LITERATURE REVIEW

Deforested areas are being rehabilitated, wherever possible, by natural succession. If natural succession can not achieve the target, planting may be necessary (Bruening,1996), but successful reforestation programs largely depend on the availability of high quality planting stock (Josiah and Jones, 1992). There are many methods of forest restoration.

The framework species method was first defined by Goosem and Tucker (1995). It was developed in Queensland, Australia for re-establishing rainforest ecosystems. Framework tree species are those which "capture the site" by rapidly shading out weeds and attracting birds and bats, which bring in the seeds of a wide range of additional tree species. The principal advantage of this method is that it involves only one planting and is a self-sustaining approach which relies on the local gene pool to increase species and life form diversity. The principal disadvantage of the method is that it relies on native vegetation being close enough to provide a seed source.

Pioneer tree species are fast growing, short lived species (Bruenig,1996), capable of invading bare sites, which become established in the early stages of succession (Helms,1998). They may grow in low and high light intensity but show a considerable stimulation after transfer from low light to high light conditions (Luttge,1997). Pioneer species are important to the framework species method for several reasons: their rapid growth suppresses weeds and forms a cool, shady microclimate beneath the canopy; their ability flower and fruit from a very early age, providing food for wildlife; they rapidly contribute to leaf litter and re-establish nutrient cycles and when pioneer species die and fall, they create light gaps and they assist lateral and upward growth of adjacent trees. Fallen logs and branches create ground habitat for wildlife. Fast growth rates increase the vertical growth of adjacent slower growing species. This may have an effect on the future structure of the new forest, by ensuring that these slower-growing species reach their full potential height and structural capacity. Many of the birds, which feed on these species can travel across open areas between patches of native forest. If the framework species method is used, pioneer species should comprise 30% of the total trees planted. Using this method, natural regeneration generally begins within two years of plot establishment (Goosem and Tucker,1995).

The Forest Restoration Research Unit has been testing the suitability of the framework species approach for reforestation by planting mixture of 20 - 30 native tree species in the north of Thailand (FORRU, 2000).

The Maximum Diversity Method or Miyawaki Method

These two methods use the same principle for reforestation. They attempt to recreate the species composition of the original forest as quickly as possible by collecting seeds and seedlings of climax species, raising them in a nursery and after adaptation, by planting the young trees on adequately prepared sites (Miyawaki, 1993). These methods use as many native species as possible, based on the potential of the natural vegetation. Seedlings with well-developed root systems up to 80 cm tall are planted. The soil is prepared and adequate drainage provided.

Organic fertilizers and mulching with rice straw is used. Two or three years after, planting no further management is needed (Fujiwara,1993).

Goosem and Tucker (1995) said that the disadvantage of this method is the intensive maintenance required because of the slower growth of the climax species.

Nursery Management

Seedling quality is determined by two factors: firstly the genetic make–up of the parent stock and secondly the seedling's immediate environment, i.e. nursery conditions and practices (World Bank, 1993).

Transplanting seedlings into containers (pricking out) is carried out after expansion of the 1st leaf pair. Roots can be pruned to fit the depth of the hole in the containers. Some tree species grow very fast in the nursery . If these species are potted too early, they will be too tall by planting time. Sometimes tall seedlings do not have enough roots to support many leaves. When these seedlings are planted in the field, they may grow slowly or even die because the roots cannot supply the leaves with enough water. The tops of seedlings (shoot) that have grown too tall should be cut before planting (Wightman, 1999). Josiah (1992) recommended using a sharp knife or scissors to trim the top leaves and the roots of plants raised in containers. Root pruning should be done regularly as soon as the root begin to grow through the bottom of the containers into the soil of the nursery. As soon as the roots begin to grow out of the containers, the containers should be moved, cutting the roots off with knife or a pair of scissors. The frequency of root pruning will depend on the species and its rate of growth which may vary from once a month to once a week. Jaenicke (1999) recommend root pruning twice a month. It is easy enough to check when root pruning is necessary by lifting the containers up. If there is resistance, root pruning is needed. Root pruning makes seedlings deficient in water, so root pruning should be followed immediately by watering. Periodic checks are better than a rigid timetable. During root pruning, the opportunity can be taken to grade plants according to size and get rid off weeds (Jackson, 1987).

