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Silvicultural prescriptions for management of woodfuel species

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1.0 Introduction

Woodfuel is a widely used energy source of the world. More than 50% of the world's annual wood production is utilized as fuel and of this 90% is used in the developing countries ("ref"). There is high demand for woodfuel for domestic and export markets. In Ghana, majority of households (about 80%) depend on woodfuel for cooking and water heating in addition to commercial, industrial and institutional use. The demand for woodfuel has for the past years been on the increase. In order to sustain this demand, better management of woodfuel from the natural forest or through woodlots and plantation establishment is imperative.

An ITTO funded project on 'Rehabilitation of degraded forests for sustainable woodfuel production and climate change mitigation in the forest-savanna transition zone of Ghana' seeks to develop silvicultural prescriptions for the management of woodfuel resources in Ghana. The project has supported farmers in the Kintampo Forest District in the establishment of woodfuel test plots using eight species suitable for woodlot production. The aim is to sustain wood energy production and supply for both the domestic and export markets and also for restoring the degraded lands in the forest savanna transition zone of Ghana. This report seeks to determine the silvicultural prescriptions for management of the eight planted woodfuel species. The report was put together by undertaking desktop research from online databases on plants, books, journal articles and other publications.

The report consists of three (3) sections. In the first section an introduction to the study together with the objective and methodology are stated. Section two presents silviculture practices (Seed production, propagation and planting, plantation maintenance and rotation and harvesting) on each of the eight planted species. In the final section, conclusion and recommendations are presented.

2.0 Silvicultural practices of planted species

2.1 Acacia mangium

2.1.1 Seed production

Seed collection

Acacia mangium starts to flower and produce seeds 18–20 months after planting (National Research Council 1983). The flowering and fruiting seasons differ according to geographical location. In general, fruits mature 5–7 months after the flowering period. The fruits are ready for harvesting when they change to dark brown and begin to crack open. Harvesting of fruits is done by clipping the fruits from the trees with pruning poles. Ideally, fruits are harvested before they are fully open, (Bowen and Eusebio 1981 *in* Adjers and Srivastava 1993), although pods with hanging seeds remain available on the trees for several weeks.

Seed Preparation

The pods of *A. mangium* should be processed as soon as possible after collection. Many techniques are used to separate *A. mangium* seeds from their pods. Seeds can be extracted manually after sun-drying for several hours (24–48 hours) until the pods turn brown/black and split. The drying temperature should remain below 43 °C to avoid loss of seed viability (FAO 1987). Seeds can also be separated from the pods after drying by turning them for 10–15 minutes in a cement mixer with heavy wooden blocks. Another method is to put the dry pods into sacks and then beat them in a mechanical thresher. The seeds are then sieved clean of pod debris and winnowed by hand or machine to remove chaff.

Seed storage and viability

Storing the seeds of *A. mangium* is relatively easy. Once the seeds are dried (to 6–8% moisture content) and placed in an airtight container, they maintain a germination of 75–80% for several days (National Research Council 1983). Good storage protects the seeds from high temperatures, light and excessive oxygen. FAO (1987) recommends storing *A. mangium* seeds in sealed, air-tight containers in a refrigerator at a temperature of 0–5 °C. Supriadi and Valli (1988) *in* Adjers and Srivastava (1993) recommend using clean jerrycans or small jars that can be closed tightly. According to Evans (1982), *A. mangium* has long seed viability under almost any conditions if seeds are kept dry and free from insect and rodent damage. Before sowing, seeds should be placed in boiling water for 30 seconds, and then cooled by soaking in cold water for 2 hours. Germination may begin after 1 day and continue for 10–15 days (Adjers and Srivastava 1993).

2.1.2 Propagation and planting

Sowing

Seeds may be sown in seedbeds and transplanted 6–10 days after sowing. However, the recovery rate using this method is only about 37%. Sowing in germination trays and transplanting the seedlings 6–10 days later, when the radicle emerges, leads to more than 85% recovery (Adjers and Srivastava 1993). Another option is direct sowing in containers followed by transplanting to maintain 1 seedling per container. As direct sowing reduces the cost of seedling production and has minimal risk of root deformation, it is commonly preferred by many tree growers (Adjers and Srivastava 1993). This method requires good-quality seeds with a high germination percentage. FAO (1987) recommends placing several seeds in each container: 3 seeds per container if the germination is 30–50%; 2 seeds per container if the germination is 51–80%; and 1 seed per container if the germination is more than 81%. Direct sowing should be carried out under shading net, as only light shade is suitable for *A. mangium*. Seeds should be covered after sowing. Suitable materials such as coarse, washed sand, crushed rock or gravel prevent damping-off, allow rapid emergence of the cotyledon and provide good air exchange and water drainage (FAO 1987).

