# FUNDAMENTAL ADVANCES IN BAREROOT AND CONTAINER NURSERY PROCESSES AND PHILOSOPHIES

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## Introduction

This is the year 2000. The past 100 years have brought extraordinary changes in the way forests have been viewed by society. The objective of this paper is to take a brief look at some of the major changes in ideas and technology that have taken place over the past century and to make some observations about where nursery and forest regeneration practices might go. Our past was guided by many changing processes brought on by different philosophies of how to integrate fundamental biology with field application in order to solve forestry problems. Many of our steps along this path to our present position have come after the development of concepts, which took us forward to the next level.

I would not pretend to be a "futurist" thinker as some in the social and technology fields. On the other hand my qualifications and beliefs come from 28 years of experience in forestry and traveling around the world advising on matters of nursery management, forest regeneration, and conservation. In so many ways there have been great advances in forest regeneration, yet in some places in the world nothing has changed very much for 100 years!

This paper deals first with various "concepts" that make up the fundamental beginnings of the systems we use now. As you will see some are still with us, while others appear amusing when taken in the context of what we know now. It was only 100 years ago that Carl Alwin Schenck thought to have a "forestry school" in North Carolina – a log cabin school that only lasted around 10 years. He was a German trained forester with a PhD and his backwoods "foresters" needed some principles by which to manage the forest. It is a little know fact that when he needed white pine seedlings, he shipped the seed back to Germany on a clipper ship, and then three years later had them shipped back to Asheville, N.C. for planting! It is amusing to me at times these days when people get concerned about shipping seedlings across state lines or have major failures due to storage. All it tells me is that much more needs to be taught about "concepts."

The second part of this paper speaks to the issues we need to work on in the future. There is still much to learn. Probably one of the biggest changes that need implementing is the application of the technology we already possess. Forest regeneration and nursery management are still looked upon within corporate boardrooms and our very own Congress as "the price of doing business," "part of the after-cost of cutting timber," and "something to be accomplished as cheaply as possible." (I am paraphrasing comments I have heard over the years.) Adding further, investment within the forest industry has always been historically low in this area. Only in very recent times have some companies come to the realization that a good quality seedling that beats the brush can have tremendous value as a tree in several decades, compared to marginal growth over that same time. It still amazes me that some conservationists do not understand that a good quality native plant will better survive in the native forest if that plant gets the investment attention it needs, including the "surgical" application of carefully chosen herbicides.

## Advancing One Concept at a Time

### The nursery concept

The very idea of having forest nurseries in the early part of the century represented a singular break through in forestry that has gone completely unnoticed even to this day. Today, some 100 years later we think of advanced ideas as being gene splicing to attain disease or herbicide resistance, increased specific gravity through bioengineering, and unique medicines from plants. In the early part of the century forests were seen as this natural resource that would regenerate itself. There was so much forest to cut over the next ridge that it was assumed the forests would just regenerate naturally.

The nursery concept came about quickly as it became apparent that our forests were being cut at a phenomenal pace. Fire was severally reducing whole local stocks of timber as were insect outbreaks. Sitting around and waiting for the forest to reappear one day gave way to more of an agricultural approach. That is, grow seedlings and planting them out. This seems almost stupidly obvious to us today. However, starting nurseries was not something a person or organization 'just did' back in those days. There certainly was no money in it and right from the start the US Forest Service had to subsidize the effort. Forest nursery management, as we know it today, grew out of the USFS during its early formative years when Gifford Pinchot ran it.

Prior to the nursery concept catching on foresters used wildings. Seedlings growing in the forests were transplanted to the open areas. Few foresters today have any idea of what it is like to dig and plant a wilding. A small seedling around a foot tall might have been 10 or more years old back then. Its roots ran out all over the surrounding area, making it impossible to get much more than a portion of the taproot and some long stringy laterals. Success with these was always "good" – meaning that not much was done to measure actual performance. Had wildings been wonderfully successful there would have been no need for nurseries. It is amazing how failure can cause changes in philosophy.

### The seedling concept

Once forest tree seedlings started to be seen as worth the effort forest regeneration as a quasi discipline began to come into being. The early seedlings to come out of nurseries were ridiculously small by today's standards, taking up to four years to get to a size acceptable for planting. The notion of stocktypes grew out of these early struggles to produce seedlings that would live after outplanting. Bigger was not seen as better back then. Philosophically, *smaller* seemed to be seen as better in most cases. In fact, some nurseries grew their seedlings at ~460 seedlings to the square foot, which is around 25 times greater than we do now 100 years later.

