Elaboration of a technical note on criteria determining the threshold of a well-established young forest plantation for guiding in the process of accepting plantation works

FINAL REPORT

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1. INTRODUCTION

1.1. Background information on forestry practice in Rwanda

It was common practice in traditional Rwanda to plant or leave some indigenous tree species such as *Ficus thoningii, Euphorbia tirucalli, Erythrina abyssinica, Vernonia amygdalina, Dracaena afromontana*, etc., around household compounds (urugo). However, major reforestation efforts with woody perennials for timber, energy generation or other services, date from 1920 to 1948 (Twagiramungu, 2006). During this colonial period, the target was to afforest one ha of woodland for every 100 persons. By independence in 1962, about 20,000 ha of communal land had been afforested mainly with Eucalyptus species. The launching of the Kibuye Pilot Forestry Project (PPF) in 1967, with funding from Switzerland, marked the beginning of true forestry practices in the country. By 1976, PPF had established more than 5,000 ha of forest plantations (FAO, 2002).

Intensive reforestation efforts were carried out between 1975 and 1990. Actually, 1975 marked a turning point in the practice of forestry in Rwanda, with major reforestation campaign and launching of large scale development projects, each with a major forestry and agroforestry component. The compulsory community works ("Umuganda") launched in 1975, and the annual National Tree Planting Day institutionalized in 1976 helped to mobilize the population for tree planting activities. As a result, the forest plantation area rose from 25,500 ha in 1975 to 247,500 ha in 1989 (FAO, 2002). Major donors to forest projects during the period 1975-1990 included the World Bank, the European Union and Switzerland through the Swiss Development Agency (SDA) and INTERCOOPERATION.

The main objectives of most forest plantations established during this period were protection of vulnerable soils against erosion, reduction of pressure over the remaining natural forests and protected areas (buffer zone) and fuelwood supply to an ever growing population. The law no. 47/1988 organizing the forest regime in Rwanda was enacted in 1988 but due to the war that broke out in 1990 and culminated in full scale genocide of Tutsi in 1994, this law was never adequately implemented. From 1989 to 1993, there were a number of projects to establish public and private forest plantations with free distribution of tree seedlings from forest nurseries. Forestry activities were suspended from 1993 to 1995, and a number of forests (both natural and plantations) were completely destroyed by displaced people fleeing the war and later on for new settlements for the returning refugees. Between 1995 and 1999, forestry activities resumed on a modest scale with the resumption of the national tree planting day and of some NGOs and small projects involved in reforestation and tree seedling production. However, from 1999 onwards, seedlings were distributed freely to farmers, which helped to increase the area under private forest plantations in recent years (Nduwamungu, 2011). The launching in 2003 of the Forest Management Support Project (PAFOR) funded by the African Development Bank (ADB), the first National Forest Policy of 2004, the creation of the National Forestry Agency (NAFA) in 2008, the launching of the new forest support project (PAREF) funded by the Netherlands and Belgium; the adoption of the award-winning National Forestry Policy in 2010 which was revised in 2018, the new forest law in 2013 (now under revision), the National Forest inventory in 2015 and many other policy documents recently published including the Forestry Strategic Plan (2018-2024), National Tree Reproductive Materials Strategy (2018-2024), Forestry Research Strategy and Guidelines for Rwanda (2018-2024), Forest Investment Program (2017), National Agroforestry Strategy (2018-2027), the Rwanda forest cover map (2019) which revealed that forest cover has now reached 30.4% of Rwandan territory; and the recent creation of the Rwanda Forestry Authority (RFA) are evidences of relevance and positive developments of the forestry sector in Rwanda.

Meanwhile, for many years, the Government has focused on the sole target of increasing forest cover at the expense of the sustainable forest management. In the process, silvicultural treatments were overlooked and the majority of forests underwent degradation in terms of reduced productivity and low standing stock caused mainly by overharvesting (MINILAF, 2018). Since the Government target of achieving a forest cover of 30% of the country land has been attained, efforts need to be directed more towards sustainable management of forestlands with much focus on private forests that are estimated to be 68% of the total country forest cover (RFA, 2019).

Most early forest plantations were established for fuelwood supply to an ever growing population, protection of vulnerable soils against erosion, protection of road alignments, and reduction of pressure over the remaining natural forests and protected areas (buffer zone). The majority of tree species planted then were exotic species including mainly *Eucalyptus* species and a few *Pines, Cypress, Callitris* and *Acacia* plantations. Due to shortage of land for large afforestation projects, tree planting is now targeting trees on farms (agroforestry on both cropland and pastureland) and for beautification of settlements (Urban forestry). Again exotic species such as *Grevillea, Calliandra, Leucaena, Alnus* and *Senna* species are predominant in agroforestry. In accordance to the environment law, other niches for tree planting also now include protection of river banks, lakeshore and some wetlands. Native species such as *Markhamia, Entandrophragma, Podocarpus*, and bamboos are now emerging as most preferred for protection plantations. While the type of species and stocking density may vary from one plantation objective to another and from one region to another, there are acceptable norms for most forest plantation activities.

Most of the forest establishment operations have long lasting impact on the forest and can dramatically affect the performance of the site positively or negatively. Hence the importance of monitoring and evaluation of forest plantation and/or rehabilitation works from nursery management to harvesting and regeneration activities. When all forest plantation activities are properly and timely executed, the performance of a forest plantation site will be enhanced leading to shorter rotation ages and more quality yield. At nursery level, the aim should be to produce vigorous and healthy seedlings. The planting site should be well prepared, ensuring a suitable environment for the young seedlings and adequate stocking for an optimum growing space depending on desired products. In addition to effective early maintenance including beating up and frequent weeding, the site should be well protected against soil erosion and wild fires.

Currently, there are no formal guidelines on standards or norms to be achieved in order to certify that a newly established forest plantation is well established or not in Rwanda. The issue of the norms and threshold levels for a newly established forest plantation is not well documented yet. They have been various norms generally used to accept forest plantation works by the forestry department and forest projects like those funded by PAREF BE (FMBE project), PAGREF, PAFOR and others. Some of these include the number of surviving trees per unit area, the general health of the trees, and the cleanliness of the site. The accepted survival rates being 85% in rainy and termite free areas such as in North and Western Provinces and 75% in dry termite infested areas mainly in Eastern Provinces and parts of the Southern Provinces (RFA, personal communication). The reason was to account for negative effects on newly established forest plantations caused by the various factors including reduced rainfall, increased drought and termite infestations as well as grazing animals. However, it is not clear how these thresholds for acceptable norms to be achieved, were fixed to declare that a newly established forest plantation in different ecological zones is well-established. This study intends to fill this gap of knowledge and propose acceptable norms for a well-established plantation and tools for monitoring and evaluation of those norms.

1.2. Objective and scope of the assignment

The main objective of this assignment was to develop guidelines that will support technical staff in the field in determining whether a new forest plantation can be accepted or rejected. Therefore, this study has attempted to establish the tolerable thresholds for accepting newly established plantations. It is obvious that when trees are planted, some will die due to biotic and abiotic factors, and the service provider is generally required to carry out beating up and early tending such as weeding and clean up to ensure optimum survival of planted trees. However, it would be unrealistic to expect to achieve 100% survival rate. But then, how much can be tolerated? How can effective monitoring and evaluation of tree planting activities be carried out? This study attempted therefore to respond to these questions.

In the process of addressing these study questions, the following work was undertaken:

(1) Review of forest stand dynamics;

(2) Review of limiting factors for tree growth;

(3) Review of standard forest plantation and/or rehabilitation activities

(4) Development of tools of monitoring and evaluation of forest plantation activities

(5) Proposal of acceptable norms of a well-established forest plantation and thresholds of acceptance of a newly planted forest in different agro-ecological zones.

2. LITERATURE REVIEW

2.1. Review of forest stand dynamics

2.1.1. Relevant definitions

- *Forest stand dynamics* deals with changes in forest stand structure with time, including stand behaviour during and after disturbances at a given site.
- *A forest stand* is a spatially continuous group of trees and associated vegetation having similar structures and growing under similar soil and climatic conditions (Oliver and Larson, 1996).
- *The stand structure* is the physical and temporal distribution of trees and other plants in a forest stand. The distribution can be described by species; by vertical or horizontal spatial patterns; by size of living and/or dead plants or their parts, including the crown volume, leaf area, stem, stem cross section, and others; by plants ages; or by combinations of all these.
- *Stand development* refers to that part of stand dynamics concerned with changes in stand structure over time.
- *Site* refers to an area's potential for tree growth. Site usually incorporates an area's soil and climate conditions.
- *Disturbances* are any discrete events that disrupt the forest stand structure and/or change resource availability or the physical environment of the stand. Both non-human and human-caused disturbances are considered in forest stand dynamics because tree response does not distinguish between non-human and human activities (Oliver and Larson, 1996).

2.1.2. Stages of forest stand development

The development patterns of a forest stand following a disturbance or natural/artificial regeneration is generally divided into stages resulting from interactions of plants (trees) between themselves and their environment. Four stages of forest stand development are generally recognized (Figure 1): Stand initiation, Stem exclusion, Understory re-initiation, Old growth stages (Oliver and Larson, 1996).