Preparation for planting out

Adequate moisture and a suitable source of fertilizers are essential for good seedling growth in the nursery. Excessive watering can result in watery seedlings, whereas insufficient watering can lead to stunted seedlings (FAO 1987). The watering schedule will depend on the temperature, rainfall, air humidity, evapotranspiration, wind velocity, tree size and substrate. NPK fertilizer is generally applied 10 days after transplanting and twice weekly in the nursery (Adjers and Srivastava 1993). After applying fertilizer, light watering is necessary to wash any fertilizer residue off the leaves. Seedlings are usually retained in the nursery for 12 weeks or until they have attained a height of 25–40 cm. Srivastava (1993) recommends 2 root prunings and hardening off of the seedlings before planting out.

Planting

Seedlings are planted manually during the rainy season on freshly prepared sites, on which the recommended spacing has been marked out. Seedlings are planted in contour lines on slopes and in straight lines on flat areas. After its polythene bag is removed, each seedling is carefully placed into a planting hole of about 13 cm in diameter and 20 cm in depth (Srivastava 1993).

Spacing in plantations depends on the intended uses and soil fertility. Initial spacing can vary from 2×2m to 4×4m. For fuelwood production where form may not be important, seedlings should be planted at wider spacing to produce multi-leaders and heavier branches, which may result in higher volume (Srivastava 1993), although it may increase harvesting costs. Dense planting for the production of saw logs reduces the incidence of large branches and the inherent risk of fungal infections (Weinland and Zuhaidi 1991 *in* Srivastava 1993).

2.1.3 Plantation maintenance

Weeding

Weeding in *A. mangium* plantations is recommended to remove climbers, creepers and vines, but less harmful weeds can be left in the field to maintain lateral competition. The first weeding should be done 2 months after planting out, according to Udarbe and Hepburn (1987) *in* Srivastava (1993). The number of follow-up weedings will vary for each site. In areas where *Imperata* has a strong hold, weeding should be done frequently; for example, the area surrounding each seedling is often cleared at 1.5, 3 and 5 months, and weeds between rows are slashed at the third month (National Research Council 1983).

Fertilizing

On most sites, *A. mangium* trees have shown little response to fertilizer and *A. mangium* plantations are usually not fertilised (National Research Council 1983). However, 100 g of rock phosphate is usually placed in the hole at the time of planting, and on extremely poor soils. Simpson (1992) *in* Srivastava (1993) reported that application of suitable fertilizers in adequate amounts (e.g. 100 kg/ha N, 50 kg/ha P and 50 kg/ha K) has great potential to increase early growth of *A. mangium*. Depending on soil and other site conditions, the type and amount of fertilizer may vary.

Replanting

A survival count usually takes place 1 month after planting. Replanting is usually done for any dead seedlings. Replanting normally takes place in the rainy season at 1–2 months after planting. Srivastava (1993) reported a generally high survival of *A. mangium* after planting; on favourable sites it can reach more than 90%.

Singling and pruning

Acacia mangium seedlings grown in fairly open conditions and on good sites often develop multiple leaders. In addition, the species has a poor self-pruning ability. Therefore, singling and pruning are necessary in an early stage of stand development if the aim is to maintain full growth potential and produce good-quality timber (Mead and Speechly 1991). However, singling and pruning are usually done only in plantations where the objective is to produce quality saw or veneer logs. Singling usually starts at 4–6 months after planting before the trees form heartwood. Pruning begins after the first year of establishment (Srivastava 1993). Pruning is usually done in Year 2 up to 2–3 m, in Year 3 up to 5 m, and in Year 4 up to 7 m. The branches should be pruned before reaching 2 cm in diameter to avoid fungal infections, especially heart rot (Srivastava 1993). In agroforestry systems, branches are usually pruned regularly to prevent competition with agricultural crops.

Thinning

The decision whether to thin for *A. mangium* plantations is based primarily on product objectives. If pulpwood production is the sole objective, there is no restriction on product size and thinning is therefore not necessary. Thinning is necessary only when the trees are grown to produce sawn timber and veneers. The optimal number of thinnings during a rotation increases as initial stand density increases. In most cases, only a single thinning is optimal. In cases where conducting multiple (2) thinnings is the optimal management option, the second thinning is conducted 2 years after the first thinning. Optimal single thinning regimes involve removal of 30–60% of stems, and optimal multiple thinning regimes always remove 50% of the stems. Optimal intensity of thinning is heavier in stands of higher stand density. For high-density stands, 60% thinning is generally optimal, whereas for medium-density stands optimal thinning intensity is about 40–50% (Krisnawati 2007).

