Aportaciones científicas del Programa de Plantaciones Forestales en el INIFAP
Scientific contributions from the Forest Plantation Program at INIFAP

Xavier García-Cuevas1*
José Trinidad Sáenz-Reyes2
Hipólito Jesús Muñoz-Flores2
Adrián Hernández-Ramos3
Agustín Rueda-Sánchez4
Jonathan Hernández-Ramos1
Gabriela Orozco-Gutiérrez5

Resumen

El Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias (INIFAP) cuenta con seis Sistemas Forestales (SF) para fortalecer la investigación. Dentro de ellos, el Sistema de Plantaciones Forestales (SPF) incluye tres líneas de investigación, nueve productos por obtener y tres objetivos específicos. El objetivo de este trabajo fue compilar y analizar la información de publicaciones de investigación en libros y revistas científicas realizadas en el SPF del INIFAP a los 35 años de su creación. Se hizo una búsqueda en sitios de la web de publicaciones entre 1985 y 2021 de libros y artículos científicos, usando palabras clave. Se analizaron nueve trabajos relacionados con la caracterización ecológica de hábitat degradado, que son la base para el establecimiento de plantaciones forestales de reforestación (PFR) con al menos 86 especies de importancia comercial, 26 sobre producción de plantas de calidad que han tenido impacto en componentes para producir millones de plantas y 61 para establecimiento y manejo de PFC, donde 84.2 % son sobre el crecimiento de las especies, de las cuales en 2020 se reporta la existencia de 230 341 ha de PFC y 101 577 ha de sistemas agroforestales (SA).
Estas investigaciones han sido la base para implementar programas de desarrollo que contribuyen a la economía de los habitantes rurales a nivel regional y nacional.

**Palabras clave:** Cambio climático, germoplasma, modelación forestal, plantaciones forestales, potencial productivo, producción de plantas.

**Abstract**

The National Institute for Research on Forests, Agriculture and Livestock (INIFAP) has six Forest Systems, among them, the Forest Plantations System (FPS), which includes three research lines, nine products to be obtained, and three specific objectives. The aim of this work was to compile and analyze information of research publications in books and scientific journals made in the FPS 35 years after the creation of INIFAP. A search was made on the websites of publications between 1985 and 2021 of books and articles in scientific journals, using keywords. We analyzed 9 works related to the ecological characterization of degraded habitat, 26 on the production of quality plants that have had an impact on components to produce millions of plants, and 61 for the establishment and management of CFPs; 84.2 % deal with the growth species, of which in 2020 the existence of 230 341 ha of CFPs and 101 577 ha of agroforestry systems (AS) were reported. These research studies have served as the basis for implementing development programs that contribute to the economy of rural inhabitants at the regional and national levels.

**Key words:** Climate change, germplasm, forest modeling, forest plantations, productive potential, plant production.

Fecha de recepción/Reception date: 14 de octubre de 2021
Fecha de aceptación/Acceptance date: 26 de enero de 2022

1Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias. Campo Experimental Chetumal. México.
2Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias. Campo Experimental Uruapan. México.
3Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias. Campo Experimental Saltillo. México.
4Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias. Campo Experimental Centro Altos de Jalisco. México.
5Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias. Campo Experimental Tecomán. México.

*Autor para correspondencia; correo-e: [garcia.xavier@inifap.gob.mx](mailto:garcia.xavier@inifap.gob.mx)*
Worldwide commercial forest plantations (CFP) are a strategy for increasing production, reducing raw material deficits, generating development, and lowering the pressure on natural forests. Between 2000 and 2010, the area of CFPs increased by 6%. By 2016, these covered 264 million hectares (7% of the global forest area); 30% were concentrated in Asia, most of them for industrial purposes (FAO, 2016).

In San Luis Potosí, Mexico, a 6400 ha CFP of *Eucalyptus* spp. was established in the 1950s, and in Oaxaca, from 1974 to 1980, 10 000 ha were planted with *Pinus caribaea* var. *hondurensis* Bar. and Golf. (Prodefo, 2000).

Since 2000, the National Forest Commission (Conafor) launched the Commercial Plantation Development Program (Prodeplan), and by 2019, 230 341 ha (78.38% of the national total) had been planted in eight states of the country; mainly, with *Eucalyptus grandis* W. Hill, *Eucalyptus urophylla* S. T. Blake (21%), *Cedrela odorata* L. (17%), *Gmelina arborea* Roxb. (11%), *Pinus* sp. (10%), *Swietenia macrophylla* King (9%), *Tectona grandis* L. f. (9%), *Agave lechuguilla* Torr. (7%), *Hevea brasiliensis* (Willd. ex A. Juss.) Müll. & Arg. (4%), *Chamaedora* spp. (3%), *Tabebuia rosea* (Bertol.) DC. (2%), certain species of Christmas pine (2%), and other taxa (Conafor, 2020).
On the other hand, since the creation of the National Institute for Research on Forests, Agriculture and Livestock (INIFAP) in 1985, there has been a Forest Plantations Program (FPP), which today has three lines of research and gives rise to nine products (Table 1); this program has generated technologies for plant production, establishment, evaluation, and management of CFPs (INIFAP, 2018).

Table 1. Lines of research and products to be obtained in INIFAP's FPP.

| Research line                             | Products                                                                 |
|-------------------------------------------|--------------------------------------------------------------------------|
| 1. Ecological characterization of degraded habitat | 1.1 Technology for the establishment and management of FPs for reforestation purposes (RFP) |
| 2. Technology for the production of quality forestry plants | 2.1. Methods for the conservation and propagation of recalcitrant priority and endemic species  
  2.2. Technology for quality plant production |
| 3. Establishment and management of CFPs    | 3.1. Technology for the establishment and management of CFPs  
  3.2. Growth, increment, and yield models for CFPs  
  3.3. Volume tables and production tables by species  
  3.4. Production potential maps for CFPs  
  3.5. Maps showing areas of productive potential for CFPs under the climate change scenario  
  3.6. Indicators of biomass productivity and carbon sequestration in FPs |

Source: INIFAP (2018).

Thus, the objective of this document is to compile and analyze the information on research publications in books, special publications and scientific journals by researchers of INIFAP's PPF, 35 years after its creation.

Methodology
A search of publications generated between 1985 and 2021—including scientific books, technical books, special publications and scientific journals was made—was made on websites such as Docplayer, Google Chrome, Google Scholar, Redalyc, ResearchGate, and SciELO; the keywords used were the names of researchers, titles of papers, terms related to lines of research, products and objectives of INIFAP's FPP. Since some documents include more than one species, each species was referred to as a study. Frequencies of the information obtained and impacts to which the technologies have contributed at the regional or national level were obtained according to the lines of research and products that make up INIFAP's FPP (2018) (Table 1).

The search resulted in 97 publications, with an annual average of 2.7 publications, distributed among the three lines of research of INIFAP's FPP (Table 1; figures 1 and 2).

**Figure 1.** Publications by line of research of INIFAP's FPP.

**Figure 2.** Publications by product of the INIFAP's FPP.
The number of publications increased from 2011 to 2021, years in which 71.9% of the documents reviewed were published (Figure 3).

Figure 3. Annual publications of INIFAP's FPP.

In the 97 publications included in this review, 128 species were researched in 228 studies (Figure 4).

Figure 4. Studies by species published by researchers of INIFAP's FPP.

Ecological characterization of degraded habitat
Nine studies were found on 86 species of commercial importance; Figure 5 shows that the characterization of the species and their uses and management account for 87.9 % of the studies.

![Figure 5](image_url)

**Figure 5.** Topics of research line 1.1 in INIFAP’s FPP.

In temperate forests of *Chihuahua*, Alarcón and Iglesias (1992) determined the best substrate mixtures and fertilization routines for producing *Pinus durangensis* Martínez seedlings in greenhouses; Muñoz *et al.* (2010) evaluated *Pinus patula* Schiede ex Schltdl. & Cham. in RFPs, protection plantations (PPs), and CFPs of *Michoacán* and conclude that the *Purépecha Sierra* has appropriate areas for its establishment. Rueda *et al.* (2013a) characterized 72 forest species, their requirements and potential zones for the establishment of forest plantations in *Jalisco*.

Hernández and Benavides (2015) tested the sensitivity to photochemical oxidants due to the effect of ozone on *Abies religiosa* (Kunth) Schltdl. et Cham. and *P. hartwegii* Lindl. in the State of Mexico and determined a foliage damage index for the 20 provenances studied; while Flores *et al.* (2021) identified Germplasm Movement Zones (GMZ) for restoration with *Pinus* and *Abies* species and determined that 27 ZMG corresponded to forest lands as priority areas: 7 418 975 ha of low production and 9 389 577 ha of medium and low degradation.

For the tropical ecosystem, Rodríguez *et al.* (1993) evaluated in the nursery the progenies of *Dendropanax arboreus* (L.) Decne. & Planch. and *Simarouba glauca*
DC. with the best development; Sánchez and Velázquez (1998) achieved the control of larvae of *Hypsipyla grandela* (Zeller) in *Cedrela odorata* L. with *Beauveria bassiana* (Bals.-Criv.) Vuill. in 71% of the trees, and with *Bacillus thuringiensis*, in 91%. In *Quintana Roo*, García et al. (2010) evaluated seed dispersal by aircrafts, germination, and growth of *Enterolobium cyclocarpum* (Jacq.) Griseb. in burned areas; after 90 days, 25% of the dispersed seeds produced seedlings with an average height of 40 cm.