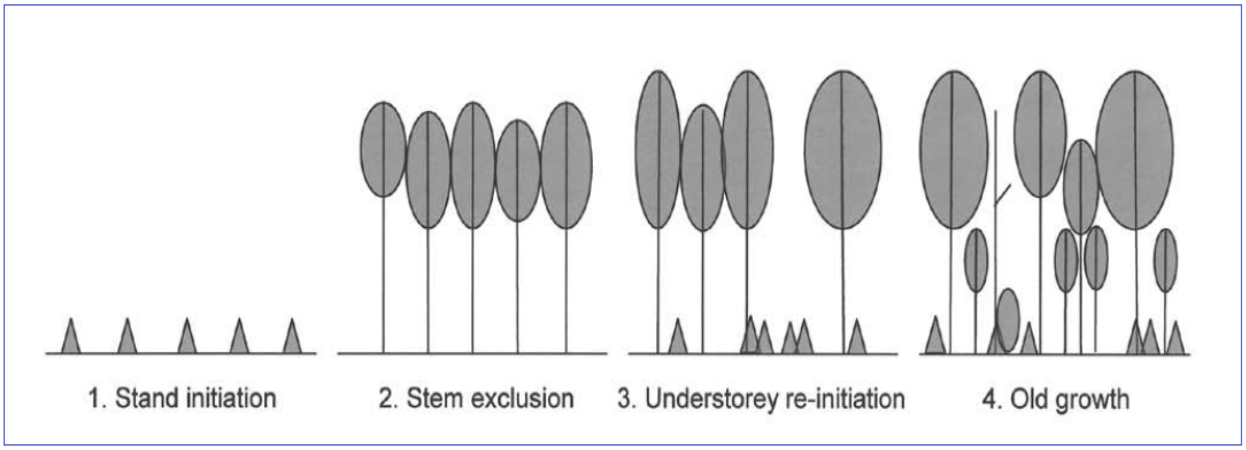

Figure 1. The four major stages in forest stand development (Oliver & Larson 1996).

The stand initiation stage corresponds to the phase of recruitment of stems to the stand. In naturally-regenerated forests this phase may last a number of years, but in plantation forests full stocking of the site is achieved generally in one planting operation. In the case of death of seedlings, beating up should be conducted in the next planting season to ensure full stocking of the newly established plantation forest.

The stem exclusion stage follows as the forest stand develops a closed canopy; deep shade in the understorey prevents further recruitment of trees to the stand while competition, site factors and genetic differences lead to differentiation of crown dimensions and stem diameters (Wilson and Leslie, 2008). The stand then continues on to an understorey re-initiation stage where herbs, shrubs and advanced regeneration of trees appear and survive as a result of gradual thinning of crowns or occasional gaps that allow increased levels of solar radiation to reach the forest floor.

Lastly, after a while without major disturbances, the forest stand reaches the old growth stage (Figure 1). The overstorey trees die in an irregular pattern, either from natural causes or disturbance, creating space for recruitment into the canopy of trees from lower strata (Wilson and Leslie, 2008).

Plantation forest stands are usually composed of one tree species, one age class and have uniform tree spacing. In most cases, they are harvested (clear-felled) before reaching the understorey re-initiation stage in order to maximize the financial return on investment costs (Evans and Turnbull, 2004). In plantation forests, individual trees undergo a variety of structural adaptations through time due to competition for space, nutrients, moisture and light (Oliver and Larson, 1996).

The time a stand appears in any stage can be prolonged or shortened with appropriate management. Single cohort stands (uniform plantation forests) can be moved rapidly through the initiation stage by planting trees and controlling weeds to stimulate tree growth, and this stage can be prolonged by removing some trees. The stem exclusion stage can be prolonged with judicious, light thinning of intermediate and suppressed overstory trees, and shortened by heavy thinning which allow an understory to develop. The understory re-initiation stage can also be prolonged by light thinning which stabilize the overstory, or shortened by heavy thinning which allow the advance regeneration to grow upward, creating a structure resembling old growth (Oliver and Larson, 1996). Operations such as weeding and planting or inter-planting to alter the species composition of a new stand are most efficient during the stand initiation stage (establishment phase).

Stand structures reached at different development stages are susceptible to certain disturbances. The forester can anticipate dangerous conditions at each stage of development. According to Oliver and Larson, (1996), progressively older stands become more susceptible to wind throw as the trees grow taller; and both fires and insect attacks tend to occur during the stem exclusion stage; activities such as thinning can reduce or increase the risk of fires or insects.

2.2. Limiting factors for tree growth

2.2.1. Tree growth factors

Under suitable climates and soils, trees will grow in size and number until one or more factors necessary for growth are no longer available (Oliver and Larson, 1996). Which factor becomes limiting to plants varies from one species to another. The degree to which each species slows in growth as each factor becomes limiting varies also, although the growth variation may not be great.

The factors necessary for tree growth are mainly those required for photosynthesis and respiration. Such factors include sunlight, water, certain mineral nutrients, suitable temperatures, oxygen, and carbon dioxide. For a tree to grow well, each factor must be available in the appropriate form and location. The physiological relation of each of these factors to tree growth are briefly discussed below.

2.2.1.1. Sunlight

Generally, trees photosynthesize increasingly faster in bright light up to full sunlight (Fig. 2. Kimmins, 1987 quoted by Oliver and Larson, 1996) if other factors do not become limiting. Some species can survive in more shaded conditions than others, since their leaves photosynthesize enough at lower light intensities to stay alive. Such species are described as *shade-tolerant (e.g. E. excelsum-Umuyove).* The lowest light intensity at which a leaf can sustain itself (the *compensation point)* is not very different among species. For instance, the compensation point of individual leaves of woody plants ranges from 0.3 to 1.5 percent of full sunlight, i.e. a difference of only 1.2 percent (Larcher, 1983 quoted by Oliver and Larson, 1996).

More light is needed for whole trees to survive, since the leaves must photosynthesize enough to keep stems, branches, and roots alive. The extra sunlight utilized by the shade-tolerant species generally contributes little to growth, although it may enable the species to survive in understory, shaded conditions. The architecture, spatial arrangement of leaves, and respiration rates of stems, branches, and roots are important in allowing some species to survive at lower light intensities than others (Oliver and Larson, 1996).

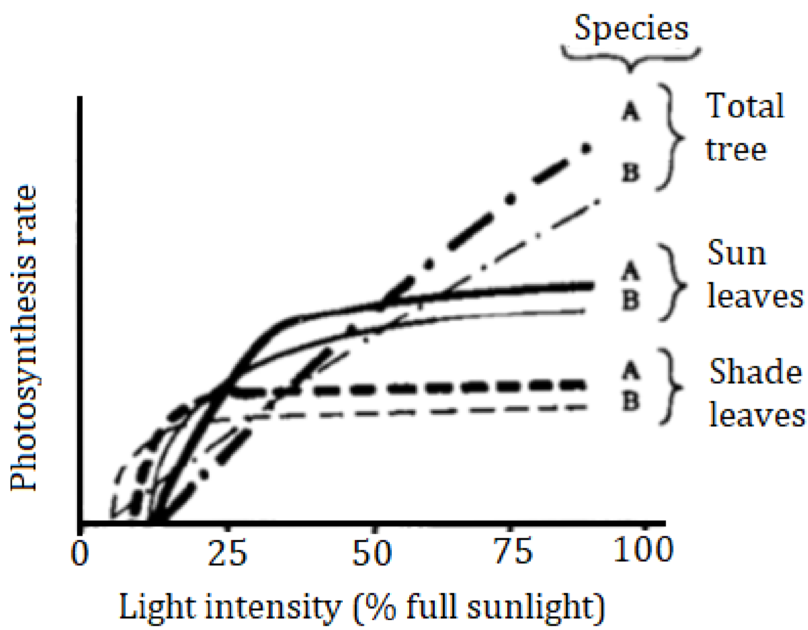

Figure 2. Schematic photosynthesis rate for sun and shade leaves of two species (A and B). The magnitudes of the curves vary for different species. Light intensity at which zero net photosynthesis occurs-the "compensation point" -varies slightly, but the general curve shape stays similar. Total tree photosynthesis continues above about 25 percent full sunlight because the leaf angles alter *(Leopold and Kriedemann, 1975 in* Oliver and Larson, 1996).

2.2.1.2. Water

Water is critical to plant life. Water is available to plants from the soil primarily as capillary water in small pores and surrounding individual soil particles. As the plant exerts tension (through evapotranspiration) greater than the attraction tension of the soil, water moves from the soil into the plant (Oliver and Larson, 1996). Plants vary in their abilities to extract water from the soil and endure conditions of high soil water tensions without injury. Most tree growth occurs at soil moisture tensions of less than -6 bars (-600 kPa). Apparently, little growth seems to occur even in site insensitive species at higher moisture tensions. Site-insensitive species may have a competitive advantage on the drier sites both through the ability to survive periods of high soil moisture tension (dry periods) and from the slight growth advantage gained from soil water extracted at very high tensions (Levitt, 1980 *in* Oliver and Larson, 1996).

The leaves of different tree species vary in ability to reduce evapotranspiration to minimal rates while living under high temperatures without the cooling effects of evapotranspiration. However, under droughty conditions, the stomata of some species *(drought avoiders)* close, shutting off transpiration and maintaining a high internal moisture level, while others *(drought endurers)* continue transpiring until their internal moisture is quite low (Oliver and Larson, 1996).

2.2.1.3. Nutrients

Plants need certain nutrients to live, grow, and reproduce. A total of 16 inorganic elements are essential for plant growth and development (Table 1). More than half of these elements, including carbon (C), hydrogen (H), oxygen (O), nitrogen (N), phosphorus (P), potassium (K), sulphur (S), calcium (Ca) and magnesium (Mg) are needed in relatively large quantities and are, therefore, called "macronutrients" (or major nutrients). Other elements, particularly iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), boron (B), molybdenum (Mo) and chlorine (Cl) are also indispensable for plant growth, but they are needed in much smaller quantities and are, therefore, called "micronutrients" (or trace elements). Mineral nutrients are generally absorbed optimally in ionic form for most tree species (FAO, 2013). Once inside the tree, most nutrients are concentrated in the leaves, phloem (inside the bark), buds, root tips, and reproductive organs.

