A Review of the Application of Aerial Seeding Technology in Restoration of Degraded Forests

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Abstract

The use or deployment of aerial seeding technology in forestry has shown to be efficient, rapid, and most suitable for restoration of large degraded and inaccessible areas. The technology is relatively cheaper compared to conventional methods of restoration. Although aerial seeding has been widely used globally in forestry, its application is comparatively new in Kenyan forestry. This paper reviews selected experiences from countries that pioneered the use of aerial seeding in restoring large degraded forestlands and highlights key requirements for successful aerial seeding programs. Literature shows that the use of aerial seeding in forestland restoration dates back in 1950s with reports showing moderate to high success rate in USA, Canada, Russia, Australia, New Zealand, China and India. Success of aerial seeding is largely determined by interaction of factors such as seed characteristics, timing of seeding, site conditions or micro-site environment. Competition from surrounding vegetation, and seed predation affect the efficiency of aerial seeding negatively. The paper concludes that aerial seeding technology is efficient, cost effective and therefore suitable for use in the restoration of the expansive degraded forests in Kenya.

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Key words: Key words: Global, Aerial seeding, Forestry, Restoration, Degraded areas

Introduction

Aerial seeding is a technique for direct broadcasting of seeds by use of aerial means such as a drone, plane or a helicopter (Buters 2019). It is an alternative to ground-based seeding methods that include planting by hand or tractor seeding (Barnett 2014). This technology is a well-established technique for sowing pastures as well as agricultural crops (Dowling et al. 1971). It is also suitable for rehabilitation of areas that are inaccessible, steep slopes, high elevation areas such as the moorland, expansive degraded woodlands, enriching grasslands/ pastures, steep watersheds, eroding mountain slopes, bare hillsides and soil-banks (Anderson et al. 2009; Bidwell 1996; Groen & Woods 2008; Xiao et al. 2015). Although this technology has wide application globally, it is relatively new in restoration of forest landscapes in Kenya. However, it has been used in agriculture to enrich pastures to improve livestock production and aerial sprays to control pest and diseases in large scale cereal production as well as rehabilitating national parks of Kenya (Mnene 2006).

In Kenya, land degradation varies from moderate to severe across different landscapes (Bai et al. 2008; MENR 2016). Forest degradation and deforestation in Kenya are mainly driven by agricultural expansion; settlements; infrastructure development; unsustainable utilization for timber, poles, fuelwood; unregulated grazing; poor governance and institutional failures in the forest sector (Kweyu et al. 2020). Effects of degradation include; habitat fragmentation, loss of biodiversity, loss of soil fertility, soil erosion, siltation and sedimentation of water bodies, water stress, flooding, landslides and climate change (Gichu et al. 2016). Therefore, restoring these landscapes is paramount towards improving human livelihoods, enhancing food security, biodiversity conservation and climate stability (MENR 2016).

Kenya has national and international commitments of restoration. These include constitution commitment to achieve 10% tree cover by 2030, international pledge of restoring 5.1 million hectares of degraded landscapes under BONN challenge and reducing greenhouse gases from the forest sector by 2030 by thirty two percent (32 %) as part of Kenya's Nationally Determined Contribution to climate change and achieving land degradation neutrality by 2030. This therefore requires fast and reliable technologies such as aerial seeding to be utilized to ensure the commitments are attained. The objectives of this paper are therefore to review global experiences and highlight lessons learnt from countries that have implemented aerial seeding with an aim of piloting this technology in restoration of degraded forest landscapes in Kenya.

Materials and methods

Online literature search was undertaken in English language according to (Nunez-Mir et al. 2015) with slight modifications. Research4Life databases were searched including Hinari, OGORA, OARE, ARDI and GOALI. Additionally, other search engines such as Google scholar, institutional websites, databases and e-libraries WoS, Scopus were used. The search was made using keywords; aerial seeding; forestry; global restoration, rehabilitation, degraded areas, inaccessible areas, Kenya. A total of 10, 000 citations were retrieved and filtered to only those focusing on restoration in forestry. A shortlist of 70 papers were reviewed by region to understand cases of aerial seeding and relevant literature was selected.

