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Are tropical agroforestry home gardens sustainable?

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ABSTRACT

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While tropical multistrata home gardens (or tree home gardens) are classically said to be sound, efficient and sustainable land-use systems, there is little quantitative evidence and detailed analysis of home gardens in the literature to support this. In order to strengthen the basis of this assumption and to contribute to an operational understanding of sustainability, a literature review was applied to home gardens, covering different bio-physical and socio-economic conditions. For this, a series of sustainability descriptors were identified, hypotheses formulated on what should be the effect of home gardens on these descriptors, and possible indicators confirming the hypotheses mentioned, when found in the literature.

Home gardens possess a number of sustainability attributes, with regard not only to their ability to meet a number of farmers' needs without negatively affecting the resource base, and in many cases even improving it, but also to their potential to meet several economic, social, ecological and institutional conditions which contribute to their sustainability.

INTRODUCTION

Many definitions have been put forward to define sustainability (see Brown et al., 1987), but there is not yet a clear agreement on what exactly sustainability is and how to measure it. As home gardens claim to have a number of attributes relevant to sustainability, it must be possible to identify and quantify these attributes. This would allow us to say whether home gardens are sustainable or not, and why, and would be a contribution toward an operational definition of sustainability.

Home gardens are agroforestry land-use systems with multipurpose trees and shrubs in intimate association with seasonal and perennial agricultural crops and livestock, within the compound of individual houses, and under

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the management of family labour (Fernandes and Nair, 1986). It should be noted that this definition applies only to home gardens with trees and that there are some home gardens which comprise only agricultural crops. A better name for agroforestry home gardens could be 'tree home gardens'. The term 'forest gardens' (or 'village forest gardens') can also be found in the literature but applies to gardens which are much larger, less densely planted and not so well tended as the home garden (see Michon, 1983). In some cases, there is a continuity between the different types of gardens.

Home gardens which are well known in many tropical countries, are classically said to be sound, efficient and sustainable land-use systems which fulfill the basic needs of the local populations, avoid environmental deterioration, etc. (e.g. Fernandes and Nair, 1986; Landauer and Brazil, 1990). Yet these assets of home gardens are seldom expressed through any quantified or functional analysis. In other words, one assumes that home gardens are sustainable without really having examined the evidence. If they are sustainable, what makes them so?

A FRAMEWORK FOR SUSTAINABILITY ANALYSIS

The following framework, which will be used in this article, is adapted from the 'Committee on Agricultural Sustainability for Developing Countries' (1987). It describes sustainability of an agricultural system as "its ability to meet evolving human needs without destroying and if possible, improving the natural resource base on which it depends". A sustainable rural production system is only one of the elements in the global concept of sustainability that includes a series of conditions outside the rural system that are classified as economic, social, ecological, political and institutional.

For an agricultural system to be sustainable, it should fulfill several main requirements. First, these are: (a) soil conservation, including erosion control and fertility maintenance; (b) the efficient use and conservation of existing resources (water, light, energy, genetic resources, labour); (c) the use of biological interactions between the different elements of the agricultural system (for example, mulching, the association of climbing plants and supports, nitrogen fixation, biological control of weeds and diseases); (d) the use of inputs that are easily available and of inputs and practices that ensure both human health and environmental conservation.

Second, and especially for the distinct case of small-scale farmers who depend both on cash crops and on subsistence crops, a sustainable system must fulfill stricter requirements, such as: (a) meet the farmers' energy needs (fuel, heat, labour); (b) meet the farmers' needs for subsistence, so that they may be assured of having an adequate and balanced diet; (c) strengthen cooperation between local community members; (d) ensure that social equity, cultural integrity, ethnic and gender issues are adequately considered. These requirements can help households withstand difficult periods caused by climatic or economic stress, improve living conditions in rural areas while bridging the gap between production seasons, take care of various social concerns and ensure the survival of traditional rural systems.

Finally, there are some external parameters that contribute directly to the sustainability of rural production systems. Some of these are: (a) the quality of infrastructures available to farmers (roads, irrigation, means of transport, etc.); (b) credit opportunities, with manageable risk conditions in case of production failure; (c) access to a minimum of social services (school, health facilities, family planning); (d) direct or indirect access to national and international markets, with prices that are favourable in relation to agricultural production costs.

SUSTAINABILITY INDICATORS

In order to be able to clearly describe attributes contributing to the sustainability of agricultural systems, it is essential to identify indicators which in turn would suggest the empirical data to test specific assumptions explaining sustainability. This procedure would permit evaluating and demonstrating scientifically whether a given system is sustainable or not and why.

