Chapter 7

Alternative Forest Restoration Techniques

Sebastião Venâncio Martins

Additional information is available at the end of the chapter

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Abstract

This chapter seeks to describe the need to adapt the forest restoration to the different regional environmental filters and the different ecological opportunities of the landscapes, through the adoption of techniques not conventional or alternative restoration. When starting this text, it should be made clear that all restoration models and techniques have their environmental and socioeconomic importance, since they contribute to the return of forest ecosystems to a non-degraded state, with direct or indirect impacts on the recovery and conservation of hydrological and nutrient cycles, biodiversity, agricultural production, and the minimization of climate change. Therefore, there is no pretension here to present a set of models and techniques that are "superior and unique" and that should be standardized and followed throughout the country. To be clear in this text, there are innumerable possibilities and alternatives for forest restoration in Brazil, given its continental dimensions, with remarkable climatic, edaphic, cultural, and socioeconomic diversity. Therefore, there is no single restoration model or technique that can be applied widely and on a large scale; what is important is to take advantage of the remaining potential for ecosystem regeneration by adapting more appropriate techniques for each situation.

Keywords: ecological restoration, natural regeneration, nucleation, direct seeding, topsoil transposition

1. Introduction

As we started this text about what is being called "alternative forest restoration techniques," it should be made clear that all restoration models and techniques have their environmental and socioeconomic importance since they contribute to the return of forest ecosystems to a non-degraded state, with direct or indirect impacts on the recovery and conservation of hydrological and nutrient cycles, biodiversity, agricultural production, minimization of climate change, and the well-being and quality of life of human populations.

Therefore, it is not our claim to present a set of models and techniques that are "superior and unique" and that should be standardized and followed all over the country. Indeed, standardization and the attempt to create rigid norms for restoration projects are strong features of the more conservative and traditional forest restoration, as it is well illustrated in the text by [1].

Forest restoration's record in Brazil and in all the world, well documented by [2–6], reveals that innumerous initiatives of restoration have begun in a more empirical way, based on practical knowledge and without following preestablished norms, even because the "Ecology of Restoration" as the Science that guides the foundations of restoration (see [7]) did not even exist at that time. However, it cannot be denied that these first initiatives of ecological restoration of the forests, although without much scientific criteria, have resulted, in many cases, in forests with good quality of restoration, within the context of total or partial return of biodiversity and environmental or ecosystem services.

Over this trajectory of forest restoration in the world, one can see from the last two decades a great advance in the number of projects and area in restoration, with important initiatives of large-scale restoration and mainly focused on the riparian forests (areas of permanent preservation), which have been intensified with the demands arising from the 21st Session of the Conference of the Parties to the United Nations Framework Convention on Climate Change (COP 21, Paris, France), reinforced in the COP 22 (Marrakech, Morocco) and COP 23 (Bonn, Germany). In this new trend of restoration, an attempt is also made to standardize or dictate very strict rules for forest restoration, which often fails to consider the differences and specificities of each region, which presents a set of filters that rule the structural and functional organization and biodiversity of natural ecosystems and, of course, of ecosystems to be restored as well.

Thus, the objective of this chapter is to explain the need to adapt forest restoration to the different regional environmental filters and to the different ecological opportunities of the landscapes, translated here as the potential for self-recovery—or resilience—of ecosystems through the adoption of unconventional or alternative techniques of restoration, either alone or combined with traditional techniques.

2. The traditional forest restoration

Although it is sometimes difficult to establish a strict dividing line between what is traditional or conventional and what is alternative in the forest restoration, it is possible to consider as traditional the reforestation in a total area with fixed spacing between the planted seedlings and, as an alternative, all initiatives that escape this pattern of restoration.

It is important to emphasize that the ecological succession responsible for the regeneration process of forest ecosystems is initiated by the seeds present in the soil bank or from the seed rain and by the growth of stalks and root buds of various forms of life, usually forming regeneration nuclei; then why do we seek to restore forests only by planting tree seedlings, following alignments and predefined spacings?

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The answer is not simple; it has a bias in the use of silvicultural and agronomic techniques, in the state of local degradation and landscape, in the differences between seed and seedling offerings, and in the costs of restoration in the different regions [6, 8].