Results

Global experiences of aerial seeding in forest restoration

In industrialized countries, aerial seeding is already regarded as a practical reforestation technique with considerable success reported in the United States of America (USA), Canada, Australia, Russia, India and New Zealand (Joshi 1986). In the USA, aerial seeding programs in the 1940s were motivated by the need to promptly re-stock areas that became degraded following storms and large scale fires as well as areas considered inaccessible and difficult to restock by conventional methods (Peppin et al. 2010; Westveld, 1949). According to Kallander and Berry (1953), the State of Oregon used aircrafts to seed approximately 200 ha in 1946, which resulted in 21.7 % stocking of forests. In the same state, another 450 ha were seeded with aircrafts in 1947 (Bever, 1953). In order to increase the establishment of aerial seeding, seed protection was identified as a solution and by 1947, research had already begun to find a practical method of protecting seeds from predation (Beal & Kraus 2002). In 1953, concerted efforts by scientists developed a non-toxic commercial repellent to enhance seed protection (Moore and Debboun 2007). Subsequent operations of aerial seeding were greatly successful, stimulating widespread adoption of the technique including successful restoration of millions of acres of southern pine forests in southern USA (Barnett 2014). It is reported that, the Minnesota DNR Division of Forestry have successfully used helicopters for aerial seeding since the early 1970s for both upland and lowland conifer reforestation (Minnesota DNR Forestry 2018).

In Canada, use of airplane seeding of burned areas dates back to 1944 with notable experience by the New Brunswick Department of Lands and Forests which carried out aerial seeding of burned areas in 1947 and realized as high as 15,000 seedlings per hectare. In 1948, the Ontario Department of Lands and Forests broadcasted seeds using airplane at a density of 12,000 to 24,000 seeds per hectare and reported moderate success in stocking rate (Campbell 2002). These initial experiences generated great insights about cost of aerial seeding compared to other forest establishment methods and development of procedures on executing aerial seeding operation for best results (Kallander & Berry 1953). In years that followed, aerial seeding became the main form of reforestation in Canada in the 1960s and 1970s, with approximately 50 % of the total area being seeded using either fixed-wing aircraft or helicopters (Grossnickle and Ivetić 2017).

In Russia, aerial seeding in forestry dates back to 1933 with wide application in former USSR forestry, including coniferous trees in the Central areas; haloxylon in desert and semi-desert areas, and grasses in numerous areas (Novikov and Ersson 2019). Reports reveal that aerial seeding was carried out on 58,000 hectares in 1952 (Pesterev, 1952) and 22,600 hectares of taiga landscapes in 1953 (Viereck 1973). During re-establishment of forest over clear-cut areas in the republic of Komi from 1950 to 1959 where 1,000 ha were recovered annually, aerial seeding accounted for 64 % of the recovery (Everett 1994). In northern and north-western Russia, 43% of total artificial regeneration in 2002 was done by aerial seeding (Grossnickle and Ivetić 2017).

In Australia, the standard silvicultural techniques of achieving regeneration relied on retaining seed trees. This technique changed in 1964 when the first aerial seeding was carried out in logged areas of Alpine Ash using a small fixed-wing aircraft (Grose et al. 1964). In subsequent years, riparian and mountainous areas were seeded using larger airplanes as they were relatively cheaper than using helicopters. Helicopters were however, tested in 1967 and were found to be useful in seeding small areas especially in difficult locations (Rolland 1996). Fine seeds for aerial seeding were balled using kaolin clay and mucilage as adhesive, resulting in even spreading. Insecticide and fungicide were occasionally added to minimize predation by pests and improve seed survival (Loch 1997).

In New Zealand, many forests and pastoral lands were established using the aerial seeding (Douglas et al. 2007) method as it allowed establishment even in very harsh terrain such as steep slopes (Philipp 1958; Raintree 1991). Kaingaroa forests in New Zealand were seeded with*Pinus radiata* using aircraft in 1960s, but the practice was discontinued due to large consumption of seeds and uneven germination (Levack, 1973; Page, 1970).

