid of the nineteenth century with Atlantic Rainforest being replaced by full-sun coffee plantations. This broke the nutrient cycling in the system, causing erosion and nutrient loss via harvesting, thus drastically reducing soil fertility. Farmers occupied new areas in search for fertile land for coffee, which aggravated deforestation and degradation. Meanwhile, pasture and staple food crops (maize, beans and others) replaced coffee in the old fields (Valverde 1958; Dean 1995). Nowadays, pasture and full-sun coffee, often intercropped with maize and beans, are the most common agroecosystems in the Zona da Mata. The main cash crop is coffee, which is cultivated on approximately 200,000 ha (IBGE 2005). Other crops include sugarcane, cassava, fruits and vegetables (Ferrari 1996; Cardoso et al. 2001). Most agroecosystems in the region have low productivity due to the long history of (increasingly) intensive soil use with practices not well adapted to the environment. In spite of this, production by family agriculture has maintained its vital importance within the region (Ferrari 1996). As the remaining forest fragments are protected, farmers cannot occupy new areas and have to search for alternative types of land use and management to cope with environmental degradation. One of these alternatives is agroforestry, which has recently become permitted by law (Ministério do Meio Ambiente 2006), to be used by family agriculture in the protected areas mentioned above. However, in the Zona da Mata, family agriculture was ahead of the law and started trials with agroforestry far before it was formally allowed.

From 1994 to 1997, 39 on-farm agroforestry experiments were established in 11 municipalities of the Zona da Mata. These municipalities are adjacent to the 'Serra do Brigadeiro' State Park (Fig. 1), one of the most important protected areas in the region, which was established in 1996 and measures approximately 10,000 ha. Another reserve which is partially in the region is the Caparaó National Park.

The agroforestry experiments involved 33 small-scale farmers, 37 of the experiments focused on coffee and two were with pasture. The experiments were established in degraded full-sun coffee (spaced at 3 × 1.5 m) fields (Cardoso et al. 2001). The average area of each agroforestry system was 0.45 ha (SE = 0.14), ranging from 0.11 to 1 ha (Franco 2000). The total area per farm was mostly less than 20 ha. Trees were planted between coffee plant rows or resulted from regeneration. The age of the coffee fields in which the experiments were started varied, but was in general less than 10 years. When the experiments were established, tree and shrub densities were very high, for instance, in one farm it reached 920 seedlings/ha, in order to maximise biomass production (Cardoso et al. 2001).

Systematisation of the trials

In total, 17 family farmers (and 17 farms) from seven municipalities (Araponga, Miradouro, Eugenópolis, Espera Feliz, Divino, Carangola and Tombos) were involved in the systematisation process. Not all 33 farmers who started the agroforestry trial could be contacted or were available to participate in the systematisation. However, we considered the families that participated representative of the 33 farmers who started the trial. The methodology of the systematisation was adapted from Diez-Hurtado (2001). It comprised of organising and synthesising the bibliography on the trial, consisting of 62 documents (theses, papers, reports, folders, etc.); visits to and observations of the agroforestry systems; interviews and a workshop with the 17 farmers, five technicians and six scientists who participated in the trial. Techniques from the PRA were used in the workshop, specifically the matrix of options and criteria (adapted from Horn and Stür 2003).

Visits and interviews

We visited and interviewed the farmers (other members of the family participated in the interviews when possible) using semi-structured interviews (Oliveira and Oliveira 1982). For this purpose, we prepared general guidelines using the following subjects: general impressions of the agroforestry systems, characteristics of the tree species (deciduousness, fruit production, wood quality and biomass production), characteristics of the trial site (slope, history of soil degradation and improvement), whether the tree species was kept or removed from the agroforestry systems and motivation to maintain or remove them, the production of the coffee plants and the trees, the design (space among the trees and position in relation to the coffee plants), and management of the agroforests (seedlings, seeds, natural regeneration, pruning—when and how), and management and quality of the soil (erosion, organic matter and soil cover). We interviewed the farmers on their properties and jointly observed their agroforestry systems with respect to the design, soil coverage, tree species characteristics and coffee quality (Souza 2006).

Matrix of options and criteria

In order to identify the criteria used by the farmers to select trees to intercrop with coffee, a matrix of options and criteria (adapted from Horn and Stür 2003) was used in a workshop with 17 participating farmers (Table 1). The farmers included trees into the matrix that, according to their experience, were the main trees used in the agroforestry system. The farmers also listed the tree characteristics that they considered valuable for the agroforestry system. The names of the trees (considered as ‘options’) used in the trial and the main characteristics ‘selection criteria’ of the trees were listed and written on cards. These cards were placed in the columns (options) and in the rows (criteria) of the matrix. The number of farmers that agreed upon those criteria was noted in the cells of the matrix. The higher the numbers the more farmers recognised the tree characteristic when intercropped with coffee. Empty cells or cells with low numbers indicate that none or few farmers valued the criterion in relation to a certain species, often because they did not have experience with the species in their agroforestry systems, in some case because they did not agree with the criterion. It was not possible to separate the latter two cases because of the methodology used to construct the matrix (only the farmers who agreed were recorded).