Control of pests and diseases

In general, *A. mangium* is relatively free from serious diseases and pests (Mead and Miller 1991). Surveys to evaluate diseases in tropical Acacia plantations have concluded that heart rot, root rot and phyllode rust (i.e. fungal infections of heartwood, roots and leaves, respectively) are the main threats (Old *et al.* 2000). Heart rot does not kill trees, but the quality of wood decreases; the wood becomes whitish, spongy or fibrous and is surrounded by a dark stain. Heart-rot fungi are wound basidiomycete parasites that enter trees through injuries and branch stubs (e.g. caused by pruning) and do not preferentially attack living tissue. Root-rot disease is a decay of roots caused by various basidiomycete pathogens, which attack living root tissue and may result in tree death or symptoms of crown decline. The disease is spread by contact of a diseased root or infested woody debris with a healthy root. Phyllode rust is caused by a fungus distorting the growing points in nursery plants and young plantations. Some groups of insects have been reported to attack *A. mangium*. Insects that may attack nursery seedlings include plant bugs, grasshoppers and bagworms, which cause various types of damage (Nair and Sumardi 2000).

2.1.4 Rotation and harvesting

According to Lemmens et al. (1995), the common rotation age for A. mangium plantations for pulpwood production is 6–8 years after planting and that for sawn timber production is 15–20 years after planting. A study conducted by Krisnawati (2007), which used a simulation approach based on a dynamic programming algorithm to determine optimal rotation age and thinning strategies for A. mangium plantations under a range of initial planting spacings and site qualities, found that the optimal rotation age for pulpwood production is about 7–8 years, except for poorer sites (site index 11 m) with wide spacing (4×4 m), in which regimes without thinning delayed the optimal rotation age to 9 years. For sawn timber production, depending on initial spacing and site quality, optimal rotation was found to be between 11 and 17 years (Krisnawati 2007). Three management options may be suggested: (1) planting trees at a wide spacing (e.g. 4×4 m) and no thinning; (2) planting trees at a closer spacing (e.g. 3×3 m) and accepting a somewhat longer rotation to obtain a product of desirable size; or (3) planting trees at a closer spacing and thinning to keep trees growing at an acceptable rate (e.g. 2×3 m and 2×2.5 m).

2.2 *Acacia crassicarpa*

2.2.1 Seed production

Seed collection

Flowering starts as early as 18 months after planting, while seed is produced in abundance after 4 years. Seeds mature 5–6 months after flowering. In its native range, the main flowering season is May–June, but light flowering may occur as late as September. The peak fruiting season is October–November, however there is variation between locations and from year to year.

Seed storage and viability

The seeds *of A. crassicarpa* have a hard seed coat, low moisture content and are well-suited to storage in an air-tight container at room temperature (24°C). The seeds weigh about 36 400 seeds/kg.

2.2.2 Propagation and planting

Sowing

Seeds remain viable for many years and heat treatment or nicking of the seed coat is required to break dormancy. Immersion in boiling water for 1 minute is also a suitable treatment. Treated seeds are sown in germination beds, and seedlings with 2 pairs of leaves can be transplanted into polythene bags containing a mixture of soil and river sand. They are raised under partial shade, then in the open, and planted out when stem height reaches 25–30 cm. Inoculation of nursery seedlings with a selected Rhizobium strain prior to planting out is recommended for maximum nodule development. Vegetative propagation through air-layering has given promising results in Thailand. Cuttings may be successful for trees up to 3 years old but older trees are difficult to root. Marcotting is effective for older specimens.

Planting

Under favourable conditions seedlings grow rapidly reaching 25-30 cm in 3-4 months. A. crassicarpa is one of the fastest growing tropical Acacia species. It appears to maintain active shoot growth almost the year round, although a few months of stagnation may occur in the dry season. Spacing of 3 x 3 m (1 100 trees/ha) to 4 x 4 m (625 trees/ha) is suitable for land reclamation, fuelwood and pulpwood plantations.

2.2.3 Plantation maintenance

Weeding

On sites dominated by *Imperata cylindrica* or other weedy plants, weed control is necessary in the first 1-2 years to ensure establishment.