Such indicators should be easy to measure, and be reproducible over time and across systems. An indicator gives the characteristics of a descriptor, chosen to be of critical importance to sustainability. Hypotheses can then be formulated to check whether the particular production system has a positive effect on the descriptor. If the system is not sustainable, the effect is negative. Different consequences can be observed from these positive and negative effects. Thus, the indicator is a measurement of the effect of the system on the descriptor.

For example, if one formulates a hypothesis that one of the sustainability attributes of a given system is the regular distribution of labour throughout the year, the descriptor is 'labour', and the effect of the system of this descriptor is that it does not induce any peak of labour but distributes it over the different months. The indicator of such a distribution is a table showing the labour units required per month over a year.

A first set of sustainability indicators must relate to the resource base. One descriptor, for example, is the soil: if the system is sustainable, soil fertility (among other factors) will be positively affected and indicators will be the organic matter and moisture content of the soil. A second set of indicators concerns the function of the system itself. These indicators will show whether, how and why the management and performance of the system are compatible with the requirements of sustainability. An example of a management indicator is the ratio of endogenous/exogenous inputs; if the system is sustainable, it will drive the use of inputs towards the endogenous rather than exogenous sources. An example could be the use of farmyard manure, as opposed to chemical fertilisers.

The last set of indicators focuses on other systems which may be influenced by the system under study. This is because sustainability is taken here in a hierarchical context: a sustainable agricultural system cannot exist without external factors also conforming to the requirements of sustainability, and a system which is sustainable influences in a positive way other systems with which it has relationships. For example, if home gardens in a given country produce a lot of fuel wood, there will be less encroachment into forest areas. So forests will be a descriptor, positively affected by home gardens, and an indicator will be the amount of fuel wood collected from forests compared with that from home gardens.

In the next section, relevant sustainability indicators are applied to home gardens. These are presented for different descriptors. They have been obtained from a survey of literature and are, unless evidence is sufficient, based on quantitative data. When no data were found to indicate the effect of the system on a particular descriptor, this is indicated. This review of literature does not claim to be exhaustive but is a first attempt to test the usefulness of sustainability indicators.

SUSTAINABILITY INDICATORS FOR HOME GARDENS

Resource base

Soil

Descriptor 1: soil erosion. Hypotheses: the multilayer plant cover protects the soil from direct impact of raindrops and the dense root system bonds the soil. As a positive consequence, erosion is generally low under a home garden. There can be, however, a negative consequence: if there is no understorey under the tall trees, the erosive power of rain may increase by coalescence of raindrops in high canopies.

Indicator: — rate of soil erosion. Low rates of erosion under home gardens were measured by Wiersum (1988) (0.06 t ha^{-1} $year^{-1}$ in Java), Krishnarajah (1984) in Wiersum (1988) (0.05 t ha^{-1} $year^{-1}$ in Kandy Sri Lanka). Such values can be compared with normally accepted values under farming conditions, e.g. the US Soil Conservation Service sets limits for tolerable erosion mainly in the range 2.2–11.2 t ha^{-1} $year^{-1}$, limits which are often not achieved (Young, 1989). Lundgren (1980) also reported less erosion under home garden than in adjacent forest in Tanzania. Many authors mention as an observation, but without measurements, that there is obviously litle erosion under home gardens, e.g.: Pelzer ((1948) Java, in Anderson (1979)), Anderson (1950, Guatemala), Balasubramanian and Egli (1986, Rwanda), Achutan Nair and Sreedharan (1987, India), Niñez (1987), Brierley (1985, Grenada), Christanty et al. (1986, Java).

Karyono (1990) reported that erosion under home gardens in Java is strongly related to the undergrowth and litter layers: measurements of erosion with litter and undergrowth, with litter only and without litter and undergrowth differed by factors of 2.5, 15 and 39, respectively. The importance of the undergrowth and litter to avoid erosion by big drops formed by coalescence on high canopies is stressed by Soemarwoto (1987, Java).

Descriptor 2: soil organic matter. Hypotheses: the abundant litter and root system of home gardens increases organic matter content of the soil. The multilayer root system retrieves nutrients from deep soil layers and litter releases them on soil surface. The recycling of wastes and making of compost also improves soil organic matter content.

As a consequence of these effects, biological and physical characteristics of the soil improve. The soil nutrient status (fertility) is enhanced because of the good decomposition rate of the organic matter favoured by high soil moisture content and, under warm climates, reduced soil temperature (see also Descriptors 3 and 4). Soil structure is improved by abundant organic matter; this increases soil porosity and aeration, hence the soil bulk density decreases and the cation exchange capacity (CEC) increases. A negative consequence of this mixture of many species is that some allelopathic effects can exist from litter and roots.

