Follow-up BUS-report[1]
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Biosaline (agro) forestry: a literature review

1. Introduction

Biosaline forestry projects deal with marginal areas, characterised by saline soils and brackish water and species that have the ability to cope with high salinity levels. Although salt tolerant tree species spend part of their energy on internal salt management and therefore usually have lower production levels than species grown under fresh water conditions, salt affected areas do provide an interesting opportunity to develop commercially, because large areas are concerned where agricultural use or nature conservation values are of minor interest. The decision to invest in these areas will be based on the aggregated socio-economic and environmental benefits, the increasing pressures on agricultural land and on fresh water resources, and the increasing demand for biomass that is foreseen in the next decades. Although the lack of alternative economic use of these areas suggests that biosaline (agro) forestry may become economically feasible, even with lower production levels, it is important to continuously try to improve the production level of salt tolerant tree species. An initial study carried out by Probos, commissioned by ODE[2], suggest that it is possible to improve production levels by developing appropriate salt-management systems, by selection and breeding and by developing and applying appropriate silvicultural techniques.
After a case study on mangroves[3], and a literature review on the use of mangrove wood[4] a follow-up study was proposed to assess the possibility that in the next few decades biosaline (agro) forestry may become an attractive alternative form of land-use in salt affected areas and that appropriate agro-forestry systems and tree plantations can be developed which contribute to the sustainable production of biomass.

Long-term perspective

The global afforestation rate of 'regular' forest stands is about 10 million ha per year, whereas the current establishment of fast growing tree plantations is approximately 1 million ha per year. In a long-term perspective, on saline sites the annual afforestation rate may amount to 5% of the total world-wide afforestation efforts, i.e. 500,000 ha per year. However, before such a level of afforestation can be achieved, considerable efforts on R&D, field experiments and on-farm testing of the most promising tree species and cultivation methods will have to be undertaken, in which a step-wise upscaling can be considered: e.g (step 1) from 20 ha of field trials to (step2) 200 ha farm-size demonstration plots, to (step 3) semi-commercial planting schemes of about 2000 ha, and (step 4) commercial operations under practical conditions with 20,000 to 50,000 ha planting units.
It will take at least 20 years before step 4 can be achieved, which implies significant funds and a long-term commitment by all stakeholders. However, given the scope and urgency of the salinity problem, no time should be wasted to take the first initial steps, i.e. to establish a series of field trials.

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[1] Copying of (part of) this report is allowed only with proper citation. This report aims to provide a quick scan of the subject matter and should therefore be used as such. The contents do not represent the official view of the BUS nor of any of its affiliates, but are personal to the writer. The BUS accepts no liability for the use of this information nor for any consequences that may result from it.
[2] Measures to enhance the productivity of tree plantations. Contribution of Probos to the ODE report “Biosaline biomass. Energy for The Netherlands”, November 2004
[3] The BUS has done a quick-scan on salt water forestry with a case study on mangroves (BUS-report 24, 2004) with the recommendation to do a more extensive literature review on salt tolerant tree species for dryland conditions.
[4] Straatsma, W. and Kuiper, L. 2005. Literature review on the production and use of mangrove wood. Probos report, Wageningen, 10 p.

2. Method

A literature review was performed to provide information about potential tree species to be used to establish tree plantations on saline (and often waterlogged) soils. For this review the library sources of the Wageningen University and Research centre were used such as: Agralin, Artik and CAB-abstracts, Biological Abstracts, Agricola and Agris. In addition, the internet was searched with the search engine Google.

While doing this literature review, it soon became apparent that different methods are used to determine the electrical conductivity (EC) of the soil, which makes results in the literature very difficult to compare. For this reason, a short description of salinity measures, units and classes is presented in annex 2, mainly derived from the Department of Agriculture of Western Australia.

3. Current research on biosaline (agro)forestry

A selection of organisations that are involved in current research on afforestation of salt affected soils is given in table 1.

Table 1. Organisations which perform research on afforestation of salt affected soils.