Inventory of Leguminosae

In order to identify the Leguminosae tree species, we collected plant material (leaves, fruits and flowers) in seven agroforestry systems in the municipality of Araponga. The owners of the agroforestry systems were among the 17 participants of the participatory systematisation. As the species do not flower at the same time and the flower is the most important organ for species identification, we sampled plant material monthly during 1 year. Plant materials were herborised (Bridson and Forman 1999) and deposited in the collection of the VIC Herbarium (Plant Biology Department, Federal University of Viçosa). Species identification was based on the morphology of the collected plants and taxonomic literature and checked through comparison with collection material of the

Table 1 Matrix of criteria (tree species characteristics) and options (tree species) constructed with the farmers, with the aim to select trees to use in agroforestry coffee systems, Zona da Mata, Minas Gerais, Atlantic Coastal Rainforest, Brazil

Options (trees)	Criteria (tree characteristics)						
	Compatible[a] with coffee	Biomass production	No need of pruning	Food production[b]	Use as wood and fire wood	Compatible[a] with pasture, or fodder	Attract insects
Aegiphila sellowiana	7	12		6	12		12
Bombax marginatum	10	4	3	7			3
Carica papaya	3		1	3			
Cecropia sp.	1	1	1	1	2	1	1
Dalbergia nigra	2	4	5		5	4	4
Eriobotrya japonica	1			3	3		3
Hovenia dulcis	4	3	4	4	3	2	3
Inga spp.	10	11	5	15	12	4	5
Musa paradisiaca	9	11		16			4
Persea americana	8	2	3	8		5	
Senna macranthera	6	8	1	5	11	2	
Solanum mauritianum	17	17	7	7	12	5	3
Spondias lutea	1			4			
Toona ciliata	2	2	5		5	1	

Numbers in the cells refer to the number of farmers out of 17 who mentioned the tree characteristics; blank cells indicate that farmers did not mention this criterion

[a] Compatibility indicates that the tree is good to intercrop with coffee or pasture

[b] Food for human consumption, or for domestic and wild animals

VIC Herbarium. For genus identification, we used the classification system adopted by Lewis et al. (2005). For species identification, we used taxonomic reviews of the sampled genera.

Economic benefit

In order to compare the economic benefit of agroforestry and full-sun coffee systems, we carried out a survey of both systems. The information was gathered during the systematisation process. For this comparison, we re-interviewed three farmers who started the trial with agroforestry systems and participated in the systematisation. We also interviewed five farmers who cultivated only full-sun coffee. We questioned the farmers on the density of coffee trees per hectare, the production of coffee per tree, the price per bag of coffee and the production costs per hectare. The results were based on years of maximum coffee production because coffee plants are bi-annual (years of good production are interspersed with years of lower production). This problem occurs less in the agroforestry systems, but it was not considered in our comparisons of full-sun coffee with agroforestry coffee. We also obtained the production, the costs and the price of the commercialised products (mainly fruits) of the agroforestry systems. Based on these data, we scored the benefits as the money earned by the farmers when selling coffee without discounting the costs. Economic benefits are presented as the cost/benefit ratio.

Results

Visits, interviews and matrix of options and criteria

The information obtained through visits, interviews and the workshop, resulted in a list of 85 tree species or genera used in the agroforestry systems (Table 1). Most trees were native of the Atlantic Rainforest (55 species or genera, 65% of the total). Of the 30 exotic species, 20 (67%) were fruit trees. From the native trees, 39 (71%) were also found in forest fragments or observed in regenerating spots nearby agroforestry systems (Table 2).

The main criteria and indicators for selecting trees to use in the agroforestry coffee systems that were given by the farmers during the visits and interviews and especially during the construction of the matrix (Table 1) are summarised in Fig. 2. Two hierarchical levels could be defined. The main criterion (first hierarchical level) for selecting a tree species was the compatibility with coffee. Indicators of compatibility were the depth of the tree roots and phytosanitary aspects of the coffee trees. Incompatible species had superficial roots or caused sanitary problems to the coffee (for instance, the coffee leaves would become yellow). If compatible with coffee, other criteria and indicators (second hierarchical level) were also considered (Fig. 2), mainly: (a) the amount of biomass produced, (b) the labour needed to manage the trees, and (c) diversification of the production.

The main indicator for biomass production was the amount of residue produced, which includes senescent or pruned material, and soil cover, which includes the herbaceous stratum. Besides the management of trees, taking care of the herbaceous stratum is also important for the production of biomass, for soil cover, and for food production. This was done either through the introduction of species (for instance sweet potato and Leguminosae as green manure) or the management of spontaneous vegetation (so-called weeds). The farmers did not use herbicides to manage the spontaneous vegetation, but trimmed it manually or mechanically.

With respect to labour input, it was important for the farmers to use species of which seedlings or seeds could be easily obtained and species that did not need pruning or were easy to prune. The architecture of the branches was also considered important; the branches should not rest on the coffee plants. If they did, the branches should be pruned in order to avoid damaging the coffee plants. When trees were planted in the coffee fields, the seedlings were sometimes taken from naturally regenerating spots outside the coffee fields, often from fragments of the native forest. The use of deciduous species was preferred because these do not need to be pruned, except for the lowest branches. Pruning, when necessary, was done during the dry season (winter, from June to September).