Indicators: — soil organic matter content and soil bulk density. A good soil organic matter content under a home garden seems obvious and is commonly mentioned but has never been checked and no data were found in the literature. The following references are observations rather than measurements. The ability of home gardens to maintain soil fertility has been mentioned by Anderson (1950, Guatemala), Balasubramanian and Egli (1986, Rwanda), Achuthan Nair and Sreedharan (1986, India) and Niñez (1987). Achuthan Nair and Sreedharan (1986) observe that this is owing to good nutrient cycling and use of waste materials in the home gardens and that soil physical and biological characteristics are improved as a consequence. They also mention that the mixture of other plants with coconuts in a home garden reduces the effect of the wilt root disease of the coconut. Christanty et al. (1986) observed in Javanese home gardens that crops with high nutrient requirements were planted near the garbage dump. Nair and Rao (1977) in Achutan Nair and Sreedharan (1986), observed a high rhizosphere microbial activity under home gardens in Kerala (India).

Descriptor 3: Soil moisture. Hypotheses: by intercepting and holding water through litter and plant cover, home gardens keep soil moisture at high levels. Run-off and erosion are also reduced by the plant cover and good conditions are created for the development of the soil fauna and flora. Climatic hazards (drought) are buffered by this 'sponge effect'.

A high soil moisture content is closely linked with the reduction of temperature by plant cover (see Descriptor 4) and the soil organic matter content (see Descriptor 2). A negative consequence is that soil pests and diseases may be favoured by high soil moisture

Indicator: — soil moisture status. No measurements of soil moisture under home gardens were found in the literature, but the observation that the soil is moist is common, e.g. Anderson (1950) and Niñez (1985).

Descriptor 4: soil temperature. Hypotheses: plant and litter cover reduce soil temperature by intercepting solar radiation. Soil evaporation is reduced and the daily variations of soil temperature are buffered. The low soil temperature is good for the biological activity of the soil: flora, fauna, fungi, symbionts which would otherwise not grow under high temperature and moisture stress.

Indicator: — soil temperature. No measurements were found in the literature. Niñez (1985) mentions that tropical multistrata home gardens maintain a constant soil temperature.

Climate

Descriptor 5: light. Hypotheses: light is utilised by several layers of vegetation, so the overall biomass yield of home gardens is high. Photosynthetically active radiation (PAR) decreases downwards in the canopy, and shade-tolerant crops can grow in the lower layers, but not the light-demanding ones. As a consequence, temperature decreases downwards and the resulting light and temperature microclimate is good for the seedlings and saplings of future tall trees. The albedo (reflected radiation) is low and the biomass/solar energy ratio is high.

Indicators: — understorey PAR, albedo, understorey temperature, and biomass yield per hectare. Christanty et al. (1980) in Soemarwoto (1987) noted the close resemblance of the light interception curve between a home garden and the tropical rain forest. In a Javanese home garden, Christanty et al. (1986) found that 20% of the incident light is intercepted by the top layer, 64% by the second layer, 10% by the third layer and that 6% of the light reaches the bottom layer; well-known shade-tolerant crops are found in this bottom layer.

Omta and Fortuin (1978) and Noor (1981) both in Soemarwoto (1987) noted the good photosynthetic rates of *Solanum nigrum* (leaf and fruit vegetable in Java) and *Xanthosoma atrovirens* (cocoyam) under shade in a home garden. A review of useful shade-tolerant crops and their agroforestry potential in different parts of the world (especially in Indonesia), has been made by Bahri (1984). Several shade-tolerant crops (e.g. ginger, turmeric, taro), are grown in home gardens in Bangladesh (see Abedin et al., 1990).

Descriptor 6: water. Hypotheses: rainfall is efficiently intercepted by the several plant layers, so water retention in the aerial parts of the plants is good and the impact of raindrops on the soil is reduced if there is an understorey of vegetative cover near the ground. Macroclimatic variations of air wetness are buffered under the canopy of the home garden. This is closely linked with water retention in the soil and the control of run-off and erosion (see Descriptors 1 and 3). Excessive air moisture may, however, favour the proliferation of pests and diseases.

