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Acacia albida and other multipurpose trees on the fur farmlands in the Jebel Marra highlands, Western Darfur, Sudan

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Abstract. This paper describes the traditional agroforestry systems based on *Acacia albida* and other multipurpose trees as practised by the sedentary *Fur* people on the lower slopes and highlands of the Jebel Marra massif, Sudan. The basic agrosilvopastoral system consists of terraced village fields, where semipermanent rainfed cropping of staple millet and other subsistence crops takes place under stands of multipurpose trees dominated by *Acacia albida*, *Cordia abyssinica* and *Ziziphus spina-christi*. Trees have been retained primarily for food, wood and fodder. Thorn from cut and browsed branches makes a good fencing material.

This system has been able to sustain self-sufficiency of a densely settled population over centuries. However, recent out-migration of people from the montane dry-farming areas has caused gradual return to shifting cultivation. As a consequence, the present-day subsistence farming in the region is characterized by a general level of carelessness and exploitative management and this is reflected in a successive decrease of the tree cover.

The evaluation of the AF practices described includes a discussion on their regional importance and extrapolability within the framework of similar situations, especially in Africa, emphasis being given to mountain and highland conditions. The outstanding potential for *Acacia albida*-based AF systems to be sustained and spread almost all over semiarid to semihumid Africa is highlighted by illustrating its ecologic and economic variability. Extrapolation of such examples, however, is not feasible, without thorough feasibility studies concerning the ecologic, ethnologic and socio- economic conditions in the respective project areas. Basic research needs for improving and extending the system are also indicated.

Introduction

The Jebel Marra massif is an isolated volcanic complex which rises up to 2000 m from the surrounding peneplain. The area has elevations of up to 3000 m a.s.l. and therefore moderate climatic conditions, contrasting with the Sahelian surroundings. At present the massif is inhabited by the *Fur* tribe who are negroid, sedentary hoe agriculturalists of still unknown origin. They succeeded earlier cultivators who could be traced back to neolithic times [3], and who presumably started to convert originally wooded slopes of the

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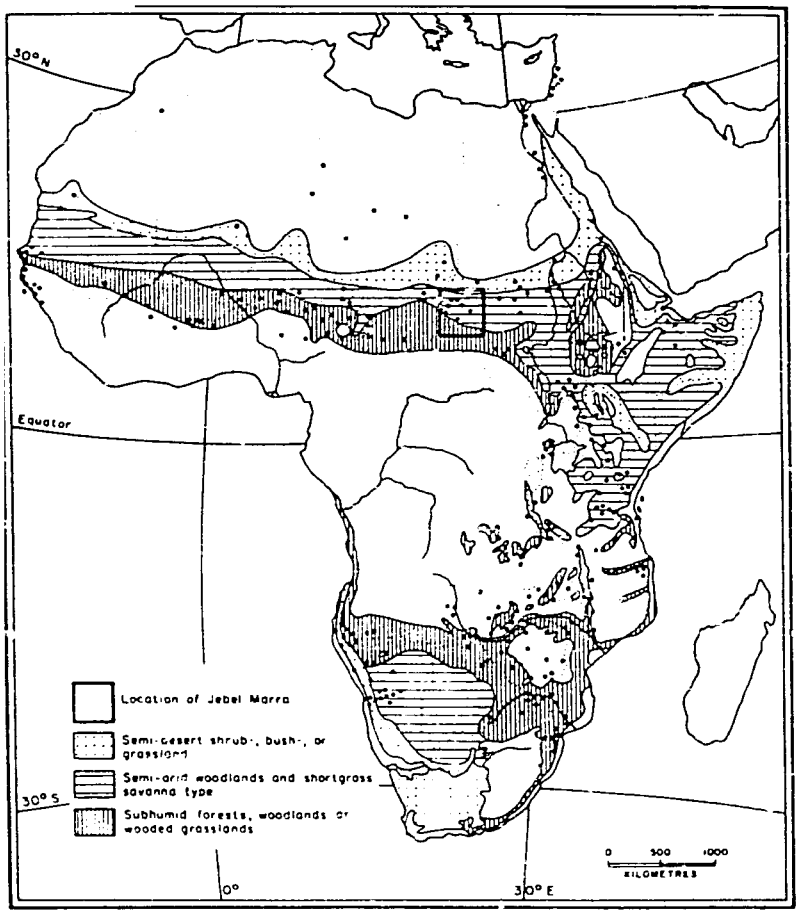

Figure 1. Distribution of *Acacia albida* in Africa and the Near East. Each dot indicates either a literature reference or a herbarium record at Kew. Information is inadequate especially from the francophone West Africa. The box indicates the location of Jebel Marra highlands. (Acknowledgement: re-drawn from Wickens, 1969, with kind permission).

mountains into the terraced anthropic landscape which is to be found nowadays almost over the entire area. Obviously there have been several drastic fluctuations in population density and type/intensity of land use, being caused mainly by climatic changes, historical events and epidemics. The population density (1976) in the Jebel Marra massif is about 20–37 persons/km^2 [30], so that more or less extensive types of land use, such as shifting of fields and (periodically whole villages) are predominant.

Semipermanent cultivation types with significant integration of trees and animals (agrosilvopastoral systems) are maintained only in small areas, where historic agglomerations of population are still densely inhabited. Here, *Acacia albida* may be the dominant tree component in the altitudinal range between 1,400 and 1,900 m a.s.l. This 'ideal farm tree' [26] has been the subject of several studies and scientific publications [12], and basic data are now available about its ecology and geographic distribution ([34]; Figure 1).

Most descriptions of *Acacia albida* agroforestry systems, however, refer to lowland localities in West Africa – especially Senegal and Bourkina Fasso. Previous investigations on *Acacia albida* in the Jebel Marra area – which were undertaken mainly in the course of the UNSF-Jebel Marra Project [11, 20, 35] – concentrate on the most conspicuous *Acacia albida* farmlands of the Wadi Azoum alluvial system in the pediplains west of the massif [36, 28]. In contrast to those riverine habitats, the special feature of the montane *Acacia albida* populations in the Jebel Marra massif is their zonal distribution in all topographic situations that have sufficient fine textured rooting substrate, thus seemingly independent of a perennial groundwater-table.

Although the mountain regions are of limited extent within the Sudano-Sahelian zone, these agroforestry systems represent a most spectacular, indigenous land-use system. Therefore, the Fur agroforestry systems are described here and the description is based on the field visits to selected villages in 1982 and 1983. The major scope of this paper is the evaluation of the Jebel Marra example within the framework of similar practices reported from other comparable (African) regions, in order to highlight the potential of *Acacia albida*-based AF systems in a wide ecological range.

2. General description of the area

2.1 Geographic location

The volcanic massif of Jebel Marra is located in the Western Darfur Province of the Sudan Republic almost in the centre of the African continent (12.5–14° N, 24.0–24.7° E), forming the watershed between the basins of Lake Chad and the Nile (Figure 1). Uplands and highlands with summits around 3000 m a.s.l. cover an area of at least 3500 km^2.

2.2 Biophysical environment

2.2.1 Climate. Arising within the Sahel/Sudan zones of the tropical margin, the Jebel Marra massif is characterized by a semi-arid climate with unimodal rainfall and a pronounced dry season of six months. The regional climate, however, is strongly modified within the massif; the average annual rainfall rises from c. 600–1000 mm, with maxima on the western flanks and on the highlands above 2,000 m a.s.l. The temporal variability of rainfall is reduced, and the effectiveness of rains is increased due to moderation of temperatures (lapse rate about 0.6 °C/100 m). The mean annual temperature in Koronga is c. 20 °C. Night frosts occur during the generally cloudless winter months. Frequent hailstorms are an important agro-ecological factor. The mean growing period in Koronga when precipitation exceeds potential evapotranspiration extends between July 5 and September 20, approximately 78 days [22].