The soil pH determines the availability of the nutrient to the plant (whether its soluble or not). For example, in cases of extreme pH ranges, some micronutrients are unavailable, while others are available in toxic quantities. Most tree species grow optimally on slightly acid soils, and trees generally live between pHs of 4.0 (very acidic) to 7.5 (slightly basic; Spurr and Barnes, 1980 in Oliver and Larson, 1996). Certain species have the ability to grow at more extreme pHs than others. In fact, some species are found on extremely acidic or basic soils *not* because they grow best there, but because they are uniquely able to survive there.

Species vary in their ability to extract elements from either organic or inorganic media. Mutualistic associations between microorganisms and tree roots increase the ability of the tree to absorb essential elements. Mycorrhizal associations between fungi and roots expand the tree root systems' surface area for absorption because of the large surface area of fungal mycelia. Mycorrhizal fungi also extend the life of fine, absorbing roots; they break down complex organic molecules and pass the extracted nutrient elements to the roots. Under high soil nutrient conditions (such as in a green house or nursery), the mycorrhizal association develops less. For some species like pines, seedlings without mycorrhizae do not survive if planted in soils without fungal inoculum (Oliver and Larson, 1996)

2.2.1.4. Free-growing microorganisms and nutrient availability

Microorganisms require the same factors for survival and growth as photosynthesizing plants do, except that non-photosynthesizing microorganisms obtain their energy from organic compounds in litter from dead roots, abscised leaves, fallen branches or trees, and dead animals (or living plants and animals in the case of parasites). In the process of obtaining energy, microorganisms decompose (respire) the organic material into small organic compounds and release carbon dioxide, water, heat, and inorganic nutrients. Since microorganisms take up nutrients more efficiently than higher plants do, higher plants are usually able to get nutrients either through their mycorrhizal association, or after the microorganisms no longer require them for growth.

Energy becomes limiting to microorganisms with the depletion of organic matter. Inorganic nitrogen is then less needed and so may be released by the microorganisms. According to Oliver and Larson, (1996), nutrient fertilization can have a "snowballing" effect on fertilizer availability to the trees. Some fertilizer is immediately taken up by the trees, while that taken up by microorganisms increases their growth and respiration, which leads to increased decomposition and nutrient release from previously undecomposed organic matter. In warm and moist climates such as in tropical forests, microbial decomposition of forest floor organic matter proceeds rapidly, and little litter remains on the ground. Consequently, nutrient recycling through the litter and back to the plants occurs rapidly than in cooler or drier climates (Oliver and Larson, 1996).

2.2.1.5. Temperature

Life processes for most animals and plants are restricted at slightly below 0^0 C by the freezing of water and above 55^0C by the death of cells. Respiration of photosynthesizing and non-photosynthesizing plants increases steadily through this range, although the rate of change varies with species. Gross photosynthesis, on the other hand, increases rapidly from the freezing point to a relatively constant "plateau" of photosynthesis within a narrow range of 8 to 25^0C (Nobel, 1976 in Oliver and Larson, 1996). The plateau level is species and genotype-specific. Temperatures above the plateau create a decrease in net photosynthesis because of the increased respiration.

2.2.1.6. Oxygen

Oxygen is absorbed through bark lenticels, leaves, buds, and roots. Oxygen becomes limiting when not available to roots in the soil. As with other growth factors, most tree species grow best when soil oxygen is optimum; however, some species have mechanisms which allow them to live in anaerobic soil conditions.

2.2.1.7. Carbon dioxide

Carbon dioxide is diffused from the atmosphere through stomata on leaves. Except when leaf stomata are closed to reduce water loss, absence of carbon dioxide does not limit growth. Photosynthesis increases with increased concentrations of carbon dioxide, although species vary in their rate of response to its increase. Carbon dioxide concentrations in the atmosphere vary slightly with time of day, weather conditions, and elevation (Decker, 1947 in Oliver and Larson, 1996).

2.2.2. Growing space concept

Each tree in a forest utilizes the growth factors discussed above until its growth becomes limited by unavailability of one or more factors. Any one factor may limit growth either because it is not present in the area, it has been taken up by another plant, or it is available at such a slow rate that it is essentially absent. When the limiting factor becomes available, growth will proceed until another factor becomes limiting. The availability of one factor can also influence the efficiency with which a tree can use another growth factor (*law of Compensation)*.

The limiting factor varies between areas and between times of the day, year, or longer in the same area. Lack of one factor may prevent a plant from acquiring another factor. For example, a lack of sunlight in an understory may reduce an understory plant's growth so that it cannot grow enough roots; water then becomes limiting, and the plant dies (Oliver and Larson, 1996).

To simplify the issue of limiting growth factors, it is often convenient to consider that a site contains a certain amount of intangible *growing space,* or capacity for plants to grow until a factor necessary for growth becomes limiting. Growing space may be dimensional when growth is most limited by the volume of space available for shoot or root penetration or by the surface areas available for nutrients, water, or light accumulations. Growing space may also describe more abstract situations, such as when nutrient conditions limit the site's capacity to support growth (Oliver and Larson, 1996).

2.2.2.1. Factors which limit growing space

The amount of growing space varies spatially and temporally. Some species are capable of utilizing growth factors in a form unavailable to other species. Such differences among species are not great but can give different species competitive advantages on different sites. The specific factors which can limit growing space are those described above including sunlight, water, mineral nutrients, temperature, oxygen, and carbon dioxide.

Plant species usually do not vary much in their ability to grow under different availabilities of growth factors, so that what is growing space on a site is approximately the same for nearly all species. However, various competitive advantages of some species under different conditions seem to lie largely in two characteristics:

- Species vary in their allocation of photosynthate to shoot extension, root extension, height growth, limb spread, insect and disease resistance, and other uses. Consequently, species vary in their rate of obtaining growth factors, their stability, and their ability to resist adverse conditions.
- Species vary in ability to endure low levels of certain growth factors, even though the amount of each growth factor which will produce optimum growth varies little among species.

2.2.2.2. Growing space available to each plant

When growing space (i.e. the sum of factors necessary for growth) is present but not occupied by other plants, the growing space can be considered "available" to a plant. Planted seedlings, germinated plants or surviving plants after a severe disturbance expand into the available growing space. The rate of this expansion is limited by the availability of growth factors and by the genetically predetermined growth rates of the species. The expanding plants come literally or figuratively into contact with others also expanding into the available growing space. After contact, the rate of growth of each plant is limited by the growing space it occupies. The amount of growing space each plant occupies is defined by the surrounding plants.

As a result of their unique anatomies, plants must expand in size to live. A plant first allocates the energy obtained through using its available growing space to maintain its presently living cells (*maintenance respiration*). After respiration demand is fulfilled, any extra energy is used for growth (*photosynthesis*). A tree occupying a fixed growing space increases in size at progressively slower rates, because it obtains a fixed amount of energy through photosynthesis, while increasing amounts of energy are allocated to maintenance respiration demands of the increasingly larger living system. Size eventually reaches a maximum in a fixed growing space when all photosynthesis is used for respiration. The tree cannot grow larger unless its growing space is increased (Figure 3).

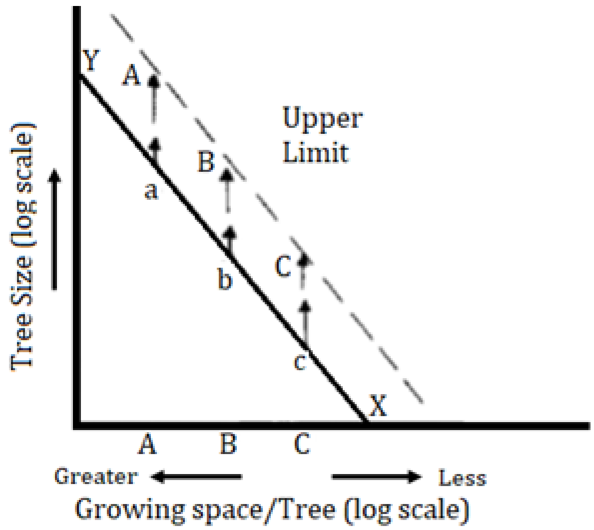

Figure 3. A tree growing without competition will increasingly occupy growing space and grow in size along line XY. *The growing space axis has been reversed to read from large to small values Trees encountering competition at points a, b, or c increase in size along aA, bB, or cC, respectively, with limited growing space until an upper size limit is reached for that amount of growing space (Oliver and Larson, 1996).*

When plants have filled all available growing space, they begin competing with other plants to obtain and to maintain growing space. The varied ways the different species survive and grow allow a species to have an advantage and hence expand into another's growing space under certain conditions but to give it up under others. If one plant has a competitive advantage, it expands at the expense of another. The plant whose growing space is reduced may be able to survive if it can utilize some growing space which the more aggressive plant cannot, or it may die if there are no such differences in growing space utilization. Plants of the same species utilize the same growing space, and so a plant soon dies if outcompeted by another of the same species.

2.2.2.3. Applications of growing space to forest management

Most forest management activities are generally geared towards increasing or decreasing the total growing space of an area. Thus, management activities should be timed to utilize periodic fluctuations in growing space. Harvesting operations and site preparations can decrease total growing space when they damage the soil structure or reduce nutrients by causing them to be leached, volatized in the case of fire or taken from the site during harvest. Management activities can also increase the total growing space by fertilization or proper site preparation (e.g. digging of standard planting holes some time (at least 2 weeks) before actual tree planting) which increases soil rooting depth or reduces unfavorable microsites.

In general, much of silviculture is either making the stand's growing space available to desirable species and individuals or putting these individuals in a competitively advantageous position. For example, pruning and various thinning and regeneration practices give the competitive advantage to desirable species or individuals trees in a plantation forest.

3. METHODOLOGY FOR THE STUDY

3.1.1. Review of forest stand dynamics and limiting factors for tree growth in tropics

An extensive review of dynamics of forest stands and limiting factors for tree growth in the Tropics was conducted through search on internet and online libraries of available relevant publications (published and unpublished forestry reports, silviculture textbooks and articles, etc.)