The heterogeneous reforestation with seedlings of native species has its origin and mirror, the forestry, that is, this type of traditional forest restoration follows exactly the silvicultural techniques applied in the reforestation with *Eucalyptus* and *Pinus* to produce wood for cellulose, charcoal, etc., exchanging species, only.

To make it clear, this approach does not seek to criticize or diminish the socioeconomic and even environmental importance of *Eucalyptus* or *Pinus* forestry for timber production, which generates thousands of jobs, strengthens the country's economy, and helps to reduce pressure on forests and to protect soils from erosive processes, among many other benefits [9].

When, for example, a forest restoration project is implemented with seedling planting following an alignment and spacing of 3 × 3 m between seedlings, with fertilization of 200 g of NPK 6-30-6 per pit, nothing else is being done than to follow exactly the spacing and fertilization used in many reforestations with *Eucalyptus* in soils with low levels of phosphorus. Although the defenders of this restoration model may refute by claiming that restoration uses a high diversity of native species, in some cases from 80 to 120, following functional groups with pioneer and non-pioneer lines or fill and diversity lines.

Once more, with the artificial organization that tries to impose the forest to be restored, the classic paradigm of ecology and succession [10] is present as never when defining functional groups, spacing, number of species, and, worse, strict parameters and criteria for monitoring such forests in restoration, based on control of mature forests. It is important to highlight that a diversity similar to that of the original ecosystem can be achieved over time, even with the planting of a single or few species, provided that the landscape is resilient, as verified, for example, in the Forest Garden of Campos do Jordão, State of São Paulo, Brazil, where the planting of *Araucaria angustifolia* alone served as a catalytic regenerating forest of the other regional native species [11].

It must be made clear that native forests have the diversity and arrangement of species controlled by ecological processes such as dispersal, predation, competition, nutrient cycling, and physiographic factors such as altitude and terrain slopes, among others, and that besides tree species, various other life forms compose the forest ecosystem, such as epiphytes, creepers, understory plants, and associated fauna. So, it is not uncommon to find forests considered as "restored" that even after two or more decades of traditional reforestation still maintains planting alignment and a virtually empty understory with extremely low density of regenerant shrub-trees.

Nevertheless, it cannot be disregarded that in certain situations, it is necessary to plant native tree species, for example, in the case of highly anthropic landscapes where resilience has been lost or is very low.

In addition, in the context of wood production of native species ("e.g., see [12]"), which is more like a rehabilitation of degraded areas, and not actually restoration, reforestation is more recommended, actually, since it allows the combination of groups of species of wood of different uses and characteristics in the planting lines, since a production control is necessary. Moreover, in relation to implantation of agroforestry or agroforestry systems—rehabilitation models—the planting of predefined lines of native trees and agricultural crop lines seems to be the most appropriate. It is worth noting that these rehabilitation models for the production of timber and non-timber products, when temporary, can be converted into restoration models, although they maintain the characteristics of the productive system for a long time [13].

In the context of forest restoration, interpreted as an ecological restoration of forest ecosystems, what is also essential to make clear is that planting of seedlings does not always need to be in the total area, nor does it always have to have a predefined, narrowed spacing, regardless of region, landscape, climate, etc. Therefore, it is not possible to accept for forest restoration a generalization of reforestations with predefined spacings, usually 3 × 3 m or even 2 × 2 m, and many species, which neglect the potential for forest regeneration, which could be stimulated through alternative techniques, with sensible reductions in restoration costs and the formation of forests through a more natural and sustainable process in the long term.

It is not possible to adopt in a generalized way for the different Brazilian regions, with their different ecological peculiarities, public policies of forest restoration based only on the reforestation through the planting of seedlings in total area, which ends up being more unfeasible than contributing to the advance of the restoration.

A good example of this paradigm shift has been occurring in the State of São Paulo, Brazil, where a set of legal norms, through resolutions issued by the Secretariat for the Environment (SMA), was initially launched to improve project quality and to speed restoration. These first resolutions, although well intentioned, unfortunately complicated and made it difficult rather than facilitating or stimulating restoration in the State and, after a long debate between the scientific community of São Paulo and of other states, which resulted in at least three publications of great impact [1, 14, 15], ultimately have become appropriate and have accepted different restoration models and techniques, provided that the final result is successful. In this context, the following are some alternatives for forest restoration, which, in general terms, pursue the formation of restored forests in a more ecological and sustainable way and with lower costs than traditional reforestation.

