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Silviculture and tree breeding for planted forests

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Abstract

One of the main issues facing the forestry sector is balancing the demand for forest products and the sustainable management of forest ecosystems. Efficient plantation management and intensive silviculture practices are needed to grow timber in forest tree plantations. Due to the tangible impact on wood production, the plantations area in the world has constantly increased during the last several decades. The annual increase of plantation was 3.3 million ha in the period of 1990-2015. Over the past decades, tree improvement programs have progressed to the second, third, and fourth cycles to provide genetically improved planting stock to plantations. Substantial genetic gain has been realized from major tree improvement programs around the world. The effect of tree breeding on wood and fiber production per unit area has further increased by the modern plantation silvicultural applications, such as soil preparation, fertilization and thinning. Combination of tree breeding and silvicultural applications shortened the rotation ages of plantations, increasing the wood and fiber output per unit time. In this study, the importance of silvicultural treatments and plantation management has been reviewed and how such practices could enhance sustainable management of natural forests.

Key words: Forest management, wood production, wood demand, breeding program

Introduction

Forestry has been an integral part of human beings and included in components meeting human needs. One of the components of forestry is silviculture. Curtis et al. (2007) concisely explained forestry and the role of silviculture in forestry as

> "*Forestry is the science, art, and practice of creating, managing, using, and conserving forests and associated resources for human benefit to meet desired goals, needs, and values. Silviculture is that portion of the field of forestry that deals with the knowledge and techniques used to establish and manipulate vegetation and to direct stand and tree development to create or maintain desired conditions. It is the application of knowledge of forest biology and ecology to practical forestry problems.*"

These explanations underlined that silviculture needs knowledge and technique for vegetation, stand and tree development for desired conditions. On the other hand, the history of silviculture has a fragmentary record from the 13th century. Forestry administrative organizations developed forest management and silvicultural plans in France and Germany in the 17th and 18th centuries with focus on sustainable timber production (Curtis et al. 2007).

Tree breeding alters the genetic composition of the tree population to better meet human needs, to produce the best material for the plantations (Ruotsalainen 2014). Tree breeding focuses on developing genetically improved varieties in an economically efficient manner by maximizing producing per unit time at the lowest possible cost (White et al. 2007). Historically, although some provenance experiments started in the eighteenth century, large-scale tree improvement programs began in the 1950s in 14 countries around the world (Zobel and Talbert 1984, White et al. 2007). Today tree improvement is widespread in the world including many countries in Africa, Asia, Australia, Europe, North America and South America (White et al. 2007). Tree breeding is historically a younger practice than silvicultural practices and it uses genetic principles to select superior individuals for seed orchards or production population.

The man-made forests or planted forests[1] were developed in forestry for different objectives; ranging from the need to obtain sustainable wood and other tangible products, to soil conservation (Shepherd 1986, Evans 2009). In the 1980s, Daniels (1984) characterized that planted forest was a comparatively modern development unlike in classical forestry fixed and positioned in the concept of 'sustained yield'. Besides the concept of sustained yield, using management, he added to securing annual production in a given forest estate and keeping it's in continuity. Increasing trend of plantations in the 1980s and maturing of old plantation, the effect of plantations in forestry was increased (Shepherd 1986, Evans 2009).

Tree breeding was broadened as tree improvement with the application of forest genetics principles and good silviculture to develop high yielding, healthy and sustainable plantation forests (Zobel and Talbert 1984, White et al. 2007). Today, an expansion of tree breeding programs on a global scale has increased yields and value of plantations to meet the rising demand for forest products, while lessening the need to meet this demand for natural forests Therefore, forest tree breeding is an essential part of modern silviculture to increase the economic profit over enlarged wood production (White et al. 2007).

Silviculture and tree breeding are the two most important disciplines that complement each other. The combined effect of silviculture and tree breeding is maximized in plantation forestry. In the literature, there are not many papers covering their joint importance on forest productivity. I hope this article fills a gap. The objectives of this study were 1) elucidate the relationship between silviculture and tree breeding and 2) come up with some recommendations for plantation management for better return from tree improvement programs.