3.1.2. Technical specifications for forest plantation and/or rehabilitation

The technical specifications outlining different activities in forest plantation and/or rehabilitation were elaborated in consultation with the Rwanda Forestry Authority (RFA) and other relevant stakeholders that are involved in forest landscape restoration (tree planting) including REMA, ENABEL, IUCN, NFC, ICRAF, RAB, ARCOS, and FONERWA. A checklist of relevant information was used to talk to key informants (Annex 1). However, the elaboration of the technical specifications was also greatly inspired by literature review of relevant publications and reports (both published and unpublished) on standard practices in establishing new forests or rehabilitating old ones.

3.1.3. Developing tools of monitoring and evaluation of plantation forest activities

Basing on the established standard practices in establishing new forests or rehabilitating old forests (technical specifications elaborated in the previous section), relevant tools of monitoring and evaluation of forest plantation activities including timing of relevant silvicultural activities and parameters to be monitored were developed to guide in following up and evaluating forest plantation works before acceptance. The monitoring and evaluation tools were set to go hand in hand with thresholds of acceptance of newly established plantation forests.

3.1.4. Proposing acceptable norms of a well-established forest plantation and thresholds of acceptance for a newly planted forest or rehabilitated forest

The acceptable norms of a well-established forest plantation were further proposed on the basis of extensive literature review of published and unpublished forest project reports and silvicultural articles. The threshold levels of acceptance of a newly planted forest of rehabilitated forest for three ecological zones were proposed taking into account the forest stand development dynamics, growth limiting factors as well as recommended standards for different forest plantation establishment activities. After statistical analysis of different survival rates reported by a number of restoration projects in different parts of the country, the confidence level of the mean at 99% probability was used to set up the minimum acceptable survival rates in the three altitudinal ecological zones. Some of the project reports include PAFOR, PEGREF, FMBE, PAREF be, EWMR, and others.

4. RESULTS

4.1. Technical note for forest plantation and/or rehabilitation

4.1.1. Sourcing of seeds or planting materials

A successful tree planting project start with proper sourcing of seeds or planting materials. Once the species to be planted have been chosen, the amount of required seeds or planting materials should be estimated and then ordered from the only official seed provider in the country, which is the National Tree Seed Center (NTSC). The procurement process of good seeds or planting materials is regulated by the Rwanda Forestry Authority (RFA) which manage the NTSC. Seeds or planting materials acquired from other sources should not be accepted.

4.1.2. Nursery management

The decision of starting a tree nursery should be carefully made on the basis of its advantages and disadvantages. This is because tree nursery management is complex and needs availability of experienced staff in nursery activities or a commitment to train own nursery staff. Therefore, the scale of the tree planting project, that is the planting area size (e.g. 200 ha) and the required amount of planting materials, should determine whether or not to start own nursery or source out quality planting materials. The quality of planting materials is governed by two factors: the genetic make-up of the parent trees and the physical growth of the seedling in the nursery. A poor quality tree will always be a poor quality tree even if planted on a well-prepared, good site. Therefore, it is important to source out planting materials (tree seedlings) a reputable nursery which uses quality seeds from recognized sources.

In case a tree nursery is started, attention should be paid on ensuring proper nursery management practices. In general, key issues in nursery management are nursery location, nursery care, soil mix, pot sizes, pricking out and transplanting, hardening off and grading plant quality.

4.1.2.1. Nursery site selection

A good nursery site should have the following features:

- *Close to the source of water* (to ensure continuity of water supply).
- *Relatively flat area* (ideally with a 2 - 5% slope, otherwise terracing is necessary)
- *Good soils* (well-drained sandy loam or loamy sand with adequate nutrient, and pH 5.5 to 6.5)
- *Good accessibility* (all-weather road to the site and to reduce the cost of seedling transportation, nursery may be established as close as possible to the planting site).

4.1.2.2. Nursery infrastructure, seed beds, containers and potting medium

Nursery facilities commonly needed are office, water storage, substrates preparation house, storage house (to store equipment, fertilizer, pesticides etc.), shaded and open nursery beds, soil dump site and compost area.

Seedbeds should be about 1.20 m wide with paths at least 1 m wide between them. The beds can be any length, but 10 – 12 m is often convenient to facilitate hand tending and watering. Pot beds, like seedbeds, should also be 1.20 m wide so that working at the centre of the bed is not difficult when pricking-out, weeding and watering. The beds can be any length, but 10-12 m is most convenient. Paths between beds should be at least 1m wide to allow access for workers and wheelbarrows. Shaded bed height should be 1.30 m on one side and 1.25 m on the other side to allow for rain water control (Unique, 2015).

There are many types of containers which can potentially be used for growing tree seedlings in nurseries. The choice of a certain type of container has direct implication on container cost, weight, durability, ease of supply, longevity, practicability of recycling by repeated use, and environmental pollution. Black and clear polythene tubes are commonly used in raising tree seedlings in Rwanda. The size of container depends primarily on the size of seeds and type of seedling that can be grown. A general guide is that seedling height should be no more than twice the length of the used tube i.e. a root: shoot ratio of no more than 2:1. According to Unique (2015), the recommended pot size for eucalypts is a 7.6cm width measured and

12cm height (filled pot diameter of 4.8cm). Bigger pot size is recommended for pines and cypress, 10.1cm width and 15cm pot height (filled pot diameter of 6.4cm).

Potting soil should from a correct mixture of sand, clay and organic matter. Poor soil can be made better by mixing different amounts of sand, compost, clay and forest top soil. Mix the soil as well as possible for example by turning the mixture 3 or 4 times. The standard mixing ratio for 100% pure soils should be; 1 part of sand: 3 parts topsoil (Unique, 2015). Some species like pines requires *Mycorrhizae* addition in the potting soil mixture. A soil mixture of 1part sand; 2 parts Mycorrhiza; 3 parts topsoil would be adequate for raising pine seedlings. The use of fertilizers is also recommended to encourage fast growth, strong root development and a healthy seedling. NPK 17:17:17 or TSP is adequate at a rate of 1.0 kg/cubic meter of soil substrate. The fertilizer should be mixed thoroughly and homogenously to the soil substrate.

4.1.2.3. Seed sowing, pricking out, and transplanting

The seed should be sown in the center of the pot or in the germination bed at a depth equal to 2 - 3 times its smallest dimension, but in any case the top of the seed should be no more than 10 mm below the surface. There are two main categories of sowing methods depending on seed size and time for germination: (1) direct sowing into containers (filled pots) and (2) sowing into germination beds (broadcast sowing and drill sowing)

When seeds have germinated on germination beds, pricking-out and transplanting into seedling pots should always be done. Pricking-out should be restricted to the coolest times of the day, such as early morning and late afternoon. Cloudy days with little wind are especially suitable for pricking-out, and on such days, this operation can be done throughout the whole day. Generally, the shoots of seedlings suitable for pricking-out should have three leaves besides the cotyledons for broad-leaved and four leaves for coniferous species. After pricking out, the seedlings should be transplanted on the same day. Using a small stick, make a hole in the center of the pot and holding the seedling by a leaf, lower the roots into the hole ensuring that they go straight down and are not bent upwards. The final depth of the seedling should be such that the root collar is level with or a few millimeters below the surface of the soil in the pot. Never bend the roots and do not force the seedlings into the hole. Refill the hole around the seedlings with dry soil and immediately water the freshly transplanted seedling to wet the dry soil. Transplanted seedlings should be kept under proper shade until they have recovered.

4.1.2.4. Caring for the seedlings

Healthy growth of seedlings requires appropriate levels of light, moisture, temperature, and the nutrients required for the various stages of growth from seed germination to hardening-off. Moreover, there should be minimal weeds, pests and pathogens affecting the seedlings so that they can be grown efficiently and economically to the desired quality standards.

a) Watering, shading, weeding, and pest and disease control

Good nursery hygiene is very important to produce healthy seedlings. It is therefore recommended to ensure careful watering (before sunrise and after sunset) and shading when necessary. Every effort should be made to control weeds in and around the nursery as weeds may host insects and pathogens. Damping-off is a collective name for a number of non-specific fungal diseases that cause a serious threat to seedlings after germination. The seedlings begin to rot from the stem tissue just above the root collar resulting in the seedlings toppling over. The disease begins in patches and finally spreads to the entire bed. Damping-off can be prevented by controlling humidity, shading, watering, and thorough cleaning of sowing tools and equipment.

b) Culling, sorting (grading) and hardening off

Good nursery practice is to discard poor quality trees as soon as you detect them. Such poor seedlings can be a source of infection. It is a greater waste of hard work and money to maintain trees of poor quality in the nursery and in the field, than to **throw away poor quality seedlings** in the nursery. Therefore, allowances must be made for culling (i.e. rejecting poor seedlings) – at least 15% extra should be allowed for culling. Good and healthy seedlings should be therefore sorted out (grading)from bad seedlings and packed on different standing beds.

Hardening off is the conditioning of the seedlings to survive outside the nursery. A few weeks before planting, it is important to condition the seedlings so they are better adapted to harsher conditions in the field. This is achieved by progressively reducing watering and exposing seedlings to full sunlight. Root pruning has to be done at the end of the rapid growth phase and during hardening off to prevent the roots from penetrating into the soil. Seedlings should not be planted earlier than 3 days after root pruning as they will be stressed and need time to recover.

4.1.2.5. Seedling dispatch, handling and transport

All efforts made in raising quality plants can be easily wasted if little care is taken while transporting the seedlings to the field. This phase includes transport from the production nursery to the holding nursery, time spent at the holding nursery and transport to the site where seedlings will be planted. The effect of stress on seedlings during packaging and transportation to the planting sites has a significant effect on the survival and subsequent growth of the trees.