For arid zones, Martinez (2013) compiled information on *Lippia berlandieri* Schauer, *Prosopis* spp., *Agave lechuguilla*, *Dasylirion* spp., *A. salmiana* B. Otto ex Salm-Dyck ssp. *crassispina* (Trel.) Gentry, *Euphorbia antisyphilitica* Zucc., *Turnera diffusa* Willd. ex Schult. and *Olneya tesota* A. Gray. in natural populations and classified the productive potential and zoning for their use and conservation.

In Mexico, from 1993 to 2019, 2 296 794 ha of RFPs have been established (Figure 6), with over two billion plants (Semarnat, 2020), where INIFAP has generated technology for plant production, establishment and management of plantations and are a reference for planters (Prieto and Sáenz, 2011).

![Figure 6. Reforestation areas in recent years in Mexico.](image)

**Technology for the production of quality forest seedlings.** 26 research papers on 27 species that have had an impact on the forestry sector were located, mainly on seed quality, germination rates and speed, dormancy elimination, plant quality in the nursery, and field survival.
The massive production of quality plants for the establishment of RFPs and CFPs began with the emergence of Conafor in 2000. In this regard, INIFAP has contributed with the generation of technology that has increased plant quality by up to 40%, and the survival of plantations, by 80% (Prieto y Sáenz, 2011).

In addition, methods have been developed for the conservation and propagation of priority, recalcitrant, and endemic species. Recalcitrant seeds have limitations for storage and further propagation (Magnitskiy and Plaza, 2007); contrary to what happens with the orthodox ones. INIFAP has conducted 29 studies with 27 species; this has resulted in the storage, for several years, of seeds which naturally lose viability in two to three months, whose subsequent reproduction has also been achieved (Parraguirre and Camacho, 1992) (Figure 7).

In temperate climates, Camacho (1985; 1987), Camacho and Ramírez (1987) conclude that soaking is the best option to stimulate the germination of *Schinus molle* L. Its seeds can be stored for up to one and a half months, without reduction of germination percentage, and dormancy is eliminated when the seeds are soaked for 24 hours; while, in *Eysenhardia polystachya* (Ortega) Sarg., complete and rapid germination is obtained by separating the pericarp. De la Garza and Nepamuceno (1986) carried out radiological analyses of forest seeds applied in viability control analysis of seeds of different species. Camacho and Molina (1991) determined that stratification and desalination suppress dormancy in *Atriplex canescens* (Pursh)
Nutt., since more than 50% of ten utricles with seed germinated after being subjected to the above-mentioned treatment.

Bustamante-García et al. (2012a; 2012b) studied insects affecting seed set, seed quality, pollination and seed production potential in Pinus engelmannii Carr.; their results showed that Leptoglossus occidentalis Heidemann is the causal agent of the greatest damage to seed development; Bustamante-García et al. (2014) determined the quality and seed potential of P. durangensis; obtained averages of 100.3 seeds per cone, of which 73.4% were full; 53.4% germinated, and the aborted seeds were damaged by L. occidentalis in the early stages of their development. Prieto et al. (2014) generated a methodology to determine the quantity and quality of seed in cones, as well as the average daily germination, germination speed, and germination value.

For the tropical climate, Parraguirre and Camacho (1992) established germination rates and speed of germination for 21 species and indicated that the time to achieve 75% germination is the appropriate indicator for good germination; and Camacho (1994) described seed germination inhibition and techniques to eliminate dormancy, either naturally or by the action of chemical or mechanical treatments.

**Technology for the production of quality plants.** The success of FPs depends on the quality of nursery-grown plants. In the field, the desired survival rate has not been achieved; thus, from 2013 to 2015, the survival rate averaged 54.2% (Conafor, 2020). In Mexico, 80 989 872 plants were produced in 154 nurseries between 2018 and 2019 (Conafor, 2020).

INIFAP researchers have published 13 papers on 18 species that support the work of forest nurserymen, mainly regarding plant quality (Figure 8). For example, Prieto et al. (2011) evaluated plant quality indicators in 51 forest nurseries in Chihuahua, Durango, Nayarit, Jalisco, Colima and Michoacán, where, from 2005 to 2009, 43.2 million plants per year\(^1\) were produced for the reforestation of 40 016 ha year\(^{-1}\).
In cold temperate climate, Prieto y Sáenz (2011) described the plant quality of hardwood and conifer species in nurseries in five states of the Western Sierra Madre; Rueda et al. (2012, 2014a) did the same for Jalisco and Nayarit. These authors indicate that the hardwood and coniferous plants produced are of average quality, according to the standards established in the norm NMX-170-SCFI-2016.

Benavides et al. (2011a; 2011b) carried out a nursery diagnosis of the provenances of *P. hartwegii* Lindl. and *Abies religiosa* (Kunth) Schltdl. et Cham. from the Neovolcanic Axis, between which no variation was found. Sáenz et al. (2014a) determined the plant quality in species of the genus *Pinus*; Muñoz et al. (2015a) did the same in conifer taxa, both in Michoacán; according to their results, the plants were rated as high quality.

Sigala et al. (2015) assessed survival in *P. pseudostrobus* Lindl. plantations; they concluded that diameter is the morphological variable most closely related to the risk of mortality at the plantation sites; Martínez et al. (2015) determined the effect of the inoculation of *Russula delica* Fr. on *P. engelmannii* Carr. seedlings; the best results were obtained with irrigation inoculation at a low dose, and the highest percentage of mycorrhization, when the substrate was inoculated at a high dose. Sáenz et al. (2017) evaluated the plant quality of *P. pseudostrobus* L. in response to fertilization; they found that the substrate with 2 kg of Osmocote m$^{-3}$ + 5 % compound liquid biofertilizer applied every 30 days led to better results for morphological and physiological variables.
Gómez et al. (2017), in Oaxaca, when studying the genetic potential in nurseries of *P. greggii* Englem. provenances, observed a differentiated behavior at the variety level; and, in study on their morphological attributes, Pineda et al. (2020) registered good quality for *P. greggii, P. leiophylla* Schiede ex Schltdl. & Cham., *P. cembroides* Zucc., *P. ayacahuite* Ehren., and *P. hartwegii*. Basave et al. (2021) examined the effect of aerial pruning on the morphological quality of *Caesalpinea coriaria* (Jacq.) Willd plants and concluded that its use in nurseries is not recommended.

For the tropical climate, Patiño and Marín (1993) address issues of nursery planning and establishment, production, handling and transport of forest plants, and Patiño et al. (1993) propose ways of seed selection, production, plant handling and transportation, site determination, establishment and economic aspects in FPs of *Gmelina arborea* Roxb. and Santiago et al. (2015), in Veracruz, point out that the use of different substrate mixtures in bags vs. containers has a greater influence on the growth of *Hevea brasiliensis*.

**Establishment and management of CFPs**

**Technology for the establishment and management of CFPs.** In 2020, Conafor recorded the existence of 230 341 ha of CFPs, 78.4 % of which are located in eight states of the country, and 101 577 ha of agroforestry systems (AS), 77 % of which are distributed among five states (Conafor, 2020). Along this line, 22 papers have been published on 38 commercial forest species; of these, 47.4 % are related to the growth evaluations of the species (Figure 9).
Figure 9. Topics in INIFAP’s research line on technology for the establishment and management of CFPs.

Within this context, García et al. (2005) tested the effect of pruning intensities on the growth of *Alnus acuminata* spp. *glabrata* (Fernald) Furlow and concluded that pruning at 50 % of the height does not affect height growth, but does affect increase in diameter. Muñoz et al. (2009) evaluated the growth and survival of CFPs of *Tectona grandis* L. f., *Acrocarpus fraxinifolius* Wight et Arn., and *G. arborea* in Michoacán, and they point out that *G. arborea* has potential for CFP development in the dry tropics. In a study on the growth of a mixed plantation in Veracruz, Mexico, López et al. (2010) register *G. arborea* as the species with the largest increases in all its variables, and, in a mixed plantation of *C. odorata* L., *Cordia alliodora* (Ruiz & Pav.) Oken, *T. grandis*, and *S. macrophylla*, Hernández et al. (2011) cite *T. grandis* as having a superior growth compared to the other three species.

Muñoz et al. (2011a) determined the survival and growth of *G. arborea*, *T. grandis*, *Acrocarpus fraxinifolius*, *C. odorata*, and *Eucalyptus camaldulensis* Dehnh. CFPs in Michoacán; the authors recommend the ones that obtained the best results based on their productivity. In a research study on growth, survival and phytosanitation in *P. pseudostrobus* Lindl. and *P. greggii* CFPs of the Purépecha region, Muñoz et al. (2011b) concluded that these species grew in the same way and that their phytosanitary status was healthy in 95.12 % of the cases.
Muñoz et al. (2011c) document technology generated for six native and introduced hardwood species; Sáenz et al. (2012) compile information on Pinus taxa for the generation of their maps of potential areas for CFPs in Michoacán, and García et al. (2011), in Quintana Roo, defined financial indicators for Swietenia macrophylla CFPs, which serve producers and funders in the decision-making process.