[1] Definition based on Evans (2009a), 'Planted forest' includes all of what is generally understood as 'plantations' or 'forest plantation', but also incorporates other forest types originating largely or wholly from tree planting.

Tree Breeding for Planted Forests

Tree breeding aims to increase the quality and quantity of wood products per unit area from the intensively managed plantations using forest genetics principals (Zobel and Talbert 1984). Many methods in forest tree breeding are characterized like selection (level of species, provenance, population-stand, individual tree), breeding to combine desired traits, polyploidy, breeding with mutations, molecular markers, and genetic engineering (Zobel and Talbert 1984, Eriksson et al. 2013). Tree breeding is a cyclic process, that includes selecting the best trees, intermatting between them, testing their progeny for estimation of genetic merit (White et al. 2007, Eriksson et al. 2013). The progeny tests are an integral part of a breeding cycle. They serve to rank genotypes based on progeny performance, created by intermating and to constitute the next generation breeding population in a recurrent selection method (Namkoong et al. 1988, White et al. 2007, Eriksson et al. 2013). Tree improvement starts with choosing the species(s) for the targeted plantation area. The choice of a species for a breeding program and thus for plantation is a crucial decision. They must be adaptive to the climatic and edaphic factors and resistant to pests and pathogens. After identifying one or more species, the tree improvement program utilizes the natural genetic variation included within species to repackage it into desirable individuals with fast growth, pest/pathogen resistance created by intermating to use in plantations (White et al. 2007). Simply stated, the practical intend of tree breeding is to allow us to alter certain traits of trees or their products to improve their utility, quantity, or value (Daniels 1984). As can be seen, the use of production population, like seed orchards, generated by tree breeding is essential for plantation forestry to increase quality and quantity of wood and fiber in a unit area. The gain from a tree breeding program can be realized by transferring genetically improved material to seed orchards and mass production for the plantations.

Historically, Evans (2009b) indicated that the first woody species which was selected and planted was olive trees about 4000 BC and divided planted forest history into four main periods for: before 1900, 1900-1945, 1945-1980 and 1980-present. Between 1900-1945, most tropical plantations for wood production consisted primarily of pines, eucalyptus, and teak. However, major plantings of trees were non-wood forest products. After 1945, with evidence of the increasing awareness of the silvicultural potential, the plantations were subjected matter of international conferences and meetings like Fourth World Forestry Congress (1954) in India, the Seventh British Commonwealth Forestry Conference (1957), the FAO Seminar on Tropical Pines in Mexico (1960). Then, these initiatives and the gathering momentum of interest prompted the crucial ‘FAO World Symposium on Man-Made Forests and their Industrial Importance’ in 1967. The symposium, with participants from 41 countries produced over 2000 pages of manuscripts confirmed the essence of plantation and widening position all over the world. With the effect of understanding genetic principles on increasing productivity of plantation in the 1950s and maturing of an old plantation, plantation forestry accelerated in 1980's. Indeed, Daniels (1984) characterized the plantation forestry as a relatively modern development meaning a significant departure from classical forestry practice based on the concept ‘sustained yield’.

The importance of plantations and silviculture of plantations were covered extensively (Shepherd 1986). This work described detailed explanations and directions of silvicultural practices for sustainable management of intensive plantations. As an indicator of plantations' importance, it was understood that many countries continued plantation programs whereas some countries massively expanded plantations in the 1980s. Genetically improved material use was also expanded in that period (Evans 2009b). Then, FAO started a ‘Global Planted Forest Thematic Study’ including comprehensive examination of whole planted subsets, determining quantity and quality planted forest resources and analyzing regional and global status of planted forest development (Carle et al. 2009). In the period of 1990-2015, they have annually increased 3.3 million hectares and have reached 291 million hectares in 2015, constituting 7% of the totally 4 billion hectares forest areas in the world (FAO 2016). When plantations constituted 5% of the total forest area, they produced 35% of total wood production in the world (FAO 2001, Carle et al. 2002). An essential tendency continued to increase the sharing of plantations in total wood production. Indeed, Payn et al. (2015) indicated that roundwood production from plantation in the world was 46.3% and could be reached to 89.8% in South America in 2012. On the other hand Carle and Holmgren (2009) estimated that plantation areas would change from 261 to 303 million hectare by 2030. Considering that the plantation area in 2015 was 291 million hectares, the estimation of Carle and Holmgren (2009) seems reasonable. Consequently, plantations have been an integral part of compensating wood demand in the world.