Diversification of the agroforestry systems was indicated by the quality and quantity of food produced for humans, cattle, pigs, poultry and native fauna, and the production of wood for rural buildings, fences and fuel. If compatible with coffee, at least some, but not all of the other criteria had to be met for

Table 2 Family, species and common Portuguese names of native and exotic trees used in agroforestry systems, Zona da Mata, Minas Gerais, Atlantic Coastal Rainforest, Brazil

Family	Species (common names)	Origin	Neighbouring forest fragments or regenerating spots
Anacardiaceae	*Mangifera indica* L. (manga)	E[a]	
	Schinus terebinthifolia Raddi (aroeirinha)	N	Yes[b]
	Spondias lutea L. (cajá manga)	E[a]	
Annonaceae	*Annona muricata* L. (graviola)	E[a]	
	Annona squamosa L. (fruta-do-conde)	E[a]	
	Rollinia dolabripetala A.St.-Hil. (araticum)	N[a]	Yes[b]
Apocynaceae	*Aspidosperma polyneuron* Müll. (guatambu)	N	Yes[c,d]
Araucariaceae	*Araucaria angustifolia* (Bertol.) Kuntze (pinheiro-brasileiro)	N	
Arecaceae	*Bactris gasipaes* Kunth (pupunha)	E	
	Cocos nucifera L. (coco-da-bahia)	E[a]	
	Euterpe edulis Mart. (palmito-jussara)	N	Yes[e]
	Syagrus romanzoffiana (Cham.) Glassman (coco-babão)	N	Yes[e]
Asteraceae	*Eremanthus erythropappus* (DC.) MacLeish (candeia)	N	Yes[b,c,f]
Bignoniaceae	*Jacaranda macrantha* Cham. (caroba)	N	Yes[b,c]
	Sparattosperma sp. (cinco-folhas)	N	
	Tabebuia impetiginosa (Mart. *ex* DC.) Standl. (ipê-roxo)	N	Yes[e]
	Tabebuia chrysotricha (Mart. *ex* A. DC.) Standl. (ipê-mulato)	N	Yes[b,c,d]
	Tabebuia serratifolia (Vahl) G. Nicholson (ipê-amarelo)	N	Yes[e]
	Zeyheria tuberculosa (Vell.) Bureau (ipê-preto)	N	Yes[e]
Bixaceae	*Bixa orellana* L. (urucum)	N	
Cannabaceae	*Trema micrantha* (L.) Blume. (crindiúva)	N	Yes[b]
Caricaceae	*Carica papaya* L. (mamão)	E[a]	
Casuarinaceae	*Casuarina equisetifolia* L. (casuarinas)	E	
Ebenaceae	*Diospyros kaki* L. f. (caqui)	E[a]	
Elaeocarpaceae	*Muntingia calabura* L. (calabura)	E	
Euphorbiaceae	*Alchornea triplinervia* (Spreng.) Müll. Arg. (pau-de-bolo)	N	Yes[c,f]
	Croton urucurana Baill. (adrago)	N	Yes[b]
	Joannesia princeps Vell. (cotieira)	N	
	Hyeronima alchorneoides Allemao (liquerana)	N	Yes[c,d]
	Mabea fistulifera Mart. (canudo-de-pito)	N	Yes[e]
Lamiaceae	*Aegiphila sellowiana* Cham. (papagaio)	N	Yes[b,f]
	Vitex montevidensis Cham. (maria-preta)	N	
Lauraceae	*Persea americana* Mill. (abacate)	E[a]	
Leguminosae	*Anadenanthera peregrina* (L.) Speg. (angico-vermelho)	N	Yes[e]
	Calliandra houstoniana (Mill.) Standl. (caleandra)	E	
	Caesalpinia pluviosa DC. (sibipiruna)	N	
	Cassia ferruginea (Schrad.) DC. (canafístula)	N	Yes[d,g]
	*Erythrina verna*Vell. (pau-abóbora)	N	
	Erythrina speciosa Andrews (mulungu)	N	
	Hymenaea courbaril L. (jatobá)	N	