Likewise, Muñoz et al. (2013) studied T. rosea and E. cyclocarpum FPs in different containers. T. rosea in coconut fiber containers showed higher survival than in polystyrene trays; while, for E. cyclocarpum, there were no differences between the various types of containers. Sáenz et al. (2014b) applied fertilization in P. pseudostrobus FPs in Michoacán, registered higher increases with compound liquid biofertilizer and the formula of 20 g of 14-07-12 NPK, with values of 27.9 and 16 % higher, with respect to the control. Guzmán and Cruz (2014) determined the growth of Amphipterygium adstringens (Schltdl.) Schiede ex Standl. in the field; they conclude that the species shows morphological variation of the fruit and percentages of fruit with a single seed.

In Puebla, Muñoz et al. (2015b) estimated the growth, survival and phytosanitation in a Pinus chiapensis (Martínez) Andresen, P. greggii and P. patula CFP; they claim that P. greggii and P. patula have good potential for CBP; in Durango, Mejía et al. (2015) determined the survival and development of 72 coniferous plantations and point out that in most of them, survival was higher than 60 %, and they could be incorporated into utilization due to their excellent growth. Muñoz-Flores et al. (2019) did something similar for P. pseudostrobus planted on different dates in Michoacán, and they document higher growth and survival of this species when planted at the beginning of the rainy season. Finally, Muñoz et al. (2021) in Michoacán evaluated the survival and growth of Guadua aculeata Rupr. ex E. Fourn., G. inermis Rupr. ex E. Fourn., G. amplexifolia Presl., and G. angustifolia Kunth; report that G. inermis was well adapted to the conditions of the planting site.

Another important issue is that of AS; therefore, Sáenz et al. (2014b; 2016) define potential areas for the establishment of silvopastoral systems with pine species and
fodder crops; their results confirm the productivity and profitability of *Pinus michoacana* Martínez associated with *Festuca arundinaceae* Schreb. var. cajun, applied fertilization in silvopastoral systems with *Pinus devoniana* Lindl. and *Chloris gayana* Kunth, and a silvopastoral system with *P. devoniana* associated with *Avena sativa* L. var. Avemex. Muñoz *et al.* (2014) established AS, all of them in Michoacán, Mexico.

Cuevas-Reyes *et al.* (2020) evaluated the profitability of a silvopastoral system of *Leucaena leucocephala* (Lam.) de Wit. associated with *Cynodon dactylon* (L.) Per. Besides, they defined financial indicators and potential areas in order to establish AS, as well as yields and profitability with different forestry and agricultural components, which will be used for decision making by producers.

**Growth, incremental and yield models for CFPs.** Knowledge of growth and yield through allometric models of trees or stands allows the reconstruction of development, which is basic for the planning of CFP management (Hernández-Ramos *et al.*, 2019). Nine papers have been published on five species, 75 % of which refer to growth curves and site indexes (Figure 10).

![Figure 10](image)

**Figure 10.** Topics in the line of research concerning growth, increment, and yield models for the CFPs of INIFAP's FPP.

This is an area of opportunity for research development. In this regard, García *et al.* (1992) and García and Rodríguez (2005) modeled height and diameter growth for *S. macrophylla* and *C. odorata*; García *et al.* (1996) developed a density guideline
for the management of *S. macrophylla* CFPs. The equations generated have served to define guidelines for the management of the more than 2 500 ha of CFPs of precious species in *Quintana Roo*.

Site Indices (SI) have been proposed to rate CFPs according to the productivity of the site. García *et al.* (1998; 2007; 2021) generated dominant height (*Dh*) equations for *S. macrophylla* and *C. odorata*; Gómez *et al.* (2009) did it for *Eucalyptus grandis* W. Hill ex Maide and *Eucalyptus urophylla* S.T Blake, and Tamarit *et al.* (2014a), for *T. grandis*. Ordaz-Ruíz *et al.* (2020) adjusted allometric equations for *P. patula* CFPs. The equations generated have been used to define the productivity of the soils for the establishment of CFPs of the species mentioned above in *Quintana Roo, Tabasco, Campeche* and the State of Mexico.

**Volume and production tables by species.** The volume equations, tapering and volume systems allow estimating the actual stock for each tree or part of a tree, and per unit area; at the same time, it is possible to determine the level of reliability of these estimates. INIFAP researchers have published six papers on five forest species (Figure 11); this subject has been little studied, a fact which provides a great opportunity for its development.

![Graph](image)

**Figure 11.** Topics in the line of research related to the tables of **volumes and production** by species of the INIFAP’s CFPs.
Within this context, Muñoz (2000) developed tariffs and volume tables for *E. camaldulensis*; Honorato (2011) generated a model for *A. fraxinifolius* that estimates diameters and volumes at different heights; Muñoz et al. (2012) adjusted models for volume in *P. greggii* FPs. For their part, Tamarit et al. (2014b) constructed a single-tree cubing system, based on a segmented taper function for *T. grandis*; Hernández et al. (2017a; 2017b) adjusted compatible taper-volume systems for *P. greggii* and *E. urophylla* CFPs. In the south and southeast, these systems serve to estimate the inventory in 17 500 ha of *T. grandis* and 12 500 ha of *E. urophylla* (Tamarit et al., 2014b; Hernández et al., 2017a).

**Production potential maps for commercial forest plantations.** Federal Government promotes a planned forest policy; this requires knowledge of the location of the areas with the greatest potential for each species (Muñoz et al., 2018). INIFAP's scientific staff has published 12 research papers on 32 species of interest, most of them for cold temperate taxa (68.8 %) (Figure 12).

![Figure 12](image)

**Figure 12.** Ecosystems addressed in the research line maps of productive potential for commercial forest plantations of INIFAP’s FPP.

In temperate climate forests, Sáenz et al. (2011) conducted the regionalization of potential areas for CFPs in Michoacán; in Jalisco, Rueda et al. (2006) did it for 10 species of *Pinus*, in which *Pinus devoniana* f. procera and *Pinus montezumae* Lamb stood out with over 500 mil hectares; Muñoz et al. (2011d) did something similar
for *P. pseudostrobus* and *P. greggii* in Michoacán, and identified surfaces with good potential for CFPs.

Rueda *et al.* (2007) determined potential surface areas for *Pinus tenuifolia* Benth., *Eucalyptus globulus* Labill., *Roseodendron donnell-smithii* Rose, *T. rosea*, *E. cyclocarpum*, and *C. odorata* CFPs in Jalisco, and Muñoz *et al.* (2015b; 2016; 2017; 2018) did the same for four *Pinus* species in temperate climate, as well as for *E. cyclocarpum*, *Tabebuia rosea* (Bertol.) Bertero ex A.DC., and *Brosimum alicastrum* Swarts., in the tropical areas of Michoacán.

In tropical areas, Reynoso *et al.* (2016) identify 135 869 ha (17 % of the total surface area) as potential *Agave americana* L. CFPs in Chiapas.

In arid zones, Castillo-Quiroz *et al.* (2014a; 2014b) developed maps of areas with a high potential for *A. lechuguilla* CFPs in Coahuila and Tamaulipas; they estimated a potential surface area of 106 272 ha in Tamaulipas, and of 1 194 877 ha in Coahuila. Martínez *et al.* (2015) did likewise for *Lippia berlandieri* Schaurer, *A. lechuguilla* Torr, *Dasylirion* spp., *Agave salmiana* Otto ex Salm.-Dyck ssp. *crassispina* (Trel.) Gentry, *Euphorbia antisyphilitica* Zucc., *Olneya tesota* A. Gray, and *Agave angustifolia* Haw.

The aforementioned works have served as guidelines for producers and institutions to make decisions for the establishment of CFPs (Rueda *et al.* 2006). As a result, a large part of the 230 341 ha of CFPs (Conafor, 2020) has been selected with the support of the maps of areas with productive potential.

**Maps showing areas with productive potential for CFPs in the face of climate change scenarios.** Identifying conservation areas, refuges and future cultivation zones is fundamental for the conservation of natural resources (Hernández *et al.*, 2018). INIFAP's scientific staff has published seven research papers on six species (Figure 13); which indicate changes in the distribution of species under different climate change scenarios.
Figure 13. Topics in the research line. Maps with areas of productive potential for CFPS in the face of climate change scenarios of INIFAP’s FPP.

In Jalisco, Rueda-Sánchez et al. (2017) developed maps of current and future CFPS production potential for C. odorata, T. rosea, and E. cyclocarpum; they proved that changes under future scenarios will have consequences for the habitat of the species due to climate change. Rueda et al. (2018) did the same for Pinus maximinoi H.E. Moore and R. donnell-smithii, and they point out that, under the scenarios considered, the distribution areas for the establishment of CBPs will not be significantly affected, as they will decrease by 9 to 12 % with respect to the current optimal areas.

Hernández et al. (2018) modeled the historical, current and future distribution under two climate scenarios for C. odorata; the authors found that the species has a high probability of experiencing a reduction of its ecological niche in the country. For their part, Reynoso et al. (2018) used the concept of ecological niche to generate potential areas for CFPS in the face of climate change effects; the variable of greatest influence for the presence or absence of P. oocarpa and P. pseudostrobus was the altitude (84.5 % and 97.3 %, respectively). These results delimit the optimal areas for the establishment of Forest Germplasm Producing Units (FGPUs) for the two species.

**Indicators of biomass productivity and carbon sequestration in FPs.** As a consequence of climate change caused by greenhouse gases, there is a need for carbon sequestration (C) in biomass (B) and soils, and FPs are the option for C sequestration and storage (Acosta et al., 2020). INIFAP has carried out studies on
this subject that have resulted in eight publications on 13 forest species, 48 % of which refer to the determination of B and C stocks sequestered in CFPs (Figure 14).