Control of pests and diseases

Three pests and diseases of economic value have been reported. They include Platypus spp., an ambrosia beetle (Xyleborus spp.) and pinhole borer. The tunnels and associated bacterial staining destroy the appearance of the wood, may lower the strength properties and may contribute to a greater bleaching agent requirement during paper making. Sinoxylon spp., a twig- and branch-boring beetle, may girdle and break stems of young trees. An unknown fungus sometimes causes severe spotted chlorosis and premature senescence of older phyllodes, while the narrow creamy yellow sapwood is susceptible to rapid fungal decay. Cercospora can affect productivity, particularly during prolonged periods of drought.

2.2.4 Rotation and harvesting

Coppicing ability varies with cutting height and provenance, but is not a suitable method of regeneration, since trees do not coppice well.

2.3 Pterocarpus erinaceus

2.3.1 Seed production

Seed Preparation

The seeds of this species are expected to be physically dormant (based on members of the same family). The weight of 1000 seeds is about 50 g. The germination rate of untreated seed is about 50%. Soaking in water for 12–24 hours and treatment with sulphuric acid for 30–60 minutes improve germination, which starts 6–10 days after sowing, with a germination rate of over 70%. A germination rate of 100% can be achieved by using mechanical scarification, sowing in 1% agar, incubation at 21°C and a 12-hour photoperiod. Optimal germination temperature is 25–35°C.

Seed storage and viability

This species has Orthodox seeds - dry to 15-20% eRH and store at -20ºC, or as cool as possible.

2.3.2 Propagation and planting

Sowing

Pterocarpus erinaceus is a prolific seed producer and is easy to propagate by planting nursery-raised seedlings or rooted cuttings. The fruit, an indehicent pod, must be cracked open. There are about 3500 unshelled seeds per kg (19,800 per kg if shelled). The recommended seed pretreatment is immersion in water at room temperature for 18–24 hours, or in sulfuric acid for 30–60 minutes and then in tap water for 5–10 minutes (Roussel 1996). Germination occurs within 6–10 days. Seeds are sown in pots (2–3 seeds per pot) or in nursery beds at spacing of 20 x 30 cm or 30 x 30 cm. Watering is done twice a day, morning and late afternoon, at 10 liters per 20 m^2 of planted area.

Preparation for planting out

Outplanting can be done with both potted seedlings and bare-root seedlings, as stumps or entire seedlings. Rate of survival is high, but growth is slow. The recommended size for the planting hole in dry zones is 40 x 40 cm at 5 x 5 m spacing for woodlots or 1 x 2 m for fodder banks.

Planting

Seedlings can be planted out from pots or as bare-root plants, either as stumps or as entire seedlings. The survival rate is generally high when the seedlings are protected from livestock and wild herbivores. Suckers are developed regularly and can be used for vegetative propagation. Propagation by cuttings has also been successful. The recommended size for the planting hole in dry zones is 40 x 40 cm at 5 x 5 m spacing for woodlots or 1 x 2 m for fodder banks and 3–5 m × 3–5 m in timber plantations

2.3.3 Plantation maintenance

Singling and pruning

Seedlings develop a deep taproot, which must be pruned frequently, first done 6 weeks after seed sowing, then every 3 weeks afterwards. Pruning may help the foliage remain on the tree for a longer period.

Thinning

The tree readily regenerates after cutting for forage and wood, and once established it requires very little attention.

Control of pests and diseases

The fungus *Phyllachora pterocarpi* has been reported as a pathogen, producing dark spots on leaves; it spreads by air dispersal of ascospores. Seedlings are often severely attacked by rodents and crickets.

2.3.4 Rotation and harvesting

In dry forest in northern Côte d'Ivoire, a tree with 50 cm dbh (diameter at breast height) yields about 0.8 m^3 of timber and 1.2 m^3 of firewood; a tree with 70 cm dbh yields about 1.7 m^3 of timber and 2.1 m^3 of firewood. A feedlot of 1 ha can feed about 24 heads of cattle of 250 kg.

In the dry season, trees are often lopped or coppiced for forage and leaves from regrowth after coppicing are higher in nutritive value for livestock than mature leaves. Coppicing at a height of 10 cm above ground has been recommended as a means of harvesting wood and fodder, but a coppicing height of 50 cm has also been recommended. In addition, it is recommended that the tree be topped before the onset of the dry season. Trees do not resprout well when coppiced at ground level. Trees recover quickly from pollarding and coppicing. Young plantations should be protected from browsing until 5 years old, requiring fencing. To avoid browsing of new growth, cutting at a height of over 1.5 m seems recommendable.

