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FOREST & LANDSCAPE

# *A review of direct sowing versus planting in tropical afforestation and land rehabilitation*

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Directly sown pinus in Brazil, 1988
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# Preface

The use of direct sowing as an alternative to conventional planting has increased in high income countries, e.g. in Europe, USA and Australia. The drawback of poor germination and survival rate, which used to be a crucial limitation, has been improved by progress in seed technology, land preparation and management. The relative cost of various inputs for tree establishment varies with species and site, as do the economic requirement and gain of various alternatives. There are few comparative studies on the two types of afforestation technique, and in particular the economic benefits of them. A previous review of direct sowing was compiled by Peter Ochsner in 2001 (Ochsner 2001). The present paper is both an update and a more comprehensive review, where direct sowing is considered a potential alternative to conventional tree plantings under a wide range of conditions.

Different objectives, economy and priorities in afforestation programmes lead to different establishment methods. The shift towards more environmental plantings and land rehabilitations with multiple species tends to foster alternatives to conventional planting methods. This paper highlights some of the basic considerations connected to direct sowing as an alternative to planting. However, far more documentation is needed to be able to chose and adapt the most appropriate way of afforestation technique in the tropics. The prime aim is thus to encourage experiments with alternative ways of establishment where short term and long term benefits are considered.

The task of tropical afforestation and land rehabilitation is enormous and so are the expenses. There is an obvious economic benefit in using the most suitable afforestation technique. Where afforestation budgets are meagre, efficient establishment methods can in practice mean a large difference in how much afforestation is actually implemented.

July 2007

# Content

# 1. Introduction

Planting is such a common practice in tree establishment that any type of established forest is almost invariably considered a synonym with a 'plantation'. During traditional plantation establishment seeds are germinated and plants raised in nurseries. When plants are 'plantable size' they are moved from the nursery to the field, their permanent growth site. Growth rate and desired plantable size vary with species and site, and thus does duration of nursery period. Plantable size is for most species some 50 cm high, but this can vary considerably from site to site. Where field plants are facing considerable competition from weed (herbal or woody), larger size is preferred. In urban areas large planting size is preferred both to improve the chances of surviving accidental mechanical damage, e.g. by unaware pedestrians, and because urban trees are part of an 'architectural design'. Fruit trees planted in private gardens are generally preferred as large as possible at the time of planting. This is both so they will start bearing fruits as soon as possible after planting and thus utilise the site of small garden better, and because all garden trees are ornamentals and part of a 'design'; garden owners generally want full display of their planted material immediately (Arnold 2005). Two to three meter high plants are thus rather common for temperate fruit and ornamental trees for private gardens. Large trees are obviously more expensive than small ones, since they have a longer nursery tender period. However, for private gardens, the price may not be crucial, and for productive fruit trees, the extra cost of large plants may easily be balanced by earlier production.

Fast growing plants of some forest trees may reach plantable size in a few months. Slow growing species may require two years, occasionally even more, to reach a desired size. During that period plants take up space and resources in the nursery. Nursery raising requires regular care, e.g. watering, while field plants are generally less demanding. Therefore, an opposite trend of delaying planting and using large plants prevails in some situations viz. to eliminate nursery cost altogether by sowing tree seeds directly in the field without previous nursery raising. This is generally known as 'direct sowing' or 'direct seeding'. In addition to cutting away the direct nursery costs, direct seeding also cut away the derived costs of plant transport and planting of seedlings. An indirect aim is, in some situations, to simplify afforestation efforts by cutting away the more complicated nursery and planting phase. In bureaucratic and 'slow' systems, organisation of planting can be complicated and direct sowing can in such cases be a 'shortcut' alternative. Applicability depends, obviously, on whether it is ecologically suitable, i.e. whether seeds have a fair chance of surviving field stress. In most cases, plant survival after direct seeding is lower than of planted ones. To be economically feasible, the expected poorer survival rate, which implies for example higher seed cost, must be balanced against the costs saved for nursery, transport and transplanting.

The dilemma of direct sowing versus planting is not new. Direct sowing has been widely tried, yet found limited applicability in practical plantation forestry in the past (Evans and Turnbull 2004). However, some development trends tend to favour the method suggesting it could be more applicable in the future:

1. Labour cost and thus nursery and planting costs increases.
2. Better field equipment makes application more reliable.
3. Improved weed control measures reduce the problems of competition from weed.

In addition, the method is relatively competitive for raising multi tree species forests and afforestation of wasteland and former agricultural land.

# 2. Why are trees usually planted and not sown?

Raising plants on seed beds with later planting out is used for certain annual crop species. In seasonal climates, plants are often raised before the growth season to give them a 'head-start' and thus extend the growing season. In temperate regions, plants are often raised in greenhouses during the cold and dark period and are thus established for out-planting once days get longer and warmer. In the tropics, water is the main seasonal factor. Raising plants on a seedbed during the dry season can prolong the growth season. Among tropical crop species, planting is mainly performed for rice. In seasonal wet tropics the planting practice allows above mentioned 'head-start' before the rainy season for the first crop. For the second and sometimes third crop planting allows an overlapping generation: plants are sown in the seed bed and plants are raised before harvest of the previous crop. Raising paddy rice from seed to plantable size takes about three weeks. The overlapping generation gives thus a better land utilisation where land is scarce. Since plants are established and actively growing when planted out they have a competitive advantage over weeds. Rice is particularly good for establishing by plants since they are planted and grow under very wet conditions, which in turn makes planting relatively easy and potential 'transplanting chock' small.

Forest trees have, in comparison with rice and other annual crops, a longer nursery season, longer generation time and large land occupation when mature. However, the elements of coping with seasonality, weed competition and efficiency in land use are similar to short rotation crops: land can be used more efficiently by using plants and competition with weeds is better; however, planting implies higher cost in labour and transport during establishment.

Fig. 1. Both nursery work (here prickling out seedlings in 'poly-pots') and planting of seedlings is very labour intensive. In countries with high labour costs, direct sowing is becoming increasingly competitive with traditional planting

**a. Seasonality**

Trees' life spans over several years and must cope with the prevailing climatic seasonality once planted out in the field. However, young plants are usually more sensitive than older plants. Plants are typically planted out when field conditions are appropriate with regards to temperature and moisture. Under marginal or highland tropical conditions temperature is a limiting factor. Although plants may survive during cool periods, they are always more vulnerable to e.g. attack by diseases when growth conditions are poor, and it is thus advisable to plant only when the soil temperature is appropriate. Since plants are obliged to cope with the next coming stress season, planting should be as early as possible during the growth season, so they can establish themselves before the stress season. In seasonal dry tropics that would be the beginning of the rainy season. Plants should be raised with a time schedule that makes them 'plantable' size at the time of best out-planting. Optimal planting season is usually also the best time for direct sowing. However, seasonality can be manipulated under nursery conditions, while directly sown seeds are left to the fate of seasonal stress. It does not necessarily mean a lower immediate survival, but planted seedlings will have a better starting point to form for example a deep root and compete with weed.

**b. Weed competition**

Weed includes all undesired plants growing together with the target species. Many trees are slow starters as compared to e.g. herbs, and tree seedlings inevitably suffer from competition with weed. Competition depends on weed type. In dry areas weeds are mostly grasses and herbs. In humid areas weedy vines and climbers can form a dense 'carpet' that overgrow trees and prevent most sunlight reaching lower vegetation including small tree plants. Planting gives trees a small head-start in the competition with weed. Light is the main limiting factor during the establishment stage. As trees grow taller, they generally gain competitiveness, as they reach over the herbal weed and grass and in turn shade them out. However, vines continue to be a problem, as they often grow together with trees. Competition also includes water and nutrients. As tree roots often grow deeper than herbal roots, this type of competition also declines with age. Weed is often a major problem in forest establishment and the better competition from plants is one of the strongest arguments why planting is often inevitable. This fact also implies that direct seeding is only applicable if the weed problem can be reduced by appropriate field control, and the tree species are relatively tolerant to competition when young while at the same time growing so fast, that they will quickly outgrow the competitive weed (Venning 1990).

**c. Land use efficiency**

A very long juvenile period and different space requirement between young and mature trees make land utilisation of trees relatively inefficient during the years of establishment. In plantation forestry various measures are taken to make land use more efficient.

1. *Use of thinning material.* Late thinning permits commercial use of thinning material for poles, small timber and firewood.

2. *Taungya system*. A plantation system practiced in some tropical countries, where the land between the tree plants is used for crop growing until the competition from trees makes this practice unfeasible. Crop production thus utilises land, that would otherwise be unused or occupied by weeds. Taungya systems usually include a clause, that farmers weed and tender the trees during the cropping period.

3. *Natural rejuvenation*. A forest type where a young generation is established before the mature trees are logged gives an efficient use of both land and growth conditions. Several systems exist; in some systems rejuvenation takes place closely before logging and there are thus only two strata. In other systems there are multiple strata (and sometimes several species) in which logging is continuous. In terms of area utilisation the latter system is the most efficient, but it can have some operational drawbacks, for example in terms of logging damage, transport and increased labour cost per logged tree.

Delayed transplanting allows land to be used for something else while the plants are still in the nursery. As mentioned above, some extreme cases are in small city gardens, where trees are close to maturity when planted out. In agroforestry systems, fruit trees would normally be planted out as seedlings and not as seed. This is also due to the fact that many fruit trees are grafted, an operation which is essentially carried out on seedlings and which is often more easily done successfully under nursery conditions. Shade trees are another type of tree which obviously only yield the desired return when large and full grown, and such plants would usually be planted out when they are as large as possible.

Fig. 2. Weed competition after selective logging. In the humid tropics vines, climbers and bushes form a dense carpet over logged over areas, making establishment of seedlings of timber trees very difficult. Both plants and germinating seeds face this competition.