Failure kept stepping into the situation to provide reality checks for the ongoing seedling philosophies of the day. At one of the early Society of American Forester's Meetings in Vermont in the 1920's one forester noted at how more serious attention should be paid to roots. It seemed to make sense to him that the top, while important, had to have enough root system to support growth. It seemed by his observations that seedlings with larger roots survived better after out planting. If anything this kind of thinking began the process of looking at morphological characteristics of seedlings. It was not uncommon after this for field experiments to start grading trees on the basis of seedling size, even if it was qualitative features like "small, medium, and large." The discipline of quantification was still decades away in 1960's.

One of the more interesting philosophies that held on from the early part of the century up until the 1980's in some places was the notion that seedling density in the nursery was not overly important. Nurseries with fixed growing areas could grow millions of seedlings at densities of 150 + seedlings per square foot. Some nursery managers actually "fought" the idea of lowering their densities, but changed their minds when the managing foresters complained that stand growth was so poor and wanted to know why. It bears repeating that it took some 80 years in some U.S. nurseries to get across the concept of seedling size as a function of growing density. Men like Wahlenberg in 1925 knew seedling density was important, but there were no numbers.

## The seedling handling concept

Right from the very start of nursery and reforestation practices in the U.S. seedling handling became the immediate problem. Growing the seedlings was tough enough and losses were often high because many nursery operations did not have irrigation much less storage facilities. Seedlings were lifted and in some areas put on pack mules for the trek to the planting site.

Probably one of the most interesting and even amusing aspects of seedling handling were the many attempts to get bundled seedlings to remote areas. Early on in the century it was mules and horseback. Trucks were certainly used a lot later on and to this day. Trains were even used. After the Korean War in the early 1950's handling and shipping took on new meaning when some foresters came up with air dropping bundles of seedlings. They tried parachute and free fall! One forester noted that bouncing did not seem to have much impact on survival. Of course, why bundle them at all, why not just air drop them as single seedlings and let the force of the "free falling" bullet seedling plant them in the ground? That was tried, too! We do not do that today because … I guess having all those projectiles shooting toward earth and bouncing off the rocks did not work real well. It is not clear in the literature as to exactly when someone figured out 'bullet' plugs did not work too well. An idea was tried and was quietly let go.

## The concept of seedling physiological quality

Without a doubt the concept of physiological quality came from Dr. Phillip Wakeley who wrote widely on this topic starting in the late 1940's. Up until that time nursery managers and foresters had pretty much exhausted (for the time being) most of their ideas about what it took to get a "good quality seedling." 'Phil's' work was done in the South where there had been a huge effort for the previous 30 years to reforest old played-out cotton lands with Southern Pines. It was more than obvious to him and others that seedling mortality could not be explained by morphology alone. He was the first to push for studying physiological factors like carbohydrates, water deficits, and nutrients in seedlings. His early views completely altered the philosophies about seedlings at the time and are still having their impacts today, even though very few foresters have actually heard of him. His "Planting the Southern Pines" was an amazing piece of work for its time. Find it and read it.

Others like Scholander in the early 1950's came up with the pressure bomb for measuring seedling water potentials. By 1960 Dr. Paul Kramer at Duke University had speared headed some of the first really good work on carbohydrates in seedlings. With OSU's Brian Cleary there came the development of a commercial version of a pressure bomb that could be used on seedlings in the nursery and the field. Brian's instrument led to an explosion in research that went to all aspects of nursery management and reforestation. It has been extremely interesting to watch the cross-pollination in research findings between east and west.

With the advent of the concept of seedlings having a 'physiology' that needed to be considered, nursery management and reforestation management practices became more highly connected with research.

## The target seedling concept

In the early 1980s the "target seedling" term cropped up in Weyerhaeuser literature and later I coined the term, Target Seedling Concept, here at Oregon State University. The definition I came up with was "targeting those seedling physiological and morphological characteristics that can be quantitatively linked with reforestation success." It proved to be a simple way to get people to see that seedling quality and growth in the field are a function of the many factors that are built into the seedling through nursery cultural practices. It was a matter of integrating and synthesizing the work of others under one definition. Seedling physiology and morphology needed to be put together.

