

BIOMASS PRODUCTION AND ROOT DISTRIBUTION OF EIGHT TREES AND THEIR POTENTIAL FOR HEDGEROW INTERCROPPING ON AN ULTISOL IN SOUTHERN SUMATRA

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ABSTRACT

Long term productivity of upland soils for food crops may be improved by using a 'hedgerow intercropping' or 'alley cropping' system. However, information on trees suitable for hedgerow intercropping on acid soils is scarce. Suitability of trees for hedgerow cropping depends on a number of above and below ground characteristics of the trees, such as pruning tolerance, biomass production, N-content of the prunings, decomposition rate of prunings, rooting depth, presence of horizontal branch roots, nodulation, mycorrhizal infection. Desirable tree characteristics further include the production of useful products such as firewood, browse for goats and/or edible pods. Trees which provide a sufficiently dense cover, when left unpruned, to shade out weeds may help to save labor.

Pruning of trees affects their growth in many ways. Based on preliminary observations the hypothesis was formulated that a lower pruning height leads to more, but smaller branch roots originating from the stem base. In an experiment with five tree species this hypothesis was confirmed.

Eight trees were evaluated for the characteristics mentioned on an acid soil; six relatively well known agroforestry trees: *Leucaena leucocephala*, *Gliricidia sepium*, *Calliandra calothyrsus*, *Cassia siamea*, *Erythrina orientalis*, *Albizia falcataria*, and two local tree species: *Peronema canescens* and *Peltophorum pterocarpa*. Averaged over the first three years of pruning, the highest biomass production and N-yield was found for *Calliandra* (12 Mg/ha and 360 kg/ha, respectively). *Calliandra* requires regular pruning, however, to avoid excessive shading of intercropped food crops. Overall, the best results in hedgerow intercropping on this acid soil may be expected from the relatively deep-rooted *Peltophorum*, or from alternating hedgerows of *Gliricidia* and *Peltophorum*, with a biomass of around 8 Mg/ha and an N-yield of about 200 kg/ha. *Peltophorum* forms the densest canopy in a small hedge volume when pruned in a 3-months cycle.

INTRODUCTION

On acid infertile soils, such as ultisols, in the humid tropics the efficiency of nutrient use is generally low due to a combination of high leaching rates and shallow root development of annual food crops because of a high Al-saturation and low levels of Ca and P in the subsoil. Lack of weatherable minerals in the soil, nutritional constraints to N₂-fixation and probably poor mycorrhizal infection of roots may aggravate the problem. Under such conditions it is difficult to produce enough dead plant material as litter inputs to the soil ecosystem to maintain sufficiently high soil organic

matter levels. According to an estimate by Young (1989) inputs of above ground biomass should be around 8.5 Mg/ha (dry weight) to maintain a desirable carbon content of 2 % in the top soil in the humid tropics. Agroforestry techniques, integrating trees and food crops, might help to improve soil fertility on such soils by providing sufficient organic inputs (Nair *et al.*, 1984).

Alley cropping or hedgerow intercropping is an agroforestry system in which food crops are planted in alleys in between hedgerows of regularly pruned trees or shrubs (Kang *et al.*, 1986; Nair, 1984; Young, 1989). The main functions of the trees, apart from any directly economic products, are to maintain soil fertility, by reducing erosion, by nutrient recycling from deeper soil layers and by providing organic matter. This system has been presented as a stable alternative to shifting cultivation, with the potential to improve or to maintain soil productivity without or with low fertilizer input (Kang *et al.*, 1986). Kang *et al.* (1981, 1985) and Duguma *et al.* (1988) have recommended *Leucaena leucocephala* and *Gliricidia sepium* as suitable hedgerow trees for humid and sub-humid areas. Kang *et al.* (1985), reported that the giant *L. leucocephala* var. K-28 grown on a sandy entisol, at 4 m spacing of hedgerows, produced between 15 - 20 Mg/ha of fresh prunings (excluded stakes) or 5- 6 Mg/ha of dry weight with 5 prunings per year. The prunings represented a substantial nutrient input to the soil: 160 kg N, 15 kg P, 150 kg K, 40 kg Ca and 15 kg Mg. Successes with the system appear to be restricted, however, to soils where a deep root development by the trees is possible. *L. leucocephala* the main tree species used, is not well adapted to acid soils (Szott, 1988). Hutton and de Sousa (1987) reported that *L. leucocephala* (Cunningham) performed poorly on an acid Oxisol in Brazil (pH 4.5-4.7) and that at lime applications up to 2 Mg/ha still large numbers of dead root tips indicated Al-toxicity. Although selection of acid soil tolerant strains of *L. leucocephala* has been attempted, no real improvement has been achieved. For the second tree, *G. sepium*, problems on acid soils are less pronounced, but still selection of a good tree for hedgerow intercropping on acid soils scores high on the research agenda (Kang *et al.*, 1986; Hairiah and Van Noordwijk, 1986).