Fig. 3. Taungya system, here with pines in Java, Indonesia. Farmers grow crops between trees while the trees are small. The system seeks to optimise the use of the land and farmers also help weeding the trees

In agroforestry nitrogen fixing plants are important for nitrogen supply. Nitrogen fixing bushes such as *Sesbania*, *Caliandra*, *Flemingia* and *Leucaena* are interplanted with crops. Some plants, e.g. *Tephrosia* and Crotolaria spp. are also used in improved fallow. The purpose of fallow is to build up a nutrient source for the subsequent crops. The shorter the time to build up the resource, the shorter the potential fallow and thus the shorter the time the land stays out of production. Improved fallow is a method to accelerate nutrient accumulation and thus shorten the fallow. Direct sowing is by far the cheapest way of establishing legume trees. However, it takes several months before N2 fixing starts, and this period is, in an N-supply context wasted. Planted seedlings are ready to fix nitrogen immediately after outplanting (Kwesiga *et al.* 1999). In addition nursery plants can be inoculated with selected *Rhizobium* to maximise N2 fixation. When direct sowing, despite that, is practiced for improved fallow it is because of the fast and cheap establishment, and because the high plant density usually compensates for the delayed start of nitrogen fixing (Niang *et al.* 2002).

**d. Plant distribution**

A precise and even plant distribution facilitates weeding, beating up, thinning and other operations in plantations. During plantation establishment, seedlings are usually planted at even space of 2x2, 2½x2½, 3x3 meters depending on species and plantation site (Evans and Turnbull 2004). Smaller plantings like shelterbelts and hedges have the same advantage of even distribution. Even plant distribution can be achieved in direct sowing, e.g. by precision sowing in rows. However, poor germination implies a relatively high sowing intensity, and since it is unpredictable which seedlings will survive, the final distribution will be less homogenous than in planting (Madsen 2005). Where seeds are sown by aerial sowing or broadcasting, plant distribution is completely random.

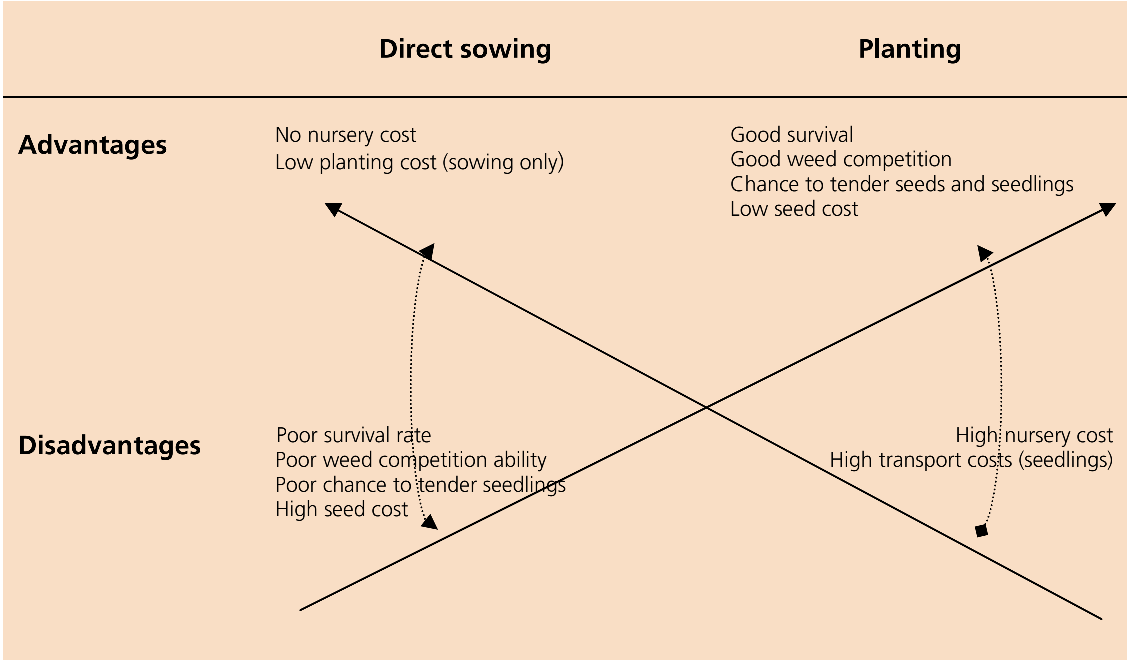


Figure 4. Balance between various positive and negative parameters in seed sowing and planting respectively. Considering a vertical scale on relative advantages and drawbacks, steep lines tend to favour an alternative method. For example, if the relative difference between survival rate of directly sown seed and nursery plants is low, while there is no difference in nursery and transport cost, direct sowing is favoured.

# 3. Some benefits of direct sowing

### a. Biological aspects

Seedlings, which are grown in tubes, pots or even seed-beds, have some restrictive root development. In container plants, root development is restricted to the space within the container. Roots that are physically restricted in development grow twisting or spiralling. Tap-roots that grow out of pots are normally pruned or otherwise restricted in their development (Motz 1995). Bare-root seedlings are usually also pruned; although the root development is less restricted by physical barriers, strong competition with other plants will restrict development. A standard poly-tube of 6 cm diameter and 12 cm tall holds about ⅓ litre, which is the space the roots have got for their development. For an average medium size plantable size seedling of some 40 cm, the unrestricted root development could be 100 times larger. The difference can be much larger in dry zone tree species (fig. 1 and 2). Restricted root volume in relation to height can have various drawbacks during field establishment: 1. Restricted root penetration area implies restricted water absorption area - 'top-heavy' seedlings may thus be prone to desiccation damage. 2. Wind-throw and mechanical uprooting, e.g. by browsers, are risk factors until plants have established a firm grip in the soil (Hall 1991).

Plants grown and tendered in the nursery will be moved to the field for planting, which implies exposure to a very different environment. In addition to different soil environment, both container plants and bare root plants are likely to suffer some root damage during planting. Damage may happen both during lifting from the nursery, removal of plastic tube and during planting (Ezell 2004). A frequently encountered stress factor is poor root-soil contact resulting from, e.g. inappropriate care during planting (Sands 1984). Transplanting stress depends much on species and field environment. Seedlings planted out where soil is moist quickly establish a good root development. Seedlings planted in relatively dry soil often suffer high mortality because the roots are not capable of absorbing sufficient moisture to compensate for top evaporation. Even when planted during the relatively moist season, root development is often insufficient and plants die during the first coming dry season. Experience from Niger revealed that direct sown plants had a higher chance of survival than planted seedlings (Eden Foundation 1996). The same trend was found for *Faidherbia albida* in Senegal. Four months after sowing and planting respectively the direct sown plants were both higher and had much greater root mass than planted seedlings (Shamba 1992). Transplanting stress is obviously not experienced during direct sowing.

If conditions are favourable to germination and establishment of seedlings in the field, direct sowing may compensate for their less advanced development stage by the absence of planting and field stress event. Many dry zone species form deep taproot before the onset of significant top growth (Eden Foundation 1992a and b). Such species are generally prone to damage if root pruning is attempted. Seedlings that suffer heavily from root pruning and field planting stress have a comparative advantage when sown directly (Green *et al.* 1999).

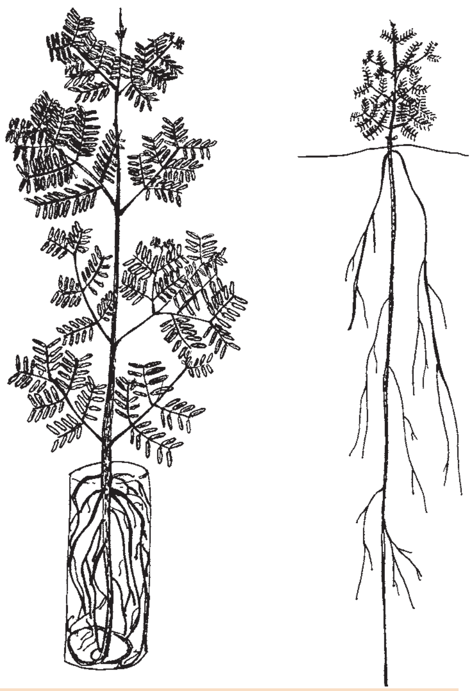

Figure 5. Root development of a dry-zone species sown in containers and in the field. Container sown plants tend to develop a large shoot because they are watered regularly. Root development is restricted because of physical barrier of the container and pruning of outgrowing roots. Seedling development of directly sown seed shows a large deep taproot while the shoot development is still small. The top typically remains small until the root encounter a good water supply (Redrawn from Eden Foundation 1992).

Figure 6. Seedling development of a dry/ zone *diospyros* spp. The seedlings develop a very long root while maintaining only 2/3 leaves.

**b. Reduced transport and labour**

Labour input is a major cost for plantation establishment, since very little can be mechanised (Evans and Turnbull 2004). Labour cost for propagation and plant tender include e.g. seed bed preparation, sowing, plant pot filling, transplanting into pots, root pruning and watering during the time plants are kept in the nursery. Transplanting into pots is sometimes omitted: large seeds are often sown directly into the pots. Transport of plants from nursery to the field is labour intensive; the actual amount depends on distance and to some degree the plant size. Eventually, planting usually requires manual labour. The total investment per plants may easily approach an economic critical ceiling on how much can be invested in one tree. In USA Ezell (2004) estimates that the initial cost of establishment can be reduced by one half to two thirds by direct seeding.

Justification of planting is the anticipated higher survival rate as compared to direct sowing. What is invested in planting seedlings may thus be saved in re-planting /re-sowing and weeding.