**Figure 14.** Topics in the research line on biomass productivity indicators and carbon sequestration in the FPs of INIFAP's FPP.

Using the RothC model, González *et al*. (2012) simulated the changes in soil C in corn-squash systems, compared to AS and monocultures with *Ricinus communis* L., and obtained a rate of change of soil organic C (Mg ha$^{-1}$ year$^{-1}$) of 0.1 to 0.7 after 40 years of simulated land use change with FP of tropical species without management; while, with management, it was -0.2 to 0.3. Rueda *et al*. (2013b; 2014b) estimated B and C in CFPs of eight tropical species and adjusted equations for their prediction; their results indicated that *T. grandis*, and *E. cyclocarpum* had the highest B content and the highest C storage potential; Sigala *et al*. (2016) fitted equations to predict B (aerial, root and total) in *P. pseudostrobus* seedlings under different production systems; their results showed that the diameter was the best predictor variable.

Based on the B stocks, Hernández *et al*. (2017c) generated B expansion factors (BEFs) in *E. urophylla* CFPs. The average EF of total B and the shaft was 510.09 kg m$^{-3}$ and 472.56 kg m$^{-3}$; furthermore, the conversion factor for stem biomass to total biomass was 1.17. They also estimated a volume of 156.08 m$^3$ ha$^{-1}$ and 80 Mg ha$^{-1}$ of aerial B in the evaluated plantation.
In *T. rosea*, *T. grandis*, *G. arborea*, and *E. cyclocarpum* CFPs of Jalisco, González *et al.* (2018) evaluated the changes in organic C when the land use was changed from agricultural to a FP; they determined that the rate of change in soil organic C (Mg ha$^{-1}$ year$^{-1}$) after 40 years of simulation with unmanaged plantations was 0.1 to 0.7; whereas, with management, it was -0.2 to 0.3. Acosta *et al.* (2020) determined C in herbaceous plants, shrubs and leaf litter in a mixed FP; the authors pointed out that *E. cyclocarpum* had the highest amount of total C, while *T. grandis* had the lowest content (73.94 Mg ha$^{-1}$ and 45.63 Mg ha$^{-1}$). In the soil, C decreased by approximately 35 % as depth increased.

Martínez *et al.* (2020) fitted equations to predict B in foliage, branches, stem and root of *P. hartwegii* in RFPs of *Izta-Popo Zoquiapan* National Park and obtained equations as a function of diameter at base. Sáenz *et al.* (2021) estimated B and C in mixed plantations and fitted aerial B models for four tropical species, their results indicated that normal diameter was a good predictor of total dry aerial B of these species. *T. grandis*, *G. arborea*, and *E. cyclocarpum* exhibited the highest biomass content (161, 134, and 130 kg ha$^{-1}$, respectively) and the highest carbon storage potential (144.6, 120.8, and 117.5 Mg ha$^{-1}$, respectively). Finally, in *C. odorata* plantations of Jalisco and Colima, Benavides *et al.* (2021) generated equations for predicting B and C, which exhibited levels of confidence above 97 %.

This shows that FPs are a viable option for C fixation, as they maximize the production of volume per surface area unit and have a high C storage capacity. On the other hand, timber is transformed into durable products; therefore, the fixated C will remain in the structures for long periods of time (González *et al.*, 2019).

**Conclusions**
The published research papers have emphasized the establishment and management of CFPs in the first place, followed by the technology for the production of high quality plants and for agroforestry systems in temperate and tropical ecosystems. Technologies have been generated for determining morphological plant quality parameters for temperate climate and tropical species with an increase of up to 70% of the field survival rate.

Some areas of opportunity identified from the contributions to knowledge included in the publications considered in this review make reference to growth models, cubic capacity, productive potential under climate change scenarios as supports for the management and selection of areas with potential for the establishment of CFPs.

Most of the published studies deal with evaluations of species that grow in tropical climates, followed by those of cold temperate and arid zones, which implies that certain aspects of the ecology of the taxa of these ecosystems have been neglected.

Conflict of interests

The authors declare no conflict of interest.

Contribution by author

Xavier García-Cuevas, José Trinidad Sáez-Reyes, Hipólito Jesús Muñoz-Flores, Adrián Hernández-Ramos, Agustín Rueda-Sánchez, Jonathan Hernández-Ramos and Gabriela Orozco-Gutiérrez: data collection, and drafting, review, and discussion of the manuscript.

References
Acosta M., M., F. Carrillo A., E. Buendía R., J. D. Benavides S., E. Flores A. y L. González M. 2020. Carbono en suelo, hierbas y arbustos en una plantación forestal en Jalisco, México. Revista Mexicana Ciencias Agrícolas 11 (6): 1377-1387. Doi:https://doi.org/10.29312/remexca.v11i6.2427.

Alarcón M. y L. Iglesias G. 1992. Influencia del sustrato y la fertilización sobre el desarrollo de Pinus durangensis Mtz., en invernadero. Ciencia Forestal en México 17 (71): 27-61. http://www.conafor.gob.mx:8080/documentos/docs/13/959Pinus%20durangensis.pdf (2 de agosto de 2020).

Basave V., E., V. M. Cetina A., M. Á. López L., C. Ramírez H., C. Trejo y V. Conde M. 2021. La poda aérea como práctica cultural en vivero para Caesalpinea coriaria (Jacq.) Willd. Revista Mexicana de Ciencias Forestales 12 (63): 139-162. Doi:https://doi.org/10.29298/rmcf.v12i63.799.

Benavides M., H., M. O. Gazca G., S. F. López L., F. Camacho M., D. Y. Fernández G., M. P. de la Garza L de L. y F. Nepamuceno M. 2011a. Crecimiento inicial en plántulas de 12 procedencias de Pinus hartwegii Lindl. bajo condiciones de vivero. Revista Mexicana de Ciencias Forestales 2 (5): 73-89. Doi:https://doi.org/10.29298/rmcf.v2i5.584.

Benavides M., H., M. O. Gazca G., S. F. López L., F. Camacho M., D. Y. Fernández G., M. P. de la Garza L y F. Nepamuceno M. 2011b. Variabilidad en el crecimiento de plántulas de ocho procedencias de Abies religiosa (H.B.K.) Schlecht. et Cham., en condiciones de vivero. Madera y Bosques 17(3): 83-102. Doi:https://doi.org/10.21829/myb.2011.1731144.

Benavides S., J. D., O. Torres G., J. G. Flores G., M. Acosta M. y A. Rueda S. 2021. Ecuaciones alométricas para estimar biomasa y carbono aéreos de Cedrela odorata L. en plantaciones forestales. Revista Mexicana de Ciencias Forestales 12 (65): 90-11. Doi:https://doi.org/10.29298/rmcf.v12i65.791.

Bustamante-García, V., J. A. Prieto-Ruíz, R. Álvarez-Zagoya, A. Carrillo-Parra, J. J. Corral-Rivas and E. Merlín-Bermudes. 2012a. Factors affecting seed production of
**Pinus engelmannii** Carr. in seed stands in Durango State, Mexico. Southwestern Entomologist 37 (3): 350-359. Doi: [https://doi.org/10.3958/059.037.0311](https://doi.org/10.3958/059.037.0311).

Bustamante-García, V., J. A. Prieto-Ruíz, E. Merlín-Bermudes, R. Álvarez-Zagoya, A. Carrillo-Parra y J.C. Hernández-Díaz. 2012b. Potencial y eficiencia de producción de semilla de *Pinus engelmannii* Carr., en tres rodales semilleros del estado de Durango, México. Madera y Bosques 18 (3): 7-21. Doi: [https://doi.org/10.21829/myb.2012.183355](https://doi.org/10.21829/myb.2012.183355).

Bustamante-García, V., J. Á. Prieto-Ruiz, A. Carrillo-Parra, R. Álvarez-Zagoya, H. González-Rodríguez and J. J. Corral-Rivas. 2014. Seed production and quality of *Pinus Durangensis* Mart., from seed areas and a seed stand in Durango, Mexico. Pakistan Journal of Botany 46 (4): 1197-1202. [http://www.pakbs.org/.../06.pdf](http://www.pakbs.org/.../06.pdf).

Camacho M., F. 1985. Identificación del mecanismo que inhibe la germinación de *Schinus molle* L. y forma de eliminarlo. Ciencia Forestal en México 10 (55): 35-49. [https://agris.fao.org/agris-search/search.do?recordID=MX19900107153](https://agris.fao.org/agris-search/search.do?recordID=MX19900107153) (2 de diciembre de 2020).

Camacho M., F. 1987. Germinación de la semilla de palo dulce (*Eysenhardia polystachya* (Ortega) Sarg.) en siembras densos. Ciencia Forestal en México 12 (62):3-13. [http://cienciasforestales.inifap.gob.mx/index.php/forestales/article/view/1167](http://cienciasforestales.inifap.gob.mx/index.php/forestales/article/view/1167) (5 de diciembre de 2020).

Camacho M., F. y M. Ramírez P. 1987. Dormición química de semillas de pirú (*Schinus molle* L.) en tres tipos de siembra. Ciencia Forestal en México 12 (62): 15-31. [http://cienciasforestales.inifap.gob.mx/editorial/index.php/forestales/citationstylelanguage/get/associacao-brasileira-de-normas-tecnicas?submissionId=1168](http://cienciasforestales.inifap.gob.mx/editorial/index.php/forestales/citationstylelanguage/get/associacao-brasileira-de-normas-tecnicas?submissionId=1168) (4 de noviembre de 2020).