Organization		**Country**	**Website**
CSSRI	Central Soil Salinity Research Institute	India	www.icar.org.in/cssri/cssri.html
CSIRO	Commonwealth Scientific and Industrial Research Organisation Forestry and forestry products	Australia	www.ffp.csiro.au/
ICBA	International Centre for Biosaline Agriculture	United Arab Emirates	www.biosaline.org/
DDC	Desert development centre Of the American University of Cairo	Egypt	www.aucegypt.edu/academic/ddc/
IAR	The Institutes for Applied Research Ben-Gurion University of the Negev	Israel	www.bgu.ac.il/IAR/index.php
KIS	Kuwait Institute for Scientific Research	Kuwait	www.kisr.edu.kw
USSL	United States Salinity Laboratory	United States	www.ussl.ars.usda.gov
PARC	Pakistan Agriculture Research Council	Pakistan	www.parc.gov.pk
LDD	Land development department	Thailand	www.ldd.go.th/index_lddeng.htm
TERI	The Energy recourses Institute	India	www.teriin.org
ODE	Ocean Desert Enterprises	Netherlands	www.oceandesertenterprises.com

4. Plantation establishment techniques for salt tolerant tree species (salinity management)

The method showing the best results to establish tree plantations on salt affected soils is the furrow method. This method shows the highest sapling survival in different field studies (Tomar, 1997) and is recommended by the handbook of Quershi and Barret-Lennard (1998). It is an example of how to control soil salinity in the root zones (salinity management). The furrow method works as follows: furrows about 0,6 m wide and 0,2 to 0.3 m deep are created with a tractor mounted furrow maker. The furrows are used for irrigating the saplings for at least two years. The seedlings are planted at a uniform distance. The place where they are planted, depends on the degree of internal drainage of the soil. In soils with good internal drainage the seedlings should be planted at the bottom of the furrow. In soils with poor drainage the saplings are planted on the shoulder of the furrows so that they are not affected by water logging after irrigation. In waterlogged soils the trees should be planted on buds or mounds to avoid water logging. The trench-ridge technique is widely used in Pakistan and India on waterlogged soils. As soils are heavier, more salt-affected and waterlogged mounds should be taller and wider, and have a distinct trough. Such double-ridge mounds have proven very effective by providing (1) site drainage, (2) elevation of the seedling above the water table (thereby increasing oxygen availability) and (3) salt leaching from the root zone. These mounds are particularly useful where there is sufficient rain and/or irrigation water before planting time to leach salts from below the trough at this critical time. It is best to construct mounds several months before planting. Single-ridge and flat-topped mounds are not as effective, but are better than no mounds. Several techniques are available for mechanically forming mounds. Equipment includes: press wheels attached to the mounds of the plough, modified direct seeding machinery and twin discs (Marcar and Crawford, 1996, Lambert and Turner, 2000).

Results of the study by Minhas et al (1997) indicate that irrigation should at least be applied in the first two years after planting. In most cases the trees have developed their rooting system after two years and are able to reach the groundwater. Irrigation should be managed for trees on saline soils in such a way that it avoids water logging and aeration problems, and the accumulation of salt in the root zone. These objectives are met with the furrow irrigation method (Tomar, 1997). With the furrow irrigation method, saline waters of EC up to 15 dS/m in sandy loam and on loamy sand soils can be used (see annex 2 for salinity definitions). In finer textured soils, waters of EC up to 8-10 dS/m can be used for irrigating saplings. The recommended irrigation interval for brackish water is the same as for normal water. In India they have the following scheme: a monthly irrigation during Oct-Mar, and fortnightly irrigation during April-June (Tomar, 1997).

The distance between the saplings in a row and between rows is dependent on the species, but also on whether the trees are to be planted in blocks, mixed with shrub species, or used in alley cropping.
In case of the presence of a dense soil layer or hardpan the furrow planting method is combined with the auger hole method. Auger holes (0.2 m in diameter and 1.2 m deep) are dug at the sill of the furrows spaced at the desired intervals. These holes may be refilled with a mixture of original soil, farmyard manure, super-phosphate, zinc sulphate and iron sulphate to give the saplings a good start.