3. Revamping traditional reforesting

It is possible and feasible to make a reforestation with less traditional and less conservative. To do so, it is necessary to innovate and to create new alternatives of planting arrangements in the field, and this is configured as an open field for avant-garde studies.

Changing planting spacings according to the reality of each landscape or region means allowing the intensification of planting of seedlings to the regions or farms that really need this type of intervention. Thus, changing spacing may represent a reduction of 1100 seedlings per hectare (at 3 × 3 m spacing) to half or even a third of that, which at first may seem a reduction in the demand for seedlings, but when it is considered that using fewer seedlings per hectare can restore more hectares, all in all, the production and commercialization of seedlings may be little impacted or not impacted at all.

It is very common in reforestation to clean the area to be planted first. Such cleaning often eliminates everything; nothing is left after cutting followed by application of herbicide in a dirty pasture. In this cleaning of the area, it is common for many seedlings that were starting a process of succession to be eliminated, to give place to the planted seedlings, some that do not always occur in the region.

One of the first assumptions to make reforestation more ecologic and alternative is the use of regenerants, for example, if spots or nuclei of natural regeneration occur in an area of a few hectares, they must be maintained and the planting spacing altered. As a rule, in the vicinity of forest fragments, natural regeneration is more abundant, and it is reduced as it moves away from the remnant; this is a pattern of forest succession [16] in abandoned pastures [17–19], for example, and for these cases, the planting of seedling in broader spacings, such as 4 × 4 to 6 × 6 m in the parts with more regeneration, or even no planting of seedlings if regeneration is already very intense (**Figures 1** and **2**) is an alternative.

Another important aspect to be considered in traditional reforestation in total area is the uniformity, represented by the more or less standardized height of the seedlings. Although certain pioneer species show very rapid growth, for example, *Schizolobium parahyba*, as a rule, most native species grow slowly in height, and thus in the first years of planting, the area becomes a uniform carpet of seedlings of short height. Such an environment is unattractive for seed dispersal birds to move from isolated forest fragments in the landscape.

An alternative to make the planted area more attractive to birds is the installation of artificial perches made of bamboo, *Eucalyptus* sticks, and other materials [3, 20]. From these perches,

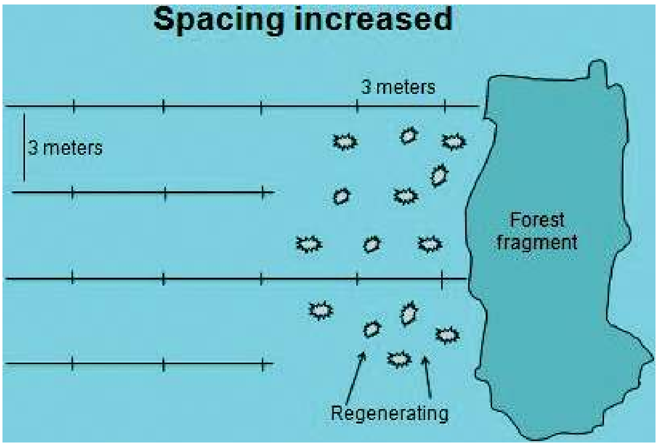

Figure 1. Schematic representation of the increase in spacing between seedlings according to regeneration potential.

Figure 2. Extracts with different regeneration potentials; in the upper part of the slope (A), only the enrichment with planting of seedlings in nuclei in the regeneration faults was indicated; in the lower part of the slope (B), the planting in smaller spacing, always maintaining the regenerants, was pointed. Picture: Sebastião V. Martins.

installed at intervals of 20–50 m, birds can move and disperse fruit seeds that they used in forest fragments still existing in the landscape. With the installation of perches in the reforestation, larger spacings can be adopted inasmuch as nuclei of natural regeneration tend to be formed around the perches.

There may be also natural perches by planting fast-growing species, including exotic species, since some have much higher growth rates than most native species, provided they are not invasive. In this sense, the planting of isolated trees of fast-growing species, at 50-m intervals within the wide space of the reforestation with native ones, can be a good alternative. When these isolated trees reach a height of about 10 m, they can be killed with herbicide application on the stem and become dry perches for some years.