Table 2 continued

Family	Species (common names)	Origin	Neighbouring forest fragments or regenerating spots
	Inga edulis Mart. (ingá)	N	Yes[d,g]
	Dalbergia nigra (Vell.) Benth. (jacaranda-caviúna)	N	Yes[g]
	Enterolobium contortisiliquum (Vell.) Morong (orelha-de-macaco)	N	Yes[e]
	Machaerium stipitatum (DC.) Vogel (canela-de-velho)	N	Yes[g]
	Machaerium nyctitans (Vell.) Benth. (jacarandá-bico-de-pato)	N	Yes[c,f,g]
	Piptadenia gonoacantha (Mart.) J.F. Macbr. (jacaré)	N	Yes[g]
	Schizolobium parahyba (Vell.) S.F. Blake (breu)	N	Yes[e]
	Senna macranthera (Collad.) H.S. Irwin and Barneby (fedegoso)	N	Yes[g]
Malpighiaceae	*Byrsonima sericea* DC. (massaranduva)	N	Yes[c]
Malvaceae	*Bombax marginatum* (A. St.-Hil., Juss. and Cambess.) K. Schum. (castanha-mineira)	E[a]	
	Ceiba speciosa (A. St.-Hil.) Ravenna (paineira)	N	Yes[d]
	Luehea grandiflora Mart. (açoita-cavalo)	N	Yes[b,d]
Melastomataceae	*Tibouchina granulosa* (Desr.) Cogn. (quaresmeira)	N	Yes[b,d]
Meliaceae	*Cedrela fissilis* Vell. (cedro)	N	Yes[d,f]
	Melia azedarach L. (cinamomo)	E	
	Toona ciliata M. Roem. (cedro-australiano)	E	
Moraceae	*Artocarpus heterophyllus* Lam. (jaca)	E[a]	
	Morus nigra L. (amora)	E	
Moringaceae	*Moringa oleifera* Lam. (moringa)	E	
Musaceae	*Musa paradisiaca* L. (banana)	E[a]	
Myrsinaceae	*Rapanea ferruginea* (Ruiz and Pav.) Mez (pororoca)	N	Yes[b]
Myrtaceae	*Campomanesia xanthocarpa* (Mart.) O. Berg (gabiroba)	N[a]	Yes[f]
	Eugenia malaccensis L. (jamelão)	N[a]	
	Eugenia uniflora L. (pitanga)	N[a]	
	Myrciaria jaboticaba (Vell.) O. Berg (jaboticaba)	N[a]	
	Psidium araca Raddi (araçá)	N[a]	
	Psidium guajava L. (goiaba)	N[a]	
	Syzygium jambos (L.) Alston (jambo)	E	
Pinaceae	*Pinus* sp. (pinus)	E	
Rhamnaceae	*Hovenia dulcis* Thunb. (ovenia)	E[a]	
	Colubrina glandulosa Perkins (só-brasil)	N	Yes[e]
Rosaceae	*Moquilea tomentosa* Benth. (oiti)	N	
	Eriobotrya japonica (Thunb.) Lindl. (ameixa)	E[a]	
	Pyrus communis L. (pêra)	E[a]	
	Prunus persica (L.) Batsch (pêssego)	E[a]	
Rutaceae	*Citrus* sp. (limão-cravo)	E[a]	
	Citrus sp. (mexerica)	E[a]	
	Citrus sinensis (L.) Osbeck (laranja)	E[a]	
	Citrus sp. (turanga)	E[a]	
	Dictyoloma vandellianum A.H.L. Juss. (brauninha)	N	Yes[e]

Table 2 continued

Family	Species (common names)	Origin	Neighbouring forest fragments or regenerating spots
Sapindaceae	*Litchi chinensis* Sonn. (lichia)	E[a]	
Solanaceae	*Solanum lycocarpum* A. St.-Hil. (lobeira)	N	Yes[e]
	Solanum mauritianum Scop. (capoeira-branca)	N	Yes[e]
Urticaceae	*Cecropia* sp. (embaúba)	N	Yes[b]
Verbenaceae	*Citharexylum myrianthum* Cham. (pau-de-viola)	N	

[a] Fruit trees; *N* native of Atlantic Coastal Rainforest, *E* exotic; *Yes* found in the neighbouring (distance ranging from a few metres to hundreds of metres) forest fragments or regenerating spots, according to [b] Siqueira (2008), [c] Saporetti-Júnior (2005), [d] Soares et al. (2006), [e] authors' observation, [f] Ribeiro (2003) and [g] Fernandes (2007); *empty cell* no information found in the literature

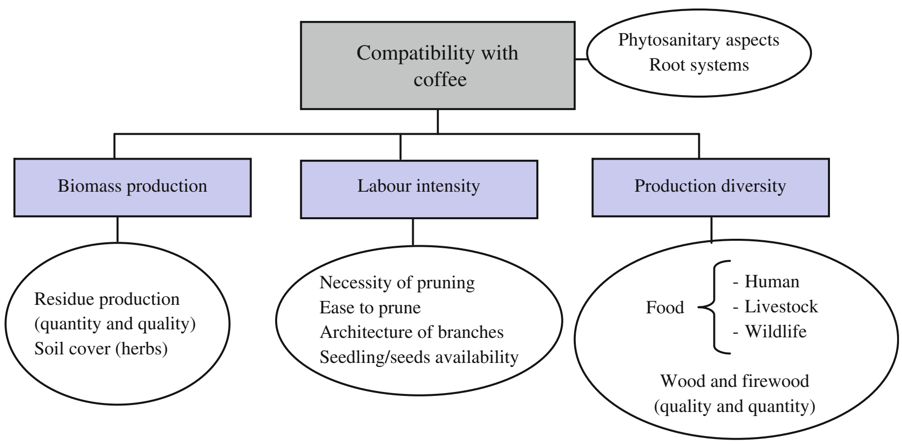

Fig. 2 Criteria (*boxes*) and indicators (*circles*) used to select trees used in agroforestry coffee systems of the Zona da Mata region, Minas Gerais State, Brazil. The first box presents the main criterion or the first hierarchical level to select a tree, which is compatibility with coffee

the species to be accepted. For instance, banana and avocado were included because they produce fruits even though they are not deciduous.