What is interesting is that this concept removes practitioners from having conflicts over whether or not a bareroot seedling is superior to a container seedling. It does not matter if one stocktype looks better than another. If two different stocktypes can reach the same target growth expectation in so many years, it makes no difference if they are different stocktypes. What matters is if the physiological and morphological characteristics of one stocktype impedes growth as compared to some other stocktype. In the Nursery Technology Cooperative we have run more than enough studies to witness container trees outperforming bareroot and vice-versa to know that some growing regimes have failed to take into account some target characteristic like dormancy, nutrition, root volume, and the like.

Barbara Thompson wrote an article in Evaluating Seedling Quality that is worth reading. In that piece she lays out all of the various characteristics of seedlings known in 1984 to promote successful survival and growth after outplanting. Most of the parameters were morphological. She provided a fantastic start on the "target" path for the many things we now know about seedlings. One of the most fantastic findings to come forth later came from Jay Falconer at International Paper Co. who helped define the best cold hardiness $LT_{50}$ for Douglas-fir. His $LT_{50}$ of –15 is a very nice target characteristic to use when lifting trees for maximum handling and long-term storage. We still have a long way to go in the area of seedling physiology.

## Assessment of the Present

The primary objective remains the same. The work of forest nurseries and forest regeneration is to produce seedlings that will grow quickly into forests. All things being equal we would sum up the present research situation as a grouping of mixed results. This is to say that in the past one hundred years we have come a long way, but more breakthroughs to spark an exponential increase in productivity are needed. When compared to gene splicing biology and glyphosate resistance in soybeans our work looks down right mundane. It is imminent that we will lose methyl bromide, which was one of the true "magic bullets" we relied upon in the past. Herbicide use in the nursery and the field are facing ever-increasing restrictions with some companies basically stating that they are unwilling to register some products for our market because it is too small. The big money is in soybeans and corn. Genetics and gene splicing companies are under public attack in some parts of the world over fears of uncontrollable genes loose in the environment. The mixed blessing I am referring to has to do with the fact that we are not alone. Whole aspects of plant biology are under attack and we are but a player. We are NOT the small player some consider us. We plant forests, forests fix carbon, and we are at the epicenter of sustainability. We are not recognized for our own importance because we do not see ourselves as that important. We need to change. We need to increase the intensity with which we seek to make better seedlings and ensure their success after planting.

On the other hand there is primary evidence that we have done our job for the past 100 years very very well. The South became known as one of the "wood baskets" of the world. Due to the hard work and dedication of our predecessors we now look out over vast forests all over the United States. One of the more remarkable achievements our discipline deserves full credit for is the replanting of America so that it became a net fixer of carbon (Fan et al. 1998). With all of the concern and gossip over global warming it is a great injustice to all of us to have ignored this achievement.

We have a long way to go. At present we still do not have any where near the depth of knowledge concerning the most consistent practices needed to produce high quality seedlings. We desperately need more and better physiological tests. Ask most foresters what their target seedling should look like and they cannot tell you. Believe it or not but decades of research on seedling carbohydrates and mycorrhizae did not pan out with much needed breakthroughs. These are but two of many examples where there was a lot of enthusiasm. Starch, simply put, does not correlate well with how a seedling does after planting. Mycorrhizae do make seedlings grow better on adverse sites, but these fungi are not capable of miracles. Two fine breakthroughs were the measurement of water potential in seedlings that gives very reliable seedling stress data. The freeze test for seedlings has provided superb data on seedling cold resistance. Then on the other hand, we are about to lose methyl bromide and we desperately need concepts, strategies, and alternatives to grow disease tolerant seedlings.

The present situation is indeed a series of mixed results. Funding the research that we need is probably our single most pressing problem. It strikes me often what a sad irony it is that so many millions have been spent on tissue culture and gene splicing in agriculture, yet so few professionals in our area of endeavor have worked with such plant material in trees. While the high technology plant biology sector gets so much attention we need millions to develop alternatives to methyl bromide, develop ways to deal with disease and insects in nurseries, develop highly reliable physiological tests, develop fertilizers that will improve growth of seedlings in the nursery and field, and environmentally friendly herbicides. All of this takes money.

I would like to illustrate our present situation through one of the many dilemmas foresters face all the time. Faced with the prospect of never clearcutting again, forestry has started to look for silvicultural systems to cut and replant various sized “openings” in the forest. While this is not acceptable to some, it has been brought up many times as a political alternative to a never-ending intractable debate. Every now and then over the past 12 years I have had questions asked of me that go like this: “What sort of seedling do we need in such small openings? We are not supposed to control vegetation in these openings, so what do we do? Since those seedlings will be in the shade, should we grow them in the nursery under shade? Overall, how does one tailor a seedling for this outplanting environment?” As you might guess the answers are to be found deeply imbedded in several aspects of basic biology that have never gotten much funding. We are left with integrating-type answers and speculations from other experiments. Suddenly, it seems, many realize that we have never asked enough questions about shade tolerance differences among species. Suddenly, some recognize that technology is not going to solve this issue any time soon. In so many ways our present situation is one of too little funding to solve some very difficult biological problems. We have reached a point where we have done as much as we could on the little we have been given. We have been down so long, it is beginning to look like up!