Indicators: — undercanopy rainfall (throughfall, stemflow) and understorey air humidity. Nair and Balakrishnan (1977) observed in India the buffering effect of a home garden with coconuts and cocoa on the daily variations of relative humidity (and temperature) and on the evaporation, compared with an open field or a coconut monoculture. Baldy (1963) noted a high humidity in oasis as well as a high potential evapotranspiration. Niñez (1987) mentions that tropical home gardens maintain good air moisture conditions, but Leiva and López (1985) mention the risk of fungal diseases associated with moisture in home gardens in Guatemala. High pest incidence in home gardens is also mentioned by Amir and Ana (1980) in Christanty (1990) for Java and by Alvarez-Buylla et al. (1989) for Mexico. Amir and Ana (1980) in Christanty (1990) noted many insect pests in home gardens in Java, but they also noted the abundance of insectivorous birds controlling the insects.

Alvarez-Buylla et al. (1989) observed in southeast Mexico that favourable microclimatic conditions in home gardens allow for the growing of varieties with different microclimatic requirements and a management calendar much more independent of climatic fluctuations.

Biological resources

Descriptor 7: useful plants and animals. Hypotheses: a very high diversity of plants and animals are used in the home gardens. This is valuable for farmers' everyday life because it provides a high diversity of foods and incomes and should also be regarded as a valuable asset for future breeding programmes in the form of germplasm banks, the latter being relevant for long-term sustainability. There is good space and time utilisation by plants and animals with different biological cycles and growth forms. The high diversity of crops, the low density per species and the different biological cycles of the crops are all factors which reduce the risks linked with pests and diseases.

Indicator: — diversity of useful plants and animals (species numbers, diversity indices). The high diversity of plants in home gardens has been recorded by a large number of people and data are available from many parts of the world. Record figures are probably for Java where 219 (dry season) to 270 (wet season) different plant species have been recorded across home gardens of a west Javanese village of 41 households (Soemarwoto, 1987) or for southeast Mexico with 338 plant species growing (not necessarily planted) in the home gardens of southern Veracruz (Alvarez-Buylla et al., 1989). In Bangladesh, farmers grow 52 different tree species in home gardens (Abedin and Quddus, 1990).

Balasubramanian and Egli (1986) mention that local varieties of plants are well adapted to home gardens in Rwanda, and Thaman (1990) thinks that home gardens are the most effective avenues for the introduction and acceptance of new species. The preservation of wild fruits and other useful trees is mentioned by Alvarez-Buylla et al. (1989) for home gardens in southeast Mexico, where 15% of the woody plants are local wild species. In the tree gardens of the Yap Islands (Micronesia), Falanruw (1990) found 21 varieties of coconuts, 28 of breadfruit and 37 of bananas. Data on abundance of medicinal plants in home gardens can be found for many countries, e.g. southeast Asia, Mexico.

Few studies provide quantitative information on diversity of domesticated animals in home gardens, other than saying that animals are present. Alvarez-Buylla et al. (1989) mention an average of seven domesticated animal species by household in home gardens in southeast Mexico. Fish ponds are a common feature of home gardens in southeast Asia (Soemarwoto, 1987).

System

Technical management

Descriptor 8: inputs. Hypotheses: the use of endogenous inputs (e.g. mulch, manure, wastes, bio-control of pests) is optimised in home gardens and few exogenous, cash-demanding inputs are required.

Indicator: — inputs per hectare from farm and off-farm source. The following references are mainly of descriptive nature, as no detailed quantitative analysis of inputs in home gardens was found in the literature. Balasubramanian and Egli (1986) noted that farmers in Rwanda do not use chemical fertilisers for their home gardens. The same observation was made by Alvarez-Buylla et al. (1989) in Mexico, by Achuthan Nair and Sreedharan (1986) in India, by Alam et al. (1990) in Bangladesh and by Thaman (1990) in the Pacific Islands, the latter also for pesticides and other chemical products. Luu (1989) mentions the importance of coconut husks pits for the management of soil fertility in home gardens in Sri Lanka, while Leiva and Lòpez (1985) mention the use of home refuse for the same purpose in home gardens in Guatemala.

Thaman (1990) and Niñez (1985) observed that plant material for home gardens is obtained either by self-production of seeds or by vegetative reproduction of plants, so that no planting stock needs to be bought. Niñez also studied the capital and labour inputs for home gardens in Lima and concluded that they were very low. Finally, Alvarez-Buylla et al. (1989) mention that all harvesting in home gardens in Mexico is done by hand or home-made tools. In a survey of 482 urban home gardens in Papua New Guinea, Vasey (1990) found that no gardeners used tiller or other power implement for tillage, cultivation or any other task; none used herbicides or pesticides and few used chemical fertilisers.