2.2.2 Soils. The soils of the massif are poorly developed from basalt flows covered or interbedded with ashes, pumice and agglomerate. Regional characteristics are a tendency to acidity, negligible concentrations of soluble salts and very low $CaCO_3$ and low organic matter contents, wide C/N ratio, and a predominance of kaolinite clay mineral. The agricultural value of steep rocky slopes is limited by stoniness, but terracing brings about an efficient conservation of soils. The ash soils on which *Acacia albida* dominates are mostly deep and porous, have relatively high nutrient reserves (35 me P and 160 me K per 100 g) but low organic matter content (1%, C/N 13.6); are slightly acidic (pH 5.9) with relatively high values of cation exchange capacity (12 me/100 g) and base saturation (> 50% of CEC) [32]. Even though these soils may be classified as Andosols in a wider sense, they differ considerably from the dark, humic montane soils occurring under more humid highland conditions.

2.3 Vegetation

As a consequence of several thousand years of human occupation, the natural vegetation of montane woodlands and forests has been converted to savanna formations. At least 60% of the massif surface has been terraced, causing an initial or subsequent removal of the woody vegetation. The secondary vegetation established under the influence of frequent fires, woodcutting and grazing on abandoned ancient terraces resembles the 'savanna' types of unterraced land; the sub-montane zone (1200–1800 m.a.s.l.) below the thermic upper limit of most tropical lowland plants including sorghum and millet, constitutes the main area of rainfed cultivation. Secondary vegetation is characterized by short and tall grasslands, woodlands dominated by *Anogeissus leiocarpus, Combretum* spp. and *Terminalia* spp., with *Azanza garckeana* occurring as characteristic fallow pioneer. On remote sheltered basalt slopes, some *Khaya senegalensis, Dombeya quinqueseta* and *Cordia*

Figure 2. A general view of the prevailing land-use system in Jebel Marra: an example of Wadi Saria plateau (2300 m a.s.l.; ash-basalt mixed soils; February, 1983). Centre: modern, irrigated cash-cropping on re-cultivated, ancient terraces; taungya-like agrisilviculture (onions under young mango and citrus trees). Top left: rough grazing-lands dominate the highlands: *Acacia albida* trees can be found scattered there. Centre background: one of the *Cupressus lusitanica* plantations; these are low-yielding and have little contribution to the villagers' firewood needs. the summit region of the Jebel Marra (3042 m a.s.l.) can be seen in the background, extensive grazing is practised there.

abyssinicc, Erythrina abyssinica, Cussonia arborea, Maesa lanceolata and *Syzygium guineense* may also be found. The herbaceous layer consists largely of perennial Gramineae (*Andropogon, Cymbopogon* and *Hyparrhenia* species; *Heteropogon contortus* etc.). Between 1,800 and 2,300 m a.s.l., *Acacia albida* dominates and forms the transition to the proper montane zone; in the herb layer of this pseudo-climax, bracken (*Pteridium aquilinum*), *Hyparrhenia hirta, Themeda triandra* and tall *Andropogon* spp. prevail, and these are replaced by *Hyparrhenia multiplex* and other weedy annuals in heavily grazed areas.

Acacia albida extends into the montane zone, where a partially evergreen dwarf-shrub and 'tussock' grassland formation is combined with sparsely scattered evergreen trees and shrubs. *Olea laperrinei* and *Ficus palmata* (Saharo-montane and Afroriental flora elements) are the only woody species occurring above the proper limit of *Acacia albida* (2500 m a.s.l.). *Themeda triandra, Hyparrhenia hirta* and *Andropogon distachyos* are the dominant perennial grasses in this region whereas the dwarf-shrubs include members of Labiatae (*Lavandula pubescens, Satureja punctata*) and Compositae (*Conyza, Helichrysum, Gnaphalium* spp.) The percentage of ground-cover

by trees in the highlands above 2000 m is very low, usually below 5%. Figure 2 shows a general overview of the prevailing vegetation and land use in the Jebel Marra highlands.

2.3 Landuse systems

2.3.1 Agriculture. At present, only about 10% of the total area of the Jebel Marra massif is cultivated annually, the remainder comprises either steep inaccessible slopes and 'badlands', or fallow land which is utilized as rough grazing land. With this low degree of human occupation, the fire hazard is considerable all over the massif.

Rainfed, smallholder cultivation of the staple cereals is the predominant agricultural system in the region; millet and sorghum, grown up to 2,000–2,200 m a.s.l. form the daily diet 'asida' (a kind of porridge eaten with a vegetable sauce, usually enriched with some (dried) meat or curdled milk). Whereas livestock raising is less important in the Fur economy, irrigated (off-season) cultivation constitutes a traditional part of the smallholder production wherever perennial watercourses occur. In the olden days onion, tomato, and chilli pepper used to be grown irrigated for home consumption, and wheat as a cash crop. Only very recently (since c. 50 years ago), has the irrigation sector been drastically extended as a part of rural development projects. The introduction of cash crops such as mango, citrus, and guava as well as potatoes and other vegetables, and the improvement of infrastructure and marketing facilities transformed the Fur economy into an at least partially commercialized production system. The highland plateau above 2,300 m a.s.l. is almost exclusively cropped with cash crops such as potato, wheat, onion, and garlic. Minor traditional occupations such as hunting, gathering of honey (wild bees and/or beekeeping), insects and wild plants, cotton-growing and weaving, etc. are vanishing rapidly. Local salt production from saline soil around Koronga is still economically important within the massif.

The influence of agricultural extension activities on the traditional rainfed cultivation sector in the Jebel Marra massif has been negligible so far.

2.3.2 Forestry. Governmental timber plantations have been established on the massif since 1937, mainly on abandoned terraces, between 1200 and 2500 m a.s.l. (present extent: 1 151 ha; [22]. Main plantation species are *Cupressus lusitanica, Pinus radiata, P. patula, Grevillea robusta* and *Eucalyptus* spp. The plantations are managed in a rather haphazard manner; *Cupressus lusitanica* has been regarded a failure under the semi-arid climate of Jebel Marra, and the risk of fire could not be reduced. Apart from some part-time employment for plantation work, the forestry plantations are of little value for the local population.

In addition, 2283 ha of fallow land has been declared a forest reserve for conservation purposes, where cultivation, grazing and woodcutting have been restricted. Although grazing continues and fires still occur periodically, a noticeable regeneration of woodland has been achieved in the submontane part of the forest reserve.

2.3.3 Agroforestry

(i) Silvopastoral systems – These are widespread all over the Jebel Marra where livestock grazes in wooded grasslands. Occasionally transhumant Arabic herders enter the submontane zone at the end of the dry season in case the lowland pastures do not provide enough fodder, but those are regarded with mistrust and not welcomed by the mountain Fur (in contrast to the Wadi Azoum area, no manuring contracts exist). The stocking rate of livestock in the highlands above the millet-sorghum zone is rather low (1–13 LSU/km^2), and the fodder provided by the grassland is usually sufficient. Thus the *Acacia albida* trees, though locally abundant, are only occasionally lopped by the herders. Goats, however, climb up and browse all accessible trees and shrubs, even *Olea laperrinei.*

(ii) Agrisilvicultural systems – With the introduction of fruit trees to irrigated cropland, a 'taungya' type of agrisilviculture was developed by the Fur. During the establishment phase of fruit tree plantations, herbaceous subsistence and cash crops are interplanted on the same irrigated terrace fields: maize, sugarcane, onion, garlic, tomato, chilli pepper, okra, sweet potato, and herb spices are the usual crops.

(iii) Agrosilvopastoral systems – These are only maintained in the most densely populated areas of traditional rainfed cultivation.

3. Structure of the system

The AF system described in detail here consists of semi-permanently cropped village fields where the staple cereals are grown under preserved multipurpose trees, especially *Acacia albida.* The distant montane grasslands with scattered *Acacia albida* trees can be regarded as a supplementary subsystem of the main system described.

