East African Journal of Forestry and Agroforestry, Volume 3, Issue 1, 2021
Article DOI: https://doi.org/10.37284/eajfa.3.1.336

East African Journal of Forestry & Agroforestry
eajfa.eanso.org
Volume 3, Issue 1, 2021
Print ISSN: 2707-4315 | Online ISSN: 2707-4323
Title DOI: https://doi.org/10.37284/2707-4323

EAST AFRICAN NATURE & SCIENCE ORGANIZATION

Original Article

Factors Influencing Tree Seedling Survival in Plantation Forestry: A Focus on Sustainable Forest Productivity.

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Article DOI: https://doi.org/10.37284/eajfa.3.1.336

Date Published:

17 August 2021

Keywords:

Quality Seedlings, Silvicultural Management Practices, Species-Site Match, Seedling Performance, Seedling Regeneration.

ABSTRACT

Forest plantations provide important ecological services and are key source of raw materials for the timber industry and other sectors. Planted forests are also seen as a plausible approach to increasing forest cover in an effort towards combating the effects of climate change. While the objectives of forest establishment in state forests is for social, cultural and environmental functions, private forestry practices mainly aim at attracting economic gains. Nonetheless, existing literature indicate that a significant proportion of forest plantations are still understocked while mature trees when harvested yield less profits due to poor tree forms attributed to delayed silvicultural treatments and planting of low-quality seedlings. Therefore, understanding the factors that influence seedling survival is a key step in addressing the predominant barriers to forest plantation establishment. The purpose of this review paper is to highlight the factors that influence seedling survival under plantation establishment, underscore the components that enable young seedlings withstand post-planting stress and provide recommendations towards raising quality seedlings. This article also aims at generating knowledge to help forest silviculturists to minimize plantation failures and seedling mortality for creation of adequately stocked stands to yield maximum ecological and economic gains at the end of the rotation period.

APA CITATION

Masaba, P. W., & Etemesi, I. N. (2021). Factors Influencing Tree Seedling Survival in Plantation Forestry: A Focus on Sustainable Forest Productivity *East African Journal of Forestry and Agroforestry*, *3*(1), 54-61. https://doi.org/10.37284/eajfa.3.1.336

CHICAGO CITATION

Masaba, Protus Wanjala., & Issa Nduku Etemesi. 2021. "Factors Influencing Tree Seedling Survival in Plantation Forestry: A Focus on Sustainable Forest Productivity". *East African Journal of Forestry and Agroforestry* 3 (1), 54-61. https://doi.org/10.37284/eajfa.3.1.336.

HARVARD CITATION

Masaba, P. W., & Etemesi, I. N. (2021), "Factors Influencing Tree Seedling Survival in Plantation Forestry: A Focus on Sustainable Forest Productivity", *East African Journal of Forestry and Agroforestry*, 3(1), pp. 54-61. doi: 10.37284/eajfa.3.1.336.

IEEE CITATION

P. W. Masaba, & I. N. Etemesi, "Factors Influencing Tree Seedling Survival in Plantation Forestry: A Focus on Sustainable Forest Productivity", *EAJFA*, vol. 3, no. 1, pp. 54-61, Aug. 2021.

MLA CITATION

Masaba, Protus Wanjala., & Issa Nduku Etemesi. "Factors Influencing Tree Seedling Survival in Plantation Forestry: A Focus on Sustainable Forest Productivity". *East African Journal of Forestry and Agroforestry*, Vol. 3, no. 1, Aug. 2021, pp. 54-61, doi:10.37284/eajfa.3.1. 336.