Expansion of plantations in the world has been related to tree breeding programs. The breeding material as the output of tree breeding programs has been widely used in the plantations and wood production from plantations was tangibly increased (Li et al. 1999, White and Byram 2004, Burdon et al. 2008, Haapanen et al. 2015, McKeand 2019). The advanced tree programs reached the 4th cycle and beyond to increase genetic gain from plantations (Isik and McKeand 2019). Using genetic material supplied by tree breeding in plantations can increase the yield, quality, resistance to insects or disease substantially. For example, in *Pinus taeda* the estimated genetic gain in volume for the third-cycle loblolly pine was 63% compared with the unimproved checklot in one of the most advanced tree breeding programs in the world (McKeand 2019).

The Combination of Silviculture and Tree Breeding for Planted Forests

The importance of planted forests to meet global needs for wood and provide various environmental services has been well documented. In this context, tree breeding and silvicultural applications were categorized as the major disciplines to increase the productivity of plantations (Burdon and Moore 2018). They underlined that tree breeding covered selective breeding, delivery systems for genetic gain, arrangement for the deployment of improved breeds or clones to site and silvicultural regimes, whereas silviculture involved to raise or keep site productivity using fertilizer and controlling vegetation competition, pests and disease, to safe stocking control for using of site potential and growing in target trees, and to enhance wood quality by handling of stocking.

Tree breeders commonly use the following formula to explain the derivation of the character of the individual we observe: $G + E = P$. In this equation, P is phenotype, G is genotype and E is environment. Using this equation, Hubert and Lee (2005) characterized the relation between silviculture and breeding. According to this, G is the genotype or genetic make-up of the individual. The E is the environment of genotype. Tree breeding focuses on G to improve the desired traits for silviculture to practice on. Silviculture focuses on E to alter the environment to increase the yield. Some of the silvicultural tools commonly used in plantations are planting spacing of trees, vegetation control, nutrition, thinning etc. The sum of all individual tree characteristics that makes a plantation are contributed by G and E. On the other hand, P is most commonly assessed in terms of external appearance. While G means tree breeding, partly E and partly G means silviculture. Climate variables are part of the E but they cannot be altered by the silvicultural practices. Stanturf et al. (2003) estimated the contribution of tree breeding and silviculture components in southern pine plantation. Silvicultural practices include the stocking control, nutrition, vegetation management, seedling quality, pest management, soil site classification, and site preparation. The contribution of site preparation (silviculture) and tree breeding were the top two factors, and explained 21% and 20%, respectively (Fig. 1). The rest of the contribution was made by the factors related to silviculture.