## c. Stand density

Seed price is usually a small figure on the total afforestation budget. The cost of the sowing operation is little affected by seed density. Therefore, if seeds are available and reasonably priced, aerial sowing and drilling will normally use excess seed to make sure that enough seeds germinate to form a stand of trees, also at relatively poor sites. The density of seedlings will thus usually be much higher than for plantations. High plant density has some immediate advantages, for example higher resistance to/escape from pest and predation, faster land cover and thus ousting of grass and weed, and the chances of conducting phenotypic thinning once the plants have grown up (Minnesota DNR 2006, Purnell *et al.* 1999)

# 4. Drawbacks and limitations of direct sowing

Mortality of tree seedlings normally declines with their size and age: mortality is high during germination and early seedling stage, while established seedlings and saplings are much more resistant. As stated above the key idea in raising plants in the nursery is to reduce mortality during the most vulnerable stage, e.g. by reducing competition and providing better germination and growth environment.

### a. Biological / germination problems of direct sowing

Various biological factors restrict establishment of seedlings after direct sowing. Pre-germination predation can be severe if seeds are broadcasted on top of the soil since they are very conspicuous for any predator (Woods and Elliot 2004). Birds foraging can take a heavy toll of dispersed seeds. In hillsides in Hong Kong area close to 100% of seeds are reportedly removed by rodents (Hau 1997). Conspicuousness will be greatly reduced if there is some covering vegetation. Here a balance is necessary between the positive effect of coverage against the negative effect of competition (Stevenson and Smale 2005, Viera and Scariot 2006).

Moisture is often the most critical factor since both germinating seeds and small seedlings are vulnerable to both desiccation and excess moisture. Desiccation during the critical stage after radicle penetration and before the new root is able to absorb moisture often leads to the death of seeds. Also water-logging can be critical because it causes anoxia. Drought and water logging can be very local at the soil surface, where moisture will drain off from higher elevation coarse grained material and collect in small depressions. Mortality of germinating seeds due to desiccation and to water logging respectively may thus occur within the same small area. An established plant has better chance to absorb moisture and oxygen from an extended root system, even if part of its growth site is desiccated or waterlogged, and thus has a much better chance to survive periodic adverse conditions. Stress conditions are often exacerbated by fungal infection, in particular during water excess. Adverse light conditions also have a stronger effect on small newly germinated plants than on larger ones. Partly because low plants are more likely to be covered by other vegetation, partly because larger plants have a higher chance of having some of the leaves in light, and they can develop in a direction where light conditions are better.

Experiences of direct sowing show that germination failure and early

**Germinants and small seedlings are more vulnerable than larger plants to:**

1. Shading
2. Desiccation
3. Anoxia (water logging)
4. Washing away
5. Predation
6. Grazing
7. Mechanical damage
8. Fire

seedling mortality can be very high. For example, in a direct sowing test with *Pinus kesiya* only 4% germinated and survived one year (Dalmacio and Bangaran 1976). However, the success rate is very dependent on sowing methods and conditions. In Denmark the success rate after direct sowing of *Quercus* spp. on farmland is 20-30% (Madsen 2005). Direct sowing on dry sites in southern USA caused a very high mortality and the method is not recommended for excessively dry areas in that region (MSU 2005). It should be noticed that this observation contradicts the finding of Eden Foundation (1996) mentioned above, who found dry land of the Sahel particularly suited for direct seeding.

Mechanical weed control can be significantly more labour intensive for seedlings of directly sown seeds than for planted seedlings because of their smaller size; small plants are simply difficult to find. The problem is accentuated by random distribution. Machine drilling eases this problem because the plants appear regularly in rows and machine weeding can sometimes be practiced. In spot sowing of individual seeds it is advisable to demarcate sowing spots, e.g. by using coloured sticks.

**b. Economic drawbacks**

Where poor survival rate undermines possible gains in saved nursery, planting and transportation costs, direct sowing is clearly not applicable. Where both establishment methods are possible alternatives, the economic benefit or drawback depends on the balance between various activities necessary during plant establishment and the land occupation (fig 3). Direct sowing implies saved nursery, plant transport and planting cost, but is likely to require additional cost on land preparation, beating up, weeding and thinning. For example, because mortality is patchy, some areas will end up with high, others with low plant density. Although the high density may give an immediate advantage in terms of faster crown closure and thus better weed competition, high density stands must usually at a certain time be thinned, an operation inevitably implying some additional costs (Venning 1990). In an economic plantation rotation, the nursery period is time saved for the plantation, where the land can be used for something else, e.g. growth of mature trees, cf. section 2, land use efficiency. The relative value of the individual activity depends on various input, e.g. seeds, required labour, labour cost, terrain, transport and possible pesticides. The higher the relative seed cost and the lower the potential field survival, the less attractive becomes direct sowing. High seed-production costs inevitably makes seed more expensive. Hence, seeds of rare species, seeds of species with high procurement cost, e.g. collection involving climbing, and seeds from improved seed sources (seed orchards) are thus often considered less attractive for direct sowing. However, direct sowing does not necessarily imply poorer genetic material. Firstly, the use of lower grade seed may to some extent be compensated for by a higher selection intensity during thinning; if germination is reasonably high, stand density will be much higher than after planting, and there can thus be done an intense phenotypic thinning (Minnesota DNR 2006). Secondly, improved seed orchard seeds are generally larger, have better vigour and genetic growth potential. They are thus likely to suffer lower mortality. If this is the case, seeding rate can be significantly reduced when using orchard seed rather than random seed (Wennstrøm *et al.* 1999).

*Table 1. Relative cost of input during natural sowing and seedling planting*

| Input / Activity | Relative cost | |
|---|---|---|
| | **Direct sowing** | **Plant raising in nursery** |
| Seed | High (high seed demand) | Low |
| Sowing | High | Low |
| Plant transport | Not applicable | High |
| Nursery tender | Not applicable | High |
| Land preparation | Variable | High |
| Plant pit preparation | Low | High |
| Planting | Not applicable | High |
| Weeding and plant tender | High | Low |
| Plant replacement / beating up | Rarely practiced | Low |

# 5. Experiences of direct sowing of trees

### a. Aerial sowing

The practice of sowing seeds from small aircrafts for afforestation of large inaccessible areas, have been used in e.g. China P.R (National Research Council 1981, Xinhua, C. and Jingchun, Z. 1988), India (Prasad 1988, Lahiri 1991) and Vietnam. In Vietnam aerial sowing is mainly used for pines. In China the main species are pines but include also e.g. *Hippophae rhamnoides*, *Schima* and *Acacia* species. The terrain is mountainous and mostly grass covered. Prior to sowing, the grass is usually burned. Seeds are sown during the dry, cool season (January – March) (Xinhua and Jingchun 1988). According to the two authors timing is very crucial for success; late sown seeds generally germinate well but have very poor survival during the succeeding dry season. Aerial sowing, as part of afforestation programme has been practiced in China for many years, the first experiments dating back to the 1950'ies. Out of about 30 mill hectares of 'hillside closure system', aerial sowing was used for approximately one third of the area (Sannai 2006). India has used aerial sowing for afforestation and rehabilitation of different types of environment. Most successful were the rehabilitation of eroded ravines (Sharma 1985, Prasad 1988). A mixture of fast growing legumes and grasses was used.

Figure 7. Forests transformed to vast grassland areas cover large parts of northern Vietnam and southern China. Inaccessibility makes reforestation by planting very labour demanding. Large areas in both of these countries have been reforested by aerial seeding from small aircraft

### b. Mine spoil rehabilitation

Open mines exist in both dry and humid areas. Open mines are mostly devoid of any woody vegetation because soil has been dug up repeatedly. Many mine spoils have coarse-grained structure with little or no organic matter and concomitant lack of nitrogen and phosphorus, low cation exchange capacity and base saturation (Jim 2001). In addition many mine spoils contain toxic metal residues and are almost devoid of microbial activities (Panday *et al.* 2005). Because of recent mechanical digging and moving, many mine spoils are strongly prone to erosion, which exposes seeds and seedlings to yet another hazard viz. movement of loose soil. The aim of mine spoil rehabilitation is primarily to stabilise the soil. Terrain problems sometimes makes some levelling and terracing necessary prior to rehabilitation (Panday *et al.* 2005). In Australia several mine spoils have been afforested by conventional agricultural methods: the soil is harrowed and seeds are drilled by sowing machines. A number of different species are used, in Australia mainly small seeded Myrtaceae, casuarinas and acacias.

Figure 8. Mine spoils consist of piles of dug up mineral soil without vegetation. Direct sowing of hardy pioneer species is often suitable because there is no competing vegetation. A drawback on sloping sites is that many seeds are washed away by rain and soil flow before they get a firm grip on the soil after root formation.

**c. Small legume agroforestry species**

Agroforestry makes use of a range of legume woody species primarily for soil improvement and fodder for livestock (Nair 1993). The legumes may be grown as permanent live fences or alleys, or they are used for improved fallow. In all these situations the legume trees are grown at high density, which implies relatively high planting cost. Direct sowing is applicable because the species are fast growing and weeding is integrated in crop cultivation. Establishment by direct seeding does thus not have major drawbacks and it requires considerably less labour (Owour *et al.* 2001). Agroforestry species found suitable for direct seeding are e.g. *Sesbania sesban* (Roshetko *et al.* 1991, Owour *et al.* 2001), *Gliricidia sepium* (Chintu *et al.* 2004), *Leucaena leucocephala* (Rimando and Dalmacio 1978), *Tephrosia*, *Crotolaria*, *Desmodium* (Niang *et al.* 2002). Probably many other agroforestry legumes can be used for direct sowing.

