General ecological features of miombo woodlands and considerations for utilization and management

Anders Malmer

Department of Forest Ecology and Management, Swedish University of Agricultural Sciences, 901 83 Umeå, Sweden, ph. +46 90 786 8416, Anders.Malmer@sek.slu.se

Miombo is a significant biome covering about 10% of the African landmass. Climate semi-aridity is the main edaphic determinant. Range of annual rainfall and dry season length is high, but the unimodal rainfall distribution is common for all miombo. Dry season fire is the other main determinant for succession of vegetation and soils in a stand-age time perspective. Soils, again, has a wide range in mineral properties, but the organic content is typically low with low nitrogen availability as a result of the frequent fires. Major environmental considerations for the use of miombo include the management of soil quality, water quantity & quality, fire, biodiversity and structural and functional changes induced by climate change. Organic matter, water and fire is discussed in general and as affect of miombo forest management. In general it is concluded that descriptive data for key ecological variables are lacking to apply process based modelling of soil development and water in complex miombo landscapes. Not least is this a problem for the understanding of miombo land use under climate change and the proper representation of the biome in regional and global modelling and policy formation.

1 Background

The understanding and wise management of miombo woodlands is crucial to a large part of Africa. It gives the livelihood to millions and is a distinct and unique biome. This review aims to give a basic description of miombo ecology and input to a scientifically based discussion on future uses and management of these complex woodlands and how to make more research to enlighten this discussion.

2 Defining Miombo

Miombo woodland is a significant biome covering about 10% of the African landmass (ca 2.5–4 million km² depending on definition, White 1983, Millington et al. 1994). Miombo can be found in most countries of Southern and central Africa and is the dominant forest component of Angola, Zambia, Tanzania, Malawi, Mozambique and Zimbabwe (Fig. 1). Miombo ranges of physiognomic and functional properties as well as within landscape spatial variation is high which makes definitions broad and overlapping with deciduous forests and open savannas. Frost et al. (1986)
gave a useful definition; "Those tropical and some near tropical ecosystems characterised by continuous herbaceous cover consisting mostly of heliophilous C4 grasses and sedges that show clear seasonality related to water stress. Woody species (shrubs, trees, palms) occur but seldom form a continuous cover paralleling that of the grassy layer.” However, there are many definitions and in common language terminology varies with terms like; woodland, bushland, thicket, wooded grassland and savanna.

Miombo trees are dominated by genera *Brachystegia*, *Julbernardia* and *Isoberlina* (*Fabaceae*, subfamily *Caesalpinioideae*). Miombo is also related to Sudano-Sahelian parklands which have the abundant genera *Isoberlina* in common. These eco-zones have for long time had strong human influence on structure of vegetation. While small scale shifting cultivation is dominant in miombo (Campbell et al., 1996), the parkland of West Africa is dominantly under more permanent traditional agroforestry systems (Pullan, 1974).

### 3 Edaphic Determinants

#### 3.1 Climate

Climate semi-aridity is the main edaphic determinant. Rain input is typically unimodally distributed (Fig. 2). However, high ranges (annual rainfall 55–1200 mm; length of dry season 3–7 months; mean annual temperature range 15–25 °C, Frost 1996) give way to division of into dry and wet miombo woodlands with wide floristic and functional differences (White 1983). The dry miombo is found in areas of less than 1000 mm annual rainfall. Wet miombo has higher tree height (typically > 15 m) and has higher floristic diversity. Wet miombo mainly occurs in the northern part of miombo distribution; eastern Angola, northern Zambia, south-western Tanzania and central Malawi.
### Geology and Soils

Apart from sections of inselbergs or escarpments geomorphology is dominated by old surfaces of low relief. In these areas the balance of weathering and erosion over long time has produced relatively deep soils (typically > 3 m, FAO 1974). Soils have a wide range in mineral properties but means of pH, cation exchange capacity and total exchangeable bases are low (Table 1, Frost, 1996). In general it has been argued that richer geology and mineral soils support more open Acacia savannas (Frost et al., 1986; Campbell et al., 1996), but miombo do occur on as wide soil groups as Ferralsols, Acrisols, Luvisols and Nitisols (FAO, 1974; Frost, 1996).

Table 1. Typical miombo top soil chemical properties and nitrogen contents of senescent leaves of N-fixing and non N-fixing miombo trees. After Frost (1996).

<table>
<thead>
<tr>
<th>Top soil contents</th>
<th>mean</th>
<th>range</th>
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<tbody>
<tr>
<td>CEC me 100g-1</td>
<td>7.6</td>
<td>1.8–25.1</td>
</tr>
<tr>
<td>Tot. exch. bases me 100g-1</td>
<td>4.7</td>
<td>0.3–20.8</td>
</tr>
<tr>
<td>Base sat. %</td>
<td>57.6</td>
<td>3–100</td>
</tr>
<tr>
<td>Exch. Ca %</td>
<td>2.7</td>
<td>0–15</td>
</tr>
<tr>
<td>Exch. K %</td>
<td>0.3</td>
<td>0–2.3</td>
</tr>
<tr>
<td>Extract P ppm</td>
<td>13.4</td>
<td>0–54</td>
</tr>
<tr>
<td>Carbon %</td>
<td>1.4</td>
<td>0.3–3.8</td>
</tr>
<tr>
<td>Nitrogen %</td>
<td>0.10</td>
<td>0.02–0.62</td>
</tr>
<tr>
<td>pH (H2O)</td>
<td>5.6</td>
<td>4.2–6.9</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Senescent leaves</th>
<th></th>
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<tbody>
<tr>
<td>Non N fix N %</td>
<td>0.6–1.8</td>
<td></td>
</tr>
<tr>
<td>N fix. N %</td>
<td>1.9–4.7</td>
<td></td>
</tr>
</tbody>
</table>
Top soil organic content is typically low (Frost 1996; Walker and Desanker 2004). Nitrogen availability is low as a result of the frequent fires and relatively slow decomposition from high acidity (Table 1).