The right amount of light is critical for healthy development of seedlings. Too much shade, for example, leads to etiolated and elongated of seedlings and makes them weak and prone to fungal disease. Too much light leads to scorching and drying out of tender tissue. Good quality shade cloth provides durable and uniform shade to the seedlings. Shade should be used permanently installed. Plants can be used from one shade level to another (Jaenicke, 1999).

During transportation of seedlings from the nursery to the planting site, seedlings should not be handled by the stem. In a truck, seedlings should be covered by canvas or shade cloth to protect them from wind damage (FORRU, 1998).

The Target Seedling Concept

The target seedling concept involves specific physiological and morphological characteristics that can be quantitatively linked with reforestation success (Rose and Haase, 1995). There is a negative relationship between survival and height of seedlings. Shorter seedlings are preferred for arid sites and taller seedlings are better in areas with high weed competition. Quality seedlings targeted for different sites may look different from each other, but they all have one thing in common: a well-developed root system with many root tips, from which new roots can quickly develop. In areas with adverse environments, such as dry, flooded, saline, or nutrient-deficient sites, only well-developed plants have a good chance of survival. For dry areas, seedlings should have a deeper root system. For weedy sites, larger plants are better because they can quickly out grow weeds (Jaenicke, 1999).

No single characteristic determines seedling quality. It is a combination of height, diameter, nutrition, health, root size, and root shape. Together, these characteristics determine how well a plant will establish itself in the field. They directly affect the rate of survival (Wightmam,1999).

Seedling quality depends on:

1. the ability to produce new roots quickly,
2. a well developed root system,
3. sun-tolerant foliage,
4. a large root collar diameter,
5. a balanced shoot : root ratio,
6. good carbohydrate reserves,
7. an optimum mineral nutrition content, and
8. the establishment of adequate mycorhizal or rhizobium infection (Jaenicke,1999).

Many seedling characteristics, such as shoot : root ratio are difficult to observe and require destructive sampling. The shoot : root ratio is important for seedling survival (Romero *et al.*, 1986). The ratio varies with conditions of the internal and external plant environment (Kolek and Kozinka, 1992) and has been used to express a morphological balance (Wightman, 1997). Many different suitable shoot per root ratios indicate a healthy plant have been reported, *e.g.* 1 : 1 to 1 : 2 (Jaenicke,1999), but Sirilak (1997) recommended 1 : 3 or 1: 2 and 1 :4 depending on species or nursery practices.

Quality tree seedlings have the following characteristics:

1. They are healthy, vigorously growing, and free of diseases.
2. They have a robust and woody single stem, free of deformities.
3. The stem is sturdy and has a large root collar diameter.
4. The crown is symmetrical and dense.
5. They have a dense root system with many fine, fibrous hairs with white root tips.
6. They have a root system free of deformities (Figure 1).
7. They have a balance between shoot and root mass.
8. Their leaves have a healthy, dark green color.
9. They can survive short periods without water.
10. They can tolerate full sunlight (Wightman, 1999).

Many reforestation projects determine seedling quality by height. The Forest Restoration Research Unit uses seedlings up to 50 – 60 cm tall, 30 cm for faster growing species (FORRU, 1998) and FAO (1989) reported that seedlings 15 – 40 cm tall, with a woody tap root have a higher survival rate than smaller seedlings with poor root systems. Most tree seedlings have a straight, slightly tapering main root and a large mass of fibrous roots. Healthy roots are not bent, crossed, or damaged. Knotted and bent roots are common in plants that have been left in the nursery too long or have been pricked out carelessly. These plants cannot survive in the field because damaged or deformed roots die back and become vulnerable to disease and termite attacks (Jaenicke, 1999). Root systems with a high percentage of fibrous root and a large surface are can efficiently absorb nutrients and water (Rose and Haase, 1995). Boudoux (1972) reported that root growth is determined more by container diameter than height. This was confirmed for *Pinus ponderosa* by Tinus (1974). Hocking and Mitchell (1975) showed that growth of seedlings in larger diameter containers is better than in smaller diameter containers although the containers had similar (Romero *et al.*, 1986).

