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Supplementary file S9. Teak management practice in Panama

Soil preparation

Typical lands used for teak establishment in the Panama Este and Darién regions are cattle farms with grass cover. Soil preparation on these lands depends on topography. If the site allows mechanical site preparation, max 30% slope, it is recommended to apply mechanical soil preparation with a Savannah forestry plough or similar equipment. Mechanical preparation reduces soil bulk density and increases drainage, aeration, and microbial activity in the soil. In addition, it reduces soil microsite variation and hence improves the plantation homogeneity. In steep sites with >30% slope, the only soil preparation is manual pitting. Flat or nearly flat sites require bedding or other drainage works. In Panama, bedding is typically done with a tilting bulldozer blade, or with an excavator. Soil preparation must be done during the dry season.

Pre-planting weed control

Prior to planting, pre-planting weed chemical weed control is done by applying 2 kg ha^{-1} of glyphosate at 65% concentration on already emerged weeds and grasses. For broad-leaved grasses, metsulfuron can be mixed with glyphosate at a rate of 10-20 g ha^{-1}. Tank mix with clean water is applied at a rate of 100-200 litres ha^{-1} with manual or motorized backpack sprayers, or mechanically with booms attached to agriculture tractors. The use of pre-emergent herbicides is not a common practice in Panama.

Plant material

Until recently, plant material in Panama has been of seed origin, often sourced from seed production stands in Costa Rica. Since 2012, clonal plantations have become more frequent and currently all professional teak growers plant exclusively clonal teak, either as monoclonal blocks or as a clonal mix. Teak genotypes are sourced from Costa Rica, Brazil or Asian countries. Local phenotypic superior tree selections are being tested in clonal trials by some teak companies.

Planting

Manual planting is done during mid-May until September. Early establishments have clear advantages in comparison to late planting, as trees take full advantage of the first full growing season. Conventional planting spacing is 3x3=1100 trees ha^{-1} or 4x2.5 m=1000 trees ha^{-1}. Clonal teak is recommended to be planted 4x3.5=710 trees ha^{-1}, 5x3=670 trees ha^{-1} or 4x4=625 trees ha^{-1}. In bedded sites plant spacing is, for example, 6x3=550 trees ha^{-1}.

Fertilization

Given the favourable soil characteristics in the region, fertilization does not play a significant role in teak establishment. However, given the small soil volume where recently planted teak trees can source nutrients, it is considered beneficial to apply e.g. NPK 10-30-10 or a similar fertilizer soon after planting at a rate of 100-200 g $tree^{-1}$. In underperforming sites, the fertilization can be repeated at the beginning of the second growing season, given however that soil drainage or weed competition has not been limiting the tree growth during the first growing season.

Post-planting weed control

After planting, intensive weed control is essential for proper tree growth. Standard teak weeding regime during the establishment phase consists of six times manual weeding in year 1; 1x manual weeding and 3x chemical weeding during the second year; manual weeding 1x and chemical weeding 2x during the third year. During year one, only manual weed control is recommended, because teak is very sensitive to glyphosate and other herbicides, and chemical control is complicated without affecting the teak tree crop. Chemical weed control is done during the second year onwards with backpack sprayers by applying 1.5 kg ha^{-1} of glyphosate at 65% concentration and 10-20 g ha^{-1} of metsulfuron. In well-performing teak plantations the canopy is closed after three growing seasons. Given the high rainfall and good soil fertility, it might be necessary to continue with weed control on a case-by-case basis, depending on site conditions and previous land-use of the plantation site.

Pruning

Teak trees require multiple prunings at a young age because the bark has dormant buds that the tree activates to grow new branches soon after pruning. Only when the tree is physiologically mature, the branch sprouting is reduced. In a standard regime, pruning is implemented once a year until age 7-8 years, except twice during the second growing season. In years 1 and 2 the pruning activity is focused on singling/elimination of base sprouts, in years 3-5 in actual branch pruning up to 7 meters, and in years 6-8 cleaning the branch sprouts. The objective is to lift the pruning height gradually up to 7 meters, in order to recover three high-quality 2.3 m logs in thinning and final harvest. Appropriate pruning intensity (i.e. share of the pruned stem height over the total tree height) is 50-60% in seedling plantations, and 65% in clonal plantations. As branching habit is one of the phenotypical selection criteria in clonal plus tree selection, clones often have less and smaller branches than seedling material.

Thinning regime

The first thinning in teak is pre-commercial, and it is done at age 4-5 down to 450-550 stems ha^{-1}. This pre-commercial thinning is omitted in bedded sites with lower initial stocking. A second thinning is done at age 9-12 years, depending on site quality and timber market conditions. Recommended stocking after the second thinning is 300-400 stems ha^{-1}. Finally, a third thinning is performed at age 14-16, and the remaining stocking is about 200-250 trees ha^{-1}. Rotation age for plantation teak is often 20-22 years. In high quality sites, clear felling can be performed at the age of 18 years, while lower site index sites may be grown up to 25 years. In terms of basal area, Pérez and Kanninen (2005) recommended managing the stand basal area in mid-rotation plantations between 15 and 25 m^2 ha^{-1} and in late rotation stands between 15-20 m^2 ha^{-1}. Malmström (2013) studied financially optimal thinning regimes in teak using the yield models published by Pérez and Kanninen (2005). He reported that optimal basal area oscillates between 20 and 25 m^2 ha^{-1} in high and medium quality teak sites.