Maybe we need to be much more aggressive in the future?

## Future Directions

We do need to be much more aggressive in the future. Those that work and do research with forest tree seedlings are literally the backbone of the huge political movement called sustainability. Our future directions need to be much more focused on slow release fertilizer technology and physiological testing. These two issues and others represent focus points where we can learn from our past lessons and move forward. We need to develop strategies that make each succeeding experiment capitalize on the one before it. Each failure and success should be compared to how far it took us in the direction of our primary objective to get seedlings up and growing into forests. Tangents should not be allowed to distract us from this primary objective. With this in mind I have listed some future directions for us to follow.

### Fertilizers and nutrient uptake

Forest regeneration and nursery management practices were immensely slow to embrace research in seedling fertilization, but the pace has greatly quickened in recent years. The reason for this is that the "unit costs" per seedling upset the perceived 'cheapness' that it should be to produce a good quality seedling. In so many words, many organizations were hamstrung by the past view that forestry seedlings need to be cheap without much regard for quality. Horticultural practices have advanced immensely because their plants command much higher "unit revenues." Forestry has constantly been hampered by the reality that few in the business see the trees for the forest.

Field fertilization has gone on in the South and West for a long time, but the doing of this practice has depended on "market forces." If profits are up, it gets done. If profits are down, the forest of the future "probably does not need it that badly" (as I once heard). Dropping fertilizer by helicopter has gone on sporadically and has shown up as worth doing in some places.

What do we need to know? We need to put in place on a larger scale research on the following:

1. Study the impacts of slow release fertilizers in container media and in the planting hole with the seedling at the time of planting.
2. Study the interactions among different slow release formulations, soil water, different kinds of clay chemistry, and soil organic matter.
3. Study the mode of action by which increased amounts of balanced levels of different nutrients get to the root interface for uptake.
4. Study the range of soil water levels necessary over given periods of time that provide optimum uptake.
5. Study the interactions among slow release fertilizer formulation, temperature, and release of nutrients from the pril.
6. Study the release pattern of the different nutrients from different slow release fertilizers.

These research directions would certainly have important biological and financial implications for industrial forestry and conservation plantings.

## Physiological quality

No area goes more wanting in nursery management and reforestation than this does. Somewhere along the way gene splicing technology took a giant leap ahead of seedling physiology for reforestation and jumped right into splicing genes for herbicide resistance, disease resistance, insect resistance, flowering, and a lot more. While these advances have been spectacular and down right eye popping (it is amazing to see a cotton wood seedling sprayed with glyphosate and not have one leaf turn brown!), the need for physiological studies has not decreased one single bit where improving seedling quality is concerned. While gene splicing is focused on literally altering the genetic behavior of a plant, it has yet to figured out how to get the plant to survive a harsh site, compete better against weeds, go without nutrients, AND still grow fantastically. Genetics is powerful, but it has its limitations.

Just to make nursery managers feel better, I have to relate a common theme I've witnessed in some gene splicing labs. While they have come to better understand the genes and some physiological changes, it seems to have been a common experience in some labs that they have needed to seek expert advice on how to propagate rooted tissue in potting media. Along the way to inserting genes someone forgot to learn how to turn the callus tissue with a few rootlets into a plant that will grow in soil. At one lab I once witnessed these tiny little plantlets right out of agar in two gallon pots filled with 50:50 peat:vermiculite and enough slow release fertilizer for a 1 inch diameter sapling! At other labs I heard them wondering why "the losses are so high here in the greenhouse." Some would do well to just bring in a local nursery manager. Seedling physiology is a wide-open area.

What do we need to know?

1. While focusing on the genetics of seedlings, more emphasis should be placed on dormancy and the mechanisms that control dormancy. This includes seedlings from seed, cuttings, somatic cell embryogenesis, and tissue culture.
2. Seed dormancy is a major scientific issue in many plants.
3. The soil:root interface is a massive area that needs more work and fits in with knowing more about plant nutrition. How seedlings first mobilize nutrients and water after thawing would be a superb area to study since so many forest tree seedlings are cold or frozen stored.