4.1.2.6. Record keeping

It is good practice to keep nursery records including seed purchases, sowing dates, germination dates and percentages, seedling sales, pest and disease outbreaks, etc.

4.1.3. Planting site preparation

Land preparation is an essential part of plantation establishment which enables to achieve high survival and rapid early growth of planted seedlings. Land preparation involves removing (or controlling) the competing vegetation (clearing), stump uprooting or debarking and control of coppices, digging of erosion control ditches, creation of firebreaks and lining out and pitting.

4.1.3.1. Clearing, stump extraction/debarking

Clearing ensure the removal of the vegetation that occurs on the site to be planted. Land clearing can be done in a number of ways depending on the nature of the vegetation such as manual cutting and/or slashing, burning, spraying with herbicide, and mechanical means such as mulchers or bulldozers. During clearing, stumps can be also extracted (uprooted) or debarked and coppices controlled until the stump completely dies. The initial clearing prepares the land for all subsequent operations such as lining out, pitting and weeding.

4.1.3.2. Digging of erosion control ditches

As a land conservation measure particularly on steep slope sites, erosion control ditches must be created along the contour lines in an alternating and discontinued manner to ensure maximum protection against soil erosion. Good erosion control ditches are 40-50 cm wide, 60 cm deep and 2.5m to 4 m in length.

4.1.3.3. Creation of firebreaks

Firebreaks should be established as a protection measure of the plantation forest against wild fires. Firebreaks serve also as access road or tracks that facilitate maintenance and silvicultural activities in the plantation forest. There are two types of firebreaks: internal and external firebreaks. External firebreaks are belts or areas around a forest that are not flammable. External firebreaks should be wide enough to stop a normal fire by themselves. The width of external firebreaks depends on the fire risk but a minimum of 10 m clear of vegetation is a good guideline.

Internal firebreaks are firebreaks within the plantation forest. Internal firebreaks are generally narrower than the external breaks because they are not usually designed to stop the fire themselves but to allow access in case of fire and other management activities. The number of internal firebreaks and their width depends on the risk but, a minimum width of 5m is recommended as a guideline. Firebreaks should be cleared regularly and all grass and inflammable biomass removed especially at the onset of the dry season.

4.1.3.4. Lining out and pegging

Planting spacing refers to the distance between plants, which determines the plant density (stocking) on the site. There are an infinite number of different spacings that can be used depending on site types, species and end product. Common spacing range from 2x2 m for fuelwood production to 3.0x3.0 m for timber production with various combinations depending on species, desired products and even maintenance costs.

Lining out and pegging is done to ensure that trees are planted at the required spacing in straight lines (on flat ground) or along the contour (on sloping ground). Lining out and pegging enables for equitable growing space to each tree and some competition among trees.

4.1.3.5. Pitting

Pitting consists in digging planting holes. Pitting is generally preceded by lining out and pegging. Good pitting creates the best environment for the young seedlings roots to grow fast. The ideal time of pitting is when the ground is at least a bit moist from early rains and at least two weeks before planting. The pitting standard is 25x25x25cm (Unique, 2015), but up to 40x40x40 cm may be required depending on the type of soil and species.

4.1.4. Planting and early maintenance

Good land preparation and pre-planting weeding are key to successful establishment of a plantation forest. The newly planted trees must have minimum competition and a good rooting environment to ensure optimum early growth. Planting should be done during the early rains, to give trees the best chance of a good start prior to the onset of the hot and dry periods that generally follow rainy seasons.

Planting is a critical operation because even with the best seedlings and excellent land preparation, bad planting will still result in a poor crop. The seedling should be placed upright in the hole, but deep enough to cover the root plug and some of the stem (up to 2cm). The soil should be returned into the hole around the roots, making sure that the seedling and roots remain in a vertical position.

4.1.4.1. Blanking (Beating up)

It is important to raise (or order) up to 15-20% extra plants to replace the failures from the initial planting. A quick survival assessment, preferably within two weeks of the initial planting, should be carried out by counting the failures in a sample number of lines. In general, if the survival is below 90% (i.e. over 10% deaths), blanking is recommended using the same seedling stock that was used for the original planting. Late blanking and using different seed stock from the original planting are the main causes of growth variability in many plantations.

4.1.4.2. Weeding /cleaning

Weeds have a negative impact on tree growth and can seriously reduce the productivity of a newly established plantation forest. This is because weeds compete with the trees for nutrients, light and water. The most effective way of controlling weeds in plantation forestry is by dealing with them before planting (pre-planting weed control).

There are several methods of weed control including chemical (e.g. Glyphosate herbicides), manual (e.g. hoeing, slashing), mechanical (e.g. tractor) methods and even animal browsing. Timing and follow-up of weeding operations is vital to ensure that weeds are eradicated when they are still small.

4.1.4.3. Pruning

In timber or pole production, pruning is a quality operation by removing lower branches to allow the formation of clear, knot-free timber. Timely and good quality pruning produces clean stems. Pruning should be done using the right tools and trained personnel to prevent damaging the stem. Late pruning or leaving the trees to self-prune (as explained in the next section)- results in dead knots in the wood and these can be a serious cause of degrade in sawlogs. Early pruning (brushing or access pruning) in young conifer plantations also allow easy movement in the plantation and prevention of damages from rodents. The timing of pruning varies depending on site and species. Access pruning can be done at 1-2 years for eucalypts and 3-4 years for cypress and pines.

4.1.4.4. Thinning

Pruning and thinning are intimately linked when the objective of management is the production of good quality timber or poles. In timber or pole production, thinning is a key forest management tool to improve stands by removing poor stems and concentrating increment on the remaining, superior trees. Thinning will increase the growth rate and the value of the remaining trees. It is important that thinning is carried out on time and by well trained personnel. If well planned and executed on time, thinning can yield an important, early income for growers. The first thinning can be carried out at 2-3 years in eucalypt plantations and at 4-6 years in Cypress and pine plantations.

4.2. Monitoring and evaluation of forest plantation activities

Monitoring and evaluation is an essential part in ensuring adherence to standard specifications of plantation establishment activities. A proper monitoring and evaluation plan will among others control and assure acquisition of good seeds/planting materials, efficient pre-treatment and handling of seeds, proper tree nursery management activities (germination, transplanting, nursery care, grading and hardening of seedlings), planting site preparation, early and intermediate tending/maintenance of a newly established plantation forest (e.g. beating up, release treatments (weeding, cleaning and liberation cutting), and pruning). The staff in-charge of monitoring and evaluation of newly established plantation forests can proceed with the following monitoring procedures and tools.

4.2.1. Tree nursery level

The Forest Service Provider (FSP) should produce sufficient good quality seedlings equal to the number of surviving tree to be planted defined in the contract, plus a provision of 15-20% of extra additional seedlings in order to allow for:

- Compensation of seedling mortality during first planting operations of October-December (transport, transplanting, after shock first weeks growing);
- Beating-up (Blanking, blank filling-up) after first dry season (February-April) just after first planting, in order to compensate mortality due to dry season, eventual

grazing, termites, etc.

The exact percentage of additional seedlings to be produced (15-20%) must be defined in the contract and should depend on the resistance of the concerned species and the site context and potential risk of seedling mortality (e.g. intensity of dry/rain season, soil quality, existence of termites, risk of grazing, risk of fire, etc.).

Generally, the nursery should be prepared from **March** and seed sowing should consider the species propagation characteristics in order to have tree seedlings ready to be planted in the field by **October**. So the acceptance of seedlings production should therefore be organized at the latest end of **September**.

The tree nursery should be constructed in such a way to allow an easy monitoring and evaluation of the quantity/quality of plants. Therefore, the contractor should ensure the systematic arrangement of the seedlings in the nursery beds:

- By species;
- Separate in different nursery beds:
    - Good seedling ready for planting (Standing beds): acceptable seedlings should be placed one next to each other in rows and complete columns (seedlings pots of different sizes should not be mixed) in order to facilitate counting;
    - Good seedling but not yet ready (still growing phase); and
    - Seedlings in bad condition to be discarded;

Acceptable seedlings for planting must be:

- ✓ Young enough with high recovery rate potential and rapid growth;
- ✓ Having a height greater than or equal to 15cm but not exceeding 30 cm or 2 times the length of the pot (shoot/root ratio: 2:1);
- ✓ Healthy, vigorous (freshness), not puny, well balanced with stem non-bifurcated and injury free;
- ✓ Have received hardening-off treatment (reduction of shading, gradually exposed to the Sun, cut of the roots protruding pots).

During monitoring, for each species, the total number of seedlings should be counted and

Table 1 completed in the nursery.

Table 1. Assessment of seedlings in the nursery

<table>
<tr><td colspan="6">Nursery name & Location:</td><td colspan="4">Assessment Date:</td></tr>
<tr><td>Species</td><td>Source of Seeds</td><td>Quantity of seeds (kg)</td><td>Sowing date</td><td>Expected number of seedlings QP Including 15-20% extra (A)</td><td>Actual healthy, acceptable number of seedlings really produced, ht≥15cm QR(B)</td><td>Healthy non acceptable seedlings, ht<15cm</td><td>Number of bad quality seedlings</td><td>% seedling production success rate (=B/A*100)</td><td>Recommendation</td></tr>
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<tr><td colspan="10">Assessment team:</td></tr>
<tr><td colspan="5">Name</td><td colspan="2">Institution / Position</td><td colspan="3">Signature</td></tr>
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4.2.2. Site Preparation level

Site preparation activities include vegetation clearing, extraction/debarking of stumps, digging of anti-erosion ditches, creation of fire breaks, lining out and digging of planting holes.

4.2.2.1. Clearing and extraction/debarking of stumps

In some afforestation or rehabilitation, stump extraction or simply debarking may be needed. In the case, the contract stipulates stump extraction, the stump must be uprooted. In case the agreement is on stump debarking, the stump bark should be removed and coppices controlled until the stump dies completely.