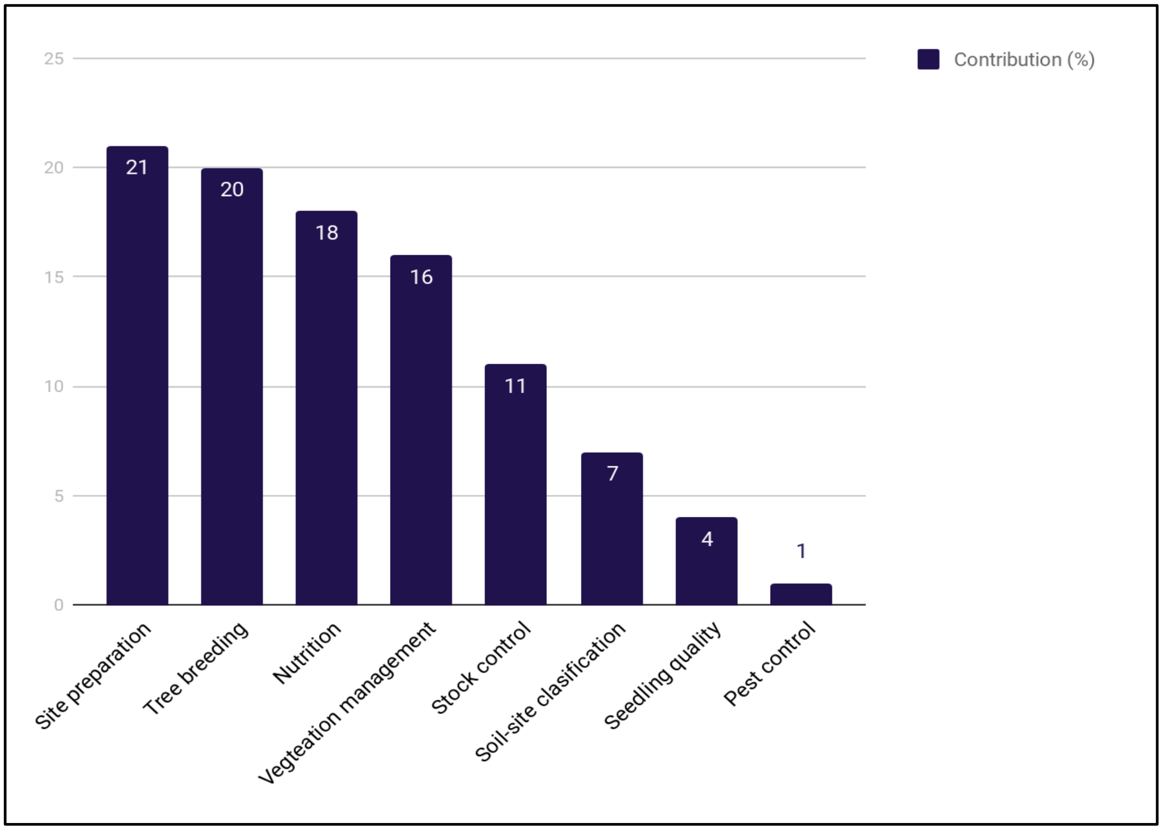

Figure 1. Contributions of the silvicultural practices and tree breeding to wood and fiber productivity in pine plantations in the southern United States (after Stanturf et al. 2003).

Southern United States pine plantations were the major success story in the world for forestry mainly contributed by the tree breeding and silviculture applications (McKeand et al. 2003, Schmidtling et al. 2004, Fox et al. 2007). While the plantation area was less than 2 million acres (~810 000 hectares) in the 1950s in the US South, they reached 32 million-acre (~13 million hectares) by the end of the 20th century. Similarly, production in plantation in the 1960s was ~1 m^3 ha yr^{-1} and it increased to ~4.5 m^3 ha yr^{-1} in the 2000s. The success was a combination of genetic improvement and intensive silviculture in these plantations. Therefore, this region has been characterized as the world's wood basket.

Fox et al. (2004 and 2007) also estimated contribution of production in plantation and compared with natural stand production. The contributions to the production of plantations were site preparation, fertilization, weed control and tree breeding. The contribution of tree breeding in these studies was limited in 1960 and increased in 2010 to about 5 times that of 1960. That is, the rate of contribution of tree breeding to production has steadily increased. Related to the same plantations, McKeand et al. (2003) indicated that 1st, 2nd and 3rd generation seedlings contributed to plantations as 46%, %54 and %0, respectively. In 2018, these contributions of loblolly pine (*Pinus taeda*) for 1st, 2nd and 3rd generation's seeds were 0%, 25% and 75%, respectively (TIP 2019). The 3rd generation seeds also include 4th generation seeds. These trends also reflected seedling prices. The price of open pollinated, the best full sib and clonal varieties were $50, $230 and $350 per thousand seedlings, respectively in the southern United States. Therefore, the estimated gain in volume for the third-cycle was 63% compared with the nonimproved checklot (McKeand 2019).