**d. Rehabilitation of tropical grassland**

Abandoned agricultural land, degraded by subsequent cycles of shifting cultivation with concomitant nutrient loss, dominates vast areas of former forested land in the humid tropics. The areas often appear as grassland or shrub land. Other areas have deliberately been converted to pasture for cattle, but deforestation has implied problems with erosion and watershed, and there are attempts to reforest such areas for environmental purposes. Grasses are strong competitors to trees when they are young, but when trees grow older, they shade out the grasses. Once woody vegetation has

Figure 9. Many agroforestry species are suitable for direct sowing. Most species have fast establishment once seed dormancy is broken, and cultivation in agricultural areas allows some weed control. Agroforestry legumes are used for soil improvement and fodder for livestock. Above are *Sesbania sesban* (left) and *Crotolaria* spp (central), both used for improved fallow, and *Calliandra calothyrsus* (right), here cultivated as a fence around a small field. Photo sources: left, L. Schmidt; Centre, Forest Research IInstitte Uganda; Right, ICRAF Nairobi.

established, new species are likely to invade from neighbouring areas, provided there are patches of natural forests and natural dispersers within normal dispersal distance from the rehabilitating forest (Elliot *et al.* 2003, Sun *et al.* 1995). Previous afforestation of grassland used mostly pine monoculture. Many pines have relatively high fire resistance and can survive low-intensity burning during the sapling stage; fire is a prevailing stress factor in grassland and often destroys newly planted tree seedlings. However, if the fire problem can be managed, a shortcut to establish a species rich forest is to establish pioneer trees of broadleaves, which are more attractive to animal dispersers. This method has been used in northern Thailand (Elliot *et al.* 2003). Planting is, however, a very costly operation and direct sowing has been used as one among several methods for rehabilitation. Although mortality was quite high in some types of trials, the experiments also showed that some limiting factors such as predation and desiccation could be dealt with by appropriate establishment technique, e.g. covering seeds. Among several species used experimentally were *Sapindus rarak*, *Lithocarpus elegans*, *Spondias axilaris* and *Erythrina subumbrans* (Woods and Elliot 2004). Trees must grow fast and aggressively in order to overcome competition with grasses especially when established by direct seeding without the head-start a nursery plant has. In a Jamaican field test only 5 out of 11 tested legume species showed good competition with grass, which they were able to overgrow after one or two years. The most competitive were *Sesbania sesban*, *Sesbania grandiflora*, *Bauhinia variegata*, *Cajanus cajan* and a *Leucaena* hybrid (Roshetko *et al.* 1991).

In Australia a local species *Alphitonia petriei* (Rhamnaceae) was used for gully stabilisation in pasture land. However, directly sown seeds suffered high mortality due to weed competition (Sun *et al.* 1995).

### e. Forest restoration in Amazonia, Brazil

A number of studies have been carried out on forest rehabilitation of former rain forest areas in the Brazilian Amazonas. The areas exhibit various stages of degradation, from almost recovered natural forest vegetation with 25-30 m high canopy, low secondary vegetation of shrubs and pioneer saplings, old pasture and sites with barren soil appearing after severe disturbances such as road construction. A direct sowing experiment conducted by Camargo *et al.* (2002) using 11 local species showed that both germination and seedling survival was significantly higher on barren soil than any other vegetation type. This can hardly surprise as competition is significantly higher under any established vegetation. However, none of the three tested pioneers survived in any environment, and survival seemed primarily correlated with seed size: large seeded species survived significantly better than species with small seed.

Applicability of direct sowing for restoration of riparian forest plantations of Trema species was investigated in Brazil (Santos Jr. *et al.* 2004). The experiment included 5 species viz. *Cedrela fissilis*, *Copaifera langsdorfii*, *Enterolobium contortisiliquum*, *Piptadenia gonoacantha*, *Tabebuia serratifolia*. It was conducted in 3 different environments viz. understorey under *Trema micrantha*, full sunlight and under pioneer species *Guazoma ulmifolia* and *Senna multijuga*. The experiment showed that direct sowing was applicable for all species and in all the environments studied, but the survival rate was highest under direct sunlight (minimal competition).

**f. Degraded forest rehabilitation in Colima, Mexico**

Direct sowing has been used successfully for rehabilitation and enrichment planting of degraded forests in community forest programmes in Mexico. Species used were *Caesalpinia platyloba*, *Hura crepitans*, *Fraxinus* sp., *Juglans* sp., *Casimiroa edulis*, *Swietenia macrophylla*, *Crisophila nana* [*Cryosophila nana*] and *Theobroma cacao*. A total of 824 ha were planted over a 4 year period with a reported survival of 80% (Deniz-Aguilar 2003).

**g. Dry zone planting in the Sahel**

Tree planting in dry zone Niger (about 225 mm annual rainfall) suffers from permanent lack of water. Tree nurseries are not popular because water is a scarce resource; watering plants would be seen as an exorbitant luxury or 'wasted'. Where nurseries have been established, the results of plantings have been poor because of high mortality. Eden Foundation, an active NGO working with farmers' planting thus favour direct sowing as the suitable method for tree establishment on farms. > 70 species have been tested by the organisation who claim that direct seeding has almost entirely become the means of establishing woody perennials on private farms in their area (Eden Foundation 1992a and b, 1996). Seeds are sown in holes, i.e. covered with soil at the beginning of the rainy season where the soil is moist but more rain expected; the timing gives the seeds optimal chances for germination and establishment during the short growth season (Eden Foundation 1992a).

**h. Mangrove rehabilitation**

Mangrove species of the family Rhizophoraceae, which include e.g. *Rhizophora*, *Sonneratia*, *Brugeria* and *Ceriops* are viviparous. Others like *Avicennia* are highly recalcitrant and little suitable for nursery raising. Mangroves contain very few species. Potential mangrove afforestation sites are thus typically tidal mud plains devoid of much competing vegetation. Direct sowing[1] is thus very suitable in the sense that some of the major problems elsewhere, e.g. weed competition and desiccation after germination, are small. However, a major problem is that seeds and seedlings are often washed way by the tidal water before they have anchored themselves firmly into the soil. Mangrove areas have been restored in India by aerial seeding (Lahiri 1991). Although large areas could be covered in short time using helicopters, the method encountered several difficulties: seeds are fragile and often destroyed either by the hopper or during the fall. It appeared difficult to assure a good distribution of seeds as they are quite big. And since they are quite big, they are also quite heavy for small aircraft.

Figure 10. Mangroves are important in coastal protection. Natural mangroves show a strong zonation, where species are distributed according to their salt and inundation tolerance. *Rhizophora* belongs to the outer mangroves  where very few other species grow. Left picture shows the viviparous seeds in *Rhizophora*. During natural regenerations the sprout anchors itself into the muddy mangrove soil. Right shows seedlings of *Rhizophor*a during high tide.

### i. Multi - species forest restoration

In restoration of natural ecosystems or afforestation of barren land for environmental purposes (physical protection or biodiversity) the aim is primarily to establish woody vegetation cover and there is usually less consideration on particular species composition and genetic quality. Introducing and maintaining a wide species diversity will benefit both the physical and biological environment. In these cases a mix of planting material where inter-specific competition favours the best adapted. Direct seeding is the simplest way of managing mixed species afforestation. In Australia species mix are used in most types of direct seeding. Species mix may consist of proportional parts of selected species (Knight *et al.* 1998, Bonney 1997) or be a more uncritical mix of seeds 'vacuumed' from a natural forest vegetation and then 'blown' onto the site of rehabilitation; whatever will grow may grow.

[1] Strictly speaking viviparous seeds are seedlings, and in a narrow sense planting those seeds are thus planting rather than sowing

# 6. Land and afforestation types suitable for direct sowing

Afforestation without nursery phase is applicable under conditions where seeds of woody plants can germinate and establish fast *in situ* and in competition with other plants. The efficiency depends both on field conditions and on the plants. Conditions where direct sowing has been practiced most successfully are areas with relatively low and sparse vegetation, e.g. above mentioned types of degraded or denuded land (Bird and Lawrence 1993, Venning 1990, DPI 1994, Greening Australia 2004). Such areas are, however, also stress areas for direct sowing because of a harsh micro-environment, e.g. with high fluctuations in temperature and water availability (Rao and Singh 1985, Uniyal and Nautiyal 1998). Application of direct sowing for rehabilitation of degraded land may thus, in some instances, be less successful on very degraded land as compared to land where degradation is less progressed (Sun and Dickinson 1995). A contradictory observation was made in New Zealand, where rehabilitation by direct sowing was most successful on poor soil where competition from weed was low; the observation suggests that although poor soil is a stress factor also for tree seedlings, a relative advantage over herbal weeds was established on these sites. Low weed competition may thus also be a reason for the successful direct sowing in very dry areas of Niger (Stevenson and Smale 2005). Specific stress factors prevail on certain land types, and since many stress factors affect small germinants more strongly than they affect the more robust larger seedlings, directly sown seeds can be more vulnerable at sites with high specific stress, e.g. grazing, steep slopes and occasionally flooded areas (Dyryea 2000, see also box page 11).

Flat areas, like much farmland, are often afforested by direct sowing, because the procedure can, to a large extent, be mechanised. Although most farmlands are relatively fertile and thus often support a rich weed vegetation, mechanisation make control easier. Both land preparation, sowing and weeding can be mechanised. Land use efficiency, as mentioned above as a factor favouring planting, is less important on very degraded soil with little or no alternative use.

Multi-species afforestation is particularly used in land rehabilitation and restoration programmes, where the environmental 'service' functions of forests rather than production is in focus (Elliot *et al.* 2003, Lamb 2003). Land rehabilitation with multiple species is particularly suitable for direct sowing because the many species are easiest to handle as seed mixtures. Moreover, the random distribution of plants after sowing makes forests look more like a natural forest than a traditional plantation (Purnell 1999).

# 7. Species suitable for direct sowing

Germinants of species used for direct sowing must be able to cope with a high level of field stress, e.g. germinate at relatively low water regime (Uniyal and Nautiyal 1999). On 'new' sites species should have fast germination and establishment, i.e. 'aggressive' pioneers. In humid climates weed is the main limiting factor, and the faster trees cover and shade other plants, the higher are the chances for survival. A certain degree of shade tolerance would be desirable as weed competition can rarely be avoided. Unfortunately, shade tolerance is not a prevalent character among fast growing pioneers but more so for slower growing later successional species.