Monitoring of stump extraction or debarking can be done as follows:

- full counting if the site is small and/or the number of stump is not so high (<1000)
- Sampling if the number of stumps is greater than 1000:

- Use plots of 30mx30m distributed randomly across the area (**<u>A in ha</u>**) of the site in the way to be the most representative;
- the number of plots (**<u>np</u>**) must be estimated in order to sample at least 10% of total number of stumps;
- the number of stumps really and adequately treated must be counted in every plot (**<u>ns</u>**);
- the total number of stumps really and adequately treated for the entire site (**QR** in number of stumps) is estimated as follows:

  QR = A x (sum of ns) / (np x 0.09)

4.2.2.2. Erosion control ditches

In sloping areas, erosion control ditches must be systematically arranged in a staggered arrangement (quincunx) along the contour lines with standard dimensions of 40-50 cm wide, 60 cm deep and 2.5m to 4 m in length.

4.2.2.3. Creation of firebreaks

Firebreaks should be established as set in the contracts (5-10m wide cleared, all grass and inflammable biomass removed). The disposition and space between firebreaks generally depend on each site context and should be agreed on with Contracting Authority before establishment. The estimation/measurement of quantity of firebreak (in meters) really and adequately realized in the field (**QR**) will be done according to best method agreed by the assessment team in the field in function of site and works configuration.

4.2.2.4. Lining out and digging of planting holes

Lining out is done to ensure that trees are planted at the required spacing. Lining out enables for equitable growing space to each tree and some competition amongst trees. Lining out is followed by pegging and digging of planting holes. The minimum dimensions of the planting holes should range between 25x25x25cm and 40 x 40 x 40 cm depending on soil and species types.

In each site and for each of the above type of preparation works, QR is compared with QP (quantity planned for the site) in order to determine the final quantity that has to be considered as acceptable (**<u>QRA</u>**) and fill Table 2 and 3 below.

- If QR > QP, **QRA = QP**;
- If QR < QP, **QRA = QR**.

Table 2. Assessment of site preparation works (Afforestation)

Site name & Location:								**Assessment Date**:				
Block no.	Site clearing/cleaning (ha)			Erosion control Ditches (m)			Fire Breaks (m)			Planting holes		
	QP	QR	QRA	QP	QR	QRA	QP	QR	QRA	QP	QR	QRA
1												
2												

Assessment team:		
Name	**Institution / Position**	**Signature**

Table 3. Assessment of site preparation works (Plantation Rehabilitation/ reforestation)

Site name & Location:											**Assessment Date**:				
Block no.	Stump extraction (number of stumps)			Debarking (number of stumps)			Erosion control Ditches (m)			Fire Breaks (m)			Planting holes		
	QP	QR	QRA	QP	QR	QRA	QP	QR	QRA	QP	QR	QRA	QP	QR	QRA
1															
2															

Assessment team:		
Name	**Institution / Position**	**Signature**

4.2.3. Planting and early maintenance activities level

The objective of acceptance is to get an accurate estimation of the total number of surviving seedlings (**QR**) properly planted (in accordance with agreed technical specifications), on the afforested/reforested site.

The assessment for acceptance of a newly established or rehabilitated forest plantation should be done in two instances. The intermediate acceptance of plantation should be done after beating up, one year after initial planting. The second assessment will be done at the end of the second year after initial planting and should be the reference for final handover. The assessment of stocking and survival rates can be conducted as follows.

4.2.3.1. Sampling design

The random sampling method should be used to assess stocking and planted trees survival rates. Sample points (sampling units) must be randomly distributed in the entire area of the planted site to ensure that the sample is sufficiently representative.

The following number of sample points **(NSP)** can produce reliable estimates:

- For site with area < 0.5 ha: 1 to 2 sample points
- For site with 0.5 ha< area < 2 ha: 3 to 10 sample points
- For site with area > 2 ha: 10 to 20 sample points

4.2.3.2. Estimation of plantation tree density

The method consists in sampling of approximately 10% of theoretical number of trees to be planted and recording their state/condition (good condition/dead/missing/poor condition). For each sample point, the process involves:

- Measurement of the total distance between the 1st and the 11th theoretical trees in the same line, equivalent to 10 tree spacing on the line (**SL, [meter])**.
- Measurement of the total distance between the 1st and the 11th theoretical parallel lines, equivalent to 10 spacing between adjacent lines (**SW, [meter])**

Dead trees or no planted holes must be taken into account as shown in Figure 4 (**green**: living plants; **red**: missing/dead plants).

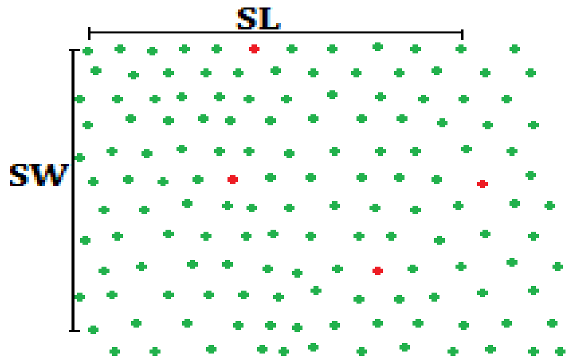

Figure 4. Sample point setting and measurement (FMBE, 2020)

The calculation of theoretical plantation tree density (Td) (number of theoretical plants or holes/ha) can be done as follows:

After **SW** and **SL** measurement in every sample point, the average of spacing between trees in line (**SLm, [meter]**) and the average of spacing between trees of parallel lines (**SWm, [meter]**) are calculated as:

The plantation tree density **(Td) = 10,000 / ((SLm) x (SWm)) [trees/ha]**

The **Survival rate (SR)** estimation (% of surviving trees / theoretical plantation tree density).

Npt = Number of theoretical trees/holes to be sampled per sample point (per sample unit)

NbST = ThNT /(10*NSP) where:

- ThNT= Total theoretical number of trees to be planted in the total area of the site
- NSP= number of sample points to be done in the site

For each sample point, every theoretical tree or hole (from 1 to Npt) will be controlled, following 2-4 lines in a given direction. The total number of theoretical plants (**Npt**) actually controlled is recorded as well as the total number of surviving plants (**Nps**).

The average survival rate is calculated as follows: **SR = Nps/Npt x 100 (%)**

Data collection for the assessment of seedling health and survival rates can be undertaken using the following form (Table 4).

Table 4. Monitoring form for seedling survival rate and health

Site name & Location:					**Assessment date:**					
Sample point no.	Distance between a number of trees (e.g. 10)				Number of Theoretical plants (Npt)	Number of Surviving trees (NPS)	State of health of seedlings			
	Along line		Between lines				Good condition	Poor condition	Dead	Missing
	SL (m)	Number of spacings	SW (m)	Number of spacings						
1										
2										
….										
Total	TSL	TNbS	TSW	TNbS	NPt	Nsp1 Nsp2	Tg	Tb	Td	Tm
Assessment team:										
Name					**Institution / Position**		**Signature**			

4.2.3.3. Early maintenance activities (wedding/cleaning)

The planned quantity **QP** (in ha) to be maintained is estimated for each site. The quantity really and adequately realized in the field (**QR** in ha) is estimated for each site as follow: **QRA = R% x QP**, where R% is the percentage of the area to be weeded/cleaned at the site that has been really weeded and cleaned. Table 4 can be used to monitor early maintenance works.

Table 5. Early maintenance works

Site name & Location:									**Assessment Date**:			
Block no.	Weeding/cleaning (ha)				Cleaning of Erosion Control Ditches (m)				Cleaning of Fire Breaks (m)			
	QP	QR	R (%)	QRA	QP	QR	R (%)	QRA	QP	QR	R (%)	QRA
1												
2												

…												

Assessment team:		
Name	**Institution / Position**	**Signature**

4.3. Norms of a newly well-established forest plantation

4.3.1. Acceptable norms for forest plantation establishment

A well-established forest plantation and/or a well rehabilitated forest should be conforming to different forest plantation specifications outlined in section 4.1. The norms of a well-established forest plantation are summarized in Table 6.

Table 6. Norms for a well-established forest plantation

Forest plantation activities	Recommended norms
Sourcing of seeds or planting materials	Seeds or planting materials should be ordered from the only official seed provider in the country, which is the National Tree Seed Center (NTSC). Seeds or planting materials acquired from other sources should not be accepted. While acquiring or producing planting materials, an additional 15-20% extra quantity should be included to take care of culling/grading and subsequent beating up.
Quality of seedlings	Vigorous seedlings with the following characteristics: • Shoot height of 15-30 cm (measured from the top of the pot); • Balanced shoot-root ratio of around 2:1; • Compact root system (that holds the soil medium in the pot); • Well root pruned (not pot-bound and coiled);

Forest plantation activities	Recommended norms
	• Seedlings must not be stressed (not root-pruned within 3 to 4 days).
Planting site clearing	All the vegetation that occurs on the site to be planted should be removed before lining out, pegging and pitting. Clearing facilitate these works (lining out, pegging and pitting), and weeding.
Planting site stump extraction / debarking	During clearing, stumps can be also extracted (uprooted) or debarked and coppices should be controlled until the stumps die completely.
Erosion control ditches	On steep slope sites, erosion control ditches must be created along the contour lines in an alternating and discontinued manner to ensure maximum protection against soil erosion. Good erosion control ditches are 40-50 cm wide, 60 cm deep and 2.5m to 4 m in length. The density of erosion control trenches/ditches depend on the slope and can vary as follows (MINILAF, 2018): **Slope** — **Distance between ditches (m)** 2% — 20-40m 5% — 15-22m 10% — 10-16 m 15% — 9-14m 20% — 8-15m 25% — 6-10m 30% — 5-9m 35% — 4-8m 40-100% — 3-7m
Creation of firebreaks	Large forest plantations should be divided into compartments of less than 30 ha separated by firebreaks. There are two types of firebreaks: internal and external firebreaks. External firebreaks are belts or areas around a forest that are not flammable. A minimum of 10 m clear of vegetation is recommended for external firebreaks.