Applications of combination tree breeding and silviculture can reduce rotation ages due to increasing production of wood per unit time and unit area. Indeed, Fox et al. (2004) showed that rotations age decreased from 50 to under 20 years from 1940 to 2010 due to tree breeding and intensive silviculture. They also underlined that tree breeding, site preparation, weed control, fertilization and density management could considerably increase the financial return from forest management. The driving factor of the realizations of return was mostly the implementation of intensive silviculture in the 1980s and 1990s. However, foresters have used genetic information and deployed better genotype to higher-quality sites that will be managed more intensively in recent decades. Therefore, contribution of tree breeding to wood production in plantations might be more in the future.

Hubert and Lee (2005) reviewed the effect of silviculture and tree breeding on Sitka spruce and concluded that silviculture and tree breeding were powerful tools in increasing the quality and quantity of tree crops. They also indicated the contribution of silviculture and tree breeding to production and suggested a specification related to tree breeding or silviculture or both of Sitka spruce (Table 1). As can be seen in Table 1, tree breeding was specified for short rotation, plantation, and highly heritable traits. However, silviculture was specified for almost all specifications. Since breeders were aware of the importance of silviculture, many literatures related to breeding indicated that genetic material should be used with intensive silviculture for the maximum potential of production in plantations (Zobel and Talbert, 1984, Li et al. 1999, Haapanen et al. 2015, Burdon et al. 2017, McKeand, 2019).

Plantations have reached an important stage in wood production, environmental and soil protection and non-wood production shoving multiple functions of plantations (Evans 2009d). Considering the trend from past to present, it is conceivable that plantations will substitute natural forests. This hypothesis would be difficult to prove. Indeed, Shepherd (1986) and Evans (2009e) stated that natural forests would continue to be important based on forested areas and wood production. Besides, they underlined that plantations would not be an alternative to natural forests, but they can reduce the pressure on natural forests, and complement natural forests (Li et al. 1999). Due to the significant contribution of the plantations to wood production in the world, natural forests can be managed for biological diversity, watershed management, soil protection, gene conservation, and national parks. In this context, forest management and specifically silviculture can be introduced new approaches to sustainable management of both natural forests and plantations. Using knowledge of forest biology and ecology silviculture should be the practice of creating, managing, and conserving forest (natural and plantation) to meet desired goals, needs, and values. On the other hand, considering new approaches like genomic selections, biotechnology, tree breeding seems to widely contribute to wood production in plantation in the near and long future.

Table 1. A list of indicators of using silviculture practices versus using genetic improvement or both to increase the productivity and vigour of plantations (Huber and Lee 2005).

Indication	Consider Silviculture	Consider breeding
Trait to be improved is highly valuable	✓	✓
The trait has to high heritability		✓
The trait has a low heritability but a high natural genetic variation		✓
Trait takes a long time to evaluate in the field	✓	
Flowers at a late age (35+)	✓	
Flowers young (<25)		✓
Easy to vegetatively propagate		✓
Suspect wide-scale interaction with the environment within given region of provenance	✓	
Large areas to be planted and management	✓	✓
Small areas to be planted and management	✓	
Want to develop populations for intolerant sites		✓
Want to immediate and long term return	✓	✓
Intend to natural regeneration	✓	

Conclusion

Plantations in the world have reached 291 million hectares compensating for 43% of wood production in the world. Silviculture and tree breeding are the two main components of plantations. Silviculture is an integral part of forest management in solving forestry problems using the facilities of biology and ecology. Using intensive silviculture in the plantation is essential to meet the demand for wood production in the world. The role of tree breeding in the plantation has also been steadily increased since 1950 and is expected to play more role in the future. However, without intensive silviculture, only using tree breeding is insufficient for maximizing gain from plantations. In conclusion, silviculture and tree breeding complement each other in plantation management to produce wood and fiber in a sustainable way while reducing pressure on natural forests in the world.