Of the initial 85 species (Table 2), Table 3 shows 22 tree species and their characteristics according to the criteria and indicators mentioned in Fig. 2. Most of these species and their characteristics were mentioned by the farmers during the construction of the matrix of criteria and options (Table 1), but the table also includes some information gathered during the visits to the systems and the interviews. This information refers specifically to the species *Erythrina* sp., *Zeyheria tuberculosa* and *Luehea grandiflora*, present in some of the best managed agroforestry systems, and to the rejected species *Anadenanthera peregrina*, *Croton urucurana, Piptadenia gonoacantha* and *Schizolobium parahyba*. During the interviews and visits, many farmers remarked that the latter species are incompatible with coffee because they have superficial roots that would desiccate the soil. However, some farmers kept them in the agroforestry systems because they can serve as wood and firewood. *Piptadenia gonoacantha* is often cut down before it is full-grown and used as firewood, thus avoiding competition with coffee. *Anadenanthera peregrina* and *S. parahyba* are sometimes left in the systems to be used as wood (Table 3). *Solanum mauritianum* is used in agroforestry systems, but their low branches have to be pruned to avoid touching the coffee leaves, which would otherwise generate sanitary problems for the coffee.

Table 3 Tree species and the characteristics pointed out by the farmers to select trees to be included in agroforestry coffee systems, Zona da Mata, Minas Gerais, Atlantic Coastal Rainforest, Brazil

Tree species	Tree characteristics					
	Compatibility with coffee	Good biomass production	Easy management	Necessity of pruning	Production	
					Fruits	Wood/firewood
Aegiphila sellowiana	Yes	Yes	Yes	No	Yes[c]	Yes
Anadenanthera peregrina[a]	No					Yes
Bombax marginatum[b]	Yes	Yes	Yes	No	Yes	
Carica papaya[b]	Yes			No	Yes	
Cecropia sp.	Yes	Yes		No	Yes[c]	Yes
Croton urucurana[a]	No					
Dalbergia nigra	Yes	Yes		No		Yes
Eriobotrya japonica[b]	Yes				Yes	
Erythrina speciosa	Yes	Yes	Yes	No		
Erythrina verna	Yes	Yes	Yes	No		
Hovenia dulcis[b]	Yes	Yes	Yes	No		
Inga spp.	Yes	Yes	Yes	No	Yes[c]	Yes
Luehea grandiflora	Yes	Yes	Yes	No		Yes
Musa paradisiaca[b]	Yes	Yes	Yes		Yes	
Persea americana[b]	Yes	Yes		No	Yes	
Piptadenia gonoacantha[a]	No					Yes
Schizolobium parahyba[a]	No					Yes
Senna macranthera	Yes	Yes		No		Yes
Solanum mauritianum	Yes	Yes	Yes	No	Yes[c]	Yes
Spondias lutea[b]	Yes			No	Yes	
Toona ciliata[b]	Yes	Yes	Yes			Yes
Zeyheria tuberculosa	Yes	Yes	Yes	No		

[a] Trees with superficial roots; [b]exotic trees; [c]mainly for wild animals; Empty cells indicate that the farmers did not mention this criterion. For common names of the species, see Table 2

Besides the tree characteristics presented in Fig. 2, other tree characteristics, such as attraction of insects, were used by the farmers to evaluate the species (Table 1). Although insect attraction was mentioned by nine farmers (Table 1), it is not a decisive criterion for inclusion of trees unless the species is attractive to honeybees. In this case, the criterion is related to diversification of food production (i.e. honey).

Most of the 22 species (64%) listed in Table 3 are native to the Atlantic Rainforest. Most exotic trees (85%, 6 species) were fruit trees. Most of the native species or genera (64%) of Table 2 were found in nearby forest fragments or regenerating spots. Among these species, *Aegiphila sellowiana*, *Cecropia* sp., *L. grandiflora, Senna macranthera, S. mauritianum* and *Z. tuberculosa* are intercropped most with coffee. Among the 22 species, 10 (45%) produce fruits that are edible by humans or wildlife, and 11 (50%) were reported to be used for wood or firewood.

At the beginning of the trial, tree densities were higher. During the trial period, the farmers re-designed the agroforests, and set the density to around 100 trees ha^{-1}. However, the variation among agroforests was considerable, depending on the amount of natural shade in the fields, which, in turn, depends on environmental characteristics such as slope. The space among trees depended on the size of the tree crowns, which should not touch each other. In general, the systems had more than ten different species per hectare; here again, there was considerable variation among systems.

Inventory of Leguminosae

We found 28 species of Leguminosae trees in seven agroforestry systems (all with an area smaller than 1 ha) (Table 4). Except for one species (*Leucaena leucocephala*), all were native to the Atlantic Rainforest. The most diversified systems had 11 species within the Leguminosae family and the least diversified had five species. *Piptadenia gonoacantha* was found in 6, *Inga edulis* and *S. macranthera* were found in 5, *Inga subnuda*, *Machaerium nyctitans* and *Platypodium elegans* were found in 3 surveyed agroforestry systems. The other species were found either in one or two agroforestry systems. Trees of the *Inga* genus were found in all seven surveyed agroforestry systems.