5. Agroforestry systems

Many of the species that may be suitable for the establishment of tree plantations on salt affected soils are used in agroforestry systems, especially in arid regions. In agroforestry systems the trees are used as sources of fodder during the dry season when there is no grass, serve as windbreaks and hedges and provide shade. If the trees are used as fodder or as shade trees, they can be planted scattered over the fields that are used as pastures, but can also be planted in blocks or as timber belts. The trees can be directly browsed by cattle or the leaves and pods can be harvested to feed cattle.
A well known species that is favoured in agroforestry systems is *Prosopis cineraria*: it fixes large amounts of nitrogen and does not affect growth of plants under the canopy (Qureshi and Barrett-Lennard, 1998).

Salt tolerant trees can also be used in agroforestry systems with the purpose of managing dryland salinity. Dryland salinity generally results from the build-up of salts in surface soil, usually as a result of a rising water table and subsequent groundwater seepage. Water tables can rise due to the removal of deep rooting native vegetation, as is e.g. the case in Western Australia. Due to the removal of this vegetation large volumes of rainfall are leaking through the upper soil and recharge the groundwater. This results in raising water tables especially in discharge sites bringing dissolved salts to the surface layer of the soil.
Trees can be used to lower these risen water tables. They are relatively deep rooting and can therefore reduce water leakage, they may use water all year around whenever it is available, and intercept a significant fraction of rainfall before it reaches the soil. In this way, strategic tree planting being part of agro-forestry and farm forestry systems, can contribute to lowering risen (salt)water tables.

Agroforestry (sometimes called: alley cropping) combines trees and shrubs with pastures and agricultural crops to maximise productivity and water use. Planting layout and density is flexible; 100 to 450 trees/ha in multiple rows up to 50 m apart will provide a satisfactory ratio of trees to pasture/crops. Tree belts in alley cropping systems have the potential to use saline groundwater. The key issue generally is to maximise the distance between tree belts in order to reduce production losses due to competition between trees and pasture or crops and to balance the local recharge of groundwater with groundwater use by the trees in the belts. Qureshi and Barrett-Lennard (1998) indicate that its better to use a few wide belts of trees than using a lot of narrow belts of trees. Using a few wide belts of trees reduces the area at which an edge effect is experienced by the pasture or the crop. In this way, the area at which loss of crop growth caused by competition with invading tree roots and by shading takes place is minimized.

The extension of tree roots depends on tree species and tree size. The roots of most trees extend 1.5 tree heights from the base of the tree. Competition between tree roots and crops occurs most often within 1.5 heights of the base of the tree. However, the roots of some species such as *Acacia* spp. and *Prosopis juliflora* may extend three to five times the average tree heights.

A number of authors refer to the accumulation of salt in the root zone of tree plantations using saline groundwater (Mahmood, 2001, Qureshi and Barrett-Lennard, 1998). This salt may eventually accumulate to salt concentrations which adversely affect tree growth, health and survival. However, this may only be the case under steady-state moisture conditions in which no leaching of the root zone due to flooding, irrigation or seasonal rainfall takes place. Further research has to be done into this process.

From all these observations and references in the literature it appears that salinity management plays a key role in the success of establishment and growth of biosaline agro forestry systems. In the Netherlands a lot of know-how practical experience exist with irrigation and salt management in agriculture in semi arid areas in the world, which, however should be applied and adapted to (agro) forestry.

Potential salt tolerant pasture and crop species that can be used in agroforestry systems on salt affected soils are listed in table 2.

Table 2
Salt tolerant crops (based on: Lambert and Turner, 2000).