A good example of the *Acacia albida* system developed by the Fur cultivators in the Jebel Marra massif was studied in a 20 km^2 area in Koronga region (13 °N, 24.2 °E), extending between 1600 and 1800 m.a.s.l. in the submontane NW aspects of the massif. Average annual rainfall is estimated to be less than 800 mm. Close to the ground, night-frosts occur in winter. In comparison with the overall population density of 37 persons/km^2 in the Jebel Marra massif, the population concentration in this area is estimated to be between 120 and 250/km^2. Koronga holds a rather important position within the well-developed network of weekly markets in the area, especially for marketing of locally produced meat and salt. All goods must be transported by burden animals (camels, donkeys), but marketing facilities are fair. The nearest major supra-regional market is Nyertete, (1160 m), 10 km (trade) westwards, recently connected with the Province capital by an asphalt road.

Figure 3. *Acacia albida* trees on terraced fields. Note the regeneration of the trees on the lower terraces lying fallow that year. Also see Figure 7.

Koronga has one each of the few governmental schools and dispensaries within the massif. The village community belongs to the traditional District Lewinge, at whose disposal a certain area of rough grazingland in the Jebel Marra highlands is placed. These pastures are located above 2,000 m a.s.l. up to one day's walk away.

The village area itself forms a topography-dependent mosaic of more or less agglomerated compounds, village fields and uncultivated marginal areas, intersected by numerous valleys and ancient gullies with seasonal or perennial watercourses, where small irrigated orchards may be found. As sloping ground prevails, most of the village fields have been established on terraces stabilized by (basalt) dry-stone walls, whereas the compounds prevail on ash (plateau) sites (see Figure 4).

3.1 Components of the village fields

The commonly cultivated crops are bulrush millet (*Pennisetum glaucum*, sorghum (*Sorghum bicolor*), hot (chilli) pepper (*Capsicum frutescens*), cherry tomato (*Lycopersicon esculentum* var. *cerasiforme*), roselle (*Hibiscus sabdariffa*), groundnut (*Arachis hypogaea*), diverse beans, maize (*Zea mays*), fenugreek (*Trigonella foenum-graecum*), melons and squashes (Cucurbitaceae). Millet as the preferred food grain dominates on the light soils. Several local varieties are known which may be divided into two groups: a dwarf (90–130 cm) variety with many lateral shoots and a tall variety (210–295 cm) with few lateral shoots, 120-days growing period and even ripening [22];

Figure 4. *Ziziphus spina-christi* tree (on the right) that has been lopped to obtain fodder and poles. Note the straight growth of branches. On the left are some leafless *Acacia albida* trees (photo taken in August, 1982).

the former dominates within the mountains. Sorghum is only cropped in small quantities near the compounds to provide flour for brewing the local beer, which is also regarded as a staple food besides the millet porridge. Also maize (eaten unripe and slightly toasted as a relish vegetable in the 'hungry season'), groundnuts and cucurbits are cultivated in small scales around the huts, whereas peppers, cherry tomatoes, roselle, beans and fenugreek are the commonly associated minor crops on millet fields. They are grown mainly for home consumption (ingredients of the 'asida' sauce); some surplus may be sold on the local market.

Three main species of trees have been preserved on the actually cultivated village fields around Koronga (Figures 3, 4 and 5).

Acacia albida, followed by *Ziziphus spina-christi*, dominates over wide areas where the (terrace) soils contain large proportions of volcanic ashes. On terraced basalt flows and ash/basalt mixed soils, *Cordia abyssinica* may gain importance and dominance. Table 1 lists the principal uses of these trees. There are also some less dominant trees, restricted to fallowland and/or the compound areas, which are also of some importance in the Fur subsistence economy; these are also listed in Table 1.

The dominance of *Acacia albida* on village fields is explained by the cultivators in Koronga by its outstanding usefulness compared with the other trees around. It is primarily valued as a dry-season fodder resource. This is particularly important because the lack of adequate grazing-ground in the

Millet fields protected with thorn against animals that graze on uncultivated slopes and ridges. *Cordia abyssinica* dominates in the field, not seem to have affected the vegetative growth of millet (photo taken in the rainy season, in August 1982).

Table 1. Woody components of Fur village fields in Koronga and their uses

Dominant species	Characteristics and uses
Acacia albida	leafless during the cropping period: leaves/pods as animal fodder and green manure, branches for thorn fences; bark for medicinal purposes, ashes for tanning; branches and wood for fuel; fair regeneration
Cordia abyssinica	evergreen seasonal*; browse/dry-season fodder reserve, fruits eaten and boiled for syrup, sweets and drinks; wood for construction (furniture), most appreciated firewood; over-exploited, poor regeneration
Ziziphus spina-christi	evergreen; browse (goats, camels); excellent fire- and construction wood (poles for hut-roofing), thorn enclosures; fruits eaten; abundant regeneration; fallow invader; potential live fence (not planted as such in Koronga)
Less dominant species	
Acacia seyal	deciduous; browse, thorn enclosures; fallow pioneer
Acacia sieberiana	deciduous; pods and leaves excellent fodder for all stock; browse (important when *Acacia albida* is leafless and the grass layer not yet developed), thorn enclosures; esp. valley slopes
Anogeissus leiocarpus	deciduous; firewood (most appreciated besides *Cordia* and *Ziziphus*), construction wood (poles), leaves and bark for tanning, twigs for tea; over-exploited in Koronga but most common tree of submontane zone
Azanza garckeana	evergreen seasonal* fruits edible (boiled to syrup), browse esp. for goats; second most common tree species in the submontane zone; dominant fallow pioneer on basalt
Balanites aegyptiaca	evergreen, wood for fuel, writing slates and construction, thorn for fencing; leaves less appreciated as browse in Koronga; weedy invader of degraded sites
Dichrostachys cinerea	deciduous; browse (camels, goats); bark for ropes; reputed to improve the soil; common fallow pioneer (basalt)
Euphorbia tirucalli	aphyllous succulent; occasionally live-fence around the compounds; introduced
Ficus palmata	evergreen, fruit edible, bark for cordage, wood for fencing, hut-roofing and fuel in case of non-availability of other wood; restricted to the highlands (above 1800 m a.s.l.)
Ficus sycomorus	deciduous; browse for all stock, shade tree, common in the village area/on valley slopes
Ficus thonningii	evergreen, shade tree of compound area, browse, dry-season fodder for all stock; epiphytic germination on *Acacia albida* and *Cordia abyssinica*, kills the host

Dominant species	characteristics and uses
Khaya senegalensis	evergreen seasonal*; young leaves for fodder/ browsed; fire- and construction wood; over-exploited· almost disappeared from Koronga area
Olea laperrinei	evergreen; excellent fire and construction wood, browsed by camels, sheep and goats; highland pastures: above 1,900 m a.s.l.; overexploited
Phoenix reclinata	possibly once retained or cultivated palm (fruit, sweet sap, seedlings as vegetable); frequent in the valleys and occasional remnants in abandoned compound areas; present uses not known apart from goats browsing young leaves
Vitex doniana	evergreen seasonal*; fruit edible, browse for all stock; fuelwood; rare relics on basalt in reach of groundwater (ancient AF component? potential: fruit processing, flowers most attractive for bees)