INTRODUCTION

Planted forests are land-use systems composed of trees that are established through planting and managed primarily for the commercial wood productions and climatic regulations (Nambiar, 2003; Free-Smith et al., 2019). Forest plantation establishment encompass both afforestation and reforestation programs where afforestation involves the direct conversion of land that was not forested for at least 50 years into the forests while the latter involves the establishment of forest in areas that were previously forested before being replaced by other species or clear fell (Dohrenbusch & Bolte, 2014). Forest establishments begun in the 14th century in Germany Nurnberger Reichswald in anticipation for firewood shortages; since then, the practice has spread across the globe under different management objectives (Dohrenbusch & Bolte, 2014). Forest plantations are mainly established for the socio-cultural needs, provision of the ecosystem goods and services and the supply of industrial products (Landry & Chirwa, 2011). Planted forested have also been acknowledged for their contributions in meeting the United Nation Sustainable Development Goals (UN-SDGs) through generating jobs thus sustaining incomes (Free-Smith et al., 2019). Both afforestation and reforestation programs contribute to physiographical stability that results in reduced erosions and help to ameliorate the effects of climate changes through carbon sequestration among other conservation needs. An adequately stocked stand can contribute in carbon sequestration by up to 8 tonnes of carbon per hectare (Dohrenbusch & Bolte, 2014). Existing literature indicate that as early as the year 2000, the global forest plantations cover was about 140 million hectares that represented 4% of the global forest cover (Kanninen, 2010).

In most countries, planted forests are state owned and managed by public agencies. However, there are other arrangements such as land purchase programs in which the forestry firms purchase or lease privately owned lands (Kanowski, 1997). Additionally, independent smallholder farmers also use their small portions of lands for the commercial forestry development programs as either forestry monocultures or smallholder agroforestry systems (Van Der Meer Simo et al., 2020). Plantation establishment is carried out both by direct seeding and planting with the nursery stock (Zhigunov, 2014). Direct seeding by aerial sowing is used in areas with limited infrastructure as an economic alternative (Dohrenbusch & Bolte, 2014; Chapman & Allan, 1978). Planting by the use of nursery stock may involve bare-rooted, ball-rooted, potted and tubes plants and cuttings. In most countries in the tropics, the use of young seedlings in plastic containers/bags/tubes is the most preferred plantation establishment technique (Chapman & Allan, 1978).

The major threats of forest plantations are pests and diseases. One important insect is *Oemida gahani* that attacks the *C. lusitanica* through the wounds and scars created after pruning, the insect *Eriosoma lanigerum* (woolly aphid) is also known to attack the pine species by targeting the twigs and needles thus weakening the tree and eventually causing its dead (Mathu & Ng`ethe 2011). The fungus

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Dothistroma pini targeting *Pinus radiata* is reported to have let to cessation of planting *Pinus radiata* in Kenya in 1961. Additionally, *Cypress canker* disease that is caused by the fungus *Monochaetia unicornis* has been observed to cause great damage on *Cuppressus marcrocarpa* and some minimal damages in *Cupressus lusitanica* (Mathu & Ng`ethe 2011). Livestock grazing is another factor affecting young tree seedlings. Grazing in young plantations inflicts damages on the seedlings delaying their growth eventually resulting to the dead of the seedlings. Protecting the young plantation by fencing off and the of control ants and small rodents by regular cleaning of the plantations may determine the early success of the established plantations (Mahari, 2014.

The increase in human population globally continues to put more pressure on natural resources and heighten the demand for non-wood forest products, wood fuel and timber (Imo, Matano, Ogweno & Orinda, 2004). Planted forests are therefore widely observed as an alternative solution for the provision of wood products in an effort to preserve and conserve the natural forests (Paquette & Messier, 2010). The importance of creating plantation forests as a buffer to the natural forests and the need of smallholder forestry practices to meet both the wood fuel and the financial needs of the rural communities is recommended. This paper therefore explored the determinants of seedling survival in plantation forestry towards the sustainable productivity in order to respond to emerging high demands for wood-based products. An attempt has been made to elucidate the factors that contribute in making plantation forestry both productive and profitable irrespective of the size the investment.