4. Forestry has as yet to really develop a series of reliable physiologically based target seedling characteristics. Chlorophyll fluorescence has been tried a lot with mixed success, starch has yet to be found functionally useful, and nutrition seems to be too variable.

5. More focused research that brings together the action of genes and physiological processes could lead to some awesome breakthroughs in understanding physiological quality.

## Mixed plantings

The monoculture plantings of the past are very likely to be less useful to forestry in the future. Monoculture plantings were never 'bad' because so many of the natural stands that were originally cut were tending toward monocultures or were dominated by a low number of dominate species. Beech and maple certainly dominated many forest covers in the Northeastern U.S. The forests of the South were made up of large tracts of loblolly or slash pine in places, much the same as the Northwest was dominated by Douglas-fir or ponderosa pine.

We already see now in the Pacific Northwest an increase in mixed or multi-species plantings due to root rots or a needle disease, called Swiss Needle Cast. Learning how to plant Douglas-fir, hemlock, larch, and white fir as well as some other species in various combinations is a major challenge to be tackled in the future. Just the shade tolerance among some species creates problems with dominance.

## Best practices

We need to begin the slow process of implementing the best practices that past research has indicated as successful. If the purchaser of seedlings wants the seedlings cheaper and smaller, then this "cost-based" decision must be built into the future growth model. So many of our "best practices" are in the heads of those who have worked in nursery management and reforestation for a decade or more. There is a tremendous need for a bridge between forest regeneration and the outcomes of forest regeneration practices starting in the nursery.

Having a collection of "best practices" is NOT just for the benefit of those of us who practice forestry. It is FOR those who do not practice forestry, but make the financial decisions in the boardrooms and management offices, much removed from the land base. Few to none of those high level managers and executives are foresters and only want to see price/cost ratios and return on capital along with other financial target measures. It sounds a bit strange, but forestry overall lacks sound growth models for many species between the time of planting and 20 years old! It has long been my personal view that trees are seen as these "low cost" photosynthesizing organisms not worth observing until they get to something close to merchantable value or a thinning. With "sustainability" all the rage these past 10 years it would seem something would have been done by now. Young trees fix large amounts of carbon and young trees are at the heart of the future of forest land sustainability.

What do we need to know? We need to put in place on a larger scale research on the following:

1. Taking into account the best that we know, describe the practices needed for different species to grow well continuously from planting to 20 years old.

2. Model the interaction between faster initial growth and time of thinning to attain the highest growth in 20 years.

3. Model the interaction of mixed forests from planting to 20 years old.

4. More importantly, develop cost models that provide risk analysis for practices that are not carried out! The impact of NOT doing a best practice needs to be weighted into the decisions.

## Vegetation management

Vegetation management is critical to our success in starting new forests. We have seen tremendous change in the use of herbicides, fire, and heavy equipment. While nursery management and forest regeneration are not thought of as disciplines to be controlled legally like cigarettes, vegetation management has found itself heavily scrutinized over issues like smoke management and herbicide toxicity. The future of vegetation management will depend a lot on how well the principles that govern its practices are improved and carried out. This is a very controversial and emotional subject for many in and out of forestry. An irrational fringe would have us abandon forest management all together because somewhere in the process vegetation management might have to be practiced.

For the sake of simplicity lets break vegetation management down into commercial and conservation. Commercial takes in the growing of a crop of trees. The weeds need to be killed so the crop can grow well in the nursery and field. In conservation vegetation management the emphasis shifts to restoring a portion of an ecosystem. Ironically, both areas include the growing of "native" plants. Loblolly and Douglas-fir are native plants that compete with weeds and much of the time, alien weeds. Some of us take the professional view that vegetation management when practiced best is practiced least, meaning if a 1% solution of glyphosate will do the job why use 2%? If a properly timed application of a herbicide mix will save the environment, time and money, why not do that instead of redoing the job next year? The days of vegetation management as "nuclear warfare/ scorched earth" are long gone. However, we still need herbicides in a big way and it is vital that professional foresters like ourselves make sure the public understands the "wise use" of chemicals.

The future is bringing on fast some of the worst problems we have faced in vegetation management. Whether it is Oregon or an island in the Pacific alien weeds, insects, and diseases are presenting ecosystems with very serious problems. One topic that is often discussed in hushed voices is the use of herbicides in conservation areas. A look at the literature reveals that in some parts of the world this "best of the bad choices" has presented itself as the only alternative. Knapweed, broom, *Lantana camara*, and miconia are nasty invaders that have not responded to pulling, grubbing, or cutting. We have alien grasses all over our forests. In many cases the forest can live with "naturalized" aliens and in other cases the alien completely alters the ecology of the area.