Another way to make reforestation less conventional and more ecological is by neither adopting planting alignments nor spacing between seedlings, that is, to carry out planting at random. Thus, in the development of the planted forest, the planting lines will not be maintained, as in traditional reforestation, making the restored forest more similar to a native forest. As the planting of the seedlings becomes more flexible, it is possible to increase the seedlings in worse stretches, for example, in exposed and compacted or eroded soils, and to increase the distance between seedlings in stretches that already present arboreal regenerants or colonization by ruderal shrubs.

4. Natural regeneration

Natural regeneration, understood as the process by which an ecosystem impacted by natural or anthropic disturbances recovers its total or partial biodiversity, its structure and functioning, through the successional sequence over time, is undoubtedly the most ecological and cheapest manner of restoring forests.

Several studies have been published and proved the viability of natural regeneration as an alternative to forest restoration in abandoned pastures [17–20], in mined areas [16, 21] and in large-scale restoration [8, 22].

The study of [19] in Puerto Rico demonstrated that one restoration strategy for tropical forest in abandoned pastures is simply to protect the areas from fire and allow natural regeneration to produce secondary forest. In accord with the authors, this strategy will be most effective if remnant forest (i.e., seed sources) still exists in the landscape and soils have not been highly degraded.

Probably the study of [8] about "Natural regeneration potential of native forests in the different regions of the State of Espírito Santo, Brazil," is the strongest evidence of the role of natural regeneration as an alternative to enable large-scale forest restoration in Brazil. This study, the result of a major project that analyzed natural regeneration on farms throughout the state of Espírito Santo, revealed that in a 33-year period, 18,979 forest fragments were naturally regenerated in lands in Espírito Santo, occupying an area of 106,554.87 ha. The study also showed that in the State of Espírito Santo, 60.88% of its total area, equivalent to 2,804,431 ha, has a high potential for natural regeneration of forests and in most of such areas, planting of seedlings for forest restoration was not necessary.

Despite all this potential of natural regeneration detected in Espírito Santo, which is probably repeated in other States, and it should be even greater in the region covered by the Amazon Rainforest, the study by [8] also revealed that there are areas of that state with low regeneration potential, notably the far North, where only the abandonment of the areas does not guarantee the regeneration of the forest and restoration interventions are necessary.

The findings of this study in Espírito Santo are very relevant because they indicate that large-scale forest restoration cannot follow a single model or a standardization. The five defining elements of ecological restoration—ecological, economic, social, cultural, and political—described in [23, 24] also move toward it, from this alternative approach.

By considering only the economic element, it is necessary to reflect on the main bottleneck to enable forest restoration through reforestation in a total area, which is its high cost, which varies greatly from one region to another, but which is hardly less than R$ 7000.00 per hectare, not being rare examples exceeding R$ 20,000.00 per ha, and being suggested an average of R$ 10,000.00 per ha [2].

Through natural regeneration, this cost is substantially reduced to one-third or even zero, since it basically comes down to the cost of fencing and to construct fire breaks of areas under regeneration, for the isolation of livestock and fire, costs that also occur in traditional reforestation. **Figure 3** shows a ciliary forest restored through the natural regeneration process, where the only intervention was the enclosure of the APP range, to prevent entry of cattle.

But as it was evident in that study in Espírito Santo, where most of the state's territory has a high potential for natural regeneration, there are areas that the forest may not regenerate naturally, and thus even natural regeneration cannot be indicated as exclusive restoration technique for all regions, landscapes and situations of environmental degradation.

Figure 3. Restored ciliary forest by means of natural regeneration. Forest restoration project LARF-UFV. Picture: Sebastião V. Martins.

As regeneration depends on three basic ecological mechanisms—seed rain, soil seed bank, and regrowth of vines and roots—in very anthropic landscapes, with a long history of intensive use only for agriculture or livestock and with forest remnants absent or very isolated and degraded, this process may not occur or be extremely slow.