Mycorrhiza are good for plants. They are beneficial fungi associated with the epidermis and cortex of roots. These fungus absorb nutrients from the soil, while the host plant provides the fungus with carbohydrates, amino acids, vitamins, and other organic substances. Infected mycorrhizal plants are more tolerant of drought and other stresses than non-infected plants (Moore and Clark, 1995).

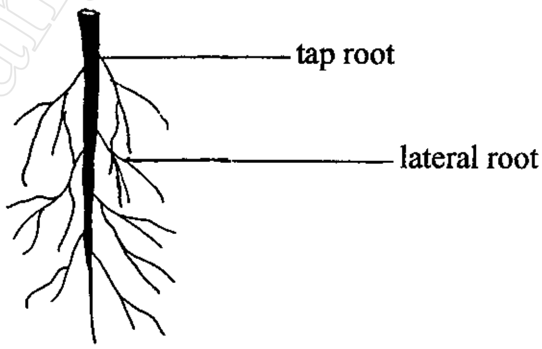

Figure 2. A good root system, where the tap root is straight with fine root hairs (Wightman,1999)

Root Deformations

Root deformities can be caused by poor pricking out from the germination bed into containers (Figure 3). Deformities generally occur within the first 10 cm under the surface of the soil. Seedlings are often squeezed into holes that are too short for the root system. When roots stuffed forcefully into bags, curl upwards. Since roots always eventually grow downwards, the roots bends back in completing a loop (Figure 3). These plants should be culled because they will never grow well in the field.

Figure 3. Root deformed by poor pricking out. The tap root was stuffed into a hole too small and the main root has twisted upwards (Wightman, 1999).

Figure 4. Root deformed by careless pricking out. The tap root is bent close to the surface of the container (Wightman, 1999).

Root deformities can also be caused by the bag. Smooth plastic bags cause the main root to coil or spiral along the side or the bottom of the bag. This inevitably happens when plants are left in the nursery too long. It can also happen to plants that are only a few centimeters tall. Some plants commonly develop roots before they begin shoot growth. So even plants with small shoots may have long roots that are coiled at the bottom of the bag (Figure 4). These roots should be cut off immediately before planting (Wightman, 1999).

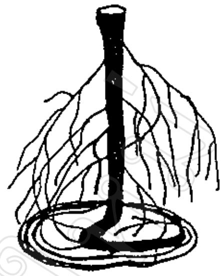

Figure 5. A spiraled root system, coiled at the bottom of the container (Wightman, 1999).

Roots can be characterized by their position and extent of deformation according to Menzie's Top Root Score (Chavasse, 1978; Zangkum,1998).

score	tap root condition
1	strong, dominant, well developed tap root
2	stunted, slightly malformed, but still a definite tap root
4	tap root distinctly hooked
6	tap root quite badly hooked, but downward development still present
8	tap root severely deformed into two or more fracture zones, but growth still downward
10	tap root dose not come below a horizontal plane, subtract one point for each strong sinker present

Containers

The size and vigor of seedlings in a nursery also depends on container size and nursery practices (Rabeendran and Jeyasingam, 1995). The optimum size of container depends on plant species, but the maximum size of seedlings in containers is determined by container size (Ffolliott *et al*, 1995). Containers have been found to reduce costs, improve seedling root morphology and vigor, increase post-planting performance and maximize program effectiveness and impact. Poly-bags are initially cheaper than root trainers, but they can usually be used only once, require large amounts of soil, are difficult to handle due to their size and weight, are poorly aerated, discourage lateral root development, and occupy large areas in the nursery. Most root trainers are reusable and durable, usually lasting 5 or more years, but are initially expensive and require a rack system for support (Josiah, 1992).