Socio-economic management

Descriptor 9: labour. Hypotheses: little labour is needed in a home garden; this labour is well spread over the different seasons (no peak) and can be allocated in a flexible manner. Hired labour is seldom necessary. As a consequence, the farmer can work in the home garden when other activities in his farm are low. Family labour is used and the use of existing, traditional knowledge is optimised.

Indicators: — home garden labour requirement per month and flexibility (cropping calendar), home garden labour requirement per hectare, gender/age labour allocation for home gardens, use of traditional knowledge and practices in home gardens.

Several authors mention the low labour demand from home gardens in different countries, e.g. 1 h morning and evening in a 500 m^2 home garden in the Philippines (Sommers, 1982); similar values in Indonesia (Hariady (1975) in Christanty (1990)); 50 min day^{-1} in a 200 m^2 home garden in Lima (Niñez, 1985); 13–57 man-days $year^{-1}$ in Sri Lanka (Luu, 1989); 35–45 days of family labour $year^{-1}$ during the year of home garden establishment and 17–22 days during subsequent years in Mexico (Alvarez-Buylla et al., 1989). Ochse and Terra (1937) in Abdoellah (1990) mention that 7% of people's time is spent in home gardens in Indonesia for potential production of 44% and 32% of their total intake of carbohydrates and proteins respectively.

Ahmad et al. (1978) in Christanty (1990) and Christanty et al. (1986) observed that the pattern of labour in the home gardens and rice fields in Java complement each other over the year. It is a traditional saying in Java that there is no heavy labour in the home gardens (Christanty et al., 1986).

The flexibility of labour in home gardens is illustrated by Penny and Singaribum (1973) in Christanty et al. (1986) who mention that people with no off-farm work in Java concentrate labour on home gardens and get better yields than other farmers who usually give home gardens low management because of the higher priority given to paddy fields. Balasubramanian and Egli (1986) also mention the flexibility of labour in home gardens in Rwanda, as well as

Luu (1989) in Sri Lanka. In southeast Mexico, Alvarez-Buylla et al. (1989) found that weeding in home gardens is done during farmers' spare time and that the good microclimatic conditions in home gardens allow for a flexible management calendar.

In India (Kerala), Achuthan Nair and Sreedharan (1986) observed that labour demand is higher in the home gardens than in the rice fields but labour utilisation in relation to outputs is higher in the home gardens. In his detailed functional analysis of home gardens in Sri Lanka, Luu (1989) has found that the use of hired labour for home gardens is uncommon.

A correlation was found by Alvarez-Buylla et al. (1989) between the diversity of home gardens in Mexico and the labour force available from farmers' families. This indicates that, although home gardens are not labour demanding, they can easily be improved if labour is not a constraint. In this same study, mention is made of the use of traditional knowledge of biological processes (e.g. selective weeding) for home garden management.

In Bangladesh, it was found that there is a clear share of tasks between women and men for the management of home gardens: women are mostly involved in the pre- and post-harvest work of vegetable production while men play a key role in timber and fruit trees growing activities (Hussain et al., 1988).

Descriptor 10: cash. Hypothesis: home gardens need few cash inputs, so the farmers can either use their money for other purposes or survive with very little cash (subsistence strategy).

Indicators: — home garden cash inputs per hectare and home gardens cash input per month. Niñez (1985) reports that the capital input for a 200 m^2 home garden in Lima is US$ 2.80 per growing season (5 months). Yang (1976) in Thaman (1990) mentions that a family of five in Hawaii can save $ 1–20 day^{-1} in food costs from a 35 m^2 home garden. Bompard (1986) observed that the production costs for home gardens in Java are about 10% of the output while it is 30–50 for wet rice. Ochse and Terra (1937) in Abdoellah (1990) report that 8% of farmers' expenses in Indonesia are for home gardens.

Abdoelah and Marten (1986) calculated for Javanese home gardens that the ratio of cash output to cash input is higher in home gardens than in rice fields because of the low cash input and high sale value output of home garden products, although the net cash output m^{-2} is twice as much in rice. A similar remark was made by Danoesastro (1980) in Christanty (1990) who calcualated in Java that the cost of production in home gardens is 15.1% of the gross income, while it is 55.9% in the rice fields. Alvarez-Buylla et al. (1989) observed in Mexican home gardens that the whole technological package (tools, etc.) used in home gardens has a value of only 0.01–0.04% of the total annual family cash income.

Technical performance

Descriptor 11: bio-physical outputs. Hypotheses: overall biomass yield is high and nutritional value of varied products is good. Complete crop failure is very unlikely because of the high diversity of products in the home gardens.