In conclusion, before recommending natural regeneration as an exclusive restoration technique for a particular area, it is essential to make a diagnosis of its regeneration potential. The diagnosis should consider the landscape in which a particular area to be restored is inserted, the distance of forest fragments remaining in the landscape, the presence of regenerants and their abundance, and, if possible, the soil seed bank [25, 26]. In this aspect, [27] point that the natural regeneration techniques, however, are not innately superior or always more appropriate for restoring forest ecosystems than artificial techniques and the intervention must be based on management objectives, informed by evaluation and interpretation of site conditions, and incorporate silvicultural knowledge and skills. Where management objectives are best served by controlling the timing of restoration and the species composition of the restored forest, active intervention at the regeneration stage is critical [27].

In regenerated forests dominated by one or a few species, enrichment management can be recommended, but costs still tend to be much lower than total area planting. A study developed by [28] about polydominant spruce-broadleaved forest long-term economic use in Moscow, Russia, found good results with two management techniques: group-selective cutting aimed at imitating the treefall gaps' natural mosaic structure of uneven-aged forests and combining gap falling with planting of species that occupied dominant position in preagricultural forest.

5. Nucleation techniques

For situations in which only the abandonment of a particular area has not resulted in progress of the natural regeneration process, by the factors already related, it is possible to stimulate and accelerate the process through the adoption of alternative techniques, such as nucleation, exclusively or combined with the reforestation.

The development and successful application of nucleation techniques as alternatives to improve—in terms of cost reduction and sustainability of restored ecosystems—has been widely documented [3, 29–37].

In a review of nucleation researches in several countries, [38] concluded that the results of experimental tests of applied nucleation indicate that the density and diversity of colonists is higher in planted nuclei than in areas where no planting takes place (e.g., passive restoration) and that these studies suggest that the applied nucleation strategy has the potential to restore deforested habitats into heterogeneous canopies with a diverse community composition while being cheaper than projects that rely on plantation designs.

5.1. Seedling nuclei

In abandoned areas, largely isolated in agricultural and pasture landscapes, the emergence over time of sparse, or even dense, coverage of ruderal herbs and shrub nuclei and even pioneer tree species, often forming monodominant communities, where one or a few species are established is common, but succession does not advance in terms of species diversity and biomass. As the main factor hindering the progress of forest regeneration in these situations is the lack of seedlings input, since the sources are very distant and the soil is degraded in terms of seed richness, the output is to potentiate regeneration through artificial introduction of propagules, either seedlings or seeds or both.

The planting of seedling nucleus in areas in slow regeneration process is an excellent alternative to make forest restoration possible in a more ecological way and at a low cost in comparison with the reforestation in a total area.

The ecological principle of seedling planting in nuclei is the realization that in many situations of degradation of terrestrial ecosystems, succession does not begin simultaneously, covering all the abandoned area, a pasture, for example, but generally small nuclei of pioneer facilitating species of succession are formed, which expand over time (**Figure 4**). In their study [39],

Figure 4. Natural regeneration nuclei in degraded pasture. Picture: Sebastião V. Martins.

on primary succession in the Canadian Rockies, pointed out that in looking for plants that might serve such nuclei for colonization during primary succession, plants that fix nitrogen should be considered.

There are several types of nuclei, in terms of number of species and distances between seedlings, but certainly Anderson's Groups are still the most used. In this model, five cross-shaped seedlings with four peripheral seedlings and one central seedling were planted at 0.5 m between the central and peripheral seedlings [35].

Alternatively, seedling nuclei can be formed by planting four seedlings at the ends of a 1-m-side square, with a central seedling, preferably the four peripheral seedlings of pioneer species (each of a species) and the central non-pioneer species (late secondary or climax) that requires greater shading.

Among the advantages of this technique, in ecological terms, is the fact that the pioneer seedlings (**Figure 5**), when growing faster, provide the necessary shading for the late species planted in the center of the nuclei, in addition, formation of nuclei, with seedlings closer than in the conventional plantations, form clusters more resistant to the weather and to the attack of herbivores and pests. The nuclei must be distanced according to the potential of natural regeneration of the area, which allows a reduction in the total of seedlings per hectare, from 1100 to 1666 seedlings from traditional reforestation to about 200–400 seedlings with the nuclei, which, ultimately, dramatically reduces the costs of restoration.

The planting in nuclei also allows a single crowning for the nucleus as a whole, that is, for the five seedlings, which represents a strong reduction in the costs of implanting and maintaining restoration projects, since the crowning around the seedlings in many regions where herbicide application is not accepted by environmental agencies is the only way to avoid competition with aggressive exotic grasses.