Camacho M., F. y P. Molina. 1991. Enfriamiento en húmedo para eliminar la dormición de las semillas de chamizo, *Atriplex canescens* (Pursh) Nutt. Ciencia
Forestal en México 16 (69): 59-75. http://www.renida.net.ni/cgi-bin/opac_cenida/wxis.exe?IsisScript=acenida.xis&Accion=búsqueda&TipoBusqueda=simple&TxtBusq=F03%2F%287%29&PrimerRegistro=201&base=renida&pub_nac=no (7 de noviembre de 2020).

Camacho M., F. 1994. Dormición de semillas: Causas y tratamientos. Ed. Trillas. México, D.F., México. 125 p.

Castillo-Quiroz, D., O. U. Martínez-Burciaga, D. Y. Ávila-Flores, F. Castillo-Reyes and J. D. Castillo-Chaparro. 2014a. Identification of potential areas for establishment of plantations of Agave lechuguilla Torr. in Coahuila, Mexico. Open Journal of Forestry 4: 520-526. Doi:http://dx.doi.org/10.4236/ojf.2014.45056.

Castillo-Quiroz., D., O. U. Martínez-Burciaga, L. J. Ríos-González, J. A. Rodríguez-de la Garza, T. K. Morales-Martínez, F. Castillo-Reyes y D. Y. Ávila-Flores. 2014b. Determinación de áreas potenciales para plantaciones de Agave lechuguilla Torr. para la producción de etanol. Revista Científica de la Universidad Autónoma de Coahuila 6 (12): 4-12. http://www.actaquimicamexicana.uadec.mx/?p=416 (4 de diciembre de 2020).

Comisión Nacional Forestal (Conafor). 2020. El sector forestal mexicano en cifras 2019. Bosques para el bienestar social y climático. Zapopan, Jalisco, México. 100 p.

http://www.conafor.gob.mx:8080/documentos/docs/1/7749El%20Sector%20Forestal%20Mx%20en%20Cifras%202019.pdf (7 de junio de 2021).

Cuevas-Reyes, V., J. E. Reyes J., M. Borja B., A. Loaiza M., B. I. Sánchez-Toledano, T. Moreno G. y C. Rosales N. 2020. Importancia del matorral desértico micrófilo para el venado cola blanca (Odocoileus virginianus) Mears, 1898) en Coahuila. Revista Mexicana de Ciencias Forestales 11 (62): 90-110. Doi:https://doi.org/10.29298/rmcf.v11i62.759.

De la Garza L., P. y F. Nepamuceno M. 1986. Análisis radiográfico de semillas forestales en México. Ciencia Forestal en México 11 (59): 1-14.
http://cienciasforestales.inifap.gob.mx/index.php/forestales/article/view/1201 (15 de diciembre de 2020).

Flores G., A., M.E. Romero S., R. Pérez-Miranda, T. Pineda-Ojeda y F. Moreno-Sánchez. 2021. Potencial de restauración de bosques de coníferas en zonas de movimiento de germoplasma en México. Revista Mexicana de Ciencias Forestales 12 (63): 5-27. Doi: https://doi.org/10.29298/rmcf.v12i63.813.

García C., X., C. Parraguirre L. y B. Rodríguez S. 1992. Modelos de crecimiento para una plantación de coba (Swietenia macrophylla King). Ciencia Forestal en México 17 (71): 87-102. http://cienciasforestales.inifap.gob.mx/editorial/index.php/forestales/article/view/1097 (10 de agosto de 2020).

García C., X., C. Parraguirre L. y H. Ramírez M. 1996. Guía de densidad para manejo de plantaciones de (Swietenia macrophylla King) caoba. Ciencia Forestal en México 21 (80):79-95. https://biblat.unam.mx/es/revista/ciencia-forestal-en-mexico/articulo/guia-de-densidad-para-manejo-de-plantaciones-de-swietenia-macrophylla-king-caoba (11 agosto de 2020).

García C., X. 1998. Índice de sitio para caoba (Swietenia macrophylla King) en Quintana Roo, México. Ciencia Forestal en México 23 (84): 9-18. http://cienciasforestales.inifap.gob.mx/editorial/index.php/forestales/issue/download/85/p2484 (6 de agosto de 2020).

García C., X. y B. Rodríguez S. 2005. Crecimiento e incremento de Cedrela odorata L. (cedro rojo) en Quintana Roo, México. Revista Trópico Rural 1 (3): 19-39. https://www.redalyc.org/pdf/617/61711316006.pdf (2 de agosto de 2020).

García C., X., J. G. Flores G. y J. D. Benavides-Solorio. 2007. Índice de sitio para Cedrela odorata L (cedro rojo) en Quintana Roo, México. Ciencia Forestal en México 32 (101): 71-92. https://cienciasforestales.inifap.gob.mx/editorial/index.php/forestales/article/view/825 (8 de agosto de 2020).
García C., X., E. Velazco B., B. Rodríguez S., A. González H. y F. Camacho M. 2010. Evaluación de la siembra aérea con Enterolobium cyclocarpum (Jacq.) Griseb en el ejido Leona Vicario, Quintana Roo. Revista Mexicana de Ciencias Forestales 1 (2): 109-119. Doi: https://doi.org/10.29298/rmcf.v1i2.6409.

García C., X., B. Rodríguez S. y J. Islas G. 2011. Evaluación financiera de plantaciones forestales de caoba en Quintana Roo. Revista Mexicana de Ciencias Forestales 2 (7): 7-25. Doi: https://doi.org/10.29298/rmcf.v2i7.562.

García C., X. C. Toledo Ch., J. Hernández R., J.A. Mendoza M., y A. Hernández R. 2021. Índice de sitio para plantaciones forestales comerciales de Cedrela odorata L. en Quintana Roo, México. Revista Mexicana de Ciencias Forestales 12(64): 93-114. Doi: https://doi.org/10.29298/rmcf.v12i64.793.

García M., J. J., H. J. Muñoz F., J. T. Sáenz R. y J. García S. 2005. Efecto de podas en plantaciones de aile (Alnus acuminata spp. glabrata (Fern.) (Furlow) en Nuevo San Juan Parangaricutiro. Ciencia Forestal en México 30(97):63-77. http://cienciasforestales.inifap.gob.mx/editorial/index.php/forestales/article/view/862 (4 de diciembre de 2020).

Gómez T., J., H. M. De los Santos P., A. M. Fierros G. y J. R. Valdez L. 2009. Modelos de crecimiento en altura dominante para Eucalyptus grandis Hill ex Maiden y E. urophylla S. T. Blake en Oaxaca, México. Revista Fitotecnia Mexicana 32 (2): 161–169. http://www.scielo.org.mx/pdf/rfm/v32n2/v32n2a12.pdf (5 de diciembre de 2020).

Gómez C., M., E. Pérez M., S. Orozco C., H. J. Muñoz F., J. T. Sáenz R., G. Rodríguez O. y A. Hernández H. 2017. Variación intraespecífica en planta de Pinus greggii Engelm. ex Parl. en condiciones de vivero. Revista Mitigación del Daño Ambiental Agroalimentario y Forestal de México 3 (3): 123-139. https://docplayer.es/89890820-Revista-mitigacion-del-dano-ambiental-agroalimentario-y-forestal-de-mexico.html (5 de agosto de 2020).

González M., L., E del C. Moreno P., K. Laksri R., A. Báez P. y M. Acosta M. 2012. Simulación de los cambios de carbono orgánico del suelo en sistema de cultivo con
García-Cuevas et al., Aportaciones científicas del...

higuera por el modelo RothC. Pesquisa agropecuaria brasileira 47 (11): 1647-1654. Doi: https://doi.org/10.1590/S0100-204X2012001100012.

González M., L., M. Acosta M., F. Carrillo A. y A. Rueda S. 2018. Simulación de los cambios de carbono orgánico del suelo en especies tropicales arbóreas con el modelo Roth C 26.3. Interciencia 43 (4): 269.274. https://www.interciencia.net/wp-content/uploads/2018/05/269-6146-GONZALEZ-43-04.pdf (18 de diciembre de 2020).

González B., O., P. Suatunce C. y L. Simba O. 2019. Carbono acumulado en la biomasa aérea en plantaciones de Terminalia ivorensis A. Chev (terminalia) y Gmelina arborea Roxb (melina), en el Litoral ecuatoriano. Ciencia y Tecnología UTEQ 12(1): 51-56. Doi:10.18779/cyt.v12i1.232.

Guzmán P., A. M. y E. Cruz C. 2014. Manejo de plantaciones de cuachalalate (Amphipterygium adstringens) en áreas de la selva baja caducifolia. Revista Mitigación del Daño Ambiental Agroalimentario y Forestal de México 1(1): 159-166. https://www.researchgate.net/profile/ayala_alejandro/publication/273886905_future_ambiental_sostenibility_of_agropecuary_production_systems_in_mexico/links/550f9c2d0cf21287416bab25/future-ambiental-sostenibility-of-agropecuary-production-systems-in-mexico.pdf (22 de noviembre de 2020).

Hernández M., E., J. L. López A. y V. Sánchez M. 2011. Crecimiento en diámetro y altura de una plantación mixta de especies tropicales en Veracruz. Revista Mexicana de Ciencias Forestales. 2(7): 27-42. Doi:https://doi.org/https://doi.org/10.29298/rmcf.v2i7.565 (16 de marzo de 2020).