Indicators: — biomass to solar energy ratio, nutritional analysis of diet provided with home garden products, and land equivalent ratio. The net primary production of a home garden in Java is reported by Christanty et al. (1986) to be about 1250 cal m^{-2} $year^{-1}$. No further references were found about overall biomass yield in home gardens, and the total bio-physical outputs are probably difficult to measure. The similarity of structure between home gardens and natural forests as observed by Michon et al. (1983), Torquebiau (1984) and Luu (1989) suggests a high biomass to solar energy ratio in home gardens, as has been measured in forests. Wiersum (1985) noted that a Javanese home garden can produce 7–9 m^3 of wood ha^{-1} $year^{-1}$; this compares well with growth rates obtained in plantation forestry.

In the Philippines, the nutrient recommended daily allowance is exceeded by a 500 m^2 home garden (Sommers, 1982). Abdoellah and Marten (1986) in Marten (1990) and Karyono (1990) found in Java that the nutrients in shortest supply in rice (vitamins C and A and calcium) are abundant in the home gardens. Marten (1990) found in Java that the number of crop species in home gardens is significantly correlated with nutrient production, especially vitamins and minerals. Thaman (1990) noted that the main staple foods in the Pacific Islands are obtained from the home gardens, while important dietary complements for children are obtained from home garden fruits in Mexico (Alvarez-Buylla et al., 1989). Similarly, the daily per capita consumption of animal products from home gardens ranges from 0.022 to 0.139 kg. In the Solomon Islands, a correlation was observed between vitamin deficiency and people without home gardens (Fitzroy (1981) and Willmot (1968) in Thaman (1990)). In Papua New Guinea, a 150 m^2 home garden supplies enough fresh vegetables for a family of four (Kesavan (1979) in Thaman (1990)). In Hawaii, a 35 m^2 home garden can provide 100% of the vitamins A and C, 50% of iron and 18% of protein for a family of five.

In Java, amounts of calories obtained from the home gardens (in percent of total calorie intake) vary according to authors and areas: 3.1% (poor people) or 8% (rich people) (Christanty et al., 1986) to 10.9% (Haryadi (1977) in Christanty (1990)) and to 44% (Ochse and Terra (1937) in Bompard et al., 1980); similarly for proteins: 4% or 9% to 5.2% and to 32%. These are quite high values, for a country where the diet is mainly rice-based.

No calculation of land equivalent ratio for home gardens was found in the literature. Data for these would be strenuous to collect, because of the high diversity of crops in home gardens, but would certainly yield interesting figures.

Socio-economic performance

Descriptor 12: socio-economic outputs. Hypotheses: outputs from the home gardens are diversified and distributed over time, and can be for subsistence, cash or re-utilisation into the home garden. There is flexibility to favour one or another kind of output. This provides a high safety factor against marketing and seasonality hazards, including the components of the home gardens which constitute a capital value for the farmer, e.g. timber trees. A drawback is that there is a small quantity of any given output. Besides, yields may be low during the early years of establishment of big trees; home gardens are theft prone and wandering animals may damage crops.

Sociological advantages of having a dense, tree-sheltered garden by a house relate to factors of socialisation for children and adults as well as opportunities for exchanges and interactions at community level and the preservation of traditional customs and beliefs.

Indicators: — value of production per hectare per month or year, value of production per household per month or year, cash income per hectare per month or year, and sociological benefits of home gardens.

The high diversity of products is a general feature of home gardens and is a natural consequence of the diversity of plants being grown (see Descriptor 7). Distribution of the production throughout the year in home gardens is mentioned by Anderson (1950) for Guatemala, Brierley (1985) for Grenada, Christanty et al. (1986) for Java, Kandaragama (1983) in Christanty (1990) for Sri Lanka, Alvarez-Buylla et al. (1989) for Mexico. Hysam et al. (1979) in Karyono (1990) observed a complementarity in time between home gardens and paddy field production in Java, which is probably linked with labour allocation for rice harvesting and indicates a good flexibility in home garden management as well as the role of home gardens in time of scarcity of other commodities. A similar complementarity is observed in Sri Lanka by Luu (1989), in terms of food balance, especially starchy products, and cash income.

Surplus of fruits or other subsistence products, including animal products, providing extra income to the farmers, is mentioned for home gardens in different countries, e.g. Philippines (Sommers, 1982), India (Abdul Khader, 1982), Mexico (Alvarez-Buylla et al., 1989).