(a) (b)

Figure 5. The nucleus of pits for planting and *Euterpe edulis* Mart. Seedlings planted in an enrichment nucleus. Forest restoration project LARF-UFV. Pictures: Sebastião Venâncio Martins.

Experimental reforestations were carried by [40] in the Sierra Nevada Protected Area (southeast Spain) with the aim of comparing the survival and growth of seedlings planted in open areas (reforestation) with seedlings planted under the canopy of preexisting shrub species. Their results showed that nurse shrubs had a stronger facilitative effect on seedling survival and growth at low altitudes and sunny, drier slopes and that pioneer shrubs facilitate the establishment of woody, late-successional Mediterranean species and thus can positively affect reforestation success in many different ecological settings.

The study of [41] in the Trevenque area, Sierra Nevada, Spain, tested the hypothesis that the use of shrubs as nurse plants is an alternative technique of reforestation with greater success than traditional techniques, in which preexisting vegetation generally considered a source of competition. They compared the traditional planting of *Quercus pyrenaica* seedlings in open areas with the planting of seedling nuclei in the canopy of a pioneer shrub *Salvia lavandulifolia*. The results showed that *Quercus* survival was 6.3× higher when planted under individuals of the pioneer shrub than open areas and, therefore, the use of shrubs as nurse plants for *Q. pyrenaica* reforestation is a viable technique to increase establishment success [41].

5.2. Plant residue and soil transposition

In areas with soil degradation, such as compaction and erosion, common in degraded pastures and mined areas, planting of seedlings may not be sufficient to provide forest restoration. In these situations, planted seedlings may present good initial growth, whether they find nutrients, organic matter, and free soil in the pits, but this growth can be slowed down as the root system depletes the resources of the planting pits and starts to explore the compacted or very poor soils around them. The final result ends up being the formation of an environment with small isolated trees, type bonsais, with soil exposed between them and without understory formation. Obviously, a vegetation with such characteristics tends to perish.

To enhance forest restoration in these highly degraded environments, the transposition of soil/litter and vegetal residues such as antlers and bark is an ecological and low-cost alternative. The surface soil, or topsoil, and the litter layer that covers it, when taken from native forests, contain, in addition to nutrients and organic matter, a rich seed bank, formed not only by pioneer tree species but also by herbaceous, shrub, epiphyte species. Therefore, the top soil/litter set is a rich and diversified component of the forests, and its transposition in nuclei or islands to degraded areas produces the necessary stimulus for the triggering of natural regeneration [29–31, 33–35]. However, it should be remembered that topsoil and native forest litter must be removed from areas where environmental licensing has authorized the suppression of vegetation for mining activities, impoundment of watercourses, among others.

In this sense, a study carried out by [42] in a secondary forest on the campus of the Federal University of Viçosa, in Viçosa, State of Minas Gerais, showed that the removal of layers of soil only 5 m in depth and litter, in ranges of 1 × 2 to 1 × 8 m, spaced at about 5 m, did not have a significant impact on forest regeneration, with retreatment sites naturally recovered after 1 year. Despite the need for new tests to evaluate the impact of topsoil and litter removal in other forests, these first results indicate the possibility of applying this technique from forests in legal reserve areas, through a project to be analyzed by the qualified environmental agency.

The plant residues that have been most used in forest restoration in degraded soils are the semi-composite bark of *Eucalyptus*, a very abundant material in pulp and charcoal production companies, and the branches resulting from legal suppression of vegetation or tree pruning. These residues provide nutrients and organic matter, which are essential for enhancing the chemical and physical properties of degraded soils, as well as to provide shelter and food source for insects, rodents, and reptiles, stimulating food chains [3, 30].

Although the application of these nucleation techniques is more common in areas with soil degradation, nothing prevents soil/litter nuclei and residues from being used also in areas with traditional reforestation. As with the installations of perches, the deposition of residues and top soil in the narrow bands or islands within the reforestation is a way to increase biodiversity and stimulate ecological processes, as well as to enable a reduction in the number of seedlings planted.