China has a 55-year history of successful aerial seeding of forests (Li et al. 2007). Aerial seeding of trees and grasses has been implemented in 931 counties across 26 provinces. This translates to about 8.68 million hectares of forests by 2001, and accounting for 25% of the total artificial forests in China (Sannai 2003). As a result of this, a high plants density establishment was accomplished (Runnström, 2003).

In India, seeds of *Prosopis juliflora* , *Acacia nilotica* ,*Dalbergia sissoo* and *Helloptelea integrifolia* were dispersed from a fixed-wing aircraft over 863.5 ha of heavily ravined and eroded land in Chambal (Vedant, 1984). In another study, aerial seeding was carried out on 3,100 ha in Bangalore state of India (Bedell, 1998) to determine effectiveness of the technique on afforestation of difficult and inaccessible areas. The study by Bedell used treated and pelletized seeds prior to aerial seeding. Use of such seeds resulted in good germination of many species (Sivakumar et al., 2010).

Currently, application of aerial seeding is low globally (Grossnickle and Ivetić 2017). In majority of the countries that pioneered aerial seeding, the practise has been on a decline since the 1970s because most of the previously large open areas have been restored (Barett, 2014; Grossnickle and Ivetić, 2017). Aerial seeding is currently being used on only 3% of forest regeneration programs in Canada, with Ontario having the largest program at 13% of its reforestation program (Vovchenko et al. 2020b). In the United States, based on the last reported statistics (i.e. 1996), less than 1% of all planting (i.e. 8,516 ha) used aerial seeding (Groen and Woods, 2008). Further, the acreage under aerial seeding in the United States is minimal such that there are no available statistics on this practice (Lark et al., 2017). In Europe, areas undergoing aerial seeding are low to moderate acreage (Sweden 5%; Serbia 15%; Finland 22%) primarily because most of the land meant for forest development has been replanted (Ignatieva and Melnichuk, 2014).

Despite the potential of aerial seeding technologies to rapidly restore large areas over a short time, there is very low uptake of the same in the developing tropical countries, (Scheper et al., 2021) which have heavily relied on expensive methods of forest restoration using seedling production coupled with the perception that direct seeding may not be successful (Broadhurst et al., 2016). Studies by Barnett (2014), reported that predation of seeds by birds and rodents were the greatest obstacles to direct seeding methods of reforestation and resulted to low establishment in the early years. Other factors included human errors that would contribute to failure of direct seeding including; use of poor quality seeds and late sowing (Derr & Mann, 1971). A review by Grossnickle and Ivetić (2017) indicated that direct seeding resulted to lower field performance (survival and growth) compared to planting seedlings. The authors reviewed 23 studies on field performance of tropical forest species established via aerial seeding and noted that the practise resulted in average germination rate of 38% and an establishment level of 17 %, indicative of low level of initial stand establishment which should attain 55 % stocking. The low establishment, coupled with the requirements of large quantities of seeds, may explain the low interest in aerial seeding among foresters in majority of tropical countries (Wilson et al., 2013). Nonetheless, it is to be noted that other factors that include influence of site conditions, seeding rates, suitability of the species used and timing of seeding are key in the determining success of the technology and subsequent establishment and growth of the seedlings.

It is clear that more studies are required in order to guide the suitability of aerial seeding in the tropics taking into account the aforementioned factors, seed predation, among others, which may influence successful stand establishment from aerial seeding (Doust et al., 2008; Tunjai and Elliott, 2012). Fortunately, the experiences from the jurisdictions where aerial seeding has been used, provide important lessons to guide the piloting of the practice in many developing tropical countries like Kenya where there are huge areas that urgently require rehabilitation and mitigation against climate change.

Discussion

Planning of aerial seeding exercise

Proper planning of aerial seeding programs is required to ensure successful establishment of seedlings. Countries that pioneered aerial seeding followed steps (or guidelines) and specifications in setting up aerial seeding projects for rapid restoration of degraded lands (Kallander and Berry, 1953; Scott, 1970). Aerial seeding guidelines were developed from lessons generated by direct seeding experiments (Scott, 1970). Although the initial experiments were haphazard, poorly designed and carried through, later they were well-planned to allow for evaluation of all important factors that determine success or failures of direct seeding (Roe, 1963). From some of these experimental studies, Kallander and Berry (1953) highlighted the key factors to be considered for purpose of determining the adaptability to aerial seeding, namely: size of area, seed source, natural stocking, cover, soil condition, degree of burn, exposure and slope. It has also emerged that success in direct seeding requires adequate description of the area targeted for seeding, the sowing or application equipment (helicopter or fixed-wing aircraft), timing and seeding rate (Scott, 1970; Bassett et al., 2015).