Direct sowing usually implies higher mortality than planting of good size seedlings. In Australia the survival rate of eucalypts was only 0.1%, acacias about 5% and most others about 1% (DPI 1994). Significantly higher survival, 20-30% is experienced with e.g. *Quercus* in Europe, using the best sowing technique and field management. Large seeds generally produce more vigorous seedlings which have a higher chance of survival (Camarga *et al*. 2002). However, where seeds are abundant a high mortality may be tolerated, provided at least some seeds survive. Hence, seed size alone does not determine the economy of direct sowing contra planting. Sowing methods and possibility to tend and manage trees and control weeds are crucial. Aerial sowing is only suitable for small seeded species, which can germinate on top of the soil. Ease of establishment by direct sowing also apply to some agroforestry methods, e.g. alley cropping, fodder hedges, soil improvement which typically uses high densities of relatively small size, trees (Owuor *et al*. 2001).

Species, which are difficult to raise under nursery conditions can have higher survival chance in direct sowing. There are two main categories:

1. Species with recalcitrant seed, most of which are shade tolerant (or demanding) when young, are often difficult to raise and keep in the nursery. They are often pre-germinated when collected and suffer during transplanting. On the other hand, they survive under some shade and can thus cope with some competition from weed in the field. Mangrove plants such as *Rhizophora* and *Bruguiera* have little competition from other plants in the field and are best established by direct sowing / planting of the viviparous seed. Some species are very sensitive to root damage during transplanting and are for that reason preferably established by direct seeding.
2. Dry zone species form deep growing roots before they grow in height. Root pruning is usually applied in nurseries to avoid the plants anchoring themselves to the nursery. However, in dry zone species root pruning implies a severe stress. In order to avoid this direct sowing was used as a suitable method for afforestation in Sahelian region (Eden Foundation 1992). Some of the earliest reports on direct sowing of plantation spe-

cies are from the Sudan, where the method was used for establishment of *Acacia tortilis* and *A. senegal* (Laurie 1974).

In both these cases physiological complications of nursery propagation could point towards the direct sowing alternative.

Land rehabilitation or reforestation activities with a strong biodiversity element may use direct sowing as a suitable method as multiple species are far easier to handle as seeds than as seedlings (Holt 1999). Less common, albeit with increasing importance, is the application for establishment of an understorey of a climax forest species under a canopy of pioneers or a part of forest conversion (Ammer *et al.* 2002). Seeds must be sown individually and the method requires a relatively open understorey and minimum weed competition.

On the other hand, some agroforestry models make use of direct sowing. Fast growing trees are used, e.g. for alley cropping and fodder. Many species of legumes have a very fast growth from seed. *Sesbania*, *Leucaena*, *Calliandra* and *Bauhinia* may reach two meters tall in less than a year under good growth conditions. Alleys are grown in rows between agricultural crops and as a complement to agricultural crops. Their return is green mulch and fodder for the benefit of the agricultural system. They do thus not have a pure competitive juvenile period such as do most other trees. Also improved fallow systems could with advantage use direct sowing as a method to improve re-vegetation. Fallow periods are usually seen purely as a nutrient management period for agriculture production. However, different types of fallows are important habitats and can form important corridors for wildlife. Managed fallows with direct sowing of key species is an applicable way to improve regeneration and thus nutrient build-up and at the same time improve biodiversity.

# 8. Optimising survival by direct sowing

The success of direct sowing generally improves where germination and seedling establishment is fast and where competition from other plants and predation can be reduced. Some techniques for improving germination and seedling survival is discussed below.

**a. Land and soil preparation**

Land and soil preparation aim at providing the best growth conditions for new established plants. The soil should provide substance for a good root structure. Most plants prefer a good 'granular' structure, which allow drainage of water and unimpeded root penetration. Hardpans and water-logging is generally not suitable for woody plants. However, there are species that have the best competitive ability under such conditions and even where a certain stress is experienced, it can be an advantage for plants, if they have a competitive advantage under these conditions. For example, *Pinus merkusii* will grow fast under moist lowland conditions. However, under natural conditions it will quickly be shaded and ousted by other vegetation in the lowland. The best growth niche for this species is in the highland, where its 'relative' compatibility is best.

A standard land preparation for both planted seedlings and direct sowing is to remove competitive vegetation by cutting, hoeing, burning or mechanical treatment. Removal reduces light and soil competition and may be necessary or highly advantageous for pioneer type trees. It should, however, be noticed that land clearing also can give a boost to aggressive weeds, and soil treatment may 'wake up' dormant weed seed from the soil seed bank.

Herbicides may in some cases be applicable, e.g. if burning is difficult to control and mechanical clearing cannot be undertaken due to safety or terrain constraints (Greening Australia 2004). Where direct sowing is applied in connection with agroforestry practices, e.g. for hedgerow establishment (alley cropping), weeding is undertaken as part of the normal farming practice (Holt 1999).

Seeds will be displaced by soil erosion whether by wind or by water because they are small (Ezell 2004). The risk will be much higher if seeds are broadcast without soil cover. Small seeds will blow away with soil particles on barren land, and they will follow water currents on sloping land (Greening Australia 2004). Shelters for preventing wind erosion and terracing may be necessary precautions to reduce the risk of losing seeds through erosion.

**b. Timing**

Seeds are sown, when they have the best chances of germination, which is when moisture is plentiful, weed competition small, and potential growth season before a stress period is as long as possible. In seasonal tropical climates this normally means the beginning of the wet season (Vieira and Scariot 2006, Venning 1990). The drawback of this season is that this is the time where all other vegetation starts to sprout as well, which inevitably implies problems with weed competition. Where weed competition is moderate or low, e.g. on barren land or where land has been effectively de-weeded, sowing is usually done at the optimal germination and growth time, i.e. beginning of the rainy season. Where surface flow is a risk, e.g. on sloping terrain and where rain tends to fall at high intensities, sowing should be scheduled so early that seedlings have anchored themselves with a root before heavy showers fall. Heavy showers/rainstorms on sloping terrain can, on the other hand, completely wash away seeds and new germinants (Ezell 2004).

Weed and predator problems tend to occur at different time, and sowing time can to some extent be used to deal with the prevailing problem. Early sowing, where seeds are not covered with soil and there is little vegetation, makes seeds very conspicuous to predators. Where this is a serious problem it may advocate for later sowing, despite the weed implications. Where competition from other vegetation is a major limiting factor, sowing may be done early to give germinating seeds a head-start, or later where weeds start to fade. The choice depends on weed type and tree species.

**c. Seed technology, coating, pelleting, priming and fluid drilling**

If seeds are cheap and in abundance, the expected poorer survival rate may be compensated for by simply sowing more seeds. However, this could easily lead to selection or purchase of seed from the cheapest possible seed source, which at least is likely not to be an improved one. Improved (e.g. seed orchard) material is usually significantly more expensive than randomly collected seed and there is thus a high incentive, especially for these seed to improve seed germinability and survival rate by using improved seed technology.

Some collection methods are cheap and may be linked with direct sowing. Ground collection by vacuum can obtain a very large amount of seed in a short time if seeds are plenty. The drawback is contamination with debris and other seed. There are basically two ways of dealing with this problem viz. by cleaning the sample or by sowing the seeds together with whatever debris may be. In practice a compromise may be followed: large and inconvenient debris is removed by seed cleaning, the seed is then sown together with remaining impurities.

Another line of improving the efficiency of direct sowing is pretreatment of seed. These methods provide each individual seed with a higher chance of survival under field conditions. Pre-treatments aim at overcoming field stress factors, either by reducing predation before germination or by speeding up germination and seedling establishment.

Post-sowing predation is highest after aerial sowing or broadcast where seeds are fully exposed on top of the soil. Bulk broadcast small seed and debris material, e.g. following above vacuum collection will to some degree hide seeds from predators. More efficient is treatment of seeds with some pesticide before sowing. Pesticides should here as everywhere be treated with caution (Schmidt 2007). There are certainly cases where birds seem to go from seed to seed and only stop when everything is gone. However, if seeds are sown just before the growth season, the risk period is usually a few days, then the critical stage is overcome, - birds rarely eat germinated seed.

Dormant seed must be pre-treated before sowing whether it is sown in the nursery or directly in the field. The most common dormancy type is physical dormancy or 'hard seed' which is a prevalent imbibition barrier in legumes and several other dry zone plants. Hard seed are scarified by hot/ boiling water, acid or mechanical abrasion dependent on degree of dormancy (Schmidt 2000, 2007).

Priming and fluid drilling are methods of accelerated germination by pre-germinating the seeds before sowing. A simple priming method consists of imbibing the seeds before sowing. This is often done in connection with nursery sowing. Imbibition tends to make sowing technically more difficult because seeds tend to stick to each other. In addition, if sowing is delayed until the first sign of germination manifestation, i.e. radicle protrusions, then the seeds are sensitive to mechanical damage during the sowing procedure. Fluid drilling is a technical method where germination is initiated under imbibed, aerated and controlled conditions until radicle protrusion, then slightly dried to temporarily stop the germination process. The seeds are then rolled in a fluid, which will slightly harden and thus protect the seed, in particular the radicle, during the sowing procedure (Bradford and Bewley 2002). Fluid drilled seed can be stored under cold conditions for a couple of weeks dependent on species.

Seed coating and pelleting can provide seeds with a start package of essential elements that will improve seedling establishment. These elements are of two kinds' viz. fertilisers and microsymbionts. Fertiliser composition consists of essential elements for initial germination e.g. NPK. Only a small amount are applied with each seed (depending on seed size), so the package is only sufficient to 'kick-start' growth. Applying larger amount of fertiliser is technically possible - it just needs a thicker covering, but it usually has negative effects: a high concentration can be poisonous to seeds and a thick matrix of carrier material may thus hamper germination.

Microsymbionts in the form of *Rhizobium* and *mychorrhiza* inoculants can be applied by coating and pelleting. Only very small quantities are necessary, as they will quickly multiply if put in the right place. Experience from Australia shows that inoculation with 'elite strains' of *rhizobia* significantly increased the growth rate and more than doubled the survival rate (Thrall *et al.* 2005).