Crop	**Scientific name**	**Use**
Alkaligrass, Nuttall	*Puccinellia airoides*	forage grass
Asparagus	*Asparagus officinalis*	vegetable
Barley	*Hordeum vulgare*	grain
Bermuda grass	*Cynodon dactylon*	forage grass
Cotton	*Gossypium hirsutum*	fibre crop
Kallar grass	*Diplachne fasca*	forage grass
Saltgrass, desert	*Distichlis stricta*	forage grass
Sugar beet	*Beta vulgaris*	Tuber
Wheat, semidwarf	*Triticum aestivum*	Grain
Wheatgrass, fairway crested	*Agropyron cristatum*	forage grass
Wheatgrass, tall	*Elytrigia elongata*	forage grass
Wildrye, Altai	*Leymus angustus*	forage grass

6. Promising tree species for biosaline (agro) forestry

A large number of species are reported in literature as being salt tolerant. However, the level of salt tolerance differs between species, but also within species and between provenances. For instance different provenances of *Eucalyptus camaldulencis* (Dehnh.) show different levels of salt tolerance.

Promising salt tolerant trees species, subdivided into three different salinity classes are summarized in table 3. A species is marked with a 'W' if it is tolerant to water logging. A 'I' indicates that a species is suitable for irrigation with saline/brackish water.

Table 3. Salt tolerant tree species.
W means it is tolerant to water logging; I indicates that a species is suitable for irrigation with saline/brackish water

Very tolerant (25-35 dS/m)			
Acacia	*farnesiana*		
Melaleuca	*halmaturorum* (F. Muell)		
Parkinsonia	*aculeata L.*		
Prosopis	*juliflora* (Swartz) D.C.		I
Tamarix	*aphylla* (L.) Kartsen / *articulata* (Vahl.)	W	
Tamarix	*Troupii*		
Tolerant (15 - 25 dS/m)			
Acacia	*ampliceps* (Maslin)		
Acacia	*nilotica* (L.) Del.		I
Acacia	*stenophylla* (A. Cunn. ex Benth.)*		
Acacia	*tortilis* (Forsk.)		I
Casuarina	*equisetifolia* (L.)		
Casuarina	*glauca* (Caloundra)*	W	
Casuarina	*obesa* (Miq.)	W	
Eucalyptus	*camaldulensis* (Dehnh.)*	W	I
Eucalyptus	*campaspe* (S. Moore)		
Eucalyptus	*kondininensis* (Maiden & Blakely)		
Eucalyptus	*occidentalis* (Endl.)*		
Eucalyptus	*platypus* (Hook) var. heterophylla Blakely		
Eucalyptus	*sargentii* (Maiden)	W	
Eucalyptus	*spathulata* (Hook)	W	
Leucaena	*leucocephala (Lam.) de Wit*		
Melaleuca	*lanceolata* (Otto)		
Melaleuca	*lateriflora*		
Pithecellobium	*dulce* (Roxb) Benth		
Prosopis	*cineraria* (L.) Druce		I
Moderately tolrerant (10 - 15 dS/m)			
Cassia	*siamea*		I
Casuarina	*cunninghamiana*		
Dalbergia	*sissoo*		
Eucalyptus	*tereticornis* (Sm.)	W	I
Melia	*azedarach* (L.)		
Samanea	*saman*		
Sesbania	*bispinosa* (Jacq.) W.F. Wight	W	
Sesbania	*sesbana* (L.) Merr.	W	

*) Species known for their difference in the level of salt tolerance between different provenances.

In a number of studies field trails have been performed to determine the level of salt tolerance of different tree species and their provenances. The field trail with 31 tree species of Tomar *et.al.* (2003) recommends the following species to be planted in arid regions with moderate levels of saline irrigation (EC 8.5-10.0 dS/m) with the furrow planting method: *Tamarix articulata*, *Acacia nilotica*, *Prosopis juliflora*, *Eucalyptus tereticornis*, *Acacia tortillis*, *Acacia tortillas* (hybrid) and *Casuarina glauca* (see Table 3). These species not only produce economic yields (>20 tons/ha) but also improved soil conditions, i.e. in terms of organic matter.