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References

Burdon, R. D., Carson, M. J., Shelbourne, C. J. A. (2008). Achievements in forest tree genetic improvement in Australia and New Zealand 10: Pinus radiata in New Zealand. Australian Forestry, 71(4), 263–279. https://doi.org/10.1080/00049158.2008.10675045

Burdon, R. D., Li, Y., Suontama, M., Dungey, H. S. (2017). Genotype × site × silviculture interactions in radiata pine: Knowledge, working hypotheses and pointers for research§. New Zealand Journal of Forestry Science, 47(1), 6. https://doi.org/10.1186/s40490-017-0087-1

Burdon, R. D., Moore, J. R. (2018). Adverse Genetic Correlations and Impacts of Silviculture Involving Wood Properties: Analysis of Issues for Radiata Pine. Forests, 9(308), 1–17. https://doi.org/10.3390/f9060308

Carle, J. B., Ball, J. B., Del Lungo, A. (2009). The Global Thematic Study of Planted Forests. In: Evans J. (Ed.), PLANTED FORESTS Uses, Impacts and Sustainability (Vols. 1–213, pp. 33–46). Rome, Italy: CABI International and FAO.

Carle, J. B., Holmgren, L. P. B. (2009). Wood from Planted Forests: Global Outlook to 2030. In: Evans J. (Ed.), PLANTED FORESTS Uses, Impacts and Sustainability (Vols. 1–213, pp. 47–60). Rome, Italy: CAB International and FAO.

Carle, J., Vuorinen, P., Del Lungo, A. (2002). Status and Trends in Global Forest Plantation Development. Forest Products Journal, 52(7), 1-13.

Curtis, R. O., DeBell, D. S., Miller, R. E., Newton, M., Clair, J. B. S., Stein, W. I. (2007). Silvicultural research and the evolution of forest practices in the Douglas-fir region. Retrieved from https://www.fs.usda.gov/treesearch/pubs/27615

Daniels, J. D. (1984). Role of tree improvement in intensive forest management. Forest Ecology and Management, 8(3), 161–195. https://doi.org/10.1016/0378-1127(84)90052-5

Eriksson, G., Ekberg, I., Clapham, D. (2013). Genetics Applied to Forestry An Introduction. Genetic Center Department of Plant Biology and Forest Genetics, SLU Box 7070, 750 07 Uppsala, Sweden.

Evans, J. (Ed.). (2009). Planted Forests: Uses, Impacts and Sustainability (Vols. 1–213). CAB International and FAO.

Evans, J. (2009a). Introduction. In: Evans J. (Ed.), PLANTED FORESTS Uses, Impacts and Sustainability (Vols. 1–213, pp. 1–4). Rome, Italy: CABI International and FAO.

Evans, J. (2009b). The History of Tree Planting and Planted Forests. In: Evans J. (Ed.), PLANTED FORESTS Uses, Impacts and Sustainability (Vol. 213, pp. 5–22). Rome, Italy: CABI International and FAO.

Evans, J. (2009c). Sustainable Silviculture and Management. In: Evans J. (Ed.), PLANTED FORESTS Uses, Impacts and Sustainability (Vols. 1–213, pp. 113–140). Rome, Italy: CABI International and FAO.

Evans, J. (2009d). The Multiple Roles of Planted Forests. In: Evans J. (Ed.), PLANTED FORESTS Uses, Impacts and Sustainability (Vols. 1–213, pp. 61–90). Rome, Italy: CABI International and FAO.

Evans, J. (2009e). Summary and Conclusions. In: Evans J. (Ed.), PLANTED FORESTS Uses, Impacts and

Sustainability (Vols. 1–213, pp. 141–154). Rome, Italy: CAB International and FAO.

FAO. (2001). Global forest resources assessment 2000 – main report. Retrieved from http://www.fao.org/forest-resources-assessment/past-assessments/fra-2000/en/

Fox, T. R., Jokela, E. J., Allen, H. L. (2004). The Evolution of Pine Plantation Silviculture in the Southern United States. In: Rausher, H.M., Kurt, J.(Ed.), Southern Forest Science: Past, Present, and Future (Rauscher, H. M., Johnsen, Kurt, Vols. 1–394, pp. 63–82). United States Department of Agriculture Forest Service, Southern Research Station.