Seed characteristics and ecosystem suitability

The success of aerial seeding is influenced by the ability of the seeds to germinate and also the capacity of the seedlings to establish during the first growing season and growth over the first couple of years (Dalling and Hubbell, 2002). Germination of seeds of individual tree species is also expected to be different depending on species requirements as determined by physiology, seed type (orthodox or recalcitrant), soil type (good or rocky) and degree of slope (gentle, flat or steep). It is known that good stand development is favoured by consistent optimum environmental conditions over a longer period after seed germination (Budelsky and Galatowitsch, 1999; Madsen and Löf, 2005; Rollett et al., 2015). Lodging of the seed in the soil is drastically reduced in sites where organic matter has accumulated thickly (Tesch et al., 1992). The best microsites for direct lodging of seeds are those that are disturbed, still 'fresh' and un-compacted, and with adequate soil moisture and moderate temperature of about $10 - 25°C$ (Winsa and Bergsten, 1994; Graae et al. 2011). Small seeding operations requires site preparation for example by burning, furrowing, or by disking. However, for large-scale aerial seeding, site preparation may not be possible or cost-effective (Birkedal et al., 2010). Weeds or competing vegetation have often resulted in low establishment rates from direct seeded operations but under certain conditions, they promote seedling emergence and survival (Valkonen, 2008).

Rate and timing of aerial seeding

Seed predation by insects, birds and rodents greatly undermine the success of direct seeding (Westerman et al., 2003; Willoughby et al., 2004). Species producing large nuts, are more vulnerable to predation and might require additional measures, such as treatment with repellents or physical barriers, to reduce the predation risk (Becker and Johnson, 2001; Renugadevi and Jayanthi, 2010; Sivakumar et al., 2010; St-Denis et al., 2013; Stanturf et al., 2014; Vovchenko et al., 2020a, 2020b). Aerial seeding also requires 25 % to 50 % higher seeding rates to establish same yields as other conventional methods like drilling (Ben-Zeev et al., 2020). This is mostly because with aerial seeding, the seed can often be on the soil surface longer making the seed more susceptible to predation by birds, insects and other animals (Leck 2012). The application of high seeding rate is therefore meant to cushion against possible losses through predation by birds, insects and other animals or unfavourable weather conditions. Aerial seeding should be carried out during the rainy seasons to ensure favourable conditions for seed germination (Harper et al., 1970; Jenkinson, 1981; Bonfil, 1998; Applestein et al., 2018).

Conclusion

Although there are few case studies in the tropics, the reviewed papers have shown that there is potential for aerial seeding not only in the agricultural sector but also in the forest landscapes. Key issues to consider should include the size of seeds, nature of the area to be reseeded and timing of seeding.

Success of aerial seeding is largely determined by interaction of factors such as seed characteristics, timing of seeding, site conditions or micro-site environment. Competition from surrounding vegetation, and seed predation affect the efficiency of aerial seeding negatively.

Aerial seeding is best suited in circumstances where forest establishment requires minimal human assistance and over landscapes where terrain hinders conventional forest establishment methods (Lamb, 2010). Ideal sites for aerial seeding, with high seed receptivity, are those with minimum organic materials and with disturbed soils that are not compacted. For success, environmental conditions should not be stressful and should be projected to consistently remain so for longer period post-seeding. Best chances for success are also greatly enhanced when seed materials have high viability and the ground has sufficient moisture. Whether to break dormancy or not prior to aerial seeding, requires knowledge on seed biology and further research. Aerial seeding generally requires large quantities of seeds to sufficiently stock the target site(s). Whenever seed supply is sufficient and conditions and tree species are right, aerial seeding would then make economic sense. Site preparation is not feasible for expansive sites targeted for aerial seeding. Choice of whether to use fixed-winged aircraft or helicopter does not matter.

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