Journal of Environmental Management 128 (2013) 204–209

Contents lists available at SciVerse ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Review

Casuarina in Africa: Distribution, role and importance of arbuscular mycorrhizal, ectomycorrhizal fungi and *Frankia* on plant development

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ARTICLE INFO

Article history:
Received 21 March 2012
Received in revised form
18 April 2013
Accepted 1 May 2013
Available online 7 June 2013

Keywords:
Casuarina
Ecosystem degradation
Mycorrhizal symbiosis
Frankia
Afforestation programmes

ABSTRACT

Exotic trees were introduced in Africa to rehabilitate degraded ecosystems. Introduced species included several Australian species belonging to the Casuarinaceae family. Casuarinas trees grow very fast and are resistant to drought and high salinity. They are particularly well adapted to poor and disturbed soils thanks to their capacity to establish symbiotic associations with mycorrhizal fungi -both arbuscular and ectomycorrhizal- and with the nitrogen-fixing bacteria *Frankia*. These trees are now widely distributed in more than 20 African countries. *Casuarina* are mainly used in forestation programs to rehabilitate degraded or polluted sites, to stabilise sand dunes and to provide fuelwood and charcoal and thus contribute considerably to improving livelihoods and local economies. In this paper, we describe the geographical distribution of *Casuarina* in Africa, their economic and ecological value and the role of the symbiotic interactions between *Casuarina*, mycorrhizal fungi and *Frankia*.

1. Introduction

The population explosion and rapid urbanisation are major threats in Africa, as they increase the dependence of the population on natural ecosystem resources. Overexploited ecosystems are degraded mainly as a result of a reduction in soil fertility. The introduction of nitrogen fixing and highly mycotrophic plant species is a promising way to increase soil fertility. Among these species, exotic trees such as *Casuarina* are widespread in tropical and subtropical zones where they play an important role due to their symbiotic relationships with mycorrhizal fungi and *Frankia* bacteria. These microorganisms increase plant growth and development (Zhong et al., 2010; Yang and Paszkowski, 2011). They also improve nutrient availability – particularly P and N- for the plant host and in return, they benefit from plant carbohydrates (He and Critchley, 2008; Smith and Read, 2008). However, the success of inoculation depends on the type, viability, efficiency and infectivity of the inoculum (Rossi et al., 2007).

Casuarinaceae species are actinorhizal plants which originated from Australia. The term casuarina comes from the Malay word 'kasuari' due to the resemblance of the twigs and the plumage of the cassowary bird (Boland et al., 1994). These trees are widely established around the world with the exception of Antarctica.

The family comprises four genera (*Allocasuarina*, *Casuarina*, *Ceuthostoma* and *Gymnostoma*) and approximately 86 species and 13 subspecies (Steane et al., 2003; Bisby et al., 2007). Among them, *Casuarina equisetifolia*, *Casuarina glauca* and *C. cunninghamia* are the most frequently introduced species in most African countries with the exception of Zimbabwe where *C. junghuhniama* is more widely planted (NRC, 1984). However, *C. equisetifolia* is the most widespread and the best known species. *Casuarina* grow best in humid tropical and subtropical climates in areas where the average rainfall ranges from 200 mm to 5000 mm, at altitudes between 0 and 1800 m above the sea level. Casuarina species are among the fastest-growing of all trees and, in their early growth stages, they can grow up to two to 3 m per year, and reach a final height of 20–30 m (NRC, 1984). The wood is dense, hard and smokeless. It produces high

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0301-4797/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.jenvman.2013.05.009

quality charcoal and burns with great heat even when green; it has low ash content. *C. equisetifolia* is one of the best types of firewood in the world (El-Lakany et al., 1990). The calorific value of its wood is up to 5000 kcal kg^{-1} and that of its charcoal more than 7000 kcal kg^{-1}. *Casuarina* is used in the reclamation of salt-affected land, as windbreaks, for the stabilization of sand dunes, and for the production of firewood and timber. However, up to now, little is known about the exact *Casuarina* distribution in Africa: its potential benefits for the rehabilitation of degraded lands and the management of soil fertility. This review focuses on: 1) the distribution and ecology of *Casuarina* in Africa, 2) its uses and 3) the importance of the symbiotic relationships between *Casuarina*, arbuscular mycorrhizal (AMF), ectomycorrhizal (EMF) and/or *Frankia* bacteria in improving the role of *Casuarina* in soil rehabilitation.

2. Geographic distribution of *Casuarina* and its ecological importance in Africa

2.1. Geographic distribution of Casuarina in Africa

Casuarina is widely distributed in Africa, where three of the four genera have been introduced: five species of *Casuarina*, three *Allocasuarina* spp. and one *Gymnosoma* sp. (Gtari and Dawson, 2011) have been introduced in Algeria, Benin, Burkina Faso, Cameroon, Central African Republic, Chad, Congo, Ivory Coast, Democratic Republic of Congo, Djibouti, Egypt, Eritrea, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Liberia, Madagascar, Malawi, Mali, Mauritania, Niger, Nigeria, Senegal, Sierra Leone, Somalia, South Africa, Sudan, Tanzania, Togo, Uganda and Zimbabwe (Orwa et al., 2009; Gtari and Dawson, 2011) (Table 1).

In some countries, including Senegal, Egypt, Benin, Kenya, South Africa, and Madagascar, *Casuarina* is widely planted, whereas in others its presence is very reduced and is limited to decoration.