Forest plantation activities	Recommended norms
	Internal firebreaks are firebreaks within the plantation forest. Internal firebreaks are generally narrower than the external breaks but, a minimum width of 5m is recommended as a guideline. Firebreaks should be cleared regularly and all grass and inflammable biomass removed especially at the onset of the dry season.
Lining out, pegging and pitting	There are an infinite number of different spacings that can be used depending on site types, species and desired end products. Common spacing range from 2x2 m for fuelwood production to 3.0x3.0 m for timber production with various combinations depending on species, desired products and even maintenance costs. Lining out and pegging should be done to ensure that trees are planted at the required spacing in straight lines (on flat ground) or along the contour (on sloping ground). Pitting consists in digging planting holes. Pitting is generally preceded by lining out and pegging to create the best environment for the young seedlings roots to grow fast. Pitting should be done when the ground is a bit moist from early rains and at least two weeks before planting. Pitting standard is in the range of 25x25x25cm to 40x40x40 cm depending on the type of soils and species.
Planting	Planting should be done in dug holes during the early rains, to give trees the best chance of a good start prior to the onset of the hot and dry periods that generally follow rainy seasons. The seedling should be placed upright in the hole, but deep enough to cover the root plug and some of the stem (up to 2cm). The soil should be returned into

Forest plantation activities	Recommended norms
	the hole around the roots, making sure that the seedling and roots remain in a vertical position.
Beating up (blanking)	About two weeks after planting, the assessment of failures in a sample number of lines should be done. In general, if the survival is below 90%, blanking is recommended immediately using the same seedling stock that was used for the original planting. Late blanking and using different seed stock from the original planting are the main causes of growth variability in many plantations.
Weeding	Weeds compete with the young trees for nutrients, light and water. The most effective way of controlling weeds is by dealing with them before planting (pre-planting weed control). Timing and follow-up of weeding operations is vital to ensure that weeds are eradicated when they are still small. A radius of about 1 m diameter around planting pits should be kept weed-free. Weeding frequently (when the weeds are small) reduces weeding costs and maximize site productivity.

4.3.2. Acceptable survival rates by ecological zones

The survival rate of planted trees is influenced by many factors such as ecological and climatic conditions (e.g. poor or inadequate soils –hardpan, rocks, shallow soils, etc.; drought, hot or cold temperature, etc.); human and animal disturbances (e.g. trampling, grazing, uprooting, etc.); pests and diseases; unhealthy seedlings, as well as lack of effective early maintenance activities (especially weeding). However, among these factors, the most limiting are ecological and climatic conditions on which management has very little influence. Since, most these conditions are generally distributed along altitudinal gradient in Rwanda (e.g. in Rwanda high altitude is associated with high annual rainfall and low temperatures while low altitude is associated with low annual rainfall and high temperatures), the assessment of acceptable survival rates was based on stratification of ecological conditions in three zones: (1) High altitude; (2) Middle altitude, and (3) Low altitude zones. Statistics extracted from various handover reports by a number of forest restoration projects in different parts of the country were used to derive acceptable survival rates in the different three zones (Table 7).

Table 7. Observed survival rates in plantation forest in different parts of the country

Ecological zone	District	Period of		Size (ha)	Plantation Forest				Sources
		Planting	Assessment		Expected (holes/ha)	Achieved (trees/ha)	Average survival rate (%)		
							Inclined surface	Plan surface	
High altitude	Gicumbi	2019-2020	June 2020	100.0	2,624	2,749	99.6	104.7	FMBE (2020)
		2014-2015	July 2015	27.9		1,853	86.03		PAREF Be (2015)
		2013-2014	May 2014	67.1	1,623	1,565	96.46		PAREF Be (2014)
	Gakenke	2019-2020	May 2020	109.7	2,694	2,850	98.2	105.8	FMBE (2020)
		2014-2015	July 2015	131.4		1,913	91.84		PAREF Be (2015)
		2013-2014	May 2014	109.4	1,645	1,536	93.54		PAREF Be (2014)
	Rulindo	2019-2020	May-June 20	114.08	2,636	2,694	96.9	102.2	FMBE (2020)
		2014-2015	July 2015	21.9		1,736	99.2		PAREF Be (2015)
		2013-2014	May 2014	26.4	1,600	1,588	99.3		PAREF Be (2014)
	Rutsiro	2020-2021	Feb 2021				96.0		EWMR (2021)
	Ngororero	2020-2021	Feb 2021				93.0		EWMR (2021)
Average (99% confidence level of the mean)							**95.5 ±3.9**		
Middle altitude	Nyanza (OSEPECCA)	2015-2016	April 2017	30.3			85.0		RWFA PEGREF (2017)

Ecological zone	District	Period of		Size (ha)	Plantation Forest				Sources
		Planting	Assessment		Expected (holes/ha)	Achieved (trees/ha)	Average survival rate (%)		
							Inclined surface	Plan surface	
	Nyanza (KOPUGIMU)	2014-2016	April 2017	65.3			87.0		RWFA PEGREF (2017)
Average (99% confidence level of the mean)							**86.1 ± 4.9**		
Low altitude	Nyagatare	2018-2020	June 2020	926.0	1,600	-	95.2	-	RFA (2020)
	Rwamagana	2018-2020	June 2020	284.0	3,443	3,074	88.0	99.9	FMBE (2020)
	Bugesera	2014-2015	July 2015	109.0		1,575	87.3		PAREF Be (2015)
		2013-2014	May 2014	26.5	2,280	1,675	72.9		PAREF Be (2014)
	Kirehe	2014-2015	July 2015	188.0		2,093	85.4		PAREF Be (2015)
		2013-2014	May 2014	166.8	1,727	1,492	86.1		PAREF Be (2014)
	Ngoma	2014-2015	July 2015	82.0		2,800	82.2		PAREF Be (2015)
		2013-2014	May 2014	141.9	2,505	1,660	80.3		PAREF Be (2014)
Average (99% confidence level of the mean)							**84.7 ± 8.0**		

In order to take care of maximum uncertainties due to weather and other unpredictable factors, the probability of success after forest plantation establishment was estimated using the 99% confidence level of the mean survival rates reported in different afforestation projects throughout the country. The lowest confidence interval limit was therefore proposed to be the minimum acceptable survival rate in that ecological zone. The following acceptable survival rates (99% confidence level of the mean) for different ecological zones are proposed (Table 7):

(1) High altitude zones: 92% - 100% survival rate

(2) Middle altitude zones: 81% - 100% survival rate

(3) Low altitude zones: 77% -100% survival rate

Assuming a plane surface spacing of 2.5 x 2.5m at planting, the theoretical planting density (stocking) is 1600 trees per hectare. Therefore, the thresholds for survival rates should be as follows:

(1) High altitude zones: 1,472 - 1600 trees per hectare.
(2) Middle altitude zones: 1,296 - 1600 trees per hectare.
(3) Low altitude zones: 1,232 - 1600 trees per hectare.

4.4. Threshold levels of a well-established forest plantation

The threshold levels of a well-established forest plantation or rehabilitation are in accordance to acceptable standards or norms for a forest plantation. A well-established plantation forest should therefore meet all the recognized norms of forest plantation. The following general threshold levels are proposed for different ecological zones.

Table 8: Threshold levels of a newly established or rehabilitated forest plantation

Standard forest plantation activities	**Recommended threshold levels**
Acquisition of seeds or planting materials	Required amount of planting materials plus 15-20% extra should be ordered from an officially recognized provider.
Production of planting materials (seedlings)	Only vigorous seedlings with a shoot height of 15-30 cm should be planted.
Planting site clearing/cleaning	All vegetation should be removed before lining out, pegging and pitting. Stump should extracted or debarked.
Creation of erosion control ditches	Acceptable erosion control ditches are 40-50 cm wide, 60 cm deep and 2.5m to 4 m in length. Recommended distance **between erosion control ditches (m)** (MINILAF, 2018):

Standard forest plantation activities	**Recommended threshold levels**
	Slope **Distance between ditches (m)** 2% 20-40m 5% 15-22m 10% 10-16 m 15% 9-14m 20% 8-15m 25% 6-10m 30% 5-9m 35% 4-8m 40-100% 3-7m
Creation of firebreaks	A minimum of 10 m for external firebreaks and 5m for internal firebreaks. The density of firebreaks depends on fire risk but forest plantation blocks must divided into smaller compartments less 30 ha separated by firebreaks.
Lining out, pegging and pitting	Spacing may range from 2x2 m for fuelwood production to 3.0x3.0 m for timber production. But other spacings are acceptable depending on desired products and maintenance costs. Pitting standard is in the range of 25x25x25cm to 40x40x40 cm depending on the type of soils and species.
Planting	Planting should be done during the early rains, to give trees the best chance of a good start prior to the onset of the hot and dry seasons. October and March are generally the best months for tree planting in most part of the country.
Survival rates assessment	Minimum survival rates by ecological zone should be: (1) High altitude zones: 92% - 100% survival rates

Standard forest plantation activities	Recommended threshold levels
	(2) Middle altitude zones: 81% - 100% survival rates (3) Low altitude zones: 77% -100% survival rates
Beating up (blanking)	Start two weeks after planting using the same seedling stock that was used for the original planting.
Weeding	A radius of 1 m diameter around planted seedlings should be kept weed-free.

5. DISCUSSION

A well-established plantation forest requires quality plants (vigorous seedlings), appropriate planting spacing (adequate stocking), cleanliness (weed- free), and effective protection against fire and soil erosion. In the case of rehabilitated plantation forests (re-conversion of old Eucalyptus plantations), stump extraction or effective control of stump coppices is also another important requirement for a well-established plantation forest.