For the hedgerow intercropping system tree species are needed which tolerate regular pruning, do not suffer from major pests or diseases, have a good biomass production and have a deep root system with few roots in the top layer in the zone reserved for the food crops. If possible, N-fixing trees and trees with a high degree of mycorrhizal infection are preferred. Blair *et al.* (1988) reported that annual biomass production of several leguminous trees in Indonesia is in a range of 6 - 19 Mg/ha, if trees are planted in inter row spacing 4 m and 0.5 m within the row.

A deep root system spreading as a "safety net" under the crops might help intercepting leached or leaching nutrients so as to improve nutrient use efficiency of the cropping system. (Fig. 1; Van Noordwijk, 1989). The notion of a "safety-net", relevant under high rainfall on all soil types, may partly replace the notion of a "nutrient pump", relevant only on soils where there is something to be pumped, i.e. weatherable minerals in the subsoil. Contrary to popular believe, however, not all tree species have a deep root system in reality. Studies on root distribution of *Bauhinia purpurea*, *Grewia optiva*, *Eucalyptus tereticornis*, *L. leucocephala* and *Ougeinia oojeinensis* on a moderately acid soil (udic haplustalf), showed that those 5 trees species have tap and lateral roots which reach deep soil levels (90-120 cm), but the bulk of their roots are found near the surface, hence root competition with food crops might be expected (Dhyani *et al.*, 1990). An abundance of superficial tree roots may lead to undesirable competition with food crops for water and nutrients (Jonsson *et al.*, 1988). By providing root barriers next to hedgerows of *L. leucocephala*, Singh *et al.* (1989) could demonstrate that the positive effects of trees on associated food crops due to mulch are normally offset by negative effects due to competition for water, in a semi-arid environment. Data on tree root distribution for sixty tree species, considered as potential undergrowth in *Tectona*-plantations on Java, by Coster (1932), showed that the fastest growing trees and shrubs generally had a dominantly superficial root system. Trees with a deep tap root and few horizontal branch roots were only found in the group with a low growth rate, at least in the period of tree establishment. The "ideal" root system may thus be difficult to combine with "ideal" aboveground characteristics (Van Noordwijk, 1989). A high biomass production by hedgerow trees is desirable for improving soil productivity. Rapid regrowth of the tree after pruning, however, will increase competition with the food crop for light (solar radiation) and for nutrition and water, if the root systems of trees and crops overlap. Lawson and Kang (1990) found that a hedgerow biomass production by *L. leucocephala* of more than 5 Mg/ha of dry weight reduced the yield of intercropped maize, due to shading. Rapidly growing trees thus have to be pruned more frequently, adding to the labor cost

monthly pruning regime, where many trees of *G. sepium* and *Sesbania grandiflora* died; increasing pruning frequency and decreasing pruning height reduced biomass production and N yield for *Leucaena*, *Gliricidia* and *Sesbania* (Duguma *et al.*, 1988). In a comparison of four tree species used for fodder production in Indonesia, Ella *et al.*, (1989) found that total leaf biomass production was higher under a 12-week than under a 6-week pruning regime. Apart from pruning frequency and height of pruning the trees, the shape of the tree canopy formed and the distance between the hedgerows should be considered to reduce negative effects by shading during crop growth.

Preliminary data on *Peltophorum pterocarpa*, a common tree on acid soils in southern Sumatra, suggested that the height of pruning has an effect on root distribution. Aboveground tree management decisions thus seem to have consequences for the belowground geometry and functioning of the hedgerow intercropping system. As no information on such pruning effects for other trees exists, we set up an experiment to test the hypothesis that pruning height influences root distribution.