### 3.3 Root Symbiosis

The strong dominance by *Caesalpinioideae* in miombo has not been fully understood, but a main reason is surely the widespread associations with ectomycorrhizae (Högberg and Nylund 1981). Poor soils and the loss of N (and P) by regular fire makes the mycorrhizal association an important advantage. Nitrogen fixing species are also important for replacing N lost. Like in other ecosystems N concentrations are considerably higher in leaves from N-fixing miombo species (Högberg 1996).

### 3.4 Fire a Principal Disturbance

About 1.3 million km² of fire adapted savanna and grassland burn annually in Africa (FAO 2001). Dry season fire is a main determinant for succession of vegetation and soils in a stand-age time perspective. Principal fuel for fires is the dry herbaceous layer and dry components of litter and top soil humus. Most mature trees and woody plants are fire resistant. This makes fire swift and relative C and N atmospheric losses moderate. Various amounts of fuel make fire contribute to the high spatial structural variability of miombo. Estimates of fire return intervals for miombo lies between 1.6–3 years (Frost 1996). Reliable studies of fire frequencies are scarce and it can be debated what is “natural”. Human use of fire has probably been part of fire impact for millennia (Clark and van Zinderen Bakker 1964). The increasing human impact today and changing vegetations (and fuel) make any estimate of what is “true” fire patterns very difficult (Malmer et al. 2005).

### 4 Environmental considerations for use and management

#### 4.1 Soil and Fertility Management

Management of organic material in soils is crucial for fertility. Harvesting, grazing and fire add to decomposition in reducing soil organic matter by reduced litterfall and oxidation. In miombo already low topsoil organic contents are typically reduced up to 50% by agriculture (Fig. 3). In the nutrient poor miombo soils top soil nutrient contents correlate closely with the soil organic matter contents (Fig. 3).

Soil organic matter also determines top soil physical properties. The soil structure determines water infiltrability and thereby to a large extent the fate of potential surface runoff, erosion and groundwater recharge/dry season streamflow (Bruijnzeel 1990, Malmer et al. 2005).

Soil organic matter management includes limiting biomass removal by grazing and harvest and/or bringing back organic matter in various forms as well as ensuring continued site biomass production by cultivation or by effective secondary succession (Malmer et al. 2005, Chidumayo and Kwibisa 2003).
Figure 3. Land use type regression of carbon and nitrogen density with depth (Bars denote SE, after Walker and Desanker, 2004)).
4.2 Water Quality and Quantity

Projected water demand and supply for Africa is problematic (Fig. 4). The role of forests for groundwater recharge is under long term scientific and policy debate (Bruijnzeel 2004). Tree based land use and reforestation improves soil quality, importantly infiltrability (cf. above), but good data for various tropical ecosystems is lacking (Ilstedt et al. in press). On the other hand regenerating forest is highly water demanding. Especially fast growing tree plantations of exotic tree species have been pointed out (Fig. 5). Recently it has also been confirmed that also indigenous first succession species are also highly water demanding (Fetene and Beck 2004). Under these circumstances expected increased groundwater recharge and stream dry season flows may be missing due to increased water use. In contrast to most modern tree plantations, or large tracts of secondary regrowth, natural mosaics of old growth forest and patches of regeneration probably in a suitable way distribute the high water demand over the landscape in a less dramatic way.

Studies of water use by miombo woodland is virtually non existent. Studies of soil physical properties as well as water use of complex miombo stands would be desirable both for the understanding of this important biome as well as for the understanding of modern, tropical and complex landscapes with various land use.

4.3 Fire Management

Typical Miombo fires are mostly swift and instrumental in forming regeneration and structural patterns. However, late dry season fire and fire in stands protected from fire (with higher fuel load) may be problematic for soil quality development and mature trees. All around the tropics increasing fires promotes fire climax successions and soil deterioration (Malmer et al. 2005, Chidumayo and Kwibisa 2003). This has fostered a general negative policy formation against the use of fire. Among the negative side of fire use is the losses of carbon and nitrogen to the atmosphere, reduced soil protection after fire, effects on water and air quality and successively deteriorating soil structure and fertility with repeated fire. However, in dry season ecosystems, controlled early dry season fires reduces the risk of devastating fires when biomass is allowed to accumulate for longer times (Fig. 6). Fire also releases nutrients tied up in less decomposable organic matter and prepares soil for seed germination. Many tree species seeds are dependant on fire for germination. In a long term perspective of management of complex miombo stands, fire will have to be handled by prescribed fire or by fire prevention or possibly by the combination of both. However, applied research and trials are urgently needed.

5 Conclusions

In general it can be concluded that descriptive data for key ecological variables are lacking to apply process based modelling of soil development and water in complex miombo landscapes. Not least is this a problem for the understanding of miombo land use under climate change and the proper representation of the biome in regional and global modelling and policy formation.
Figure 4. Predicted water availability in African countries.
Figure 5. Lower monthly mean daily runoff by eucalypt plantation compared to pine plantation and grassland in Sao Hill, Tanzania 1981 – 1989 (Mhando, 1991)

Figure 6. High biomass accumulation in fire protected plot in dry forest woodland in central Burkina Faso.
References