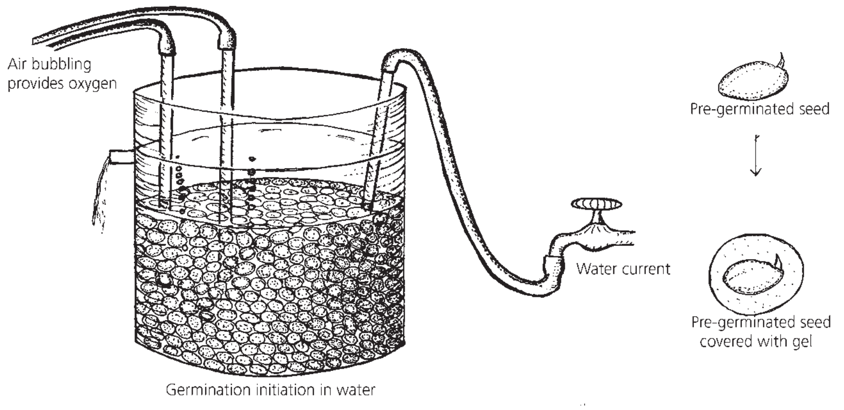


Figure. 11. Priming. Seeds are pre-germinated submerged in water with aeration to prevent anoxia. Once radicle protrusion has initiated the process is terminated and seeds encapsulated in an alginate bead to prevent mechanical damage

**d. Reducing seed predation**

Exposed seed sown by broadcasting are prone to predation, e.g. by birds and rodents. Predation by pigeons is a major drawback for direct sowing by drilling of oak in Europe and America (Venning 1990). In Hong Kong hill side rodents reportedly remove practically all seeds of native species and are a serious limitation to any seed regeneration (Hou 1997). Covering seeds e.g. by drilling reduces but does not necessarily eliminate the problem. In Europe pigeons and jays tend to quickly learn the system of finding seed in the drills. Covering seeds have shown significant reduction of predation rate for pine seeds in Sweden (Nilson and Hjalten 2002). In Thailand ants were the main predators for 4 test species: *Sapindus rarak*, *Lithocarpus elegans*, *Spondias axillaris* and *Erythrina subumbrans*. Burying seed during sowing significantly reduced ant predation (Woods and Elliot 2004), but can have some adverse effects on germination of some species. In Denmark beech nuts (*Fagus sylvatica*) are thus preferably sown on top of the soil or only slightly covered as burying restricts germination. Sowing together with leaves makes them less conspicuous to birds (Pedersen 2002). In Vietnam pine seeds broadcasted from aeroplanes were treated with pesticides. Protection by pesticides is of short duration and is generally not advisable because of environmental concern. Some pesticides have phytotoxic side effects and may restrict germination (Sun *et al.* 1995). Scarecrows, gas canons and other devices tend to have short preventive effects. However, most seed predators tend to disappear soon after germination. Predation is often species specific. Thus, sowing a mixture of two or more species will give a better chance that one species will survive where predation of the other(s) is high.

**e. Sowing technique: drilling, broadcast and individual sowing**

There are principally three ways of direct sowing viz. sowing from the air, machine sowing in rills (drilling) and direct sowing of individual seeds. Aerial sowing implies that seeds are sown on top of the soil without cover. Possible negative implications in terms of exposure to predators, washing away by water, or desiccation during germination are discussed above. Mechanical broadcast can take place from airplanes or ground bound devices.

On a smaller scale broadcast could be entirely manual by hand.

Aerial sowing is primarily for small seeds, e.g. pines, since air lifting of larger size seed by manoeuvrable small planes is too expensive. Small seed dropped from safe flight height are easily displaced by wind which makes their deposit site quite unpredictable. Wind displacement could be positive in the sense of blowing seeds further than normal dispatch distance. Deposit site is likely to be in a 'shelter', which is good if the site is prone to wind stress, but negative if 'shelters' are covered by competing vegetation. Wind displacement is smaller if sown by various ground operated equipment using centrifugal force or air pressure for broadcasting. Any type of broadcasting disperses seed with even density, which implies that the chances of being deposited at a poor site is as high as that of being deposited at a good site and visa versa.

The narrow sense economy in aerial sowing from air-crafts may be doubtful but if the activity is carried out as an aviation practice or training exercise, the cost is hidden in other core budgets. Aerial seeding has been carried out for large scale afforestation in several places in the world e.g. India, Vietnam, China, Australia and Brazil (see section 5a).

Alternatively, smaller and easier accessible areas may be sown by manual broadcasting. Seed broadcasting has the advantage of a large area coverage in relatively short time and as such efficient for remote areas[2] and difficult terrain.

Fig. 12. Mechanical sowing machine used for Fagus, Quercus and conifers in Denmark. The sowing machine can operate both on farmland and in open forests. The machine 'opens' the mineral soil and sows in one operation. Provided with two sowing outlets the machine can sow two species with different types of seeds at the same time. (Photo, Knud Stenvang, Danish Tree Improvement Station)

[2] 'Remote' is often used as geographical distance from cities or capital and therefore sometimes ignoring that people live there. Socio-economic implications of e.g. aerial sowing, are obviously essential before launching such activity.

Tree seeds can be sown the same way as most agricultural seed, i.e. in rills, and subsequently covered with soil. The method is commonly called drilling. It gives the maximum protection to the seed both from predation, washing away and desiccation during germination (Woods and Elliot 2004). Precision sowing of individual tree seed can be carried out by agricultural implements on flat terrain. This method is common in USA and Australia when reforesting barren land, e.g. former agricultural land and mine spoils (Bird and Lawrence 1993, DPI 1994, Greening Australia 2004, Illinois NRC 2006, Bonney 1997). In Denmark drilling is used both on former farmland and rejuvenation of open forests (Pedersen *et al.* 2002). Precision sowing of hedgerow and alley cropping species (e.g. *Sesbania sesban*) is used in farm forestry and agroforestry (Owour *et al.* 2001).

Fig. 13. Sowing stick from Finland suitable for sowing few seeds at selected micro-sites. *www.newforest.fi*

Very small seed is difficult to distribute evenly in very low density as required for tree species. This applies to both aerial sowing and mechanical sowing. Seed pelleting increases the size of individual seed and thus make distribution easier. Alternatively seeds may be mixed with some bulking material, e.g. sand, vermiculite or sawdust (Holt 1999).

More remote/inaccessible areas with difficult terrain are usually also areas where mechanical implements are difficult to access and manoeuvre. Single or few seed sown per spot may be carried out on cleared land or under other woody vegetation, e.g. climax species under pioneers. A planting hole is prepared by a hoe, an ordinary spade or a Hamilton Tree Planter, and the seeds are sown manually (Greening Australia 2004). Oaks and beech in temperate regions are sometimes established by direct sowing using a sowing stick (*www.newforest.fi*). Survival rate of spot seed sowing is higher than during broadcasting because germination sites are selected and seeds are covered. They are thus protected against predation and other adverse conditions (Greening Australia 2004).

### f. Field maintenance

Drilling on reasonably flat land allows mechanical weeding between rows until the plants have reached a size where they have overgrown grass and herbal weeds. Aerial sowing with consequent random plant distribution makes mechanical weeding more problematic. Three types of selective herbicides viz. two grass-selective herbicides, Fusilade® and Sertin®, and a soil-residual herbicide, Simazine®, were tried in Australia (Semple and Koen 2006). The tests were, however, not promising, partly because some species were sensitive to soil residual herbicide, partly because other weeds than grass were the main problem.

# 9. Summary and future

Afforestation by direct seeding is a relatively old yet little applied method (Willoughby *et al.* 2004). It is mostly restricted to special conditions of mine spoil rehabilitation, farmland afforestation or large scale aerial sowing of pines. In almost all other situations, plants are raised in nurseries and planted out as seedlings. However, higher nursery plant cost and more emphasis on environmental rehabilitation with many species have again turned the attention towards direct seeding as a suitable alternative to traditional planting. Experiences have shown that despite the prevailing high mortality rate during germination and early seedling establishment, the method is applicable in situations where:

1. Competition from other vegetation is low,
2. Where competition can be reduced by various types of pre-sowing management,
3. Where predation can be controlled, and
4. Where seed technology is applied to improve a fast germination and establishment. In some dry zone species the advantage of faster root development has been shown to compensate for the possible depression by competing vegetation, so that directly sown seed appear to have lower mortality than planted seedlings.

Methods to improve success rate of direct sowing include site preparation by reducing competition from herbal or secondary woody vegetation, and soil preparation. Sowing time is crucial in seasonal dry climates. Sowing should be done during the first rain so that seedlings can establish themselves and tolerate drought during the subsequent dry season. Sowing methods include large scale aerial sowing to sowing of individual seeds. Except from being very expensive, aerial sowing is only applicable in areas devoid of vegetation, as the seeds must be able to reach the ground. Such areas are in the natural dynamics restricted to floodplains, coastal sand dunes, new volcanic soil, tsunami or land slide areas. However, the number of man-made deserts has increased and include for example mining areas, destroyed mangrove areas and impoverished former farmland. Individual seed sowing is almost as labour demanding as planting, and although the nursery operation is saved, the method must rely on a relatively high survival rate. It is suitable for, for instance, enrichment planting or planting of large seeded climax forest species under a canopy of pioneers.

Various types of seed technology can enhance germination speed and thus improve the chances of survival. Pretreatment to break possible dormancy, soaking in water to assure proper imbibition and priming to initiate germination are all methods that make field establishment faster. Field survival is often dependent on proper establishment of symbiosis with *mychorrhiza* and/or *rhizobium*; symbionts may be applied by seed coating or pelleting. Field experiences from different parts of the world indicate that seed predation and early seedling mortality is much higher than germination problems.