*partial shedding of leaves or facultatively evergreen, or immediate succession of young leaves after shedding

village area is a limiting factor for raising domestic livestock. All farm-trees are heavily lopped, the crown frequently being reduced to a few, weak-regenerating shoots from the remaining main trunk. The regeneration potential is enormous, but dying of trees caused by the rather careless management is common. Usually children herding the village animals climb the trees and cut the branches in reach. Leaves and pods are browsed by all stock. The lopped thorny twigs and branches dry out and are later used for fencing the fields during the cropping period, after harvest being collected for fuel. Even though of low quality, the wood of large lopped branches and the trunk of dead trees is used for fuel and even for construction. Fences around the compounds traditionally consist largely of wood, mostly trunks, heaped on the remnants of former stone walls; these woody fences also serve as fuel reserves. Large less lopped *Acacia albida* trees are also kept in the compound area, being appreciated for their shade during the dry season. Even though the practice of collecting *Acacia albida* leaves for manuring the fields has been mentioned [34], this could not be observed in Koronga, nor being mentioned by its habitants. Very few of the present-day Fur cultivators seem to realize the fertilizing effect of *Acacia albida* on croplands; they ascribe the fertilization of the fields rather to the animals leaving their droppings in the shady places under the trees than to the trees themselves. Felling of *Acacia albida* trees is forbidden by law, but people seldom care about these restrictions at present on communal lands. In Koronga, only dead trees may be cut to use the wood. Theoretically, in the rough-grazing areas of the highlands lopping is free to all people with landuse right in the respective district, except in the section which has been declared a forest reserve. Nowadays, no religious taboos influence the attitude of the Fur people towards *Acacia albida*, even though this has probably been the case before islamization (15th–19th century), when spirits played an important role in their religious life. Some minor uses of *Acacia albida* have been reported [32], such as the use of bark for medicinal purposes, and occasionally to construct beehives, and ash for tanning. *Acacia albida* regenerates abundantly as a fallow pioneer on ash soils in Koronga – as well from seeds as from stumps or root suckers.

Ziziphus spina-christi, a weedy fallow invader in its spiny shrubby life form is widely distributed over the arid Sudan, often forming impenetrable thickets. In Koronga it attains the life form of medium trees (10 m) with well-developed trunks, which are valued as fuel and construction wood. *Ziziphus* is primarily retained for its wood: the straight branches are cut periodically, when they are long enough to form the basic construction for the thatched roofs of the round huts (see Figures 4 and 7). Smaller branches are lopped as dry-season fodder for camels and goats and later used for fencing. Though the species regenerates vigorously, it is prone to strong browsing pressure during the late dry season. Also heavy destructive cutting of fencing material and fuel affects its regrowth and encourages its shrubby life form.

The fruits are sweet and are eaten. They are collected by children and women, after having been blown to the ground by storms, and sold on the local market; they have once been important substitutes of sugar, made into various sweets and syrups before being replaced by sugar.

Fruits of *Cordia abyssinica* are also valued for this purpose: sweets prepared from pulp and nuts still form a delicacy during the Ramadhan; a mixture of fruits from *Ziziphus*, *Cordia* and *Azanza garckeana* makes an appreciated Ramadhan drink. *Cordia* leaves have been reported to be used for cooking and to ferment *Cleome viscosa* and other wild herbs used as ingredients for the 'asida' sauce. At present, the leaves of *Cordia abyssinica* are primarily appreciated as dry-season fodder for cattle. Thus, the more or less evergreen *Cordia abyssinica* trees are even more severely lopped than *Acacia albida*. In addition, the wood is most highly valued for fuel purposes; however, no advantage is taken of its potential for furniture and construction. Though often cut back to the trunk, *Cordia abyssinica* may regenerate from stump coppices. Fair regeneration from seeds has been observed on enclosed fallows, but due to its palatability it is most endangered on unprotected plots, where growing up to real trees is hardly possible under present conditions. In the Anglo-Egyptian period, *Cordia* was also protected by law, but plantation trials were given up mainly because the timber quality remained too low as to allow commercialization according to European furniture timber demands, and also because frost damages occurred [1].

3.1.3 Animals. Independent of the Arabic pastoral tribes of the surrounding plains, the Fur mountain dwellers keep a number of own animals, although they are less-skilled animal breeders

Cattle are kept mainly as an investment and saving. Cow milk (production: about 3 l per day) is a seasonal and minor constituent of the Fur diet. Only in case there is no time to visit the market (where nomads sell milk products) during labour peaks in the rainy season, small proportions of milk are taken from own cows, the majority being left for the calf. Cattle meat is sold on the market. The best males may be sold for breeding purposes; calves are never slaughtered or sold. Cattle also make a common proportion of the bride price. The dung is highly valued for manuring the fields. Number of cattle averages to 3 per family for the whole massif [30]; in Koronga, 3–10 were reported to be usual, with richest families owning 40–50.

The Fur cattle kept within the massif differ from the Zebu-type prevailing on the plains; they are somewhat smaller and have previously been characterized as 'poor' even though well-fed. But they are well adapted to cold and cold-wet conditions of the highlands, where the lowland type would suffer. Average stocking rates have been counted to alternate between 10 and 36 LSU per km² in the submontane zone, depending on whether the season is wet or dry [30].

Goats are kept by each domestic unit (average for massif: 5; in Koronga, 4 goats are the minimum). They are much more important for human nutrition (milk and meat) than cattle. Donkeys are commonly kept for riding and transport of (market) goods (1.4 per compound). They graze on the fallow plots of the village area and are additionally fed with sorghum during the working period. Horses and white mules are rather kept for prestige of the household head than as well-adapted burden animal. Sheep are kept within enclosed grazing grounds in the highlands, usually all over the year, and thus do not belong to the system proper; average (entire massif): 3 per family. The animals are sold and males eaten occasionally, especially on fesitivities as those following the Ramadhan. Poultry is usually kept in the compound area.

3.2 Arrangement and Interaction of components

The spatial arrangement of the components is indicated by the schematic projection given in Figure 6 and the photographs given as Figure 3, 5 and 7. Spatial structure is simple due to the limited number of components, which are arranged rather randomly, according to edaphic or topographic conditions. On the village fields, the only persistent feature is the presence of a tree canopy, with an average crown cover of 14% of the total area (range 5–30%), and reaching heights of 7–10 m.

Well-established terrace fields on ash soils have a tree density of 9 to 19/ha; these comprise mainly (80%) *Acacia albida* with an average height of 9 m and stem diameter (breast height) varying between 0.6 and 1 m. Trees often grow near the stone walls of the terraced fields, but are also retained on the flat portions of terraces. Most trees are mature to overmature, estimated to be at least 100–170 years old.

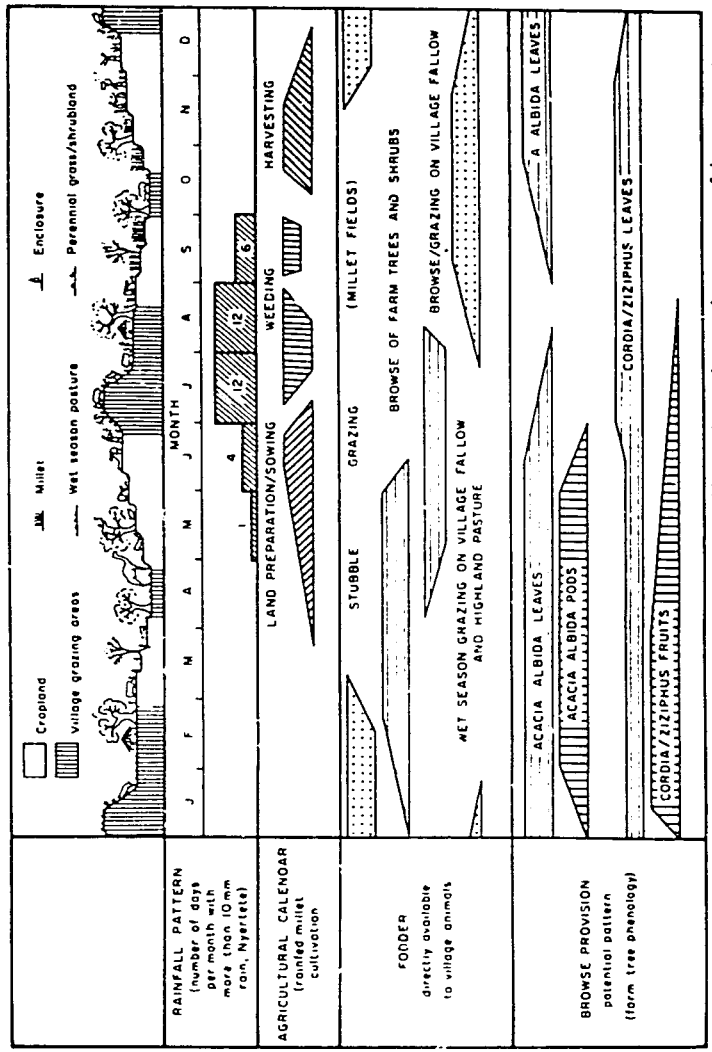

Figure 6. Schematic presentation of the agricultural calendar and temporal interactions and essential management of the components.