2.4 *Azadrachta indica*

2.4.1 Seed production

Seed collection

Seed collection from the trees when fully ripe or are swept from the floor under the trees. The pulp is washed off, dried in shade and kept in air tight tin boxes.

Seed storage and viability

Neem seeds are usually picked from open-grown neem trees. If the seeds are fresh, they are dried in the sun for a few hours before storage. Seeds are stored on the floor or plastic containers at room temperature for not more than two weeks prior to sowing in the nursery. The seeds are not given any chemical treatment in storage. Seed storage behaviour is probably intermediate. Viability is reduced from 85% to 60% after 1 month hermetic air-dry storage at room temperature and to 45% at 6 deg. C. There are about 4000-4500 seeds/kg.

2.4.2 Propagation and planting

Sowing

Propagation is generally by seeds which is sown immediately after maturity i.e December to the end of February (von Maydell, 1990). This is because the seeds are short lived and do not retain their viability for long periods (Troup, 1921). The seeds begin to germinate as soon as they fall from the trees (Evans, 1992). Loss of viability appears to be due to .and is accompanied by the fermentation of the unopened cotyledons inside the inner seed case. If the cotyledons are green, the seeds are good and will germinate, but if the cotyledons have turned brown or yellowish, they are not likely to germinate (Smith, 1939). Nagaveni et al (1987) recommend collection of neem fruits when they are greenish-yellow and still on the tree, as opposed to the usual practice of collecting fallen fruit.. If this is followed by depulping or drying, immediate germination will be delayed and therefore permit longer storage (Evans, 1992). It is advisable to use only swollen seeds, and to transplant when seedlings are 30 - 50 cm high. Neem trees start bearing fruits from the fifth year onwards and a mature tree produces more than 20 kg of fruit, corresponding to 10 - 15 kg of seeds per year. There are about 4,000 - 6,500 seeds/kg (Evans, 1992).

Planting

Nursing of seedlings starts in December/January for out planting in May/June of the same year. No pre-sowing treatment is given to neem seeds before sowing in the nursery. Seedlings are raised either in polythene tubes or as bare-root stock In either case, the seeds are first broadcast on a germination bed and pricked out into one- or half-litre polythene tubes or transplant beds about a week after germination. Germination starts three days after sowing and about 80% of the seeds germinate within 20 days. Polythene tubes are usually med with one part animal dung, two parts rice chaff and three parts mineral mil. Natural regeneration is usually profuse under mature neem trees. This can be used to supplement nursery stock, though this is not currently done.

Depulped, dried seeds are sown in raised nursery beds in lines, 15 to 20 cms a part, seeds 2.5 to 5.0 cms a part in the line and 1 cm deep. Seedlings of 7 to 10 cms tall are produced in 2 to 3 months but are usually pricked out to polythene bags where they are retained for 1 to 2 years.

2.4.3 Plantation maintenance

Weeding

Weeding of *A. indica* plantations in dry areas is essential, as the tree cannot withstand competition, especially from grasses. It responds well to chemical and organic fertilizers. Trees coppice freely, and early growth from coppice is faster than growth from seedlings. A. indica withstands pollarding well, but seed production is adversely affected when trees are lopped for fodder.

Singling and pruning

Pruning is not done except that dead branches are cut when they are a nuisance or when they are needed for fuelwood.

Thinning

Thinning is done when the product is needed and not for the sake of improving the stand. The tree coppices freely and early growth from coppice is faster than growth from seedlings (von Maydell, 1990).

Control of pests and diseases

A. indica has few serious pests, but several scale insects have been reported to infest it, for example *Aonidiella orientalis* (feeding on sap of young branches and young stems), which is the most important pest, and *Pulvinaria maxima* (feeding on sap and covering tender shoots and stems); the nymphs of *Helopeltis antonii* also feed on the sap; in India, a shoot borer damages the plant. Occasional infestations by Micotermes and Lorantus species of insects have been recorded in Nigeria, but the attacked tree almost invariably recovers. Rats and porcupines attack and occasionally kill *A. indica* seedlings and trees by gnawing the bark around the base. Mistletoes that affect *A. indica* are *Dendrophtoe* falcata and *Tapinanthus spp.*

2.4.4 Rotation and harvesting

The rotation length of neem is not currently defined and stands are generally selectively felled based on individual and community demand. The major factor determining cutting height however is the end use to which the tree is to be put. Cutting is usually done to maximize bole length. Selective felling is usually done in which the trees of best form which can serve as poles or rafters are cut first. It is difficult if not impossible to encounter an intact neem plantation three years or older. The plantation or whatever is left of it, can best be described as coppice with standards, where the standards are the crooked or malformed trees