Apart from the functions mentioned, trees may contribute to the cropping or farming system by helping to control weeds, thus reducing labor costs, by providing fodder, firewood and possibly fruits or other products of direct economic importance. When trees which are left unpruned for some time, e.g. in order to produce firewood, develop a dense canopy they may help in weed control. Weed control, as well as protection of the soil against erosion, can also be achieved by a slow decomposition rate of leaf litter and tree prunings (Nair, 1984). Apart from a high C/N ratio, slow decomposition can be caused by a high lignin and/or polyphenolic (tannin) content. On the other hand, if the trees are to be used as fodder for goats or cows, toxins and other antinutritional substances should be absent or very low in the foliage. Budelman (1988), found that leaves of *Flemingia macrophylla*, used as mulch, effectively reduced weed infestation in coffee plantations; *L. leucocephala* and *G. sepium* did not have this effect, since their leaves decomposed too fast.

In this article we present data of experiments and measurements to evaluate a number of imported and local trees for their suitability as hedgerow trees on an acid soil in S. Sumatra (Van der Heide *et al.*, 1992). Parameters presented are:

above ground: biomass production, N-content of prunings, shape of the tree canopy in view of shading of crops, firewood production during a longer growth period, light interception and weed control during such period;

below ground: root distribution, as affected by pruning height, nodulation and mycorrhizal infection of the roots.

Lamtoro) originates from N. and S. America, but is widespread in the tropics, including Indonesia. It was considered to be the best tree for hedgerow intercropping on non-acid soils, until the outbreak of the psyllid pest (*Heteropsylla cubana*) in Asia. *Leucaena* has a high biomass production and N-yield, tolerates pruning at almost any stem height and frequency and provides a very palatable fodder, which, however, contains mimosin which, in large quantities can be toxic to ruminants (Reynolds and Atta-Krah, 1989). Lines with supposedly improved tolerance for acid soil conditions and tolerance to psyllids have been selected. The variety we used for the experiments came from Purwodadi botanical garden (E. Java).

Gliricidia sepium (Jacq.) Steud (Quick stick), native to Mexico and Central America but widespread throughout the tropics as shade tree for cocoa and coffee and as a green fence (Brewbaker and Glover, 1988). It is considered to be the second-best tree species for hedgerow intercropping on alfisols in the humid and subhumid tropics (Kang *et al.*, 1986). Reynolds and Atta-Krah (1989) recommended the use of alternating hedgerows of *Leucaena* and *Gliricidia* for fodder production. *Gliricidia* is easier to establish than *Leucaena*, though its growth rate and N-yield are lower. It can be easily grown from cuttings, as any stick put in the ground roots and nodulates easily. *Gliricidia* is a suitable tree for 'improved fallow' vegetation (Adejuwon and Adesina, 1990); because it produces long, unbranched stakes it is highly valued by farmers. *Gliricidia* is more tolerant to acid soil conditions than *Leucaena*. Ghuman and Lal (1990) reported an annual production of 11 Mg/ha (dry weight) when pruned three times per year on an acid soil with 2000 mm annual rainfall. *Gliricidia* is common as live fence throughout Indonesia, including the transmigrant areas in N. Lampung on acid soils.

Cassia siamea Lmk (Kassod tree, Johar) is native to S.E Asia, although most *Cassia* species originate from tropical America, where they grow in dry open forests. In Malaysia it is commonly planted as a roadside tree (Corner, 1988). It has the capacity to grow on poor soils and is commonly used in hedgerow intercropping trials and for erosion control, although the extent of its soil-improving potential is not known (Young, 1989). It is not nodulated, as far as known, but it provides plenty of litter and is drought tolerant. *Cassia* sheds its leaves in the dry season; Ghuman and Lal (1990) reported that annual litter fall by unpruned trees on an acid soil with 2000 mm annual rainfall amounted to a dry weight of about 6 Mg/ha, containing 110 kg N. In trials at IITA it was found that due to the lateral branching habit of the species, in contrast to *Gliricidia*, weeds could be rapidly depressed by *Cassia*. After a heavy pruning *Cassia* was found to recover relatively slowly and did not need a second pruning during a food crop production cycle. The thick wood required much labor at initial pruning and leaf nutrient contents are low (IITA, 1983).