SUSTAINABLE PLANTATION FORESTRY MANAGEMENT

Sustainable plantation forestry depends on sustained forest productivity that drives key ecological process (Nambiar, 2003; Arce, 2019). The most important approach towards sustained productivity is the management systems adopted by the farmers and the treatment accorded to seedlings from the nursery to the successful establishment in the field. *Table 1* provides a local matrix of key indicators for the determinants of seedling survival and the management interventions towards sustainable plantation forest management.

Table 1: A matrix for the determinants of seedling survival and related indicators

Determinant of Survival	Related Indicators	Management Interventions
Quality of the Seedlings	• Root growth potential (RGP) • Root system mass • Shoot to root ration • Sturdiness quotient	✓ Root inoculation ✓ Nursery technology ✓ Nursery pest and disease control ✓ Watering, weeding and nutrient management ✓ Nursery management trainings
Species-site match	• Climate • Soil • Topography • Wind	✓ Soil moisture regulations ✓ Seedling hardening off ✓ Soil PH, fertility regulations ✓ Drainage controls ✓ Wind effect control
Silvicultural management practices	• Nursery management practices • Seedling handling • Site preparations • Planting time • Disease and pest control • Human factors	✓ Sorting and selection of seedlings ✓ Field accessibility ✓ Soil moisture regulation ✓ Weed controls ✓ Post planting protection

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Quality of the Seedlings

Seedling quality is an important aspect for consideration in the afforestation programmes by the forest plantation establishers in order to reduce the demands for care after field planting (Haase, 2007). Seedling quality is determined by measuring several morphological, physiological and field performance attributes (Grossnickle, 2012). Some of the indicators of quality seedlings comprise the ability to produce new roots, enhanced rooting system through the mycorrhizal inoculation, larger size with mass foliage development, shoot to root ratio, sturdiness quotient and the speed with which seedlings get anchored in the ground after planting (Johanna & Luoranen, 2018; Struve, 2009). Therefore, selecting the best planting stocks based the aforementioned indicators increases the ability of the seedlings to withstand post-planting shocks, ensures high survival in the field thereby contributes in the creation of even stands and reduces the costs associated with replacing dead seedlings (Struve, 2009).

The root mass and the root growth potential (RGP) are used to predict field performances of the seedlings as the new growth facilitates the water uptake (Haase, 2017). A greater root mass is an indicator of the absorption potential of the root which ensures that the seedlings have a greater ability to resist drought upon planting in the field (Grossnickle, 2012). Mycorrhizal inoculation enhances the water and mineral nutrients absorptive capacity of the roots in certain species. For instance, the artificial inoculation with mycorrhizal fungi in some *Pinus spp.* has been reported to increase seedling performance due to the enhanced water and nutrient uptake (Cram & Dumroese, 2012). Another indicator of seedling quality is the shoot to root ratio which is used to calculate the balance between the root and shoot volumes or the dry weights. It thus measures the transpirational area and water absorption area of the seedlings (Haase, 2017). Quality bare root seedlings are known to have shoot: root ratio of 3:1 or less while quality containerized seedlings have shoot: root ratio of 2:1 (Grossnickle, 2012; Haase, 2017). The sturdiness quotient is also an important indicator that compares the height (cm) over root collar diameter (mm), a small quotient demonstrates sturdy seedlings that have higher chances of survival on windy sites while a higher quotient greater than 6 is described as unfavourable (Grossnickle, 2012; Johanna et al., 2018; Struve, 2009). Seedling height influences the competition for sunlight with weeds where taller seedlings have a competitive advantage. Nonetheless, taller seedlings experience greater transpiration that may be of disadvantage in degraded and dry sites (Haase, 2017).