Seed predation is particularly a problem for large seeded species which are otherwise the seed type most suitable for direct sowing.
Despite technical progress in technology and experience of direct sowing, the method is still primarily applicable to situations where seeds are cheap and plentiful, and where predations and competition from other vegetation is small or can be controlled, e.g. mining areas, land slides, flood plains and some types of abandoned agricultural land. Direct sowing has been tried with success in both dry and humid climates. Field stress such as predation, drought and shading affect primarily small plants. Direct sowing thus tend to favour species with particular robustness during the juvenile stage. This can lead to a short-sighted and unintentional bias against valuable species, which are less suitable for direct sowing. The problem also exists in afforestation by planting; some species are selected more for their ease of propagation, fast growth and field survival than because of their end use quality. The bias may be accentuated in direct sowing because seed availability and price is a frequent limiting factor. However, direct sowing makes it easier to handle species mixtures and utilise micro-site variations to increase species diversity.

Many degraded forests are prevented from regenerating by current and continuous stress factors such as grazing, fire or small-wood collection. Once these stress factors can be controlled, many areas will recover 'by themselves' through natural regeneration. Forest regeneration is frequently observed in fenced areas, where grazing and burning is excluded. Any afforestation attempt must deal with the current degrading or stress factors; without controlling or eliminating these stresses, neither planting nor direct sowing will succeed.

Direct seeding is sometimes deemed counter-productive because the expected high mortality has led to the temptation to use lower quality seed. This does not need to be so. High quality seed are likely to be more vigorous and seedlings faster growing and thus have a better chance of surviving competition with weed. In addition both land management and seed technology contain a vast number of improvement options, which are likely to improve survival chances. On the other hand, time counts against nursery propagation and planting because of high labour cost and limited option for reducing labour input.

The present review has shown that published documentation on direct sowing in the tropics is scattered and scarce. Much more comparative studies are necessary to conclude not only if direct sowing is applicable, but if it can be improved and rationalised and what would be the relative gain of various methods and in comparison with traditional planting.

Some variables are worth testing in direct sowing experiments:

1. *Effect of various pre-treatment*. The 'control' group should be conventionally pre-treated seed, e.g. scarified or stratified. Alternative pre-treatments include coating, priming, fluid drilling, pelleting (with different coating material).

2. *Effect of various sowing methods*. The 'control' could be conventional aerial broadcast. Alternative methods could be manual and mechanical precision sowing at various depths.
3. *Effect of land preparation*. This would be highly dependent on vegetation type. In grassland e.g. burning and cutting; in bush-land/degraded forest e.g. selective shrub or under-vegetation removal.
4. *Species variation*. Each trial should include several species. Dependent on possible integrated factors, it could be relevant to mix species in a broadcast trial. In this way both competition with the original vegetation and competition between the used species are analysed.
5. *Predation*. Protection against predation dependent on predator species. Measures to investigate are 'escape' precaution (high density sowing, covering or several species) and seed treatment (biological and chemical).
6. *Weed control*. Chemical control of upcoming weeds may be necessary at some sites. The type of weed depends on site; grass and herbs usually dominate at dryer sites; vines and climbers are a bigger problem at more humid sites. Comparative studies on type and duration of weeding is needed.

Technically, sowing is difficult in hilly terrain and where there is vegetation. Seeds are simply difficult to place in an optimal position for germination and survival. Simple hand sowing devices and mechanical equipment need to be developed to suit different terrain types and species.

Degraded land in tropical countries can be counted in millions of hectares. Vast areas lay more or less as unproductive grassland or shrub. This is first of all a waste of resources in poor countries where land resources are scarce and all productive tilled land must yield its utmost. Hitherto few countries have had or prioritised their resources to reforestation. Conventional methods of reforestation by planting are extremely labour intensive. Direct sowing is in many cases the only realistic alternative.

# 10. References

*Ammer, C., Mosandl, R. and Kateb, H. El. 2002.*
Direct seeding of beech (*Fagus sylvatica* L.) in Norway spruce (*Picea abies* (L.) Karst.) stands – effect of canopy density and fine root biomass on germination. Forest Ecology and Management 159: 59-72.

*Arnold, M.A. 2005.*
Challenges and benefits of transplanting large trees. Horticulture Technology 15(1): 115-117.

*Bird, R. and Lawrence, J. 1993.*
Direct seeding. In: Agroforestry, trees for productive farming (Race, d. ed.). pp 191-199. Agmedia, Melbourne.

*Bonney, N. 1997 (2000).*
Direct seeding of native vegetation to achieve biological diversity. Australian plants online, Dec. 2000. *http://farrer.csu.edu.au/ASGAP*

*.Bradford, K.J. and Bewley, J.D. 2002.*
Seeds: biology, technology and role in agriculture. In: Chrispeels, M.J. and Sadava, D.E. (eds): Plants, genes and crop biotechnology. Jones and Bartlett, MA. Pp. 210-239.

*Camargo, J.L.C., Ferraz, I.D.K. and Imakawa, A.M. 2002.*
Rehabilitation of degraded areas of Central Amazonia using direct sowing of forest tree seeds. Restoration Ecology 10 (4): 636-644.

*Chintu, R., Mafongoya, P.L., Chirwa, T.S., Kuntashula, E., Phiri, D. and Matibini, J. 2004.*
Propagation and management of Gliricidia sepium planted fallows in sub-humid Eastern Zambia. Experimental Agriculture, Vol. 40: 341-352

*Dalmacio , M.V. and Banangan, F. 1976.*
Direct seeding of *Pinus kesiya* as affected by time of seeding, site preparation, and seed coating. Silvatrop. The Philippines Forest Research Journal, 1: 215-222.

*Deniz-Aguilar, A. 2003.*
Siembra directa, experiencia exitosa en el estado de Colima [Direct sowing, a successful experience in the state of Colima]. Forestal XXI. 6(3): 23-24.

*DPI 1994.*
Direct seeding. Forest Service, Tree Note B3. Department of Primary Industries, Queensland, Australia.

*Duryea, M.L. 2000.*
Forest regeneration methods: Natural regeneration, direct seeding and planting. University of Florida. Extension. Institute of Food and Agricultural Sciences. *http://edis.ifas.ufl.edu.*

*Eden Foundation 1992.*
Direct seeding by farmers – the natural solution to Sahel's problems. From conference: Reforestation by direct seeding. Zinder, Niger 5-7th Nov. 1992. *www.eden-foundation.org.*

*Eden Foundation 1992b.*
What is direct seeding, and why do it. *www.eden-foundation.org/project/articles_directseeding.htlm.*

*Eden Foundation 1996.*
Direct seeding – the natural solution for revegetating arid lands. What is direct seeding, and why do it. *www.eden-foundation.org/project/aridland.html.*

*Elliot, S., Navakitbumrung, P., Kuarak, C., Zangkum, S., Anusarnsunthorn, V. and Blakesley, D. 2003.*
Selecting framework tree species for restoring seasonally dry tropical forests in northern Thailand based on field performance. Forest Ecology and Management 184: 177-191.
*El Nour, M. and El Atta, H.A. 1992.*
Prospects and constraints of direct sowing of some forest tree seeds in Sudan. Les problems de semences forestiers, notament en Afriquw. IUFRO Symposium, Ouagadougou, Burkina Faso.
*Engel, V.L and Parrotta, J.A. 2001.*
An evaluation of direct seeding for reforestation of degraded lands in central Sao Paulo state, Brazil. Forest Ecology and Management 152(1-3): 169-181.
*Evans, J. and Turnbull, J.W. 2004.*
Plantation forestry in the tropics. The role, the silviculture, and use of planted forests for industrial, social, environmental and agroforestry purposes. Oxford University Press.
*Ezell, A.W. 2004.*
Direct seeding, a forest regeneration alternative. Mississippi State University Extension Service. *www.msucares.com.*
*Fagg, P. 2001.*
Eucalypt sowing and seedfall. Native Forest Silviculture Guideline No. 8. Department of Natural Resources and Environment, Melbourne, Australia.
*FAO 1961.*
New bird repellants for direct seeding. Forest Equipment Notes, A.25.61. FAO, Rome, Italy.
*Field, S.P. 1991.*
The effect of undersowing *Leucaena leucocephala* into a maize crop. *Leucaena* research reports Vol. 12.
*Foster, B. and Dahl, N. 1990.*
Sowing the seeds. Direct seeding and natural regeneration conference. Greening Australia Ltd.
*Green, J.J., Vallejo, R., Serrasolses, I., Martins-Loucao, M. A., Hatzistathis, A., Barea, J.M., Cortina, J., Watson, C.A. 1999.*
Restoration of Degraded Ecosystems in Mediterranean Regions (REDMED). In: Papanastasis, V.P., Frame, J., Nastis, A.S. (eds.): Grasslands and woody plants in Europe. Proceedings of the International occasional symposium of the European Grassland Federation. Thessaloniki, Greece, 27-29 May, 1999; pp 281-286.
*Greening Australia 2004.*
Hand direct sowing data sheet. *www.greeningaustralia.org.au.*
*Hall, R. 1991.*
Direct sowing trees and shrubs. Farrer Centre. *www.regional.org.au.*
*Hau, C.H. 1997.*
Tree seed predation on degraded hillsides in Hong Kong. Forest Ecology and Management 99: 215-221.
*Hipkins, P.L. and Coartney, J.S. 1987.*
A case for direct seeding of woody species on highway road sides. Journal of Environment and Horticulture. Washington D.C. Horticultural Research Institute. 5(4): 176-179