Fox, Thomas R., Jokela, E. J., Allen, H. L. (2007). The Development of Pine Plantation Silviculture in the Southern United States. Journal of Forestry, 105(7), 337–347. https://doi.org/10.1093/jof/105.7.337

Haapanen, M., Jansson, G., Nielsen, U. B., Steffenrem, A., Stener, L. (2015). The status of tree breeding and its potential for improving biomass production (Vols. 1–55). University of Copenhagen.

Hubert, J., Lee, S. (2005). A review of the relative roles of silviculture and tree breeding in tree improvement: The example of Sitka spruce in Britain and possible lessons for hardwood breeding. Forestry: An International Journal of Forest Research, 78(2), 109–120. https://doi.org/10.1093/forestry/cpi011

Isik, F., McKeand, S. E. (2019). Fourth cycle breeding and testing strategy for Pinus taeda in the NC State University Cooperative Tree Improvement Program. Tree Genetics & Genomes, 15(5)-70, 1-12. https://doi.org/10.1007/s11295-019-1377-y

Li, B., McKeand, S., Weir, R. (1999). Impact of Forest Genetics on Sustainable Forestry—Results from Two Cycles of Loblolly Pine Breeding in the U.S. Journal of Sustainable Forestry, 10(1–2), 79–85. https://doi.org/10.1300/J091v10n01_09

McKeand, S. E. (2019). The Evolution of a Seedling Market for Genetically Improved Loblolly Pine in the Southern United States. Journal of Forestry, 117(3), 293–301. https://doi.org/10.1093/jofore/fvz006

McKeand, S., Mullin, T., Byram, T., White, T. (2003). Deployment of Genetically Improved Loblolly and Slash Pines in the South. Journal of Forestry, 101(3), 32–37. https://doi.org/10.1093/jof/101.3.32

Namkoong, G., Kang, H. C., Brouard, J. S. (1988). Tree Breeding: Principles and Strategies: Principles and Strategies. Springer Science & Business Media, p.186.

Payn, T., Carnus, J. M., Freer-Smith, P., Kimberley, M., Kollert, W., Liu, S., Orazio, C., Rodriguez, L., Silva, L. N., Wingfield, M. J. (2015). Changes in planted forests and future global implications. Forest Ecology and Management, 352, 57–67. https://doi.org/10.1016/j.foreco.2015.06.021

Ruotsalainen, S. (2014). Increased forest production through forest tree breeding. Scandinavian Journal of Forest Research, 29(4), 333–344. https://doi.org/10.1080/02827581.2014.926100

Schmidtling, R. C., Robison, T. L., McKeand, S. E., Rousseau, R. J., Allen, H. L., Goldfarb, B. (2004). The Role of Genetics and Tree Improvement in Southern Forest Productivity. In: Rauscher, H. M. Johnsen, K. (Eds.), Southern Forest Science: Past, Present, and Future (Vols. 1–394, pp. 97–108). United States Department of Agriculture Forest Service, Southern Research Station.

Shepherd, R. K. (1986). Plantation Silviculture. Martinus Nijhoff Publishers.

Stanturf, J. A., Kellison, R. C., Broerman, F. S., Jones, S. B. (2003). Productivity of Southern Pine Plantations: Where Are We and How Did We Get Here? Journal of Forestry, 101(3), 26–31. https://doi.org/10.1093/jof/101.3.26

TIP. (2019). Norh Carolina State University, Cooperative Tree Improvement Program Annual Report (Annual Report No. 63; p. 41). NCSU, Department of Forestry & Environmental Resources College of Natural Resources website:

http://treeimprovement.org/sites/default/files/AR19_FINAL_web.pdf (Visited date 22/112019)

White, T. L., Adams, W. T., Neale, D. B. (2007). Forest Genetics. CABI, p.702.

Zobel, B., & Talbert, J. (1984). Applied forest tree improvement. John Wiley & Sons, p.505.

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