5.3. Direct seeding

One of the main factors that prevent or hinder the progress of the natural regeneration process in highly anthropized landscapes is the lack of seed rain with species diversity. Some ruderal and pioneer species with wide anemochory dispersion can reach in some situations great distances and colonize certain areas forming monodominant vegetation, since other species with more restricted zoocoric dispersion do not achieve the same success.

As the regeneration process does not advance in these areas due to the distance from the seed sources and/or the low supply of dispersers, the artificial dispersion through direct seeding becomes a promising alternative.

The seeding direct was recommended by [43] as technical for restoration of degraded Norway spruce forest in the Forstamt Weissenhorn, Bavarian region of southern Germany. The authors appoint that the direct seeding seemed a promising and cost-effective alternative to planting.

Despite being an alternative technique of restoration that shows good results, it also presents some limitations so it should not be recommended for every situation [37, 44–46]. In very degraded soils, such as mined areas and old pastures with exposed soils, the simple sowing of native species may not be sufficient to trigger the regeneration process. The previous prepare of soil by scarification in the case of compacted soils and the provision of a source of nutrients and organic matter is often necessary.

Also, one cannot expect much from direct seeding in brachiaria (*Urochloa decumbens* Stapf) pastures, where the main factor of inhibition of regeneration tends to be precisely the aggressiveness of the exotic grass and its previous control through herbicide application and cutting, among others, becomes necessary.

However, direct seeding has great potential for use in the enrichment of swiddens and pastures, where a regeneration process has already begun but at a very slow pace and with very low diversity. Thus, through sowing, species that have regional occurrence can be introduced into areas in regeneration, but cannot reach via dispersion.

Figure 6. Forest restoration of mined areas with random planting of seedlings and direct sowing of *Cajanus cajan* (L.) Millsp. Forest restoration project LARF-UFV. Pictures: Sebastião Venâncio Martins.

A detailed study on the viability of direct seeding as a forest restoration technique is found in [46]. In it, the authors discuss very satisfactory results of the application of a new mechanized direct seeding methodology adopted in a large scale in the state of Mato Grosso, Brazil, in which seeding agricultural machines were adapted for seed sowing of native species. In addition, they present a review with excellent results of experiments of direct seeding of different species in the Brazilian biomes.

An option to reduce the costs and the use of agrochemicals in restoration areas is the direct seeding of green manures described by [47] and implemented in restoration projects coordinated by the Forest Restoration Laboratory of the Federal University of Viçosa (www.larf.ufv.br). In this technique, seeds of herbaceous and shrub species of the family Fabaceae (formerly Leguminosae), with symbiotic association with *Rhizobium* and fixation of atmospheric nitrogen, present rapid growth in poor and degraded soils and, therefore, can be sown together with seeds of arboreal native species or together with the seedlings planted in larger spaces or in nuclei. Several species of green manure have been used in direct seeding to cover the soil fast and reduce competition with grasses such as brachiaria, and it is worth mentioning *Cajanus cajan* (L.) Millsp. that in addition to enhancing soil, it rapidly leaves the system and releases space for growing seedlings (**Figure 6**).

6. Final considerations

The progress of forest restoration in the world is undeniable, which has gained strength in recent years from the 21st Session of the Conference of the Parties to the United Nations Framework Convention on Climate Change (COP21) and the recent water crisis that has increased the perception of society about the importance of preservation and restoration of riparian forests.

In this scenario, all forest restoration initiatives already carried out or under way are very important, although some have not achieved the expected results and others have presented very high costs. All over the world, there had been a great demand for studies and forest restoration services, mainly by mining, power generation, and pulp production companies, which are being increasingly encouraged to restore their Permanent Preservation Areas and Legal Reserves, not only in compliance with environmental legislation but also to certify their activities and export their products.

As it was pointed out in this text, there are innumerable possibilities and alternatives for forest restoration, with remarkable climatic, edaphic, cultural, and socioeconomic diversity between the countries and the different types of impacts to which its ecosystems are subjected. Therefore, there is no ready-made recipe, a single restoration model or technique that can be applied widely and on a large scale. The important thing is to take advantage of the remaining potential for ecosystem regeneration by adapting more appropriate techniques for each situation.

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Author details

Sebastião Venâncio Martins

Address all correspondence to: venancio@ufv.br

Forest Engineering Department, Universidade Federal de Viçosa, Forest Restoration Laboratory, Viçosa, Brazil

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