Figure 7. A dense stand of mature (or overmature), moderately lopped *Acacia albida* trees with millet underneath. No young trees have been retained in this field. In the foreground is a partially damaged granery building, for the roof of which Ziziphus poles have been used

The temporal arrangement of components is governed by the growing period of millet (90–120 days between July and October). During this time, starting in May with land preparation and sowing, the fields are protected from trespassing of animals by thorn fences. Donkeys, horses, some goats and lactating cows with calves graze on fallow plots during the day (herded by children or old people), returning to the enclosures at night; others such as horses, mules and camels are kept in the compound and fed with collected forage. The larger proportion of livestock migrates to the highland pastures, returning after the harvest (October-December) to graze and manure the fields.

The dispersal of seeds from *Cordia abyssinica* and *Ziziphus spina-christi* is largely due to birds and especially human consumption of fruits; but *Acacia albida* seeds pass the intestine of grazing animals. Feeding and germination trials in Khartoum [33] showed that the seeds remain up to six days in cattle's intestinal tracts, 66.5% being excreted undigested. The germination rates and durations are not much enhanced by this treatment. But during 6 days' rest of the seeds within the intestines, cattle may migrate over considerable distances. This fact explains the widespread anthropogenic distribution of *Acacia albida* (Figure 1) and is also assumed to be the reason for its common occurrence in the extensively grazed highlands of Jebel Marra.

Competitive interactions between the components are negligible. Since *Acacia albida* crowns are leafless during the vegetative growing period of millet, they do not shade the millet. The shade produced by the small persistant leaves of *Ziziphus spina-christi* trees is also sparse. *Cordia abyssinica* is the only farm tree with broad, large leaves which potentially produce very compact shade when fully developed in the wet season, but it is generally lopped to such a large extent that the crown is reduced to a few isolated branches (this is usually true for *Ziziphus* also) (compare Figure 5).

The extent of competition for water is not fully recognized yet. It might be negligible for *Acacia albida* because it has a reduced demand for water during the rainy season and later it utilizes water reserves from deeper soil horizons by means of its deep taproot.

Competition between trees is generally negligible because of their low density. But several adult *Acacia albida* and *Cordia abyssinica* trees have been observed to be adversely affected by *Ficus thonningii*, a shade- and fodder tree, which is usually confined to river banks, valley slopes and compound areas (Table 1). It germinates as an epiphyte and kills its host tree by strangulation and shade. Since *Ficus thonningii* is also a useful fodder tree, the farmers do not stop this process of infestation of *A. albida* by *Ficus*.

3.3 Management aspects

Under present-day conditions, the agroforestry techniques applied by the mountain *Fur* people appear to be rather poorly developed and exploitative. The most common attitude of the small-scale subsistence farmer is to produce his few sacks of staple millet in the easiest way. Thus, only traces of that skillful management well-known from other African tribes sustaining *Acacia albida*-based AF systems [12] may be found among the contemporary *Fur*. The trees are usually not protected or replanted nor are they properly managed.

The common cultivation practices are such that clearing, land preparation and sowing start in April/May when crop residues would have been grazed away leaving only the stalks, animal droppings, some trash and tree litter on the soil. The organic material is heaped on the terrace surfaces in distances of a few meters and burnt (to destroy seeds of weeds, earwings and blackworms). The ashes are dispersed and incorporated during the subsequent loosening of the soil, which only scratches the surface to a depth of 10–15 cm.

Simultaneously, the terrace walls are repaired by cleaning the field from eroded stones. The whole family is occupied with this work, especially at the onset of rains, when sowing (usually broadcast) is combined with tillage. All cultivation work is done with a short-handled hoe of which two types of blades are common, the pointed small one being used on stony soils and a larger truncated one on light soils. After germination, one or two weedings are made, which may be combined with intersowing and thinning. Weeds and remaining stools are pulled up and aligned on the periphery of the plot or heaped at the base of a tree, being used later as a manure.

Harvesting of millet starts in October and continues, due to uneven ripening, till December. Selected heads are cut with a reaping knife and collected, most stalks remaining on the plot. Successively, the thorn fences are removed to allow the animals to roam freely about the terraces for stubble grazing.

Information about the duration of cropping periods in Koronga varies considerably: soils basically derived from basalt are cultivated continuously for at least 10 years, e.g. 16–18 years/2 years fallow, whereas ash soils may be converted into fallow after 4–5 years for a period of 3–4 years. Effectively, at least those ash soils which are most intensively manured, may also be cropped semi-permanently. Crop rotations are not practised.

4. System functioning

4.1. Resource utilization

4.1.1 Land. Common sizes of rainfed village fields managed by one domestic unit vary between 0.62 and 1.25 ha, depending principally on the number of active persons and the degree of their other occupations. A maximum of 2 ha is said to be manageable by large or well-off families.

According to Sudanese law, the State is the ultimate title-holder to all land. Fields revert to the State if a plot lies fallow for more than two years, but more ancient ancestral systems of land tenure and heritage overlap and still govern the practices in Jebel Marra massif, where land belongs to those ancestors who were the first cultivators and is inherited by the collective group of descendants. The local chiefs as the representatives of the title-holding descent group decide about land distribution and allocation of usufruct (on the basis of need), which is principally of temporary nature.

A female child also inherits farmland, though only half of the male child's share. Fallow land (e.g. the rough grazing areas in the Jebel Marra highlands) is *de facto* divided up into four traditional districts confined to different Fur groups. Within each sector, grazing and wood-cutting are free to all members of the respective community, whereas cultivation needs the permission of the chief. Grazing rights are obtained through payment of annual head-taxes on animals to the State (represented by the chief). As the village fields in Koronga are semi-permanently cropped and the remaining fallows utilized as well, they have become effectively private lands, consisting of rainfed fields, the trees growing on them, orchards and 'salt-gardens' of the valleys, and enclosed fallow plots. Marginal areas such as uncultivated and 'waste' village lands and the supplementary grazing grounds, including their woody vegetation, are communal. Within the village areas, however, trees may only be lopped, harvested and eventually cut by their effective owners. Monetarization of land is actually still confined to irrigated (cash crop) orchards.

4.1.2 Labour. A special feature of the traditional *Fur* society is the economic independence of the individual. The expectation among *Fur* villagers is that each person will cultivate what he or she needs of staple food grains and earn what he or she needs of cash. Husband and wife have their separate grain stores and separate purses. Despite this situation, the 'family' is conveniently referred to as an economic unit in socio-economic analyses. An average family unit consists of seven persons. Women are responsible to care for the food of unmarried children, thus being forced to cultivate larger areas, but the general sexual division of labour is largely limited to the domestic sphere, where special female services towards men are expected besides fetching water, cooking or making beer. Women plaster the walls of the huts, clean the floor and share with their children the duty of caring for cattle and goats kept in the village area.

Men build in the hut and terrace walls, clear fallow land and thatch the huts. Until half a century ago, they also used to weave home-made cotton cloth. Only men trade as middle men and on auction markets and undertake long-distance transport, highland-herding and large-scale cash cropping. Administration and public life is also confined to men. Children participate in all agricultural and domestic work, especially collecting wood and herding village animals. Herding is done communally, the surplus of village livestock which is sent for wet season grazing to the highlands is united to communal cattle and sheep/goat herds.