Hernández R., J., H. M De los Santos P., J. R. Valdez L., J. C. Tamarit U., G. Ángeles P., A. Hernández R., B. Méndez L. y A. Peduzzi. 2017a. Estimación del volumen comercial en plantaciones de Eucalyptus urophylla con modelos de volumen total y de razón. Agrociencia 51 (5): 561-580. http://www.scielo.org.mx/pdf/agro/v51n5/1405-3195-agro-51-05-00561-en.pdf. (20 de octubre de 2020).
Hernández R., J., A. Hernández R., J. J. García M., X. García C., G. G. García E., H. J. Muñoz F. y E. H. Olvera D. 2017b. Sistema compatible de ahusamiento-volumen comercial para plantaciones de *Pinus greggii* Engelm. en Hidalgo, México. Revista Mexicana de Ciencias Forestales 8 (39): 59-70. Doi: https://doi.org/10.29298/rmcf.v8i39.43.

Hernández R. J., H. M. De los Santos P., J. R. Valdez L., J. C. Tamarit U., G. Ángeles P., A. Hernández R., A. Peduzzi y O. Carrero. 2017c. Biomasa aérea y factores de expansión en plantaciones forestales comerciales de *Eucalyptus urophylla* S. T. Blake. Agrociencia. 51(8): 921-938. https://www.redalyc.org/pdf/302/30253817008.pdf (7 de noviembre de 2020).

Hernández R., J., R. Reynoso S., A. Hernández R., X. García C., E. Hernández M., J. V. Cob U. y D. Sumano L. 2018. Distribución histórica, actual y futura de *Cedrela odorata* en México. Acta Botánica Mexicana 124: 117-134. Doi: https://doi.org/10.21829/abm117.2016.1173.

Hernández-Ramos, J., A. Hernández-Ramos, X. García-Cuevas., J. J. García-Magaña, M. Martínez-Salvador, M. Samperio-Jiménez y J. A. Hernández-Vargas. 2019. Ecuaciones alométricas de altura-diámetro para bosques naturales de *Pinus teocote* Schlecht. & Cham. En Hidalgo, México. Acta Universitaria. 29: 1-13. Doi:http://doi.org/10.15174/au.2019.1908.

Hernández T., T. y H. M. Benavides M. 2015. Sensibilidad de 20 procedencias de pino y oyamel a los oxidantes fotoquímicos. Revista Mexicana de Ciencias Forestales 6 (30): 32-51. Doi: https://doi.org/https://doi.org/10.29298/rmcf.v6i30.

Honorato S., J. A. 2011. Modelos volumétricos fustales para *Acrocarpus fraxinifolius* Wight & Arn. en plantaciones agroforestales de la sierra norte de Puebla. Revista Mexicana de Ciencias Forestales 2 (6): 55-72. Doi: https://doi.org/10.29298/rmcf.v2i6.574.

Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias (INIFAP). 2018. Programa de desarrollo del INIFAP, 2018-2030. Mayor productividad en...
armonía con el medio ambiente. Ciudad de México, México. 237 p. https://www.gob.mx/inifap/documentos/programa-de-desarrollo-del-inifap-2018-2030 (2 de octubre de 2020).

López A., J. L., V. Sánchez M. y E. Hernández M. 2010. Crecimiento inicial de una plantación mixta de especies tropicales en Veracruz. Revista Mexicana de Ciencias Forestales 1 (2): 65-79. Doi:https://doi.org/10.29298/rmcf.v1i2.638.

Magnitskiy S., V. y Plaza, G.A. 2007. Fisiología de semillas recalcitrantes de árboles tropicales. Agronomía Colombiana. 25(1): 96-103. Agronomía Colombiana 25(1): 96-103. http://www.scielo.org.co/pdf/agc/v25n1/v25n1a11.pdf (11 de marzo de 2021).

Martínez S., M. 2013. Ecología y usos de especies forestales de interés comercial de las zonas áridas de México. INIFAP-Sitio Experimental La Campana. Cd. Aldama, Chihuahua. Libro técnico Núm. 5. 217 p. https://www.researchgate.net/profile/Martin-Martinez-Salvador/publication/261323618_Libro_zonas_aridas/links/00463533dceec7f70700000/Libro-zonas-aridas.pdf (1 de agosto de 2020).

Martínez S., M., D. E. Hermosillo R., A. S. Mojica G. y J. A. Prieto A. 2015. Potencial productivo y zonificación para el uso y manejo de especies forestales de zonas áridas. INIFAP-Sitio Experimental La Campana. Cd. Aldama, Chih., México. Publicación especial Núm. 13. 119 p.

Martínez N., L. E., H. Sarmiento L., J. A. Sigala R., S. Rosales M. y J. B. Montoya A. 2015. Respuesta a la inoculación inducida de Russula delica Fr. en plantas de Pinus engelmannii Carr. en vivero. Revista Mexicana de Ciencias Forestales 7 (33): 108-117. Doi:https://doi.org/10.29298/rmcf.v7i33.93.

Martínez L., J. E., F. Carrillo A., M. Acosta M., M. E. Romero S. y R. Pérez M. 2020. Ecuaciones alométricas para estimar carbono en brinzales de Pinus hartwegii Lindl. Revista Mexicana de Ciencias Forestales 11 (60): 144-160. Doi:https://doi.org/10.29298/rmcf.v11i60.726.
Mejía B., J. M., J. L. García R. e H. J. Muñoz F. 2015. Evaluación de plantaciones de cuatro especies forestales en el estado de Durango. Reaxión 2 (2). http://reaxion.utleon.edu.mx/Art_Evaluacion_plantaciones_cuatro_especies_forestales_Durango.html (8 de diciembre de 2020).

Muñoz F., H. J. 2000. Tablas de volumen para *Eucalyptus camaldulensis* Dehnh. Revista Mexicana de Ciencias Forestales 25(88): 75-92. http://cienciasforestales.inifap.gob.mx/editorial/index.php/forestales/article/view/9 24 (12 de septiembre de 2020).

Muñoz F., H. J., V. M. Coria Á., J. J. García S. y M. Balam C. 2009. Evaluación de una plantación de tres especies tropicales de rápido crecimiento en Nuevo Urecho, Michoacán. Ciencia Forestal en México 34 (106): 61-87. http://cienciasforestales.inifap.gob.mx/editorial/index.php/forestales/article/view/6 84 (24 de septiembre de 2020).

Muñoz F., H. J., O. Gutiérrez G., M. C. Avalos V. y J. G. Magaña J. 2010. Factores ambientales de *Pinus patula* Schl. et Cham. y su adaptación a las condiciones de la Sierra Purépecha, Michoacán. Foresta Veracruzana 12 (2): 27-33. https://www.redalyc.org/articulo.oa?id=49719770005 (5 de agosto de 2020).

Muñoz F., H. J., J. A. Prieto R., A. Rueda S. y M. Alarcón B. 2011a. (comps.). Evaluación de plantaciones forestales en la Sierra Madre Occidental. INIFAP-CIRNOC. Campo Experimental Valle del Guadiana. Durango, Dgo., México. Libro técnico Núm. 5. 208 p.

Muñoz F., H. J., G. Orozco G., V. M. Coria A., J. J. García S., Y. Y. Muñoz V. y G. Salvador C. 2011b. Evaluación de *Pinus pseudostrobus* Lindl. y *Pinus greggii* Engelm. con dos densidades de plantación en Michoacán, México. Foresta veracruzana 13 (1): 29-35. https://www.redalyc.org/pdf/497/49719786005.pdf (5 de diciembre de 2020).

Muñoz F., H. J., J. T. Sáenz R. y A. Rueda S. 2011c. Especies promisorias de clima tropical para plantaciones forestales comerciales en Michoacán. INIFAP-Campo Experimental Uruapan. Uruapan, Michoacán, México. Libro técnico Núm. 11. 202 p.
Muñoz F., H. J., J. T. Sáenz R., J. J. García M., J. H. Hernández R. y J. Anguiano C. 2011d. Áreas potenciales para establecer plantaciones forestales comerciales de *Pinus pseudostrobus* Lindl. y *Pinus greggii* Engelm. en Michoacán. Revista Mexicana de Ciencias Forestales 2 (5): 29-44. Doi: https://doi.org/10.29298/rmcf.v2i5.585.

Muñoz F., H. J., J. C. Velarde R., J. J. García M., J. T. Sáenz R., E. H. Olvera D. y J. Hernández R. 2012. Predicción de volúmenes de fuste total para plantaciones de *Pinus greggii* Engelm. Revista Mexicana Ciencias Forestales 3 (14): 11-22. Doi: https://doi.org/10.29298/rmcf.v3i14.471.

Muñoz F., H. J., J. J. García M., G. Orozco G., V. M. Coria Á. y M. B. Nájera R. 2013. Evaluación de una plantación con dos especies tropicales cultivadas en diferentes tipos de envases. Revista Mexicana de Ciencias Forestales 4 (18): 28-43. Doi: https://doi.org/10.29298/rmcf.v4i18.387.

Muñoz F., H. J., J. J. García M., G. Orozco G., V. M. Coria Á. y Á. Martínez C. 2014. Evaluación de dos módulos agroforestales con cultivo en callejones en la Sierra Purépecha, Michoacán. Revista Mexicana de Ciencias Forestales 5 (22): 40-57. Doi: https://doi.org/10.29298/rmcf.v5i22.349.