Poly-Bags

Poly-bags (polythene) are used worldwide because of their low cost, apparent simplicity and convenience (World Bank,1993) and if they are made from locally available materials, they may be more affordable. Plant development depends on the quality of the substrate more than the size of the bag. While small bags can be used with a nutrient rich substrate like compost, plants in small bags cannot stay in the nursery as long as plants in large bags (Wightman,1999). FAO (1989) reccommend that the minimum diameter should be 5 cm and height 15 cm.

A common problem with poly-bags is that roots tend to grow in spirals once they meet the smooth inner surface. This will inevitably lead to plants with restricted growth with poor resistance to stress and wind. The discarded poly-bags are a problem for nursery waste management, as they do not decay and are often burned, producing air pollution (Jaenicke, 1999).

Root Trainers

Root trainers are usually rigid containers with internal vertical ribs, which direct roots straight down to prevent spiral growth. The latest developments also encourage lateral air root pruning through vertical slits. Seedlings grown in root trainers have more vigorous and rapid root growth than seedlings grown in poly-bags. Out planting survival and, more importantly, long-term survival are much better. Plants grown in root trainers are often ready for planting when they are substantially smaller than those from conventional poly-bags. This helps to reduce space requirements in the nursery and transport costs to the field (Jaenicke, 1999).

Root trainers have been used to successfully grow high quality trees. They come in many shapes and sizes, but all have two characteristic in common; *viz.* vertical ribs and a big hole at the bottom. The vertical inner ribs direct the roots straight down as they grow, thus avoiding root deformities. The containers are set on frames above the ground, so that air circulates around the bottom hole. Roots are air-pruned as they emerge from the container. This natural pruning of the main roots encourages secondary root growth so that eventually the volume of the root trainer is filled with a 'plug' of fibrous roots. When the tree is planted in the field, the pruned roots continue to grow (Wightman, 1999).

Thapa *et al.* (1990), studied in the nursery techniques for four multipopose trees of Nepal. Experiments with *Artocarpus lakoocha, Bauhinia variegata, Dalbergia latifolia*, and *D. sissoo*, all showed significantly better seedling height, root collar diameter, and biomass production in 7.3 x 17.5 cm flats containing the growing medium of forest soil and farm yard manure.

Sunanta (1992), studied in growth of selected forest tree seedlings in different container sizes and potting media in Thailand and reported that, the container is positively correlated with seedling growth only in the case of fertilized media. The cost of producing 10,000 seedling varies from 171 to 183 US$ in *Hiko Boxes,* a type of root trainer, 34.5 cm long x 21.5 cm wide x 10.0 cm deep, 311 to 314 US$ in 10 x 15 cm black plastic bags and 452 to 523 US$ in 15 x 20 cm black plastic bags.

Rabeedran & Jeyasingam (1995) studied the effects of pot size and mulch on planting stock of exotic and indigenous species in Sri Lanka. Experiments with four sizes of poly-bag, *viz.* a) 10 x 22 cm b) 14 x 22 cm c) 10 x 44 cm and d) 20 x 22 cm, showed that wider pots are preferable for raising seedlings. Their recommendation was that rainforest seedlings should be grown up to 60-90 cm tall in 1 liter (approximately 20 cm deep) bags or similar containers. Plants of this size rapidly establish and dominate the site (Kooyman, 1996).

Zangkum (1998) reported that seedlings grown in REX trays were of significantly higher quality than those grown in other containers. A cost-benefit analysis showed that REX trays are beneficial for use on a wide scale for forest restoration in Thailand. REX trays have been studied in several nurseries and good results have been obtained. Root development of seedlings grown in these trays is generally much better than of seedlings grown in plastic bags and root deformation is reduced. REX trays are generally used in conjunction with air pruning.

For air pruning, the trays should be arranged so that there is a distance of more than 30 cm from the ground (Kamizore, 1998). Good aeration is needed for root development, since roots need more air than the stem and the leaves (Valli, 1995) for nutrient absorption because nutrient uptake requires energy, this comes from root respiration (Ignatioff and Page, 1968)

Boontawee *et al.* (1999) reported growth in terms of average height of 4 - month old seedlings of *Melia azedarach* Linn. (Meliaceae), which were planted in 4 x 6 , 5 x 8 and 6 x 8 inch plastic containers height equal to 14.63, 23.90 and 35.18 cm. From ANOVA, there were significantly differences among the container sizes. Average stem diameters at ground level of 0.26 , 0.30, and 0.46 cm were recorded at the same time as height and there were highly significant differences, but the differences among sizes of containers were not significant in terms of root : shoot ratio.