*Holt, C. 1999.*
Direct seeding of native plants for revegetation. Farmnote 40/98. Agriculture, Western Australia.
*Illinois NRCS 2006.*
Illinois direct seeding handbook: a reforestation guide. US Dept. Agric. Natural Resource Conservation Service. Illinois. *www.il.nrcs.usda.gov/technical/forestry/dshndbk.html.*
*Jha, A.K. and Singh, J.S. 1993.*
Growth performance of certain directly seeded plants on mine spoils in a dry tropical environment, India. The Indian Forester, 119(11): 920-927
Jim, C.Y. 2001. Ecological and Landscape Rehabilitation of a Quarry Site in Hong Kong. Restoration Ecology 9 (1), 85–94.
*Kermani, W.A. 1974.*
Aerial seed sowing in riverain forest areas of Sind. Paper presented at a Forestry Conference, Pakistan Forest Institute, Peshawar, Pakistan.
*Knight, A.J.P.; Beale, P.E. and Dalton, G.S. 1998.*
Direct seeding of native trees and shrubs in low rainfall areas and on non-wetting sands in South Australia. Agroforestry Systems, 39(3): 225-239.
*Kwesig, F.R., Franzel, S., Place, F., Phiri, D. and Simwonza, C.P. 1999.*
*Sesbania sesban* improved fallows in eastern Zambia: Their inception, development and farmer enthusiasm. Agroforestry Systems 47: 49-66.
*Lahiri, A.K. 1991.*
Aerial seeding in mangrove swamps. The Indian Forester. Vol. 117(3): 159-161.
*Lamb, D. 2003*
Overcoming tropical forest degradation: whether to plant many species or just many seedlings. In: Lamb, D. and Gilmour, D.: Rehabilitation and restoration of degraded forests. WWF and IUCN. Gland, Switzerland and Cambridge, UK.
*Laurie, M.V. 1974.*
Tree planting practices in African Savannas. FAO Forest Development Paper No. 19. Food and Agricultural Organisation of the United Nations, Rome.
*Madsen, P. 2005.*
Såning af skov, - en dyrkningsvejledning [sowing of forest, - a cultivation guide]. Kulturmanifest 2005. Skoven. Dansk Skovforening (in Danish).
*Mann, W.F. and Derr, H.J. 1964.*
Guides for direct seeding slash pines. US forest Service Research Paper, No. 12. US Dept. of Agriculture.
*Minnesota DNR 2006.*
Direct seeding of native hardwood trees, - an innovative approach to hardwood regeneration. Minnesota Department of Natural Resources. *www.dnr.state.mn.us/treecare/maintenance/collectingseed.html.*
*Motz, R.W. 1995.*
Acorn collection, storage, sorting and planting for the establishment of native oaks without supplemental irrigation. Proceeedings of a symposium on oak and woodlands: Ecology, management, urban interference issues. USDA Forest Service. Pacific Southwest Research Station.

*MSU 2005.*
Seeding, - a forest regeneration alternative. Mississippi State University Extension Service, Coordinated Access to the Research and Extension System (CARES).
*Nair, P.K.R. 1993.*
An introduction to Agroforestry. Kluwer Academic Publishers. ICRAF National Research Council 1981. Sowing forest from the air. National Academy Press
*Nilson, M.E. and Hjalten, J. 2002.*
Covering pine seeds immediately after seeding: effects on seedling emergence and on mortality through seed-predation. Forest Ecology and Management 176: 446-457.
*Niang, A.I.; Amadalo, B.A.; Wolf, J. de, and Gathumbi, S.M. 2002.*
Species screening for short term planted fallows in the highlands of western Kenya. Agroforestry Systems 56: 145-154.
*Noble, B.F. 1985.*
Comparative costs and survival rates of direct seeding, germinant and seedling plantings of denuded Benguet pine (*Pinus kesiya* Royle ex Gordon) areas. Sylvatrop. The Philippines Forest Research Journal, 10(4), 259-270.
*Ochsner, P. 2001.*
Direct seeding in the tropics. Paper presented at IUFRO Joint symposium on Tree seed Technology, physiology and tropical silviculture. Collage of Forestry and Natural Resources. Danida Forest Seed Centre, Humlebaek, Denmark. *www.life.ku.dk/development.*
*Owour, B.O., Gudo, S. and Niang, A. 2001.*
Direct seeding of *Sesbania sesban* for green manure in agroforestry systems – a short communication. Agroforestry Systems 52: 23-25.
*Panday, D.N., Chaubey, A.C., Gupta, A.R. and Vardhan, H. 2005.*
Mine spoil restoration. A strategy combining rainwater harvesting and adaptation to random recurrence of droughts in Rajastan. International Network on Etnoforestry. CIFOR.
*Pedersen, O. 2002.*
Såning af bog direkte I skov på gode jorde [Sowing of beech nuts directly in forest on good soil]. Skoven, Dansk Skovforenings Tidsskrift. November.
*Prasad, R. 1988.*
Effectiveness of aerial seeding in reclamation of Chambal ravines in Madhaya Pradesh. Indian Forester, 114(1): 1-18.
*Purnell, K. and Higgins, I. 1999.*
What is direct seeding? Department of Primary Industries, Victoria, Australia. *www.dpi.vic.gov.au/dpi/.*
*Rao, P.B. and Singh, S.P. 1985.*
Response breadths on environmental gradients on germination and seedling growth in two dominant tree species of Central Himalaya. Annals of Botany. 56: 783-794.
*Rimando, E.F. and Dalmacio, M.V. 1978.*
Direct seeding of ipil-ipil (*Leucaena leucocephala*). Sylvatrop. The Philippine Forest Research Journal, 3, 171-175

*Roshetko, J.M., Lantange, D.O. and Gold, M.A. 1991.*
Direct seeding of fodder tree species in Jamaican pastures. Nitrogen Fixing Tree Research Reports Vol. 9.
*Sands, R. 1984.*
Transplanting stress in radiata pine. *Australian Forest Research* 14(1): 67-72
*Sannai, J. 2006.*
Assisted natural regeneration in China. In: Advancing assisted natural regeneration (ANR) in Asia and the Pacific. RAP Publication 203/19: 29-33. FAO Regional Office for Asia and the Pacific.
*Santos-Junior, N.A.; Botelho, S.A; Davide, A.C. 2004.*
Estudo da germinacao e sobrevivencia de especies arboreas em sistema de semeadura direta, visando a recomposicao de mata ciliar. (Study of germination and survival of tree species in direct seeding system, aiming riparian forest restoration). Cerne. 10(1): 103-117.
*Schmidt, L.S. 2000.*
A guide to handling of tropical and sub-tropical forest tree seed. Danida Forest Seed Centre.
*Schmidt, L.S. 2007.*
Tropical forest seed. *Springer.*
*Semple, B. and Koen, T. 2006.*
Effect of some selective herbicide oversprays on newly emerged eucalypt and hopbush seedlings in Central Western New South Wales. Ecological Management and Restoration, 7(1): 45-49.
*Shamba, S.A.N. 1992.*
Regeneration of *Acacia albida* with direct seeding. In: Vandenbelt, R.J. and Andhra Pradesh, R.J. (eds.): *Faidherbia albida* in the West African semi-arid tropics. Proceedings of a workshop 22-26 April 1991. Niamey, Niger. International Crops Research Institute for the Semi-arid tropics. Pp 139-140.
*Stevenson, B.A. and Smale, M.C. 2005.*
Seed bed treatment effects on vegetation and seedling establishment in a New Zealand pasture one year after seeding with native woody species. Ecological Management and Restoration, Vol. 6, No. 2. pp 124-130.
*Sulaiman, R. 1987.*
Survival rates of direct seeding and containerised planting of *Acacia mangium*. In: (Turnbull, J.W. ed.): Australian acacias in developing countries, pp. 173-175. ACIAR proceedings No. 16. Australian Centre for International Agricultural Research, Canberra.
*Sun, D. and Dickinson, G. 1995.*
Direct seeding for rehabilitation of degraded lands in north-east Queensland. *Australian Journal of Soil and Water Conservation*, 8(4): 14-17.
*Sun, D., Dickinson, G.A. and Bragg, A.L. 1995.*
Direct seeding of *Alphitonia petriei* (*Rhamnaceae)* for gully revegetation in tropical northern Australia. Forest Ecology and management 73: 249-257.
*Thrall, P.H., Millsom, D.A., Jeavons, A.C., Waayers, M., Harvey, G.R., Bagnall, D.J. and Brockwell, J. 2005.*
Seed inoculation with effective root-nodule bacteria enhances revegetation success. Journal of Applied Ecology, 42: 740-751.

*Uniyal, R.C. and Nautiyal, A.R. 1998.*
Seed germination and seedling extension growth in *Ougenia dalbergioides* Benth. under water and salinity stress. New Forest 16: 265-272.
*Venning, J. 1990.*
Direct Seeding. In Cremer, K.W.: Trees for rural Australia. Inkata Press, Melborne.
*Vieira, D.L.M. and Scariot, A. 2006.*
Principles of natural regeneration of tropical dry forests for restoration. Restoration Ecology 14(1): 11-20
*Willoughby, I., Jinks, R.L., Kerr, G. and Gosling, P.G. 2004.*
Factors affecting the success of direct seeding for lowland afforestation in the UK. Forestry, 77(5): 467-482.
*Wennstrøm, U. and Bergsten, J.E. 1999.*
Mechanised microsite preparation and direct seeding of *Pinus sylvestris* in boreal forests - a way to create desired spacing at low costs. New Forest 18: 179-198.
*Wittwer, R.F., Graves, D.H. and Carpenter, S.B. 1979.*
Establishing oaks and Virginia pine on Appalchian surface mine spoils by direct seeding. Reclamation Review 2(2): 63-66.
*Woods, K. and Elliott, S. 2004.*
Direct seeding for forest restoration on abandoned agricultural land in Northern Thailand. Journal of Tropical Forest Science 16(2): 248-259.
*Xinhua, C. and Jingchun, Z. 1988.*
Sowing from the air: Chinas experience. Tigerpaper Vol. XV: No. 1. FAO Forest News, 1-11.

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# A review of direct sowing versus planting in tropical afforestation and land rehabilitationI

The task of tropical afforestation and land rehabilitation is enormous and so are the expenses. There is an obvious economic benefit in using the most suitable afforestation technique.

The use of direct sowing as an alternative to conventional planting has increased in high income countries, e.g. in Europe, USA and Australia. The drawback of poor germination and survival rate, which used to be a crucial limitation, has been improved by progress in seed technology, land preparation and management.

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