5.1. Vigorous seedlings

Seedling quality is a combination of height, diameter, plant nutrition, health, root size and shape. Altogether, these characteristics determine how well the plant will establish itself in the field, and they affect the rate of survival after planting. Only the best quality trees should be planted and the rest should be discarded.

At planting, seedlings should be vigorous with a shoot height of 15-20 cm (measured from the top of the pot), well root pruned (not pot-bound and coiled), but not root-pruned within 3 to 4 days). In order to ensure adequately fast early growth, the minimum dimensions of the planting holes can range from 25x25x25cm to 40 x 40 x 40 cm depending on soil and species types but even larger pits up to 60x60x60cm are possible. After planting, seedlings should exhibit sufficient vigor in terms of form appearance and number of healthy leaves. Malformation of leaves is often an indication of stress, diseases or nutrients deficiency.

5.2. Adequate stocking

A newly well-established plantation forest should have adequate stocking depending on objective of the plantation. In Rwanda, the recommended planting spacing is 2.5 x 2.5 m (1600 trees/ha) for timber production forests and 2.0 x 2.0 m (2500 trees/ha) for fuelwood production. However, the reality in the field revealed that spacing can be as dense as below 2x2m (i.e. more than 2500 trees/ha). For example, some plantations established in Gishwati by LAFREC project, have even more than 2700 trees/ha (LAFREC report, 2020). The same for plantation forests established by FMBE project in Rwamagana (3074 trees/ha), Rulindo (2749 trees/ha), Gakenke (2850 trees/ha) and Gicumbi Districts (2694 trees/ha) (Table 7).

In fact, due to measurement of tree spacing on inclined surfaces instead of plan surface, the planting density exceeds the planned density. This is why despite mortality of some plants after planting, the achieved survival rates were still more than 100% in many plantation forests established under FMBE project (Table 7). However, in order to adhere to standard spacing, there is need to make slope correction while measuring tree spacing during lining out and pitting. This will ensure that when planting spacing is 2.5 x 2.5 m for timber production forests, there are 1600 trees/ha and if the spacing is 2.0 x 2.0 m for example for fuelwood production, then there are 2500 trees/ha.

In terms of survival rates of newly planted trees, after analyzing a number reported survival rates in different parts of the country, minimum survival rates were proposed as:

(1) High altitude zones: 92% - 100% survival rate

(2) Middle altitude zones: 81% - 100% survival rate

(3) Low altitude zones: 77% -100% survival rate

Assuming a plane surface spacing of 2.5 x 2.5m at planting, the theoretical planting density (stocking) is 1600 trees per hectare, and the acceptable ranges for tree survival rates should be as follows:

(1) High altitude zones: 1,472 - 1600 trees per hectare.
(2) Middle altitude zones: 1,296 - 1600 trees per hectare.
(3) Low altitude zones: 1,232 - 1600 trees per hectare.

However, since the acquired data were not designed for setting up the standard survival rates and not all districts were covered, there is need to investigate further the adequate survival rate minimum thresholds through a research specifically designed for assessing success and survival rates after tree planting in different ecological zones.

5.3. Plantation forest cleanliness

A newly well-established plantation forest should be free of weeds. Good weed control begins long before planting. During land preparation vegetation that will potentially compete with the trees must be removed or controlled (this include stump extraction/debarking and control of coppices). In the case of forest rehabilitation (conversion) of old plantations or even reforestation after harvesting, if the stumps are not uprooted, they should be debarked and coppices controlled (repeatedly removed) until the stumps completely die.

A thorough cleaning of the site before planting helps to achieve high survival and rapid early growth of the planted trees. "Weed little and often" is the golden rule of weed control. The focus should be on keeping 1 m diameter around planting pits weed-free and ensure that the weeds in the inter-rows do not compete with the planting lines. Weeding frequently (when the weeds are small) also reduces weeding costs and maximize site productivity. The timing of various weed control measures generally depends on the nature and intensity of the weed problem. Wet sites generally develop more weeds than drier sites. Weeds need to be controlled until the plantation forest reaches "canopy closure‟ (around 2-3 years for

Eucalypts, pines and cypress), when the trees themselves are able to suppress them. Eucalypt plantations are particularly vulnerable to weeds competition and therefore an intensive weeding program should be developed to ensure 100% weed control after planting. This will ensure maximum growth of the trees and promotes plantation health.

5.4. Effective land and forest protection

As part of plantation site preparation, sufficient number of firebreaks should be created. The required number of firebreaks should be agreed on with the contracting authority right at the signing of contract for plantation works. External firebreaks should be wide enough to stop a normal fire by themselves. The width of external firebreaks generally depends on the potential fire risk but a minimum of 10 m clear of vegetation is recommended. Internal firebreaks (firebreaks within the plantation forest) are usually narrower than the external breaks because they are not usually designed to stop the fire themselves but to allow access in the plantation. The number of internal firebreaks and their width depends on the fire risk and the size of the forest plantation. It is important to note that the number of firebreaks should be agreed on during contract negotiation in order to avoid potential disputes during reception of forest plantation works.

In sloping areas, sufficient number of erosion control ditches should be established throughout the plantation in a staggering arrangement along the contour lines. Erosion control measures limit the threats from erosion and even landslides after heavy rains. As mentioned above in section 4.3, the density of ditches depends on the slope of the area and should be set up right before during contract negotiation to avoid potential disputes during reception of forest plantation works.

6. CONCLUSION AND RECOMMENDATION

6.1. Conclusion

During acceptance of forest plantation works, all the aspects listed in section 4.4 and proposed threshold levels should be assessed carefully and fairly using the monitoring and evaluation tools provided in section 4.2. In addition to considering the proposed threshold levels, the assessment should also take into consideration various factors which may interfere with optimum performance of a newly established forest such as weather and edaphic conditions, and diseases, pests and anthropogenic disturbances in different ecological zones. These factors are generally the reason behind proposed threshold levels for survival rates in different ecological zones instead of setting them to 100%.

High altitude zones generally enjoy high rainfall and therefore rarely experience soil water deficit, but heavy rainfall events in these zones can also lead to flooding and landslides. Low altitude zones are generally characterized by reduced annual rainfall and frequent water deficit soon after the rain season which leads to drought stress and frequency of pests including termite infestation. Animal grazing and anthropogenic activities such as mining, fodder collection, and fires can also reduce optimum performance of newly established forest plantations.

In this study, it was observed that most forest plantation establishment or rehabilitation works currently use spacing dimensions on inclined surface instead of plan surfaces. The stocking density estimated on inclined surface area is generally higher than that calculated on plan surface area. This makes it difficult to compare standard stocking and survival rates during monitoring and evaluation before acceptance of forest plantation or rehabilitation works. In fact, in many instances, the stocking in forest plantations established under FMBE project was higher than planned stocking despite mortality of some seedlings. In other words, despite mortality of some planted seedlings, the survival rates still exceeded 100%!

As a result of using inclined surface instead of plan surface during lining out and pegging, the spacing between trees (and thus the stocking density) varied from one site to another even for same desired end product. This makes it difficult to design and implement appropriate silvicultural treatments to achieve optimum performance of the forest plantation. This issue also does not make it easy to make reliable estimates of site productivity and economic returns unless silvicultural improvement treatments are applied as early as possible to ensure optimum growth for a given site. Therefore, there is need to enforce using plan surface dimension instead of inclined surface dimensions during lining out and pegging before pitting and planting.

6.2. Recommendation

This study has made use of the observed survival rates and spacing from various tree planting projects. However, not all regions were adequately covered because relevant data were missing. Furthermore, it was not easy to separate exotic and indigenous species because provided data were not segregated accordingly. Therefore, a specific study on standard tree spacing (measured on plane surface) for different desired end products and survival rates of planted seedlings for major tree species (both exotic and indigenous species) is recommended for different agro-ecological zones in the country. Such a study would provide more reliable scientific basis for allocating different thresholds for newly established plantation forests by agro-ecological zone in Rwanda for both exotic and indigenous tree species. In the meantime, the proposed thresholds should be used during acceptance of well-established plantation forests in indicated ecological zones throughout the country.

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8. ANNEXES

Annex 1: Staff Names, Qualification and Responsibilities

No	Staff Names	Qualification	Experience	Responsibilities
1	Prof NDUWAMUNGU Jean	PhD, Professor of Forestry	+ 20 years	Team Leader
2	Mr. SIBOMANA Gaad	Bachelor of Science in Forestry (Ao)	+ 10 years	Forester, Assistant to the team leader
3	Mr. NGAYABERURA Jean Bosco	Bachelor of Science in Forestry (Ao)	+ 1 year	Forester, Assistant to the team leader
4	Mr. NIYONSABA Emmanuel	MSc. Environmental Management	+ 1 year	Coordination of activities

Annex 2: Checklist for key informants from major tree planting stakeholders

Questions were refined depending on stakeholder being interviewed to reflect specialization of each one. Stakeholders consulted include: RFA, REMA (LAFREC), ENABEL, IUCN, NFC, ICRAF, RAB, and ARCOS.

(1) Do you have any guidelines for accepting tree planting works in different agro-ecological zones?

(2) Which tools do you use during monitoring and evaluation of tree planting works in different agro-ecological zones?

(3) Which parameters do you generally assess during monitoring and evaluation of tree planting activities?

(4) What are the criteria do you use to decide that a newly established forest plantation is well-established or not?

(5) Which tree species have you planted during the last ten years in different agro-ecological zones?

(6) Do you have survival rates for the different tree planting projects you have carried out?

(7) What are the survival rates do you consider as acceptable for different agro-ecological zones and why?

(8) Any other information that could guide in setting up acceptable thresholds for a well-established plantation in different agro-ecological zones for most commonly planted species.