Muñoz F., H. J., J. T. Sáenz R., V. M. Coria A., J. J. García M., J. Hernández R. y G. E Manzanilla Q. 2015a. Calidad de planta en el vivero forestal La Dieta, Municipio Zitácuaro, Michoacán. Revista Mexicana de Ciencias Forestales 6(27): 72-89. Doi: https://doi.org/10.29298/rmcf.v6i27.282.

Muñoz F., H. J., J. T. Sáenz R., G. Magaña J., M. C. Ávalos V. y M. Vega. 2015b. Áreas potenciales para establecer plantaciones comerciales de pino en la Sierra Purhépecha, Michoacán. Foresta Veracruzana 17 (2): 35-42. https://www.redalyc.org/pdf/497/49743956005.pdf (5 de noviembre de 2020).

Muñoz F., H. J., H. Zaragoza O., H. Zaragoza P., J. J. García M. y B. Ramírez R. 2015b. Comparación del crecimiento de *Pinus chiapensis* (Martínez) Andresen, *Pinus greggii* Engelm. y *Pinus patula* Schl. et Cham. en plantaciones comerciales
establecidas en Hueyapan, Puebla. Foresta Veracruzana 17 (1): 1-8. https://www.redalyc.org/pdf/497/49742125001.pdf (10 de noviembre de 2020).

Muñoz F., H. J., J. T. Sáenz R., A. Rueda S., D. Castillo Q., F. Castillo R. and D.Y. Ávila F. 2016. Areas with potential for commercial timber plantations of Enterolobium cyclocarpum (Jacq.) Griseb. in Michoacán, México. Open Journal of Forestry 6: 476-485. Doi: http://dx.doi.org/10.4236/ojf.2016.65036.

Muñoz F., H. J., Castillo-Quiroz, D., Castillo-Reyes, F., Sáenz Reyes, J. T., Ávila-Flores, D. and Rueda-Sánchez, A. 2017. Potential areas for commercial timber plantations of Tabebuia rosea (Bertol.) DC. in Michoacán, México. Open Journal of Forestry 7(1): 48-57. Doi: http://dx.doi.org/10.4236/ojf.2017.71004

Muñoz F., H. J., J. T. Sáenz R., A. Rueda S., M. Gómez C., D. Castillo Q. y F. Castillo R. 2018. Áreas potenciales para plantaciones forestales con Brosimum alicastrum Sw., con fines de restauración. Revista Mexicana de Ciencias Forestales 9 (45): 7-32. Doi: https://doi.org/10.29298/rmcf.v9i45.133.

Muñoz-Flores, H. J., J. T. Saénz-Reyes, R. Barrera-Ramírez, J. Hernández-Ramos, J. J. García-Magaña y D. Castillo-Quiroz. 2019. Fechas de plantación y su influencia en el desarrollo de Pinus pseudostrobus Lindl., en Michoacán, México. Revista Bio Ciencias 6: e524. Doi: https://doi.org/10.15741/revbio.06.e524.

Muñoz F., H. J., J. T. Sáenz R., J. Hernández R., G. Orozco G. y R. Barrera R. 2021. Plantación de cuatro especies de bambú establecidas en el trópico seco de Michoacán, México. Revista Mexicana de Ciencias Forestales 12(65): 45-66. Doi:https://doi.org/10.29298/rmcf.v12i65.788.

Ordaz-Ruíz, G., J. Hernández-Ramos, G. G. García-Espinoza, A. Hernández-Ramos, P. Delgado-Valerio y J. J. García-Magaña. 2020. Relaciones alométricas para plantaciones de Pinus patula Schiede ex Schltdl. et Cham. en el Estado de México. Revista Mexicana de Ciencias Forestales 11 (60): 98-119. Doi: https://doi.org/10.29298/rmcf.v11i60.705.

Organización de las Naciones Unidas para la Agricultura y la Alimentación (FAO). 2016. El estado de los bosques del mundo 2016. Los bosques y la agricultura:
desafíos y oportunidades en relación con el uso de la tierra. Roma, Italia. 137 p. https://reliefweb.int/sites/reliefweb.int/files/resources/a-i5588s.pdf (28 de octubre de 2020).

Parraguirre L., C. y F. Camacho M. 1992. Germinación de semillas de veintiún especies forestales tropicales. Ciencia Forestal en México 17 (72): 3-26. http://cienciasforestales.inifap.gob.mx/editorial/index.php/Forestales/article/view/1063 (19 de octubre de 2020).

Patiño V., F. y J. Marín C. 1993. Viveros forestales: Planeación, establecimiento y producción de planta. INIFAP- Centro de Investigación Regional Sureste. Mérida, Yucatán, México. Serie: Libro técnico s/n. 159 p.

Patiño V., F., A. Rodríguez P., J. Marín Ch. y E. Días M. 1993. Melina (Gmelina arborea Roxb): Producción de planta, establecimiento y manejo de plantaciones. INIFAP-Centro de Investigación Regional Sureste. Mérida, Yucatán, México. Serie: Libro técnico s/n. 167 p.

Pineda O., T., E. Flores A., A. Flores G., E. Buendía R., V. Guerra de la C. y F. Islas G. 2020. Calidad de planta de seis especies del género Pinus producidas en bolsas de polietileno. Revista Mexicana de Ciencias Forestales 11 (62): 165-174. Doi: https://doi.org/10.29298/rmcf.v11i62.809.

Prieto R., J. A. y J. T. Sáenz R. 2011. Indicadores de calidad de planta en los viveros forestales de la sierra madre occidental. INIFAP-Campo Experimental Valle del Guadiana. Durango, Durango, México. Libro técnico Núm. 3. 210 p.

Prieto R., J. A., V. Bustamante G., H. J. Muñoz F. y R. Álvarez Z. 2014. Análisis de conos y semillas en coníferas. In: Garza O., F., J. A. Guevara G., H. Villalón M. y A. Carrillo P. (eds.). Tecnologías en el manejo sustentable de los recursos naturales. Universidad Autónoma de Nuevo León. Linares, NL., México. pp. 27-44.

Programa de Desarrollo Forestal de Jalisco (PRODEFO). 2000. Manual de silvicultura y manejo de bosques templados. Ciclo económico forestal. Guadalajara, Jal., México. 135 p.
Reynoso S., R., W. López B., A. López L., A., J.A. Ruíz C., I. Castro M., P. Cadena I., L.M. Valenzuela N. y R. Camas G. 2016. Áreas potenciales para el cultivo del agave (*Agave americana* L.) en la meseta Comiteca, Chiapas. Agro Productividad 9(2):56-61. [https://revista-agroproductividad.org/index.php/agroproductividad/article/view/721/590](https://revista-agroproductividad.org/index.php/agroproductividad/article/view/721/590) (5 diciembre de 2020).

Reynoso S., R., M. J. Pérez H., W. López B., J. Hernández R., H. J. Muñoz F., J. V. Cob U. y Reynoso S. M. 2018. El nicho ecológico como herramienta para predecir áreas potenciales de dos especies de pino. Revista Mexicana de Ciencias Forestales 9(48): 47-70. Doi: [https://doi.org/10.29298/rmcf.v8i48.114](https://doi.org/10.29298/rmcf.v8i48.114).

Rodríguez S., B., J. A. Contreras G. y X. García C. 1993. Evaluación en vivero de progenies de sacchacah (*Dendropanax arbores*) y negrito (*Simarouba glauca*). Ciencia Forestal en México 18(74):3-24. [https://cienciasforestales.inifap.gob.mx/editorial/index.php/forestales/article/view/1046](https://cienciasforestales.inifap.gob.mx/editorial/index.php/forestales/article/view/1046) (3 de septiembre de 2020).

Rueda S., A., J. A. Ruiz C., J. G. Flores G. y E. Talavera Z. 2006. Potencial productivo para 11 especies de pino en Jalisco. Campo Experimental Centro Altos de Jalisco. CIRPAC, INIFAP. Guadalajara, Jalisco México. Libro Técnico Núm. 1. 175 p.

Rueda S., A., J. A. Ruiz C., J. D. Benavides S. y J. G. Flores G. 2007. Definición de áreas favorables para seis especies forestales tropicales en el estado de Jalisco. SAGARPA-CIRPAC-INIFAP. Tepatitlán de Morelos, Jalisco. México. Libro Técnico. Núm. 5. 165 p.

Rueda S., A., J. D. Benavides S., J. Á. Prieto R., J. T. Sáenz R., G. Orozco G. y A. Molina C. 2012. Calidad de planta producida en los viveros forestales de Jalisco. Revista Mexicana de Ciencias Forestales 3(14): 69-82. Doi: [https://doi.org/10.29298/rmcf.v3i14.475](https://doi.org/10.29298/rmcf.v3i14.475).

Rueda S., A., G. Ramírez O., J. A. Ruíz C., F. Moreno S., A. González H., O. U. Martínez B., J. T. Sáenz R., H. J. Muñoz F., A. Molina C. y V. M. Jiménez E. 2013a.
Requerimientos agroecológicos de especies forestales. Campo Experimental Centro Altos de Jalisco. Tepatitlán de Morelos, Jal., México. Libro técnico No. 3. 239 p. https://backend.aprende.sep.gob.mx/media/uploads/proedit/resources/requerimientos_agroe_f89fdf46.pdf (16 de marzo de 2020).