Matching Species to the Sites

Successful exotic and indigenous forest plantation establishment involves matching species to specific sites that assures rapid establishment and eventual increases in forest productivity (Parlucha, Barbadillo & Sedenio, 2017; Poyry, 1992). Some of the main site attributes that directly affect the survival of newly planted seedlings include; climate, wind, soil and topography. The climatic element includes rainfall, temperature and altitude (Camirand, 2002). Dry periods immediately after planting are the major causes of seedling mortality experienced in the tropics (Schopmeyer, 1974). The resultant droughts occurring before the roots of newly planted seedlings recover their normal absorbing capacity frequently cause considerable death of seedlings. A significant reduction in mortality might be attained by improving the drought hardening procedure used in the nursery before seedlings are ready for transplant (Schopmeyer, 1974).

Temperature influences the physiological process of the seedlings with the root growth of most species increasing with the increase in the soil temperature until an optimum is reached and above which root growth is reduced (McMichael & Burke, 1998). Temperature also affects the process of photosynthesis by varying the rates of photosynthetic enzyme and electron transport. The temperature levels is key in influencing stomatal conductance in regulating water losses in the processes of transpiration (Lloyd &Farquhar, 2007). Manipulating the soil temperatures of the newly planted seedlings may contribute in lessening the effect of fluctuations of the temperatures before the seedling establish well (Horgan, 2003).

Wind affects forest growth and development and it is described as a disturbance if by its continued exposure it results to deformation, uprooting or

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alters the normal physiological processes of the seedlings (Gardiner, Berry & Moulia, 2016). The effects of wind to seedlings range from chronic to acute, resulting in a set of lethal and sub lethal effects. When wind loads exceed the resistance of stem or root system, trees break or uproot (Mitchell, 2012). Strong wind may also result in bending of seedlings due to the lateral loading producing stress in the outer fibres and the cambium. Stems deformations increases the demands of silvicultural management and reduces the quality of wood consequently decreasing its value at the end of the production cycle (Gardiner, Berry & Moulia, 2016).

Soil characteristics are considered when establishing exotic tree species or when there is a change of soil characteristics for indigenous tree species establishment (Camirand, 2002). A change in the soil drainage affects the potential hydrogen (PH) levels and nutrient status of the soil. The soil PH is known to influence growth if at certain level particular nutrients become unavailable or toxic to the seedlings (Masaba, Hitimana, Mbeche, 2020; Matonyei et al., 2017). Consequently, there is need for the manipulation of the nutrient status through the application of the fertilizers (Ogle, 1996). The physical conditions of the soil should be favourable for seedling growth by enhancing aeration, drainage, moisture and root penetration. It is important to consider the bulk density, mechanical impedance and hydraulic conductivity of the soil since roots can rarely enter a soil when bulk density exceeds 1.5 to 1.6 g/cm^3 (Ogle, 1996).

The sites topography informs land-forming processes and predicts soil formations and associated soil attributes (Scholten *et al*., 2017). Studies indicate a negative relationship between soil fertility and slope. The slope angle affects soil organic carbon (SOC), PH and nitrogen (N) of top soil horizons. Fertile soils are reported to occur in less eroded upper parts of hills (Scholten *et al*., 2017). Topography may therefore influence seedling growth in the following ways; affect soil fertility with increasing fertility at valleys compared to ridges due to soil erosion processes and matter transport and individual soil fertility are explained by terrain attributes (Scholten., 2017). It is therefore important to stakeholders in forestry to appreciate the slope levels of the forest plantations while determining land suitable for forests plantation establishment to minimize cases of erosion.

Silvicultural Management Practices

Silvicultural treatments accorded to seedling at various stages such as site preparations, selection of planting dates, seedling handling from the nursery to planting and pest and weed control all affect the quality of the seedlings before they establish. Site preparation is thus carried out to create favourable microclimatic conditions that ensure successful seedling regeneration. Some of the site preparation approaches include the use of herbicides, ploughing, regulated fire, scalping, disc trenching and mounding with the most adopted approaches globally being the uses of herbicides, regulated fire and ploughing (Von der Gonna, 1992). The chemical removal of weeds by herbicides is mostly used due to economic costs, its minimal impact on soil biodiversity and its efficiency in weed elimination that reduces the competition for site resources such as light, moisture and nutrients (Lof *et al.,* 2015). Weeds are also known to limit seedling growth through allelopathy and may provide a breeding ground for fungi that may later attack the seedlings (Matikalo, 1999; Lof *et al.,* 2015). The use of herbicides in weed control may result in retention of the available soil moisture, may contribute to nutrient losses by leaching and fluctuations in the soil temperature through increased daytime temperature and decreased night time temperatures (Cardoso et al., 2020).