Fagg and Stewart (1994) give a number of *Prosopis* and *Acacia* species that are salt tolerant and are well suited for afforestation of salt-affected soils in arid regions with the furrow planting method. For *Prosopis* these species are: *Prosopis juliflora, P. glandulosa, P. tamarugo, P. cineraria, P. pallida and P. farcta*. For *Acacia* spp. it are: *Acacia nilotica, A. tortillis, A. ampliceps B.R. Maslin, A. maconochieana L. Pedley, A. stenophylla A. Cunn. ex Benth. and A. silicina*. However, they do not report the exact salinity levels up to which these species are tolerant.

Experiments by Van der Moezel et al (1991) in Australia on seedlings of *Eucalyptus* and *Melaleuca* showed that the most tolerant species under salt and water logging conditions were: *E. occidentalis*, *E. sargentii*, *E. spathulata*, *E. striaticalyx*, *E. tereticornis*, *Melaleuca lateriflora*, *M.* sp. aff. *lanceolata* and *M. thyoides*. In this experiment salt concentration increased every week by 7 dS/m until a concentration of 35 dS/m was reached. Under these well-drained salt conditions, survival rate of all species remained high, but a significant growth reduction took place. The species which grew best under these adverse conditions were: *E. yilgarnensis*, *E. micranthera*., *E. myriadena*, *Melaleuca adnata*, *M. eleuterostachya*, *M. lateriflora*, *M.* sp. aff. *lanceolata* and *M. thyoides*..

Species from the following genera have shown to be salt tolerant: *Acacia*, *Eucalyptus*, *Prosopis*, *Tamarix*, *Casuarina* and *Melaleuca*. The characteristics and silvicultural measures for the most important species are summarized in a provisional database (Annex 1). However, it should be noted that the tolerance of these species to soil salinity (which , by the way, may vary throughout their lifecycle) and the relation between soil salinity and growth and yield are not well understood and hardly documented yet. Important indicators for the maximum biomass production obtainable by biosaline tree species are the **salinity treshold** and **salinity curves**:

The salinity treshold represents the maximum degree of salinity at which the tree still produces at 100%. The salinity curve is a measure of decline in biomass production once the salinity treshold is passed (and salinity increases). True halophytes such as *Tamarix aphylla*, are able to maintain their productivity throughout the whole salinity spectrum, or show only a slight decrease in productivity at the higher end of the spectrum, i.e under extreme saline conditions. However, most biosaline trees are not true halophytes and they produce reasonably well in the salinity range of 15 – 25 dS/m. (the salinity of seawater is about 40 dS/m). To prevent salt accumulation in the root zone of trees, effective salinity management is needed, which include irrigation and drainage. This, of course, is a capital intensive management system which needs to be very productive in order to cover the costs. Hoek et al 2004 suggest that a maximum production level of 15 odt/ha/a is considered realistic for salinity levels in the range 10-20 dS/m[5] (i.e brackish water) and that even higher potential production levels can be obtained with tree improvements (selection and breeding) and by appropriate salinity management. This seems a rather optimistic viewpoint, which definitely need to be checked by field trials under various conditions, closely working together with international research institutes focussing on dry and saline environments, which already exist e.g. in the Unites Arabic Emirates, Kuwait, France, Spain, Turkey, Mexico, USA, India, Thailand and Australia (table 1).

ODE envisions thousands of hectares of hot, dry and salt-affected wastelands being transformed into irrigated biosaline woodlands producing a variety of products and services, which include biomass for energy. To days discarded saline land and water resources will become the input for new productivity, restoration of reserved natural areas and for postponing desertification[3]

Prospects for the future

In the long run (2040) an estimated 300 million ha of salt affected soils with sufficient water available may be potentially available for dedicated biomass production, with an average production level of perhaps 5 odt/ha/a. This would imply a technical production potential of 30 EJ, which corresponds with 7% of the current global energy production (Hoek et al 2004). However, technical potential does not mean that the same area is available for exploitation in an economic viable way. The economics of biosaline forestry will depend on the aggregated costs of the whole biomass supply chain, including the extra costs involved in biomass pre-treatment and conversion to reduce chloride levels. The farmgate costs depend on a number of parameters, such as price, yield, investment costs (e.g for the irrigation and drainage system) and annual production costs for labour, harvesting, fertilizer, pest control, etc., which are highly site specific. Especially the cost of salinity management will weigh heavily on the production costs. For biosaline biomass to be competitive on the future commodity market, the farmgate price should not exceed 2 euro/GJ (i.e 36 euro/odt). In most cases, the farmgate