2.5 *Khaya senegalensis*

2.5.1 Seed production

Seed preparation

Natural regeneration from seed is poor, although it grows from pretreated seed and transplants well. Seed yield is usually heavy. Germination is epigeal, about 90% of fresh seed germinate within 18 days. Seedlings can survive light to moderate shade. Containerized stock is best; however, bare-root and stump plantings give satisfactory results. Reproduction may also occur from root suckers. Establishment of new seedlings can be encouraged by disturbances such as cultivation or prescribed fire just before seed fall. After seedlings have emerged, a partial cut applied to allow light to reach the forest floor improves seedling establishment well before the final harvest of the existing stand.

Seed storage and viability

Seed storage behaviour is intermediate; seeds tolerate desiccation to 6% mc; 81% germinate following 3 years of subsequent storage at 2 deg. C; seeds tolerate desiccation to 5.7% mc (in equilibrium with 54.4% rh), little loss (about 3%) on desiccation to 2.1% mc (in equilibrium with 11.8% rh at 20 deg. C), complete loss in viability following 24 months of hermetic storage at 10 deg. C, 0 deg. C and -20 deg. C with 10% mc; it appears to 0 deg. C is optimal storage temperature for seeds at 2.2-5.6% mc, whereas -20 deg. C is damaging. Normally there are 6000-7000 seed/kg, but occasionally as few as 3000.

2.5.2 Propagation and planting

Sowing

Natural regeneration can be abundant in savanna areas on good soils without too much competition from herbs, and when protected from fire. In the first years, seedlings tolerate light shade. The 1000-seed weight is 140–330 g. The seeds are often attacked by insects while they are still on the tree, and undamaged seeds should therefore be selected before sowing. Soaking for 24 hours in water reportedly improves germination, but is not necessary. The seeds can best be sown in seed beds in the nursery or in pots. Fresh healthy seeds have a high germination rate, 90–100%, and they may retain their viability for 6(–8) months. However, when they are exposed to high relative humidity, they may lose their viability within 3 months. When stored at 0–10°C and a seed moisture content of 5%, seeds retain their high germination rate for at least 4 years. However, other tests showed that storage at 4°C resulted in loss of viability between 12 and 18 months, whereas storage at –20°C, 15°C and 20°C all showed good results. It is recommended to add ash during storage to reduce insect attacks.

Upon sowing seeds should be covered with only a thin layer of soil, or left partially uncovered. Germination takes 10–18 days. It has been recommended to provide light shade to young seedlings until they are 1–2 months old. To reduce damage by grazing, seedlings may be planted out when over 1.5 m tall. Normal spacing is 4–5 m × 4–5 m. Wildlings are sometimes collected for planting. Trees also reproduce by root suckers. Grafting and layering is possible, but propagation using cuttings is much more difficult. Planting of small plots with 5–9 *Khaya senegalensis* transplants 1 m apart from each other within a plantation of teak trees planted at the same time may significantly reduce borer attacks and allow good initial growth of both species. Planting *Khaya senegalensis* at wide spacing under light cover in a thinned natural forest or plantation also reduces attacks.

Planting

Strategies to obtain sufficient regeneration on poor sites should include liberation cutting of stands with advanced regeneration. Common spacings on cleared and prepared sites are 5 x 5 m and 5 x 10 m. A spacing of 5 x 20 m is used when planting in riparian forests.

2.5.3 Plantation maintenance

Weeding

In young plantations weeding is necessary, as young trees are susceptible to suppression by weeds. Young trees are also susceptible to fire, but older trees are quite fire resistant. Hoeing and weeding are recommended at the onset of the dry season. *K. senegalensis* coppices well. Although older trees are resistant to fire, seedlings are fairly susceptible.

Fertilizing

The application of a complete fertilizer at a rate of 200 g/tree at the time of planting is recommended

Thinning

Regular thinning of the shade trees in the first years is needed for good growth of the *Khaya senegalensis* trees.

Control of pests and diseases

In plantations *Khaya senegalensis* suffers seriously from *Hypsipyla robusta* shoot borers that kill the main stem of young trees, causing excessive branching and contributing to mortality. Silvicultural techniques such as overhead shading of saplings, mixed planting and removal of lateral shoots can reduce damage by shoot borers. Products based on methidathion have proved effective in plantations of up to 2 years old, but the costs are very high. Seeds are commonly attacked by seed-boring beetles and eaten by small rodents, whereas young plants can be heavily browsed by cattle, antelopes and other herbivores.