In Lima, a 200 m^2 home garden provides 10% of the family earnings, plus the subsistence productions (Niñez, 1985). In Sumatra, the income from some fruit-producing home gardens is similar to the income from paddy fields (Bompard, 1986). In Java, Christanty et al. (1986) observed that the relative income from home gardens is higher for poor people than for rich people, and it ranges from 10 to 50% of the family total income (7–56% according to Soemarwoto (1987) and 0.84–54% according to Abdoellah (1990)), with 50% of the products being directly consumed (Ahmad et al., 1980). Karyono

(1990) reports that in some areas of Java, the income per unit area per year from home gardens can be higher than that of paddy fields. In home gardens in Sri Lanka, the self-consumption rate varies from 55 to 88% (Luu, 1989).

The favourable flexibility of home garden management is illustrated by Alvarez-Buylla et al. (1989) in Mexico, who found that the proportion of plant production sold or consumed varied greatly across home gardens in the same village. Michon and Mary (1990) noted in Indonesia that the price of fruits (mostly obtained from home gardens) multiplied by 10 from 1975 to 1983, while the price of rice multiplied by 2.4 only.

Ahmad et al. (1978), and Kimber (1973), both in Christanty (1990) observed that home gardens in Java are used for playgrounds and socialisation. Thaman (1990) calculated in the Pacific Islands that 64% of households with home gardens distribute harvest products to their friends and relatives. Abdoellah (1990) stresses the socio-cultural and aesthetic functions of home gardens, among which are magical and religious values, status symbols, role for socialisation and plants being used as weather indicators. Ritual practices associated with crop management are reported by Alvarez-Buylla et al. (1989) in southeast Mexico.

In a detailed survey of home gardens in Bangladesh, Abedin and Quddus (1990) found that the first piece of land developed by functionally landless farmers (i.e. owing less than 0.2 ha of land) is for a home garden. The same study showed that farmers never sell their home gardens before their croplands.

Impact on other systems

Descriptor 13: forests and reserves (other trees in general). Hypothesis: in countries with abundant home gardens, there are less encroachments into other areas for fuel wood collection.

Indicators: — amount of fuel wood collected from home garden and time spent in fuel wood collection.

Simon (1981) noted that 51–90% of the fuel wood collected in Java is obtained from home gardens. Byron (1984) in Singh (1987) noted that 70% of the sawlogs and 90% of harvested fuel wood and bamboos in Bangladesh come from the homesteads.

Descriptor 14: wildlife. Hypothesis: the complex vegetation structure of home gardens, microclimatic conditions and recycling processes allow them to harbour a number of wild plants and animals. This, nevertheless, can have negative effects in terms of crop predation.

Indicator: — density of wildlife species in home gardens per hectare. The abundance of spontaneously growing plants in home gardens is mentioned in a number of references, and it is common that such plants yield secondary useful products and have service roles. In Java, Karyono et al. (1978) in Christanty (1981) found 121 different bird species in home gardens in four villages, out of which 15 were endangered species.

Descriptor 15: rural industries. Hypothesis: the diversity of products from home gardens provides numerous opportunities for the development of cottage and rural industries. This creates jobs and off-farm employment and marketing opportunities for different products.

Indicators: — rural industries and their sources of raw materials. Achuthan Nair and Sreedharan (1986) observed in India that there are many opportunities for rural employment (cottage and canning industries) in areas with home gardens in Kerala.

HOME GARDENS AS AGROFORESTRY SYSTEMS

In agroforestry, there should be positive ecological and economic interactions between the trees and the other agricultural components. If such interactions are properly achieved, agroforestry can combine production and conservation objectives, such a combination being the very essence of sustainability. However, all agricultural research has in some way tried to control or minimise the risk and uncertainty effects of bio–physical factors, which is precisely the greatest explicit strength of agroforestry (Avila, 1989). Because of the intimate association of trees, crops and animals in home gardens, they qualify as a good example of agroforestry, though many of the interactions taking place in them are poorly understood. The different indicators found in the literature which confirm hypotheses about the sustainability of home gardens show that, complex as they are, home gardens do have a wide range of sustainability attributes.

These attributes can be summarised as belonging to the following main categories: (a) soil conservation, both the control of erosion and the maintenance of fertility (see Young, 1989), (b) modification of the microclimate, (c) diversification and distribution of production more uniformly over the year, (d) use of endogenous inputs, (e) management flexibility, (f) sociological roles, and (g) impact on other systems.