Weeding represents the main bottleneck concerning labour availability, which, of late, is getting worse because the villagers have started managing additional cash crop fields in the highlands. On the later planted plots, weed control may therefore be inferior due to failed weedings. Thus, the maximum size of millet fields is limited by labour availability rather than land shortage.

Rough estimates run to 400 kg grain which may be cultivated per adult active habitant per year by means of labour (land preparation and sowing – 10 man-days/ha; weeding – 20 man-days/ha; harvesting – 20 man-days/ha; half of a man's labour and most of a woman's labour being tied up in millet cultivation in the rainy season [5, 22]. On the other hand, there is considerable underemployment during the winter months, especially in Koronga where orchards play a subordinate role, and no special handicrafts are being produced. Women, however, pursue their independent small business such as production of salt-cones and diverse ingredients for 'asida' which they sell on the markets.

4.2 Capital and inputs

Whatever little capital that is in the traditional rainfed cropping staple cereals is mobilized by sale of livestock. Besides, savings include grain surplus, which is kept in foodstores, and cash, which is secretly hidden in a pot in the ground under the hut. Investment, however, does not play a crucial role in Koronga, where subsistence economy prevails.

The only traditional investments for cultivation are blades for the hoes which are offered by smiths on the markets. Seed is taken from the 'savings' of the previous harvest.

Camel-drawn iron mouldboard ploughs, which have been introduced by 1965 on the piedmont plains and became widespread within the region, are of limited importance for the Koronga farmer because of the small dimensions of terrace fields. Nevertheless, a Koronga farmer reported that a maximum area of 4 ha (instead of the current 2) may be cultivated in a year by larger, well-off families if soil preparation/sowing and first weeding are done partially by ploughing. In 1982, a locally produced plough cost 50 Sudanese pounds but camel prices were between 300 and 800 Sudanese pounds*, and camels need much care and browse provision. Some farmers who do not own camels and ploughs hire them at the rate of 40 Sudanese pounds per ha in one cropping period (1982).

Piece and wage work is the dominant form of cash investment for those domestic units which need labourers in addition to the members of the family. Labourers are paid cash and provided with food, beer and tea during the period of work, which costs the employer (1982) about 80 Sudanese pounds per ha in one cropping period.

The largest amount of cash (or equivalents) is still spent, however, for social functions such as weddings (bride price: equivalents of about 400 Sudanese pounds), birth, naming, circumcision, funeral and religious festivities (e.g. haj).

4.3 Production

Information about crop yields within the sub-montane belt of Jebel Marra is scarce in contrast to the lowlands where extension activities and agricultural stations concentrate. According to the farmers' estimates, millet yields varied mainly between 3 and 4 sack per feddan (about 650–800 kg/ha) in 1982 which was a rather bad year agronomically. 'Good years' allow yields of more than 900 kg/ha. Production of millet straw in Jebel Marra massif in 1976 varied from 5.5 to 6.9 t dry matter per hectare, and that of sorghum straw between 6.8 and 7.5 t/ha, whereas the productivity of the highland grasslands was much lower (675–875 kg/ha; [21]). Production levels of the tree component have not been investigated. However, annual litter production of *Acacia albida* in Senegal in a population of 30–80 year-old trees was reported to be (in t per ha covered by *Acacia albida* crowns): leaves 2.5, flowers 1.7, fruits 5.4, wood and bark 1.9 [24]. Foliage production was between 50 and 100 kg per adult unpruned tree, and 12–20 kg for pruned trees [19]. Most estimates of pod production range between 10 and 75 kg per tree and year. As the adult trees in Koronga only reach half of the dimensions of those in the alluvial valleys, and are more intensively lopped, average production levels for both pods and leaves seem to be between 20 and 50 kg per tree annually.

* 1 US dollar = 0.4–0.5 Sudanese Pound (1982/83)

Table 2. Available data on chemical composition and nutritive value of the components

	Components Acacia albida									Crop residues		Herbaceous fallow/ montane grassland	
Fraction*	Young green leaflets with stalks	Flowers	Mature entire leaves	Pods only	Seeds only	Entire pods	Entire pods	Entire pods	Entire pods	Millet	Sorghum	below/above c. 1600 m a.s.l.	
Moisture content	63.7	82.2	8.6	8.7	9.4	6.0	9.2	8.0	6.7				
Caloric value												1824	1635
Crude protein	17.1	19.0	14.1	13.0	27.2	15.5	10.6	10.4	10.0	2.4	3.8	3.0	3.7
Digestible protein			12.8	7.7	19.7		9.8			1.2	3.5	2.4	2.2
Ether content (oil)	2.3	1.6	5.1	1.4	1.9	0.5	1.4	0.9		0.9	1.5	1.5	1.0
N-free extract	12.4	12.5	49.5	44.0	45.3	22.9	57.7	50.0	56.3	45.4	54.7	52.0	55.0
Crude fibre	59.7	57.2	14.7	28.7	12.2	57.0	26.7	27.4	33.1	43.4	29.2	38.0	35.0
Total ash	8.4	9.7	8.1	4.3	4.2	4.1	3.7	3.3	12.6	7.5	9.8	10.0	9.1
Soluble ash	6.7	7.8	1.7	2.9	1.8		3.4		12.3	2.6**	3.1**	5.6**	5.3**
Silica	0.6	1.9				0.43							
Calcium			1.8	0.4	0.4		0.7			0.1	0.2		
Magnesium										0.1	0.1		
Sodium										0.004	0.006		
Potassium										1.5	1.5		
Phosphorous			0.1	0.2	0.4		0.2			0.03	0.03		
Copper									0.1	3	3	2	2
Cobalt									1.4	2	2	2	2
Manganese									10.7	33	45	65	61
Zinc									11.8	12	32	37	23
Iron									21.4			460	366
Source	Boynes 1940	Boynes 1940	Wickens 1968	Wickens 1968	Wickens 1969	Boynes 1940	Russel 1947	Codd 1951	HTS 1977b	HTS 1977b		HTS 1977b	

*All are measured in percentage of weight except for Copper, Cobalt, Manganese, Zinc and Iron which are in parts per million, and the caloric value (in Kcal/g)

**HCL – insoluble ash

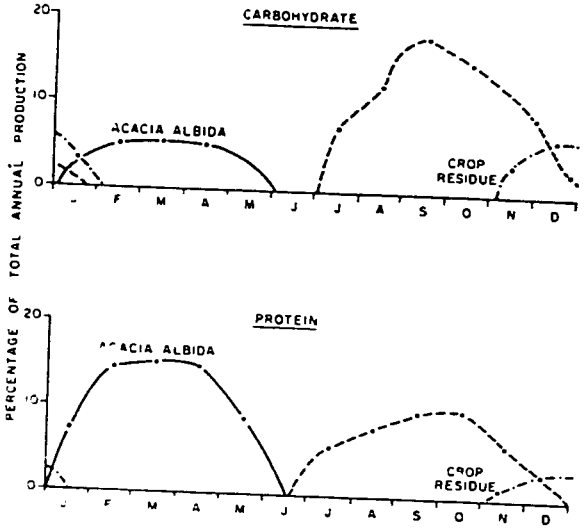

Figure 8. Seasonal availability of animal fodder in terms of carbohydrates and protein, estimated for the entire Western Darfur region. (Acknowledgement: Drawn after [36] with kind permission)

The chemical composition of the products of *Acacia albida*, using mean values obtained within Western Darfur [20, 21] and also from other regions, is presented in Table 2. Comparison between nutrient contents of *Acacia albida* products and the herbaceous components highlights the high absolute as well as complementary values of this tree within the system, due to the high protein contents of its leaves, flowers and fruits. Seasonal availability of carbohydrate and protein produced by the system components has been calculated in 1976/77, evaluating production data of the entire project area of Western Darfur, where *Acacia albida* populations of 20 mature trees per ha were estimated to cover 4% of the area [22]. Results have been presented by Figure 8, which clearly demonstrates the unusual maximum of protein availability in the mid- to late dry season, when most extensive livestock systems suffer from a severe lack of protein.