Fertilizer

Shade, water, and nutrients are all important for plant growth, development (Ignatioff and Page, 1968) and interact to produce healthy plants. A plant that grows in full light with abundant moisture and which receives all 13 basic nutrients will grow fast and have dark green leaves. Some species grows slowly in the shade may turn yellow. This does not mean that plants do not tolerate full sun – it might indicate a nutrient deficiency which did not show up in the shade because the plant did not have enough light to stimulate fast growth (Wightman, 1999).

When using soil or soil-based media, fertilizer might not be needed immediately because the substrate has residual fertility. During the production phase, seedlings need addition of balanced nutrients, but too much fertilizer can cause harmful toxic effects, burning the plants or making them grow too tall and weak (Ignatioff and Page,1968). Also, plants that do not have enough fertilizer grow slowly and become sickly. Root can take up nutrients only in dissolved form

(FAO,2000). Before applying fertilizer, the seedlings, should be watered since fertilizer can burn the roots if the soil is too dry. After fertilizer application the seedlings should be sprayed with water to wash fertilizer from the leaves so they are not burned (Josiah,1992). For large plants 1.5 to 2 tablespoons of soluble fertilizer (20-20-20) in a 3 gallon (15 litres) watering can is recommended, which can fertilize about 1,200 plants. Josiah, (1992) recommended beginning fertilizer application 2-3 weeks after germination or 1 to 2 weeks after transplanting. Alternatively slow-release fertilizers can be used, such as "Osmocote". Elliott *et al.* (1998) recommended adding about 10 granules (approximately 0.3 g) of slow - release "Osmocote" fertilizer (NPK 15 : 15 : 15) to the surface of the potting mixture in each container every 3 months.

Inorganic Fertilizers

Inorganic fertilizers are divided into single fertilizer, compound fertilizers, and full fertilizers. They can be applied by broadcasting or by mixing with irrigation water (fertigation). Fertilizers are commonly known by their main nutrients N, P, and K. The numbers on the bags show the percentages of these components. For example 20-10-10 fertilizer contains 20% of nitrogen, 10% off phosphorus, usually in the form of P_2O_5[2] and 20% of potassium, usually in the form of K_2O[3] (Jaenicke,1999).

Granular inorganic fertilizers and controlled-release fertilizers provide an attractive alternative to granular fertilizers. The release rate depends on water availability and soil temperature. Controlled-release fertilizers are more expensive than conventional soluble fertilizers, but they have several advantages:

1. The danger of over-fertilizing is reduced as the release of fertilizers is gradual.
2. Fertilizing is necessary only occasionally, sometimes only once in a season.
3. A balanced fertilizer mixture is provided at all times as the plants get what they need at different growth stages.

- Nutrients do not leach from the substrate since the plants receive all nutrients applied.

In products using the "Osmocote" technology, resins based on natural organic oils, such as soybean or linseed oil, are used to coat the fertilizer. Different thickness of resin coating are applied to the base fertilizer to achieve different release periods. Water enters the granule and dissolves the nutrients and they pass through the coating at a rate controlled by the soil temperature. As temperatures fluctuate, the rate of nutrient release changes, matching plant demand as growth rates rise and fall in correlation with these changes. The resin coating remains intact throughout the life of the product. When all nutrients are expended, the coating dissolves. There are products for specific markets, such as ornamentals, vegetables, and nursery production. The granules last from 3-4 to 16-18 months, depending on the soil temperature. Their estimated life is based on an average temperature of 21°C, release rates change by about 25 % for every 5°C. In tropical environments, with an average soil temperature of 28°C, a product labeled four months would last roughly three months (Jaenicke, 1999).