What do we need to research?

1. There need to be some much more creative herbicide compounds to come on the market. Research in this area has "died" in the past decade due to deep social concerns – some very legitimate and others flagrantly misguided. Our overly urbanized culture simply does not understand where their toilet paper comes from that they buy at the store. We need to find active compounds that do a selective job of targeting certain kinds of weeds in the same way that we have remarkable compounds to fight specific human diseases. These compounds may prove more useful in certain conservation situations than in commercial.

2. We need to research a whole lot harder the ways in which we can get around the use of chemical compounds where possible. Larger seedlings and fertilization at planting are two key areas that need a lot more focus in hundreds of locales.

## Define sustainability

Awash in buzzwords and 3-5 letter acronyms forest regeneration and nursery management have remained like Cretaceous links to the "old" forestry. Instead of visualizing forest regeneration as the heart and soul of "sustainability," the sustainability has come to be synonymous with global warming, global deforestation, and greenhouse gases without any inclusion of the very means to fix carbon at the nursery or forest regeneration (young stand) level. It is bizarre how socially driven perceptions about "sustainability" exclude from the lexicon the silvicultural or conservation mechanism to perpetuate forests where they have been cut or lost due to natural circumstances.

Among all the rhetoric, deforestation gets blamed for the rise in greenhouse gases and the certainly the loss of sustainable forests, but support for improved knowledge about seed, nursery practices, and forest regeneration (natural and artificial) get completely ignored. To "sustain" forests by never cutting them or going in them has never worked over the past 4,000 years because people want wood and rationalize getting it any way they can. There is a tremendous "disconnect" between the on-going loss of the world's forests and the means to bring them back. While industrial countries spawn virtual reality views of the pristine natural forest (always in some foreign country) the poachers continue to make off with the trees, the animals, the ground herbs, and even the soil.

A definition of sustainability would certainly help the image of many of us who labor in the background growing seedlings and planting the world's forests. Never was such an interesting and dedicated group of people more ignored that us. We need to remind others a lot more often that, if not for our work, the basic research that comes from laboratories would go unused. We are the end of the line for the propagated plant as it gets slipped into the earth and ready to grow for the next 11 to 1100 years. Our work is at the front end of sustainability.

Sustainability "paradigm shifts" have never contained concerns over alien plants competing with native trees, *much less* stricter plant quarantine rules to keep out alien insects and diseases. Sustainability advocates have to take some responsibility for why herbicides are forbidden in conservation areas. While the alien plants take over, alien plants have completely shifted the ecology of once beautiful forests. Look at what the fire ant is doing to Southern forests or *Lantana camara* is doing in tropical forests. I see this everywhere I go with my own eyes! On the one hand we have "sustainability" gurus telling the world "the sky is falling," yet nothing is ever suggested that would directly alleviate the problem. When talking sustainability the politicians cannot define the word or relate it to forest regeneration.

What do we need to know?

1. A definition of sustainability is needed that includes nursery management and forest regeneration practices worldwide.

2. Assuming that the long-term sustainability of the world's forests is based on sound reforestation practices, there needs to be far more research on seed collection and handling, nursery production practices, and forest regeneration systems.

3. If nursery management and reforestation are (indeed) *a part of* sustainability, then research funding needs to be fully expanded to reflect the importance. As it stands now the United States is a NET fixer of more carbon than it releases on a global scale, largely due to ….. nursery management and reforestation! As reported by Fran et al (1998) "North America is the best constrained continent…" which loosely translates as fixing more carbon than releasing. They go to say "The terrestrial uptake in North America is at least partly due to regrowth on abandoned farmland and previously logged forests."

## Summary

In the past 100 years nursery management and forest regeneration have come a long way starting with bareroot seedlings taken from the wild to "high tech" containerized seedlings with slow release fertilizers in the media. Forest regeneration as a sub-discipline of silviculture is still solving the same problem it was designed to 100 years ago – put a forest back where one previously existed. What has changed so much in the past 100 years is the urgency with which to get a new forest started.

Nursery management has seen incredible change in the past 100 years with much of the improvements coming from scientific research focused on seed technology, plant physiology (nutrition, water relations, dormancy, carbohydrates), morphological studies, genetics, mycorrhizae, and cultural practices.

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