Ploughing when adopted under the mechanical site preparation (MSP) approach is known to create continuous spoil berms and ridges that creates elevated planting spots. Additionally, soil surface layers are displaced and soil bulk density is increased consequently affecting seedling performance (Graham *et al*., 1989). This approach is also associated with the reduction in nutrients; phosphorous (P), nitrogen (N) and Carbon (C) on the top soils and on the forest floors which are essential for seedling establishment and growth (Cardoso et al., 2020). The use of fires for the regulated burning is ideal under the continuous cover of slash. However, this approach requires proper planning and supervision. Existing literature on the use of fire for site preparation indicate that unregulated fire accounts for more seedling

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mortality compared to the effects of rodents and ants (Masaba et al., 2020).

The planting time is important for successful regeneration and should coincide with the season that provides optimum conditions for temperature and moisture levels. Cooler temperatures (1-4°c) are ideal since they maintain moisture levels and prevent desiccation that may kill the young roots (Elefritz & Fitzgerald, 2006). To minimize mechanical damages, seedlings should be handled carefully in their boxes; there should be minimal throwing and dropping when loading to the planting sites. More attention should be on the bare root seedlings and seedlings raised in Swaziland beds during loading and transportation as the exposed roots are at more risk of mechanical damages and desiccation that affect their survival after planting (Koeser *et al*., 2009). Planting should be done in deep holes of at least 30cm x 30cm and the seedlings positioned naturally for effective establishment; the roots should not be handled while placing them into the planting hole. Rightly planted seedlings should have the soil surface midway between the top of the roots and the first limb (Elefritz & Fitzgerald, 2006; Schopmeyer, 1974).

Pest and diseases control is of great importance in plantation forestry as it enables the forest managers to maintain the stand density, species diversity and help avert any associated economic losses from seedling mortality (Roux *et al*., 2005). Some of the pests affecting plantation forestry under the participatory forest management (PFM) include livestock, ants, rats, moles, herbivory wildlife and termites (Mahari, 2014). Cattle grazing affect seedling survival because of trampling and browsing. The effects of termites and rodents is most felt in young plantations as they attack both the roots and stems eventually causing mortality. Wildlife herbivores are also reported to cause significant damages by trampling and debarking among the plantations that are adjacent the parks (Masaba et al., 2020).

CONCLUSIONS AND RECOMMENDATIONS

Successful plantation establishment is influenced by the quality of the seedlings, specie-site match and the silvicultural management practices. Selecting the planting stock should be based on the indicators of quality seedlings such as fibrous root mass with high root growth potential (RGP), roots inoculated with mycorrhiza, shoot to root ratio of 2:1 for containerized seedlings and large seedlings with mass foliage development. Additionally, seedlings with a smaller sturdiness quotient possessing the higher ability to be anchored in the ground ensures successful regeneration process. Species site matching involves the climate, wind, soil and topography and they are important attributes that influence the microclimate which influence seedling establishment. Silvicultural management practices such as site preparations, selection of planting dates, seedling handling and pest and disease control aim at manipulating the growth conditions for effective seedling performance. Higher survival levels can thus be attained when optimum growth conditions are provided by minimizing competition for site resources with weeds and controlling pest attacks. Since plantation forest establishment is costly and time consuming, actors in forestry should build synergy in raising genetically superior seedlings and accord them timely silvicultural treatments to effective regenerations.

Conflict of Interests

The authors reported no potential conflict of interest.

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