Table 4 Leguminosae trees surveyed in seven agroforestry systems, Zona da Mata, Minas Gerais, Atlantic Coastal Rainforest, Brazil

Subfamily and scientific name	Common name	Number of agroforestry systems[1]	Nodulation[2]
Caesalpinioideae			
Apuleia leiocarpa (Vogel) J.F. Macbr.	Garapeira	2	No[ab]
Caesalpinia echinata Lam.	Pau-brasil	1	Yes[b]
Cassia ferruginea (Schrad.) DC.[3]	Canafístula	2	No[b]
Copaifera langsdorffii Desf.	Pau-de-óleo	1	No[bc]
Hymenaea courbaril L.	Jatobá	2	No[abc]
Pterogyne nitens Tul.	Jacaranda	1	–
Schizolobium parahyba (Vell.) S.F. Blake	Breu	1	No[bc]
Senna macranthera (Collad.) H.S. Irwin and Barneby[3]	Fedegoso	5	No[bc]
S. multijuga (Rich.) H.S. Irwin and Barneby[3]	Farinha-seca	1	No[bc]
Mimosoideae			
Albizia cf. polycephala (Benth.) Killip ex Record	Farinha-seca	1	Yes[b]
Anadenanthera peregrina (L.) Speg.	Angico	1	Yes[c]
Enterolobium contortisiliquum (Vell.) Morong	Orelha-de-macaco	1	Yes[c]
Inga cylindrica (Vell.) Mart.[3]	Angá-feijão	1	–
I. edulis Mart.[3]	Angá-de-metro	5	Yes[a]
I. sessilis (Vell.) Mart.[3]	Angá-ferradura	1	Yes[b]
I. subnuda subsp. *luschnathiana* (Benth.) T.D. Penn.	Angá-serra	3	Yes[a]
Leucaena leucocephala (Lam.) de Wit[4]	Leucena	2	Yes[d]
Piptadenia gonoacantha (Mart.) J.F. Macbr.[3]	Jacaré	6	Yes[bc]
Pseudopiptadenia contorta (DC.) G.P. Lewis and M.P. Lima	Jacaranda-amarelo	1	–
Papilionoideae			
Andira surinamensis (Bondt) Splitg. ex Pulle[3]	Angelim	2	Yes[a]
Dalbergia nigra (Vell.) Benth.[3]	Jacaranda-Caviuna	2	Yes[ac]
Erythrina speciosa Andrews	Mulungu	1	Yes[a]
Erythrina verna Vell.	Pau-abóbora	1	Yes[ab]
Machaerium brasiliensis Vogel[3]	Bico-de-pato	2	Yes[a]
Machaerium nyctitans (Vell.) Benth.	Jacarandá-bico-de-pato	1	Yes[a]
M. nyctitans (Vell.) Benth.[3]	Bico-de-pato	3	Yes[abc]
M. stipitatum (DC.) Vogel	Canela-de-velho	1	–
Platypodium elegans Vogel	Jacarandá-branco	3	Yes[b]

[1] Number of agroforestry systems (out of seven) in which the species was found. [2] *Yes* nodulation by nitrogen-fixing bacteria; *No* no nodulation (citation), according to [a] Sprent (2001), [b] Faria et al. (1984), [c] Barberi et al. (1998) and [d] Franco and Faria (1997); – no information found; [3] also found in two neighbouring forest fragments (Fernandes 2007); and [4] exotic species

The Leguminosae family contained the highest number (15) of species or genera tested by the farmers during the trial period (Table 2). On the one hand, only two Leguminosae species (*Calliandra houstoniana* and *Caesalpinia pluviosa*) listed in Table 2 were not encountered during the inventory, on the other hand, the inventory yielded more Leguminosae species than mentioned by the farmers, which means that the number of species may increase beyond the 85 listed (Table 2) in a more specific survey. Among the 22 main tree species intercropped with coffee (Table 3), the farmers listed four species (*Dalbergia nigra*, *Erythrina speciosa, Erythrina verna* and *S. macranthera*) and one genus (*Inga* spp.) of Leguminosae. Three out of the four rejected species (Table 3) are Leguminosae (*A. peregrina, P. gonoacantha* and *S. parahyba*). Although rejected, all of them were found in the agroforestry systems (Table 4).

From the legume species identified in the agroforestry systems, 17 are known to fix nitrogen and 16 of them were native, mainly from the genera *Machaerium*, *Erythrina* and *Inga* (Table 4). *Senna macranthera* (found in 5 out of 7 agroforestry systems) does not associate with nitrogen-fixing bacteria according to the literature (Table 4).

A total of 20 legume trees species were sampled in two forest fragments neighbouring the seven agroforestry systems where the Leguminosae inventory was done (distance ranging from a few metres to hundreds of metres) (Fernandes 2007). From the total, 11 species also occurred in the agroforests, including *S. macranthera, Inga* spp. and *D. nigra* (Table 4). *Senna macranthera* and *Inga* spp. are among the main species used in the agroforestry systems (Table 3). *Dalbergia nigra* is an endangered species from the Atlantic Rainforest (Drummond et al. 2005); it was found in two agroforestry systems (Table 3) and in two fragments.