Calliandra calothyrsus (Meissn.) is a rapid growing shrub/tree, native of Central America, but well known throughout the tropics as ornamental tree because of its abundant flower production; it is used extensively for reforestation on acid soils in Indonesia and may contribute to small farmer income by honey production. The trees can be harvested after the first year, yielding 5 - 20 m³ of fuelwood per ha in Indonesia. The wood burns quickly and is suitable for use in e.g. brick kilns or sugar-processing operations because it produces a lot of heat. The cut stumps coppice readily, the sprouts often becoming 3 m tall within 6 months. The tree nodulates easily and is very adaptable to nutrient-poor soils. The quick and dense growth suppresses weeds and the tree can be used to eliminate *Imperata cylindrica*. The foliage contains a high protein content and seems palatable to livestock (NAS, 1979). Limited experience exists with *Calliandra* as hedgerow cropping tree. Gichuru and Kang (1989) reported that in 4 prunings per year 6 Mg/ha of dry matter was produced, representing 200 kg/ha of N; they rated the tree as equally suitable as *L. leucocephala* on a soil of pH 6.4, and probably more suitable on acid soils, but reported that it should be regularly pruned to avoid excessive shading of companion crops.

Albizia falcataria (L.) Fosberg (Sengon laut) is a fast growing tree native to the eastern part of Indonesia, valued for timber (poles) and pulpwood production; on good sites, stem diameter (at breast height) may increase at about 5 cm per year and in an 8 to 12-year rotation an annual increment in wood production of 25-40 m³ per ha can be expected. The trees coppice vigorously so replanting is not necessary after the first harvest (NAS, 1979). Little experience exists with the use of this tree for hedgerow intercropping; the root system is reportedly shallow which makes plantations prone to wind damage). Frequent attacks by caterpillars, monkeys and deer have been experienced in Indonesian plantations located adjacent to rain forests (NAS, 1979). The tree is successfully grown in village woodlots in N. Lampung on acid soils.

Erythrina orientalis (L.) Murr. (Coral tree; Dadap minyak) is common on banks of river mouths and not swampy beaches in Java; it is cultivated up to 1200 m above sea level (Backer and Backhuizen van den Brink, 1963). Several *Erythrina* species have traditionally been used as shade tree in coffee gardens or as support tree for pepper, because they provide a relatively open canopy. Most *Erythrina* species are thorny and are considered too dangerous for hedgerow intercropping, but practically thornless types are also known (NAS, 1979). Palm and Sanchez (1990) described a fast N mineralization from *Erythrina* prunings. The variety of *E. orientalis* (Dadap minyak) we used has no thorns, and is commonly used as green manure in S. Sumatera. It was collected from Gubuk Kemuning (Palembang).

Peltophorum pterocarpa (DC.) K. Heyne (Copperpod, Yellow Flame, False Elder, Soga, Batai laut, locally known as Petaian; synonyms: *P. inerme* (Roxb.) Llanos, *P. ferrugineum* (Decne) Bth., *Inga pterocarpa* DC.) is a common tree in the secondary forest in N. Lampung; it is almost the only local tree establishing itself in *Imperata* fields and stays green in dry season. According to the Flora of Java (Backer and Bakhuizen van den Brink, 1963) it is most common below 100 m above sea level in forest, especially behind the beach and along the inner margin of the mangrove, moreover in *Imperata* fields and teak forests; also planted as an ornamental. Corner (1988) only mentions *P. pterocarpa* for sea shores on rocky or sandy coasts (hence its name Batai laut). The tree is commonly grown as ornamental but is currently little known for other purposes. In the past the Soga bark had some commercial value for its tannin content and as a dye. According to Spaan (1909), twigs 1 m long and 5 cm thick can be planted in alang-alang fields. Because of its dense foliage it is recommended for widespread use as shade and ornamental tree, also useful for reclaiming wastelands covered with *Imperata cylindrica* (NAS, 1979). The tree is closely related to the flamboyant tree (*Delonix regia*) and is, similarly, not known to be nodulated. *Peltophorum* is resistant to wind damage, which suggests that it has a deep root system, and is not attacked by boring beetles. Cattle will eat the leaves. The wood is good for both furniture and fuel (NAS, 1979). In the past bark of the tree had some commercial value as a source of tannin for the leather industry. Although no previous reports on its use for hedgerow intercropping could be found in the literature, the tree was listed as a candidate for hedgerow intercropping for Eastern Indonesia. Initial observations of root distribution and pruning tolerance (Van Noordwijk *et al.*, 1991) showed that indeed the tree is a good candidate for successful hedgerow systems.