Rueda S., A., J. T. Sáenz R., A. Gallegos R., D. González E., J. A. Ruíz C., J. D. Benavides S., E. López A. y M. Acosta M. 2013b. Estimación de biomasa y carbono de las especies *Enterolobium cyclocarpum* (Jacq.) Griseb., *Swietenia macrophylla* King, *Tabebuia rosea* (Bertol.) A. DC., *Cedrela odorata* L., *Tectona grandis* L. F. y *Gmelina arborea* Roxb. ex Sm. en Jalisco. In: Salcedo P., E., E. Hernández Á., J. A. Vázquez G., T. Escoto G. y N. Díaz E. (eds.). Recursos forestales en el occidente de México. Diversidad, manejo, producción, aprovechamiento y conservación. Serie Fronteras de Biodiversidad. 4 Tomo II. Universidad de Guadalajara. Guadalajara, Jal., México pp. 252-284.

Rueda S., A., J. D. Benavides S., J. T. Sáez R., H. J. Muñoz F., J.A. Prieto R. y G. Gutiérrez O. 2014a. Calidad de planta producida en los viveros forestales de Nayarit. Revista Mexicana de Ciencias Forestales 5(22):58.72. Doi: https://doi.org/10.29298/rmcf.v5i22.350.

Rueda S., A., A. Gallegos R., D. González E., J. A. Ruiz C., J. D. Benavides S., E. López A. y M. Acosta M. 2014b. Estimación de biomasa aérea en plantaciones de *Cedrela odorata* L. y *Swietenia macrophylla* King. Revista Mexicana de Ciencias Forestales 5(25):8-17. Doi: https://doi.org/10.29298/rmcf.v5i25.300.

Rueda-Sánchez, A., J. A. Ruíz-Corral., J. D. Benavides-Solorio, G. Medina-García y A. Molina-Castañeda. 2017. Áreas potenciales para plantaciones forestales ante escenarios de cambio climático en el estado de Jalisco, México. Revista Mitigación del daño Ambiental Agroalimentario y Forestal de México 3(3): 61-74. https://docplayer.es/89890820-Revista-mitigacion-del-dano-ambiental-agroalimentario-y-forestal-de-mexico.html (25 de octubre de 2020).

Rueda S., A., J. T. Sáenz R., H. J. Muñoz F., J.A. Ruíz C., M. Gómez C. y A. Molina C. 2018. Áreas potenciales para plantaciones comerciales con *Pinus maximinoi* y
*Roseodendron donnell-Smithii* ante cambio climático en Jalisco, México. Revista Mitigación del Daño Ambiental Agroalimentario y Forestal de México 4 (4): 29-43. [https://www.academia.edu/37242951/Pub_Mit_Da%C3%B1o_Amb_ENE_JUN_2018_pdf](https://www.academia.edu/37242951/Pub_Mit_Da%C3%B1o_Amb_ENE_JUN_2018_pdf) (16 de marzo de 2020).

Sáenz R., J. T., H. J. Muñoz F., A. Rueda S., F. J. Villaseñor R. y J. Anguiano C. 2011. Regionalización de áreas potenciales para plantaciones forestales comerciales en Michoacán. INIFAP-Campo Experimental Uruapan. Uruapan, Mich., México. Libro Técnico Núm. 12. 254 p.

Sáenz R., J. T., H. J. Muñoz F. y A. Rueda S. 2012. Monografías de especies forestales para plantaciones comerciales en clima templado de Michoacán. INIFAP-Campo Experimental Uruapan. Uruapan, Mich., México. Libro Técnico Núm. 14. 213 p.

Sáenz R., J. T., H. J. Muñoz-Flores, C. M. Á. Pérez-Díaz, A. Rueda-Sánchez y J. Hernández-Ramos. 2014a. Calidad de planta en el vivero “Morelia” en el estado de Michoacán. Revista Mexicana de Ciencias Forestales 5(26):98-110. Doi: [https://doi.org/10.29298/rmcf.v5i26.299](https://doi.org/10.29298/rmcf.v5i26.299).

Sáenz R., J. T., H. J. Muñoz F., A. Rueda S., J. E. Sáenz C., y R. Barrera R. 2014b. Fuentes alternativas de fertilización en el establecimiento de plantaciones forestales. Revista Mitigación del Daño Ambiental Agroalimentario y Forestal de México 1 (1): 73-84. [https://www.researchgate.net/profile/ayala_alejandro/publication/273886905_future_ambiental_sostenibility_of_agropecuary_production_systems_in_mexico/links/550f9c2d0cf21287416bab25/future-ambiental-sostenibility-of-agropecuary-production-systems-in-mexico.pdf](https://www.researchgate.net/profile/ayala_alejandro/publication/273886905_future_ambiental_sostenibility_of_agropecuary_production_systems_in_mexico/links/550f9c2d0cf21287416bab25/future-ambiental-sostenibility-of-agropecuary-production-systems-in-mexico.pdf) (8 de noviembre de 2020).

Sáenz R., J. T., J. Jiménez O., H. J. Muñoz F., A. Rueda S., J. E. Sáenz C. y J. Hernández R. 2016. Fertilización en sistema silvopastoril en la cuenca del Lago de Pátzcuaro, Michoacán. Revista Mitigación del Daño Ambiental Agroalimentario y Forestal de México 2 (2): 178-187. [https://docplayer.es/96578015-Issn-revista-mitigacion-del-dano-ambiental-agroalimentario-y-forestal-de-mexico.html](https://docplayer.es/96578015-Issn-revista-mitigacion-del-dano-ambiental-agroalimentario-y-forestal-de-mexico.html) (10 de...
Sáenz R., J. T., L. M. Acosta I., H. J. Muñoz F., J. J. García M. y D. Castillo Q. 2017. Calidad de planta de *Pinus pseudostrobus* Lindl., en vivero con fertilización de lenta liberación y biofertilizante. Revista Mitigación del Daño Ambiental Agroalimentario y Forestal de México 3 (3): 85-97. [https://docplayer.es/89890820-Revista-mitigacion-del-dano-ambiental-agroalimentario-y-forestal-de-mexico.html](https://docplayer.es/89890820-Revista-mitigacion-del-dano-ambiental-agroalimentario-y-forestal-de-mexico.html) (19 de noviembre de 2020).

Sáenz R., J. T., A. Rueda S., J. D. Benavides S., H. J. Muñoz F., D. Castillo Q. y J. E. Sáenz C. 2021. Ecuaciones alométricas, biomasa y carbono en plantaciones forestales tropicales en la costa de Jalisco. Revista Mexicana de Ciencias Forestales 12(65):26-44. Doi: [https://doi.org/10.29298/rmcf.v12i65.856](https://doi.org/10.29298/rmcf.v12i65.856).

Sánchez M., V. y C. Velázquez E. 1998. Evaluación de dos insecticidas biológicos en el control de *Hypsipyla grandela* Zeller, barrenador de brotes de las meliáceas. Ciencia Forestal en México 23(83):33-39. http://cienciasforestales.inifap.gob.mx/editorial/index.php/forestales/article/view/961 (22 de agosto de 2020).

Santiago T., O., J. J. Vargas H., A. Aldrete, J. López U. y A. M. Fierros G. 2015. Sustratos y tamaños de contenedor en el desarrollo de *Hevea brasiliensis* Müll. Arg. en vivero. Revista Mexicana de Ciencias Forestales 6(31):94-113. Doi: [https://doi.org/10.29298/rmcf.v6i31.199](https://doi.org/10.29298/rmcf.v6i31.199).

Secretaría del Medio Ambiente y Recursos Naturales (Semarnat). 2020. Superficie reforestada (hectáreas). Consulta temática. http://dgeiawf.semarnat.gob.mx:8080/ibi_apps/wfservlet?ibif_ex=d3_rforesta09_06&ibic_user=dgeia_mce&ibic_pass=dgeia_mce&nombreentidad=*&nombreanio=*conaf0r, 2006 (3 de junio de 2021).

Sigala R., J. A., M. A. González T. y J. A. Prieto R. 2015. Supervivencia en plantaciones de *Pinus pseudostrobus* Lindl. en función del sistema de producción y
preacondicionamiento en vivero. Revista Mexicana de Ciencias Forestales 6(30):20-31. Doi: https://doi.org/10.29298/rmcf.v6i30.205.

Sigala R., J. A., M. A. González T., J. A. Prieto R., E. Basave V. y J. Jiménez P. 2016. Relaciones alométricas para predecir biomasa en plantas de Pinus pseudostrobus cultivadas en diferentes sistemas de producción en vivero. Bosque 37(2):369-378. Doi: http://dx.doi.org/10.4067/S0717-92002016000200015.

Tamarit U., J. C., H. M. De los Santos P., A. Aldrete, J. R. Valdez L., H. Ramírez M. y V. Guerra De la C. 2014a. Ecuaciones dinámicas de índice de sitio para Tectona grandis en Campeche, México. Agrociencia 48:225-238. http://www.scielo.org.mx/pdf/agro/v48n2/v48n2a8.pdf (4 de diciembre de 2020).

Tamarit U., J. C., H. M. De los Santos P., A. Aldrete, J. R. Valdez-Lazalde, H. Ramírez M. y V. Guerra C. 2014b. Sistema de cubicación para árboles individuales de Tectona grandis L. f. mediante funciones compatibles de ahusamiento - volumen. Revista Mexicana de Ciencias Forestales 5 (21):58-74. Doi: http://doi.org/10.29298/rmcf.v11i62.759.