The diagram represents minimum values concerning *Acacia albida* in so far as foliage production has not been considered at all, probably because of lack of available, reliable data. As *Acacia albida* sheds its leaves in July, lopping will fill the fodder gap of June in Figure 8, as it is being practised in Koronga. Here, *Cordia abyssinica*, *Ziziphus* and *Ficus* leaves are still available during the critical period when *Acacia albida* would become leafless, the fallow herbs not fully developed yet and the fields not accessible to stock.

Table 3. Recent market prices of some commodities in Jebel Marra/Darfur. Prices in Sudanese Pounds: 1 US$ = 0.4–0.5 Sud. Pound in 1982/83

Commodity	1982/83* (drought)	1984** (severe drought)
cows (4 years-old)	max 200	
young camels	150–200	
adult camels	400–> 1,000	
sheep	50–70	40
goats (male)	max 20–30	6–10
(female)	15–60	
meat (1 kg, various qualities)	1.5–3	3
millet (1 kg)	0.5	max. (September) 2.5
sorghum (1 kg)	0.6	max. (September) 2.0
wheat (1 kg)	1.2–1.3	1.6
rice (1 kg)	0.7	3
oil (1 kg; groundnut and sesame oil)	max 4	5.7
tea (100 g)		1.4
sugar (1 kg)	1.5	3.3
sardins (1 tin)	0.85–1.1	
instant milk powder (full-fat, 300 g)	3.5	4
1 bundle firewood (10 kg)		0.4
10 poles		
Anogeissus leiocarpus, 1 m long/5 cm diameter	0.5	
1 pole *Eucalyptus*/*Cupressus* 6–10 m long, 10 cm diameter, (sold from plantation)	10.0	
wage work (per man-day)	3–8	

*prices during the rainy season 1982 and dry season 1983 within the massif; results of interviews with farmers in Koronga
**prices recorded in the piedmont and foothills of Jebel Marra (F. Ibrahim, pers comm.)

Even though quantitatively different, the production pattern shown by Figure 8 represents principally the sub-montane conditions in Koronga. It should be emphasized that the availability of crop residue and *Acacia albida* products not only depends on the season but also on the farmer's management (fencing and lopping measurements).

Animal production parameters are only available for the whole area of Western Darfur [36]. According to these sources, financial returns to labour come to 0.68 Sudanese Pounds per man-day for both sedentary millet and nomadic livestock production. The conditions in Koronga, where farmers manage their own livestock in an economic way, are quite different. The proportion between heads of human and livestock population is larger (about 1:1) compared with the lowlands (about 1:2), and livestock plays a minor economic role. Some prices recorded in 1983 on Koronga market are listed in Table 3. Agricultural returns for an average family in Koronga (1 man,

1 woman, 3 children) may be outlined as follows: in 1982 (low rainfall), the family harvested 1,530 kg millet from 3.3 ha of which they would keep 450 kg for home consumption and sell 1,080 kg at the rate of 0.5 Sudanese Pound per kg. The financial return per ha from millet production will thus amount to 164 Sudanese Pound (total: 541 Sudanese Pounds, if all cultivation work is done by the members of the domestic unit). From this income, taxes have to be paid as well as additional food (at least 1,000–1,200 kg millet per year) purchased; in addition, some reserves are needed for donkeys and horses and for seed in the following cropping period. However, eventual income from the sale of animals, irrigated cash crops, saltcones and processed agricultural products will provide additional income.

5. Systems dynamics

5.1 Shrinkage/Degradation of the system

A significant degradation and shrinkage of the system has already taken place as indicated earlier. The main causes are of socio-economic rather than environmental nature, although the former might have been accelerated by the recent drought. Monetarization, commercialization, and seasonal wage work cause initial inequality and destroy the traditional attitude towards local authorities, values, dietary habits and customs. As in other African areas, political security has caused the mountain population to move downslope. Due to rapidly increasing monetary values of wage and piece work, it becomes much more attractive for men to live on these occupations. Consequently, the most intelligent and innovative of the population leave those areas where farmers sustained this former intensive AF system, the remaining people switch over to simple extensive bush fallow or shifting cultivation practices, because pressure on land decreases.

The rate of system degradation and shrinkage is very difficult to assess in the area. Air photos are available over the past 30 years based on which some interpretation might be possible But this evaluation has not been done yet for the *Acacia albida* system.

The older inhabitants interviewed in Koronga reported that population densities have been much higher 50 years ago, and larger areas were cultivated continuously for more than 20 years. Despite the pronounced pressure on land, the density of farm trees was much higher whereas the species composition remained nearly the same. For the present decline of the tree canopy, the inhabitants have no explanation except the drought. This indicates that since the past 60 years, systematic tree preservation and propagation measures have not been practised, most of the present mature farm trees being older.

5.2 Sustainability

Even though the maintenance of the *Acacia albida* system in Koronga is not yet seriously endangered, the situation becomes more crucial with every dying or cut adult tree. If the present management continues, only coppice regrowth and small shrubs will remain. *Acacia albida* and *Ziziphus spina-christi* are not expected to face the danger of extinction, as long as regeneration and seed dispersal are abundant within the entire region. *Cordia abyssinica* is apparently more endangered.

The shrinkage of the montane *Acacia albida*-based AF system of Jebel Marra contrasts with increasing demands for agricultural land and animal grazing resources in the surrounding plains, where rapid growth rates of population in the plains force numerous *Fur* settlers back to the mountains again, or the present mountain population must produce grain in excess to provide the lowland population with staple food. The 1984 drought already indicated these tendencies.

Despite these promising preconditions for sustainability and extension of the actually relic *Acacia albida*-based AF system in Jebel Marra, is is sad that most of the knowledge and management techniques gathered, refined over the ages and handed down from generation to generation, have been forgotten with the passage of time. This and several similar cases among other African tribes show that this process is irreversible, and a restoration of AF techniques now depends on external initiatives.

Despite its weaknesses, the *Acacia albida-based* AF system of the Koronga area must be regarded as an optimal land use alternative in the submontane zone of Jebel Marra: it represents not only a productive and versatile agricultural system, but is also assumed to provide an effective protection and conservation of soil and water resources. In order to realize the full potential of the silvopastoral sub-system, lopping and herding practices should be more systematized. *Acacia albida* pods are storable and could thus be collected and kept as a fodder reserve. Potential production of wood within the system has not been assessed yet. The estimates available from Senegal show that 40–60 *Acacia albida* trees/ha produced 1.8–4.7 m^3 of harvestable wood per year, according to rainfall gradient and age of trees [23]. This means that 2–3 ha of cropland containing *Acacia albida* may provide the same amount of wood as does one hectare of a pure *Eucalyptus* plantation in the same environment.

The wood of *Cordia abyssinica* and *Ziziphus spina-christi* is of much higher value, and in view of the general wood demand within the region, considerable economic advantage could be taken of this potential. On the level of smallholder production within this AF system, the ideas and initiatives of the early forestry period in Jebel Marra, viz, plantation of indigenous *Khaya senegalensis* and *Cordia abyssinica*, could be revived.

Regeneration of trees, especially of *Acacia albida*, can be encouraged by systematic management. Single young trees or entire plots lying fallow must

be enclosed with thorn or grass mats, as is usually done with fields during the cropping period. Natural regeneration of *Acacia albida* and *Ziziphus spina-christi* is abundant enough to provide both seedlings and fencing material. For *Cordia abyssinica*, transplantation of seedlings may locally be necessary; but, once protected, it is reported to grow fast [7]. In case entire plots are kept enclosed for several years for soil and tree regeneration purposes, the fallow grasses may be harvested to obtain fodder, as is already a common practice in the dry season. During the wet season, the nutritional value of the grasses is much higher, but the labour bottleneck at this time probably hinders grass harvesting. From this point of view, direct wet-season grazing of fallow fields in combination with individual fencing of selected tree regrowth should be preferred.