Economic benefit

The comparison between agroforestry and full-sun coffee systems is presented in Table 5. The amount of coffee harvested and the costs to produce it were less in agroforestry systems than in the full-sun coffee systems. Owing to the diversification, the agroforestry systems allowed more products to be harvested and commercialised, such as avocado (*Persea americana*) and banana. The diversification and the lower costs of production resulted in a lower cost/benefit ratio for agroforestry systems (0.23) than for full-sun coffee systems (0.55).

Table 5 Comparison among full-sun and agroforestry coffee systems, Zona da Mata, Minas Gerais, Brazil

Coffee	Full-sun	Agroforestry
Density (trees/ha)	2,650	2,050
Production (kg/tree)	0.79	0.62
Price (R$/bag—60 kg)	120	120
Benefit (R$/ha)[a]	4,187.00	2,542.00
Costs[b] (R$/ha)	2,300.00	750.00
Net benefit (R$/ha)	1,887.00	1,792.00
Cost/benefit	0.55	0.29
Other products of agroforestry (R$/ha)[b]		701.50
Net benefit including other products	1,887.00	2,493.50
Costs/benefit (%)	0.55	0.23

[a] *R$* Brazilian real; [b] products such as papaya, banana, citrus, mango, avocado, guava, jack fruit, palm heart and ficus fruit

Discussion

In our region, the criteria to select trees to be used in the agroforestry coffee systems and the way to manage the trees was developed during 10 years of participatory trial. The participatory systematisation contributed to clarification of farmers' criteria to select tree species and aspects of the management of the agroforestry systems. The use of native and or fruit trees provided important ecosystems services to the farmer families and helped them in restoring and preserving native forests.

The participatory trial allowed the construction of new knowledge and capacities and an understanding of the ecological processes involved in the agroforestry systems. Agroforestry systems are complex and their management requires more knowledge than full-sun coffee systems (Mercer 2004). In the trial, the farmers defined objectives, decided about the design and management, experimented, analysed and modified the agroforestry systems (Cardoso et al. 2001). The farmers controlled the process of decision-making and management and understood the objectives of the experiments. Therefore, they continued the experiments even when facing several difficulties during the long-term trial and found solutions to overcome these difficulties (Souza 2006). They had to design and re-design their agroforestry systems and many trees were removed, whereas others were introduced (Souza 2006). In our experience, the autonomy of the farmers in conducting the experiments resulted in a large diversity of design and management options, leading to specific agroforestry systems for each farmer.

Despite the specificity, the criteria for selecting trees were similar to all farmers and will apply to a wider range of environments, although they may result in the choice of other species. Selection of appropriate species is key to success of agroforestry. The species have to fulfil the requirements of different environmental niches and needs of the farmers (Scherr 1991). Some criteria found in our study are similar to those found in Chiapas, Mexico (Soto-Pinto et al. 2007), such as impact on coffee yield, amount of litter, impact on pests and diseases, additional goods and services offered by trees. However, in contrast to farmers in Zona da Mata, farmers in Chiapas preferred non-deciduous trees (Soto-Pinto et al. 2007), probably because of the preference of Chiapas farmers for more intensely shaded coffee. In addition in Mexico, tree species incompatible with coffee are sometimes retained by the farmers because of their usefulness as food, timber, firewood, provision of medicines and for other domestic purposes (Soto-Pinto et al. 2007).

The deciduous characteristic is important in the Zona da Mata because coffee needs more light during the flowering period (Morais et al. 2003), which is in the dry period (winter). In this season, several trees from the Atlantic Rainforest (in the studied region, Seasonally Semideciduos Forest—classification of Veloso 1991) lose their leaves and pruning of the crown is not necessary, thus saving labour. The root system was also judged important and was one of the indicators raised by the farmers to explain the incompatibility of certain species with coffee. Fine coffee roots (less than 1 mm in diametre) are concentrated in the first few centimetres of the soil (Cuenca et al. 1983). Therefore, fine tree roots have to be deeper than the coffee roots to avoid competition for water and nutrients. However, Jaramillo-Botero (2007) could not find competition for water and nutrients between *S. parahyba* (an incompatible species, Table 3) and coffee, and suggested allelopathy between the two species to explain the incompatibility.

The preference for native and/or fruits trees (Tables 2 and 3) is the result of the strategy of CTA-ZM and partners to specifically promote the use of native species and the diversification of production. The natural regeneration within the agroforestry systems and availability of genetic materials (seeds or seedlings) in the region give more autonomy to the farmers. Consequently, the farmers are dependent on the presence of forest fragments nearby. The effects of forest fragments and agroforestry systems on each other are twofold. On the one hand, forest fragments are important as a genetic source for the agroforestry systems, working as a seed bank or seedling reservoir. Hence, most of the species found in the agroforestry systems were also found in the forest fragments and in regenerating spots nearby (Tables 2 and 4). Among the most common species recommended, *A. sellowiana*, *L. grandiflora*, *S. macranthera*, *S. mauritianum* and *Z. tuberculosa* spontaneously occurred in the agroforestry systems, indicating that either seeds were present in the soil or that seeds were dispersed from other spots. With respect to dispersal, fruits from *A. sellowiana* and *S. mauritianum* are eaten by wild animals (Table 3) and all of the above-mentioned trees were observed nearby agroforestry sites (Table 2), suggesting the potential of seed dispersal.