Peronema canescens Jack (False elder, locally known as Sungkai), is a valuable timber tree from the native forest vegetation. It is common in open country and secondary jungle or by rivers and clearings in the forest (Corner, 1988; Backer and Bakhuizen van den Brink, 1966). After a slash and burn clearing of the forest *Peronema* readily resprouts from superficial roots surrounding old tree trunks. Although unknown as agroforestry species, we decided to include the tree in a preliminary trial.

MATERIALS AND METHODS

Two experiments were carried out on an ultisol, a Grossarenic kandiudult, on a site of Nitrogen management Project (IB/Unibraw), N. Lampung, S. Sumatra (Van der Heide *et al.*, 1992).

Experiment I. Hedgerow intercropping. (in the

established in 1986 on an area which had been manually cleared from secondary forest. A second block was established in 1987 on a plot which in the mean time had been covered by speargrass (*I. cylindrica*). The *Imperata* was once sprayed with herbicide (Round-up) and in the area in between the hedgerows a leguminous cover crop, *Mucuna pruriens* var. *utilis*, was grown.

Five hedgerow trees species were used for this experiment: 1. *Calliandra calothyrsus* 2. *Gliricidia sepium* 3. *Leucaena leucocephala* 4. *Peltophorum pterocarpa* 5. *Erythrina orientalis*. A plot with alternating rows of *Gliricidia* and *Peltophorum* hedgerows was included, as well as a control plot without hedgerows. For all tree species a plant distance within the row of 0.5 m, and an interrow distance of 4 m was used, resulting in a tree population of 5 000 per ha. Each plot contained four rows. Species were arranged in a Randomized Block Design.

Calliandra and *Leucaena* were planted as polybag seedlings, *Peltophorum* was transplanted from spontaneous seedlings around the plot and *Erythrina* and *Gliricidia* were propagated from sticks. Regular pruning and intercropping with food crops started in 1988, when block I was 2-year old and block II 1-year old. The trees were pruned approximately every 4 months for three consecutive growing seasons, at a pruning height of 1 m, forming a hedge of 40 cm wide. In the first two cropping seasons all hedgerow trees were pruned simultaneously. In the third cropping season the pruning regime was differentiated according to the shading effect of tree species on intercropped food crops. At each pruning, pruning material was collected from three randomly chosen 1 m sections (three trees) from each row, separated into stem and leaf biomass, dried at 80°C, weighed and analyzed for total N-content. Results are expressed as dry weight per ha.

Experiment II. Effects of stem pruning height and root pruning. (in the field as exp. IV)

For a second experiment hedgerow trees were established in February 1988 on a plot recently cleared (slash and burn) of the secondary forest vegetation. An area was divided into 7 plots, each sub-divided into 4 blocks. On each plot a different tree species was planted with an interrow spacing of 2 m, and a distance within the row of 0.5 m (10 000 trees/ha). Six leguminous trees species were used: 1. *Calliandra calothyrsus* 2. *Cassia siamea* 3. *Erythrina orientalis* 4. *Peltophorum pterocarpa* 5. *Gliricidia sepium* 6. *Albizia falcataria* and one local, non-leguminous tree, *Peronema canescens*. Trees were established as in experiment I. *Cassia* and *Peronema* were planted as a polybag seedling. As main treatment in half of each block horizontal tree roots were pruned by digging a 20 cm deep trench (until the subsoil) at 50 cm from the tree row. Trenches were dug in December 1988

Trees were pruned at irregular intervals of 4 - 8 months. When left to grow for 8 months most species produced appreciable amounts of stems of more than 2 cm diameter, which were classified as 'firewood'.

Aboveground parameters

Apart from data on biomass production at prunings, occasional observations were made on the shape of the tree canopy and on specific leaf area, by determining the dry weight of leaf punches of known surface area. Light interception at ground level, by comparing light intensities (photosynthetically active radiation) in the plot with that outside and weed growth was measured after an 8 month growth period in experiment II.