In order to reduce labour peaks during the weedings, the introduction of camel-drawn chisel ploughs has been proposed [22]. In Koronga, about 50% of fields are estimated to be large enough, whereas the remainder of terraces are too small for an economic application of this technique.

6.4 Extrapolability

The *Acacia albida*-based AF system described here reaches its climatic limit in Jebel Marra at altitudes between 1900 and 2200 m a.s.l. (temperature limit of sorghum and *Pennisetum*). The uncultivated grasslands in the submontane and lower montane zones provide suitable areas for extending the system. The silvopastoral potential of this area has so far been underestimated and underutilized

The agrosilvopastoral system as practised on village fields in Koronga may be extrapolated to the montane zones (above 2000 m a.s.l.) with following variations of components:

- introduction of wheat to replace millet and sorghum above 2000 m a.s.l. Wheat is less appreciated by the *Fur* for preparation of the 'asida' staple, but is partly mixed with millet to prepare asida, or with sorghum to prepare the flat traditional bread ('kisra')
- Trees such as *Ziziphus spina-christi* and *Cordia abyssinica* may be extended to the highlands up to at least 2300 m a.s.l., where mature trees have been seen in the village areas. *Olea laperrinei*, adapted to higher altitudes, is another useful tree species. The tree is very resistant to fire, drought and grazing and its wood has outstanding value for fuel and construction purposes.

Considering a wider extrapolation of the Jebel Marra types of *Acacia albida*-based AF systems, the wide ecological adaptability of this tree must again be emphasized: although its natural occurrence was probably restricted to gallery forests, it is now spread all over the African savanna zones in the widest sense (Figure 1), in a wide range of habitats.

Although *Acacia albida*-based AF systems may have their largest potential in the drier savanna areas, where cattle play a major role, they are flexible enough to be practised almost all over Africa (and other continents?), adoptable to winter and summer rains, monomodal and bimodal rainfall regimes and tropical and sub-tropical climates.

Traditional AF systems similar to the Jebel Marra example occur in various other places also (Table 4), which also gives an idea of its potential extrapolability.

Acacia albida-based agrosilvopastoral land use systems thus appear to be well-suited for restoration, conservation and increase of productivity in degraded, overexploited African highlands. Even though such highlands cover a relatively unimportant percentage of land within the tropical Africa (6.8% above 1,500 m a.s.l.: [14]), they are favoured for their potential productivity.

6.5 Research needs

1) In order to improve the *Acacia albida*-based AF system as practised at present in Koronga/Jebel Marra, and to assess its true potential, the following data need to be gathered:

- basic hydrology of the ash- and basalt-derived soils prevailing in the area, in order to estimate the optimum densities of *Acacia albida* (degree of crown coverage limited by water supply?);
  effects of closed *Acacia albida* stands on agronomic factors affecting crop growth, and on crop yields, compared with open stands;
- productivity of *Acacia albida* (pods, foliage) under the specific conditions within the area; influences of lopping techniques and intensity;
- beneficial or competitive role of the other farm trees (*Cordia abyssinica*, *Ziziphus spina-christi*): their shading and fertilizer effect on crops, competition for soil moisture within those layers rooted by the crops;
- crops: selection and improvement of local millet varieties, trials with more systematic legume mixed cropping;
- animals: determination of optimum size and composition of village herds;
- labour: possibilities to rationalize weeding procedures; and
  socio-economic/ethnologic preconditions: assessment of the possibilities to introduce tree planting and protection measures by means of economic/ecologic motivation.

2) In order to transfer the system to the Jebel Marra highlands, it is essential to undertake:

- trials to assess the climatic (temperature/aridity) limitations for the tree components;
- agronomic studies concering the interactions between the highland crops, transferred trees, *Acacia albida* and *Olea* spp.,
- determination of effective carrying capacities of the highland pastures regarding different kinds of animals, without *Acacia albida* and with integration of lopping and browse utilization,
- socio-economic and technical considerations regarding the introduction

Table 4. Examples of present AF practices and remnants of historic cultivation systems in African and Afro-oriental mountain areas, which include the tree species dominant in the Jebel Marra Systems (from arid to humid climatic conditions, roughly)

Location	Tree species and uses	Source
Israel: Upper Jordan valley	*Acacia albida, Ziziphus spina-christi*: spreading on arable lands (root suckers, coppice regrowth)	Karschon (1961)
Cape Verde Islands: 200 m (NNE-expos.)/1400 m (SSW-exp.) – max. 1900 m a.s.l.	*Acacia albida* remnants on maize/beans crop'ands, at present silvo-pastoral overexploitation. *Ziziphus (mauritiana)* accompanying fallow invader. Very rare wild olives (*Oleu europaea*). All species may have been introduced by man	Chevalier (1935) Da Silva/Barbosa (1958) White (1983)
Yemen A.R.: - humid aspects, valleys 1000–2000 m a.s.l. - humid aspects, above Ibb, above 2500 m a.s.l	*Cordia abyssinica*: shade tree for indigenous (Mocha) coffee *Cordia abyssinica, Ziziphus spina-christi*: with *Acacia* spp. (other than *A. albida*) remnants of former intensive cultivation systems	Hepper and Wood (1979)
Cameroon (NW)/Nigeria (NE) Mandara Mountains, 800–1400 m a.s.l.	*Acacia albida, Ziziphus spina-christi* among many other trees preserved/cultivated on terraced millet/sorghum/legume fields; permanent cropping and stall-fed cattle, population densities reaching 300/km². *Cordia abyssinica* not mentioned, but might be present.	Hallaire (1976)
Sudan: Kordofan, Nuba Mountains 1000–1500 m a.s.l	*Acacia albida* (also grown as a live fence), *Ziziphus spina-christi* and *Cordia abyssinica* among many other multipurpose trees: similar to Mandara mountains (above).	Lebon (1965) Wickens (1968)
Ethiopia: Rift Valley, 1600–2200 m a.s.l.	*Acacia albida* abundant between 1800 and 2000 m a.s.l. and *Cordia abyssinica* in farmed parklands created by Galla and Arussi tribes: *Cordia* is orchard-like cultivated and retained on farmlands (natural montane forest remnants). *Zizlphus spina-christi* probably present as fallow invader.	Le Houerou (1980) v. Breitenbach (1963)
Nigeria: Jos Plateau 1000–2000 m a.s.l.	*Acacia albida* retained (or spontaneous fallow invader) in acha (*Digitaria exilis*) – millet cultivation of Biron-tribe, with cattle present (Fulani herders). Trees rare.	Gosden (1978)
Tanzania: - Mbeya-district, Southern Highlands Province, 750–1850 m a.s.l. - Northern District, 900–1900 m a.s.l. Mt. Kilimanjaro	*Acacia albida* on arable lands; regarded as an indicator of fertile soil. Shade tree for coffee *Cordia abyssinica* in Chagga homegardens as shade tree for coffee, fuel, construction wood, beehive construction. *Acacia albida* recorded at the northern flanks of Kilimanjaro	Wickens (1969) Fernandes et al. (1984) Wickens (1969) compare Figure 1
Guinea: Fouta Djallon 500–1500 m a.s.l	*Cordia abyssinica* in afro-montane forest remnants; utilization other than silvo-pastoral (Fulani cattle) unknown.	Aubreville (1950)

of rotational grazing/conservation of plots and fire control, in order to increase the woody resources in the area, besides the ecologic investigations mentioned above; and
- trials to develop optimal crop associations/rotations which reduce the weed competition (bracken-invasion).

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