2.5.4 Rotation and harvesting

The logs are quite difficult to fell using traditional equipment because of the dense and fairly hard wood. Firewood is normally collected from fallen branches, as cross-cutting and splitting of larger dimensions of wood is difficult. Bark is collected whenever needed, and in many regions many larger trees show signs of debarking. In some regions the crowns are heavily affected by harvesting the branches for fodder.

Realistic rotation cycles under natural conditions are probably in the range of 80–100 years, but in plantations a rotation of 40–60 years is feasible. *Khaya senegalensis* trees planted along streets often grow faster than in those in forest plantations, but pruning is necessary to obtain a nice bole.

2.6 Senna siamea

2.6.1 Seed production

Seed storage and viability

Storage behaviour is orthodox. Mature seed has a hard seed coat, and scarification is required. Immersion in concentrated sulphuric acid for 10-30 min has been effective. With the 1st method, germination is about 90% within 60 days. Germination of untreated seeds is about 75% in 4-29 days. Seeds can also be stored for up to a year but germination rate falls with time.

Viability can be maintained for 3 years in hermetic storage at room temperature with 11-15% mc. There are 35 000-45 000 seeds/kg.

2.6.2 Propagation and planting

Planting density varies according to use. In fuelwood plantations, spacing ranges from 1 x 1 m to 1x 3 m. In hedges used for alley cropping or as a shelterbelt, spacing between plants in the row should be 25-50 cm.

2.6.3 Plantation maintenance

Weeding

Moisture conservation measures (trenching, microcatchments) help establishment and growth for *S. siamea* planted in semi-arid areas. Unless carefully pruned, the tree ages ungracefully, the crown becoming straggling and misshapen with upright and drooping branches.

Fertilizing

Fertilizer during growth: Regularly but with spacing

Singling and pruning

No pruning is required for this species.

Control of pests and diseases

No serious diseases or pests have been recorded for *Senna siamea*, but minor damage has occurred in a number of locations. The fungus *Phaeolus manihotis* occasionally causes damage to the root system.

2.6.4 Rotation and harvesting

Senna siamea is very tolerant of coppicing, lopping, or pollarding. Plantations can be harvested for fuelwood every 5—7 years, although shorter rotations are often practiced in favourable environments. Where mulch or leaf production is the primary aim of a plantation, the first cut may be 12—18 months after sowing, followed by 3—4 cuts per year thereafter. *S. siamea* starts flowering and fruiting at the age of 2-3 years. Once established, it flowers precociously and abundantly throughout the year.

For the production of fuelwood and charcoal, plantations are generally pollarded or regenerated by coppice leaving 2-3 shoots/stump after 1 year. It has been reported that sapwood should be removed as soon as possible after felling to prevent insect attack of the heartwood.

2.7 *Afzelia Africana*

2.7.1 Seed production

Seed collection

Seed collection starts soon after maturation because the seed is heavily browsed by wildlife and livestock. It may even be necessary to install a fence under a chosen seed bearer or to climb up the tree to collect the seed. Seeds exhibit a recalcitrant behavior in storage. There are 350-450 seeds/kg.

Seed Preparation

A. Africana is propagated by seed and transplants fairly well (Irvine, 1961). Seed germination under shade is epigeal and takes 12 to 24 days with a germination rate of nearly 90% but growth is slow (Taylor, 1960). Seedlings require light to grow to maturity (Stark, 1986). Roots have ectotrophic mycorrhiza (Jenik & Mensah, 1967). It can be propagated by stump using 2-year-old plant (Taylor, 1960).

Seed storage and viability

Natural regeneration is usually plentiful, although many seeds may be eaten on the ground by animals. A large quantity of seed is produced each year, and viability is high. Growth is usually slow. Stored seed will keep up to a year. The germination period is from 12-24 days and a plant percentage of nearly 90 can be expected at the end of 6 months. By this time the shoots may be about 9 in. high, but a long tap-root, 12 in. or more in length, has developed. When lifting the plants from the nursery beds, it is better to undercut this root rather than try to dig it out. Two-year-old plants, stumped, transplant well.