Root observations

In December 1988 root distribution in the vertical plane was observed in experiment II, in border trees pruned at a height of 1 m. A soil trench was prepared just outside a plot of each species. Tree roots were exposed on the profile wall by carefully removing surrounding soil with a pin. Two trees were studied per plot. Subsequently the root distribution was drawn on graph paper. Notes were taken on nodulation.

Using the same method, the root distribution of hedgerow trees and intercropped maize was observed in experiment I in 1988 from a trench bordering a 5-m section, containing two hedgerows, of one plot per tree species.

In January 1990 the effect of stem pruning height on root parameter was observed in experiment II, on plots without root pruning. A group of four trees was selected per pruning height and soil was removed in a circle of 25 cm radius around the tree stem till a depth of 15 cm. The number of horizontal branch roots originating at the stem base plus first 10 cm of taproot was recorded per diameter class. Stem diameter at 25 cm above ground and tap root diameter 10 cm below ground were measured with a calliper. A top view on the exposed part of the root system was drawn on graph paper for one tree per treatment (selected to be 'representative' of the four replicates). Some young roots were collected, washed and stored in alcohol for later staining and microscopical observations on mycorrhizal (Vesicular Arbuscular Mycorrhiza, VAM) infection (Giovanetti and Mosse, 1980).

Finally, in 1990 quantitative data on root dry weight and root length density in the topsoil (15 cm) was collected when a ditch of 15 cm wide, perpendicular to the hedgerows was dug in the middle of each plot of experiment I. Soil samples were collected per 20 cm over a length of 4 m between two hedgerows and washed over sieves of 2 and 0.5 mm mesh size.

Woody roots were collected from the sieve and classified according to their diameter. For the plot with alternating *Peltophorum* and *Gliricidia* hedgerows separation of roots of the two tree species was simple on the basis of root color and habitus. Root length per diameter class of each sample was measured by a line

intercept method (Tennant, 1975). Root dry weight was obtained by drying the root sample in an oven at 80°C for 48 hours for fine roots and 96 hours for woody roots. Results are expressed per unit volume of soil sampled.

RESULT

Aboveground characteristics:

Biomass

Cumulative biomass production of prunings for a period of three years is shown in figure 2 for experiment I. Differences between species are evident:

Calliandra produces most biomass, about 12 Mg/ha per year; for *Gliricidia*, *Peltophorum*, the *Gliricidia/Peltophorum* plot and *Leucaena* production is approximately 8 Mg/ha per year and for *Erythrina* 4. During the three years the pruning regime was modified several times, leading to variation in the interval between subsequent prunings. From the approximately straight lines in figure 2, after the initial 6 months, we can derive an almost constant production per month. When biomass production per pruning is plotted against pruning interval (Fig 3), however, we can see that pruning production is not directly proportional to the length of the period since the previous pruning. For *Calliandra*, *Gliricidia* and *Peltophorum* an intercept on the X-axis of around 0.5 month is indicated, representing a 'recovery period' after pruning, before sufficient new leaves are formed to resume the original rate of biomass production.

N yield

Data on the N-content of prunings are presented for the third year in table 1. N content of leaves is approximately three times higher than that of the stem, so the weighted average for prunings depends strongly on the percentage leaves in the total prunings. N content of the pruning appears to decrease with increasing interval since the last pruning. To obtain average values for the whole year, the average for a 4 and a 2 month pruning interval was calculated in the last column of the table. N contents on a dry matter basis are lowest for *Peltophorum* and highest for *Calliandra* and *Gliricidia*. For the plot with alternating hedgerows of *Gliricidia* and *Peltophorum* average N content is more than the average for the two species and equal to that for *Gliricidia* alone, even though the biomass for the two components was approximately similar. A possible explanation for this phenomenon is presented below. The total N yield of prunings per year can be estimated from biomass production times average N-content. We thus estimate N yield to be approximately 360 kg/ha per year for *Calliandra*, 230 for *Gliricidia* and for the *Gliricidia/Peltophorum* plot, 190 for *Leucaena*, 170 for *Peltophorum* and 110 for *Erythrina*.