[5] Hoek, J. et al 2004. Biosaline biomass. Energy for the Netherlands in 2040. Report Ocean Desert Enterprises.

price will be substantially higher (the most optimistic scenarios assume a price of 3 euro/GJ at production levels of 15 odt/ha/a), which means that biosaline biomass plantations cannot survive on farm economy alone. However, if in the near future production levels will increase by technical measures, if the price for biomass is going to rise, if government support will be available for investments in infrastructure and appropriate harvesting equipment and if externalities are being valorized properly, the economy may change in favour of biosaline energy crops. Biosaline forestry and agroforestry systems do not only try to produce biomass at competitive prices , but also play an important role in reclaiming degraded areas by using brackish water and affluent water, thereby substituting scarce fresh water resources which, in turn, can be used for other purposes.

7. Conclusions

1. Biosaline biomass production is an appealing option based on a clear vision.
2. However, ODE's view on the productivity and viability of biosaline (agro)forestry systems seems rather optimistic.
3. Worldwide, salinization is a big problem affecting large areas of (former) agricultural land, the area of which increases with 10 million ha per year, according to official FAO statistics.
4. It will require a lot of work and extensive international collaboration to develop the appropriate (agro) forestry production systems and to test these concepts in reality in a range of (salt) conditions, which will require substantial funds and a long-term commitment by research organizations, governments and the industry.
5. To establish new woodlands under such adverse site conditions will be quite an achievement in itself, with great benefits to society.
6. However, it is unrealistic to think that within the next 20-30 years they will contribute significantly to biomass production for the export market.
7. Their main asset will be the upgrading of wastelands, previously considered valueless, and the restoration of degraded arable land, thereby improving the ecology and living conditions at a landscape level ('greening the desert ')
8. The afforestation of abandoned agricultural lands and of degraded lands <u>not</u> affected by salt will be a more viable option, contributing more to the development of the emerging biomass market. In other words: dedicated biomass production has better chances for success in less hostile environments.
9. Marginal sites are marginal for a reason: they do not offer the best opportunities for a substantial increase in productivity / cost reduction and increase the silvicultural risks considerably.

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Annex 1. Provisional database on salt tolerant tree species

Acacia

Acacia ampliceps (Maslin) (Qureshi and Barrett-Lennard, 1998)
Salinity: Grows successfully in highly saline (ECe > 15 dS/m), sodic and alkaline soils (pH values up to 9.8), but is intolerant of acid soils and water logging. The growth is reduced at salinity levels ECe 10-15 dS/m. Fagg and Stewart (1994) report that this species is suitable for planting on alkaline/saline soils, where it has access to brackish groundwater.
Fuel: calorific value of sapwood: 18.9 to 19.9 MJ/kg.
Planting: The rows should be 2-3 meter apart with plants also 2-3 meters apart (1600-2500 trees/ha). It can spread by root suckering resulting in dense stands.
Production: There is little data available on the productive capacity of this species. A field trail in Sind indicates that 2 year old trees at a density of 2500 trees/ha (2 x 2 m) had an average weight of about 23 kg/tree (i.e. 5.7 tons/ha per year) (Qureshi and Barrett-Lennard, 1998)