2.7.2 Propagation and planting

Sowing

A. africana is propagated by seed, as evidenced by high natural regeneration capacity. It can be vegetatively propagated by budding. Natural regeneration is not usually abundant because seed predation by animals is high. The species is not fire-resistant, making it increasingly rare in the Sahel. The germination capacity of the seeds can be conserved quite well at ambient temperatures for up to 3-4 months, but an insecticide may be necessary. The orange cup has to be completely removed before sowing; soaking seeds in water for 24-48 hours at 20-30°C facilitates this. Scarification on concrete is also a popular pre-treatment method. Sowing has to be done with the placental end underneath. Germination takes place after 2 weeks. Treatment with concentrated sulfuric acid for 30 minutes followed by soaking in cold water for 3 hours can increase the germination percentage. Under good conditions, the stem may reach a height of 30 cm after 2 months. Bare-rooted seedlings take about 6 months in the nursery, at which point the plants will then have attained a height of 30-40 cm. Seedlings should stay in containers no longer than 4-6 months to avoid taproot twist. The best size for planting is 30-40 cm. Direct sowing is possible but has the disadvantage that very young plants are heavily browsed.

Planting

A. africana is a light demander that tolerates light shade when young. Pure stands can be established as well as mixed stands. No special soil preparation is necessary, plantation holes of 4 x 4 x 4 m should be dug early enough, particularly in savannah areas, to be able to plant if precipitation is favourable. Fertilization with PK will favour the growing process, but is not necessary. Spacing depends on the plantation type. Enrichment planting seems to be the most appropriate plantation technique in transition and deciduous forest. In the savannah, it is recommended to create a favourable microclimate before plantation of *Afzelia* to help protect the plants against fire. A first plantation can be planted with *Gmelina arborea*, *Harungana madagascariensis* and *Acacia mangium* at a spacing of 3 x 3, pure or mixed. After 2 or 3 years, when these trees reach a height of 2-3 m, some of them are harvested and A. africana can be planted in the free lines. Further management of the plantation is undertaken in favour of Afzelia.

2.7.3 Plantation maintenance

Weeding

Regular weeding is needed in young plantations.

Control of pests and diseases

Seedlings are susceptible to fungal and grasshopper attacks and should be protected against browsing by numerous mammals.

2.8 Anogeissus leiocarpus

2.8.1 Propagation and planting

Sowing

Anogeissus leiocarpa is propagated by seed, dispersed by wind, but has poor germination rate of only 5% due to low fertility of fruits. Seeds soon lose their viability (within 6 months). Seedlings, however, transplant well.

The germination of *Anogeissus leiocarpa* seeds takes a long time and seedlings are not easy to obtain. Once established the plant is slow growing. Normally the tree is evergreen, but due to bush fires (October–November) it can stay without leaves for several weeks. Flowering is year-round but most abundant at the beginning of the rainy season between January and April. The flowers have a strong sweet smell. Fruiting is most abundant between March and May. The infructescences disarticulate when they become dry and the winged fruits are easily dispersed by wind.

2.8.2 Plantation maintenance

Control of pests and diseases

Anogeissus leiocarpa is a hardy tree species and no serious diseases or pests are known.

2.8.3 Rotation and harvesting

The annual yield of dry leaves is estimated to be 20–25 kg/tree and of dry bark 0.5–1 kg/tree. Harvesting of the leaves at the beginning of the flowering period (January–February) is preferred, but because the tree is evergreen, they can be harvested any time of the year. The best period to harvest the bark is at the end of the dry season, from the end of March until the beginning of June, both because of the availability of manpower and of the optimum concentration and condition for exploitation of the active principle anogelline present in the bark. Up to now *Anogeissus leiocarpa* is mainly harvested from the wild. It is fire resistant and notably abundant around abandoned settlements in the Savanna. Large trees are more abundant in undisturbed forest. *Anogeissus leiocarpa* can be pollarded and the tree has some ability to coppice. It is very sensitive to fire.

3.0 Conclusion and Recommendations

This report has been prepared taking into consideration available information on the silviculture of the species planted in the woodfuel test plots under the ITTO funded project. There seems to be adequate information on the silviculture of *Acacia mangium*, *Acacia crassicarpa, Pterocarpus erinaceus, Adzadrachta indica and Khaya senegalensis* in the literature. However, there are gaps in the available information on the silviculture of *Senna siamea*, *Afzelia Africana* and *Anogeissus leicocarpus* especially in the area of plantation maintenance, rotation and harvesting.

In general, information on the silvicultural practices on woodfuel species are dispersed and not easily available to farmers and woodlot developers. It is recommended that information on potential woodfuel species should be synthesized, and disseminated to farmers. In addition, research should be conducted on the silviculture of woodfuel species, using the woodfuel test plots as case studies, to refine and validate the silvicultural practices of the planted species presented in this report.

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