The selection of a particular species depends on several factors: the climatic conditions in the area concerned, proximity to the sea, wind, soil erosion and soil mineral deficiencies at the plantation sites (Sayed, 2011).

2.2. Importance of Casuarina plantations in Africa

As pioneer species, *Casuarina* grows well in Africa in a range of climates and soils including disturbed, poor, coastal, and spoiled soils. In tropical and subtropical countries, it has been shown that *Casuarina* growth is stimulated by hot weather (Digiamberardino, 1986).

Casuarina plantations have been established in the Niayes region in Senegal along the western coast between Dakar and St-Louis, along the Mediterranean Coast of North Africa, in the Nile Delta and the Nile Valley in Egypt, in the Sémé zone in Benin between Cotonou and Porto Novo, and on the coastal dunes of KwaZulu-Natal in South Africa. In these countries, *Casuarina* plays a major role in sustaining ecosystem fertility.

Table 1
Members of the Casuarinaceae family introduced in Africa.

Species	Distribution in Africa
1. *Allocasuarina littoralis*	North Africa, Tropical Africa
2. *Allocasuarina torulosa*	North Africa, Tropical Africa
3. *Allocasuarina verticillata*	North Africa, Tropical Africa
4. *Casuarina cunninghamiana*	Southern, Northern, Tropical Africa
5. *Casuarina equisetifolia*	Southern, Northern Africa, Madagascar
6. *Casuarina glauca* (swamp oak)	Southern, Northern, Tropical Africa
7. *Casuarina junghuhniana*	Northern, Tropical Africa
8. *Casuarina obesa* (swamp she-oak)	Tropical Africa
9. *Gymnostoma deplancheanum*	Tropical Africa

Source: Gtari and Dawson (2011).

In the Niayes region in Senegal, the species is *C equisetifolia*. There, it stabilizes the coastal sand dunes and acts as a windbreak. This plantation produces large quantities of litter which is used as biofertilizer by local farmers. Leaf litter has been estimated at 3.3 t ha^{-1} $year^{-1}$ in plantations between 6 and 34 years old (Mailly and Margolis, 1992). Extensively used in compost, the litter reduces the use of chemical products and improves soil fertility. The addition of composted litter to sand soils improves plant growth and yield (Soumaré et al., 2004). Similar positive effects were obtained by adding ramial chipped wood. The positive role of *C. equisetifolia* in soil fertility was demonstrated by Diallo et al. (2005); who found a high mineral N content in *C. equisetifolia* amended soil and net soil mineralization primarily influenced by *C. equisetifolia*.

In Senegal, *Casuarina* is not widely used for wood production but dead branches are collected by the local populations for domestic uses such as firewood (Cisse and Gourbiere, 1993). *C. equisetifolia* is planted along streets and beaches as an ornamental tree. In other countries like Egypt, *Casuarina* is planted to protect desert highways thanks to its ability to grow well under harsh environmental conditions. In Egypt, *Casuarina* is mostly used for its significant ecological roles such as crop protection, shelterbelt, irrigation stabilisation, drainage canal banks, land reclamation and protection of buildings. In the Nile Delta and in the Nile Valley, *Casuarina* trees were planted to provide shade, to limit border effects, and as a windbreak.

Biomass productivity of 12-year-old irrigated plantations has been estimated at 496 t ha^{-1} of which the wood volume was 294 m^3 ha^{-1} (Megahed and El-Lakany, 1986). Used as a shelterbelt in intercropping systems in Egypt, *C. glauca* increased the yield of the sheltered crops (El-Sayed et al., 1983). In Egypt, this species plays an important economic role in the production of fuel timber, charcoal, wood for industry and for the manufacture of particle board.

C. equisetifolia plantations also play an important role in Benin, where their wood is used by local people for fuelwood and timber. A ten-year-old *C. equisetifolia* plantation near the sea produced around 200 stacked cubic metres per ha^{-1} (Buffe, 1961).

In Kenya, *Casuarina* is mainly grown for poles and as an ornamental plant and is much less used for firewood, charcoal and as a windbreak. The major use of *Casuarina* is for the construction of local tourist hotels, villas and homes (Mbuvi et al., 2011). *Casuarina* was also used for the rehabilitation of the Bamburi cement factory in Mombasa (Siachoono, 2010).

In Southern Africa, *Casuarina* has been used to reclaim former mining land and to stabilise the coastal dunes of KwaZulu-Natal. Two thirds of the area was replanted with *C. equisetifolia* for the development of a local charcoal industry (Van Aarde et al., 1996).

In Madagascar *C. equisetifolia* was planted in Ivoloina region for the production of improved seeds to be used in forestation programmes. *Casuarina cunninghamiana* was planted in Mahelia for the same purpose (Chaix and Ramamonjisao, 2001).

The above data confirm the ecological role of *Casuarina* in Africa, but several studies have shown that the growth and performance of *Casuarina* can be enhanced when it is associated with symbiotic microorganisms (Shah et al., 2006; He and Critchley, 2008). To ensure the sustainability of *Casuarina* plantation and to improve yield, we need to understand the relationship between the tree, mycorrhizal fungi (AMF, EMF) and nitrogen fixing *Frankia* bacteria.

3. Symbiotic relationship between *Casuarina*, AMF, EMF and/or *Frankia* bacteria

The efficiency of mycorrhizal and *Frankia* infection depends on the habitat of the host, the prevailing environmental conditions, and the associated plant species. Ectomycorrhizal, endomycorrhizal and *Frankia* symbionts can occur in the same plant root (Wang and Qiu, 2006).