On the other hand, agroforestry systems are important for conservation of regional biodiversity (Salgado et al. 2006), as the agroforestry systems mimic the forest fragments with respect to the strata of vegetation and the related microclimate. As a result, the use of the endangered *D. nigra* in two agroforestry systems can help the conservation of this species and may result in seed dispersal from the agroforestry systems into the forest fragments. Thus, agroforestry systems have the potential to interconnect forest fragments, to serve as buffer zones of tropical rainforests (Vandermeer and Perfecto 2007; McGinty et al. 2008) and even as nursery for endangered species. Moreover, the availability of wood for fuel and building from the agroforestry systems decreases the pressure on forest remains. Therefore, agroforestry systems, as developed by the farmers in Zona da Mata, meet demands in terms of production and environmental services (Altieri and Nicholls 2000; Harvey et al. 2008; Rice 2008), contribute to the conservation of species occurring in nearby reserves, have the potential to contribute to the sustainability of ecosystems, and can be used as a reference for policy makers to improve the regulation of the use of the protected areas in the region.

The agroforestry systems in the Zona da Mata were more diverse than in other Brazilian agroforestry systems. For instance, Santos et al. (2004) found 15 Leguminosae tree species in seven agroforestry systems in the Amazon region, and Vivan (2000) found six species of Leguminosae in one agroforestry system in the south of Brazil. The use of different tree species with different characteristics is important in areas with large variation in the environment, related to hilly landscapes, different pedoforms and different solar exposure, such as the Zona da Mata (Freitas et al. 2004). Moreover, it is important in family agriculture, which needs multi-use and multi-function crop fields to constantly diversify production, reduce costs and increase economic benefits (Table 5). For instance, the use of nitrogen-fixing trees may reduce costs of fertilisation. One *Inga* tree can produce 33 kg of senescent leaves per year, with a total of 710 g of nitrogen (Duarte 2007). The nitrogen can be released and used by the coffee, depending on the mineralisation rate.

Although of huge value, there is little literature available on the characteristics of most of the tree species of the Atlantic Rainforest. To the best of our knowledge, most of the species were never reported as intercropped with coffee before. To help in the design and management of agroforestry systems and to increase the use of native species in agroforestry, research has to be carried out to study the environmental services provided by the trees. Their potential is not restricted to shading the coffee systems, but also associated with the enhancement of other ecosystem services such as increasing soil quality and water quantity and quality (Jose 2009). Besides the management of trees, managing the herbaceous strata is also important in agroforestry systems for production of mulch for soil cover and nutrient recycling, and for the diversification of the production.

The diversification of production, especially with edible fruit trees (Tables 2 and 3), contributes to food security and to a lower cost/benefit ratio of the agroforestry systems compared to full-sun coffee systems. Part of the higher production costs of full-sun coffee systems is due to the use of external inputs; at least three times more fertiliser is used in full-sun coffee than in agroforestry coffee systems (Cardoso et al. 2001). The use of herbicides is common in full-sun coffee, but absent in the agroforestry coffee systems. However, more in-depth studies on the economic aspects of agroforestry systems are necessary.

Considering that all trees listed in Table 3 are compatible with coffee, we suggest that the best five tree species to intercrop with coffee are *A. sellowiana, Inga* spp., *Musa paradisiaca*, *S. macranthera* and *S. mauritianum*, because they scored highest (Table 1) in the second hierarchical level of criteria mentioned in Fig. 2. We also recommend *P. americana* (avocado) because of its high value as food for the family and animals and as a cash crop (Table 5). Moreover, *Erythrina* sp., *Z. tuberculosa* and *L. grandiflora* were highly recommended by farmers with more experience with management of agroforestry systems, and we recommend *D. nigra* because it is an endangered species. However, these are only suggestions; the criteria and indicators established by a group of farmers are undoubtedly useful to other farmers, but the farmers' systems cannot be copied. Each farmer has to be able to adapt the choice of tree species and their management to the necessities of his or her system.

Conclusions

Selection of appropriate tree species is key to the success of agroforestry. The use of tree species with different characteristics is important in family agriculture, which needs multi-use and multi-function cropping systems, offering several ecosystem services, such as shade, improvement of soil quality, pollination and diversification of products. In order to profit from the ecosystem services provided by the trees, the ideal is to use the diversity of native trees as much as possible.

In order to manage complex systems such as is agroforestry, family farmers need to have sufficient autonomy to design, modify and adapt their systems. This autonomy is only possible if they have sufficient knowledge, which can be acquired when the methodology used to develop on-farm agroforestry systems is based on participation, allowing reflection and the exchange of knowledge among farmers, technicians and scientists.

Agroforestry systems have the potential to rehabilitate the degraded landscape such as in the Zona da Mata. With the agroforestry systems, it is possible to connect important remains of Atlantic Rainforest in the region, such as the Serra do Brigadeiro State Park and the Caparaó National Park. However, policy-makers have to recognise this potential and develop actions to use it.

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