Much has yet to be done to improve home garden management in areas such as improved shade tolerance of different crops, successional stages of home garden development, increased yields, fertility management, etc. It would be useful if future research on home gardens could focus on the abovementioned areas, as well as on establishment methods for home gardens. This is because the usual claim that home gardens are sustainable concerns a stage when they are fully developed, i.e. after several years of existence. There is, however, a production gap due to the long establishment and gestation period in home garden development, before large size trees are fully productive. Different space and time combinations of trees and crops for home gardens have to be found for different agro-ecological and socio-economic conditions. The key for such combinations probably lies in the appropriate mixture of crops (both annual and perennial) which are fast or slow growing, small or large and shade tolerant or light demanding. The optimal crop mix for given nutritional needs is also a topic of importance (Marten, 1990). Recent successful examples of home garden establishment can be found in the transmigration sites in Sumatra, Indonesia (Suriamihardja, 1981) or in settlement schemes for farmers encroaching upon forest land in Bangladesh (Torquebiau and Abedin, 1991).

The role of the animal component in home gardens has also to be carefully studied, e.g. for fertility management, recycling of nutrients and wastes via compost, ponds and fish production, etc. Finally, home gardens can be promoted if associated rural industries using raw materials from home gardens are also developed.

As can be suggested by the comparison between Figs. 1 and 2, home gardens can exist in a variety of bio-physical conditions. Although they look extremely different in the two contrasting cases shown in these pictures, home

Fig. 1. A home garden in Sungai Samba, Kalimantan (Indonesian Borneo). Annual rainfall: about 4000 mm. Conspicuous tree species are: *Durio zibethinus*, *Mangifera indica*, *Cocos nucifera*, *Lansium domesticum*, and *Citrus* sp.

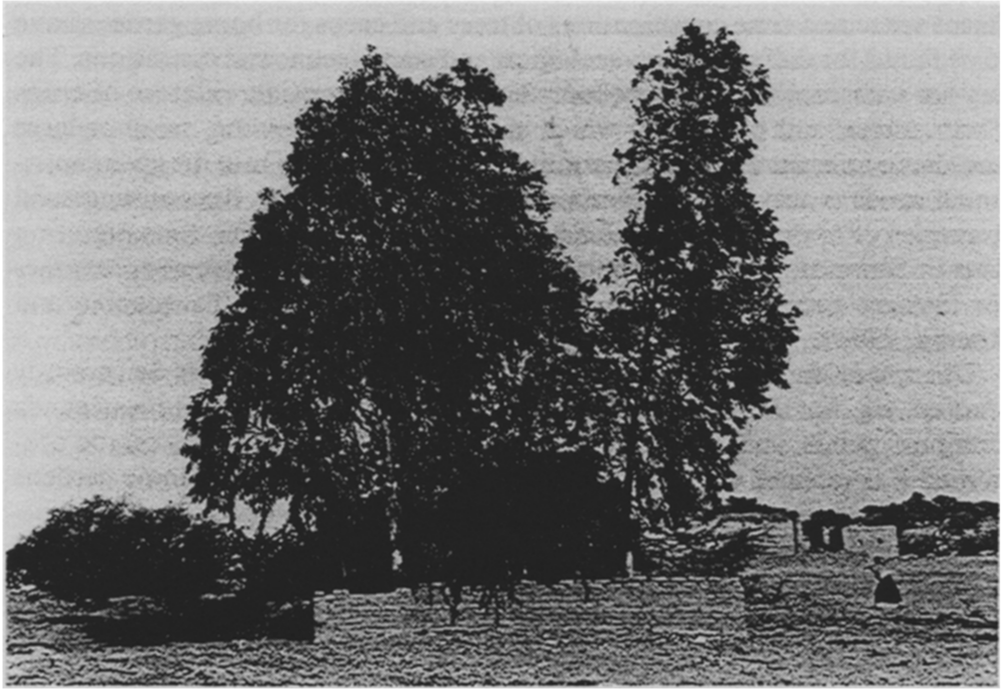

Fig. 2. A home garden ('jardin de concession ' or 'jardin de case') in Niger, near Tillabéri. Annual rainfall: about 400 mm. Conspicuous tree species are: *Eucalyptus camaldulensis* and *Prosopis juliflora.*

gardens always display a strong microclimatic difference in relation to their external environment. Such a difference arises from the intensive management of home gardens which is possible because of their small size and the use of day-to-day family labour. It can hence be suggested that home gardens, as eminently sustainable agroforestry systems, be promoted for a wide range of bio-physical conditions and not only for the humid tropics where they are presently prevalent (see e.g. Nair, 1989).

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