Acacia nilotica (L.) Willd. ex Del. (Qureshi and Barrett-Lennard, 1998)
Salinity: can tolerate moderately saline (ECe = 8-15 dS/m) and sodic conditions (SAR = 25) as well as soils with a hard pan. 40% growth reduction at an ECe of 8 d/Sm (Singh *et.al.*,1991). It is tolerant to alkalinity up to pH values of 10. Relatively tolerant to water logging. The water use efficiency with saline water (EC = 10.4 dS/m) irrigation lays between 3.6 and 5.0 Mg/ha/m (Minhas *et.al.*, 1997).
Fuel: calorific value of sapwood: 20.1 to 20.7 MJ/kg.
Planting: Furrows 10 meter apart and distance between plants: rotation 20 years 8-10 meters (125-100 trees/ha) and rotation 7-10 years 3-5 meters (333-200 trees/ha).
Productivity: With a rotation of 20 years and stem number of 100 to 125/ha wood production varies between 4 and 15 m^3/ha (not including biomass removed due to lopping). A fuelwood yield of 13 tons/ha from cuttings of side branches during a 40 month period is reported by Singh et. al. 1993. In the three years after establishment in a plantation with three years of furrow saline irrigation (EC = 10.4 dS/m) biomass yield can be 7.9 tons/ha dry weight (Minhas *et.al.*, 1997).

Eucalyptus

Pepper and Craig (1989) tested 12 *Eucalyptus* species. The best survival, health and growth of species at high soil salinities was by *E. occidentalis* Endl. (Provenance: Near Borden, WA) , *E. sargentii* Maiden (Provenance: Near Wyola, WA) and *E. platypus* Hook. var. *heterophylla* Blakely (Provenance: Como, Perth, WA). These species resisted ECe (electrical conductivity of saturated soil extract) values greater than 30 dS/m.
On saline sites in Australia, the establishment of widespaced eucalypts allows significant grazing value while providing a resource for wood products. When tree rows are spaced 20 m apart (100-150 trees/ha) and oriented north-south it maximises inter row exposure to sunlight and also increases water use which helps lower the underlying water table (Dooley, 1995). On mild (EC = 2-10 dS/m) to moderately (EC = 10-30 dS/m) saline sites eucalypt woodlots can be planted usually 500 to 1000 stems per hectare (Dooley, 1995).

Eucalyptus camaldulensis (Dehnh.)
Salinity: data on salt tolerance of this species is rather confusing. This may be caused by the large variation between provenances. Marcar *et.al.* (2003) report a number of CSIRO clone provenances (15272, 14007, 15024, 15195, CML512) that show good survival and considerable height and diameter growth on a moderate saline soil (root-zone ECe 4-8 dS/m). In this field trial the height of the trees ranged from 2.44 to 3.41 m and the dbh ranged from 3.0 to 5.0 cm after 6 years of growth.
Fuel: calorific value of sapwood: 20.5 MJ/kg it is also good for charcoal. The wood of young trees (dbh < 20 cm) has a density of 650 kg/m^3.
Planting: The trees are usually planted with 1600 trees/ha (3 x 2 meter).

Production: The species grows quickly. The average yields vary between 10 and 25 m^3/ha/year. The species is suitable for coppicing. It can be harvested six times in a 7-10 year coppice rotation. *E. camaldulensis* is a good agro-forestry tree when widely spaced, but shows heavy competition with crops for moisture and nutrients.

Prosopis

Beneficial effects and potential uses of *Prosopis* species are: agroforestry systems, control of soil erosion, sand dune stabilisation, desalinisation, prevention of salinisation, nitrogen fixation, recycling of nutrients. Prosopis can grow in a soil salinity regime up to sea water salinity. All species of Prosopis can tolerate ECe = 10 dS/m salinity with no reduction of growth. In India the most common Prosopis species are *P. juliflora* and *P. cineraria*. These species are used for the revegetation of salt lands. Prosopis growth on salty soils results in their amelioration to such an extent that it can even be used for arable farming after removing Prosopis trees (Singh and Singh, 1992).
***Agroforestry**:* The potential of Prosopis leaves, seeds and pods has been vastly underestimated. The pod yields varies considerably since there are no well established cultivation standards. Pod yields of less than 2 tons/ha and up to 8 tons/ha in optimum circumstances have been cited. Many rangelands in the semi-arid areas produces less than 2500 kg/annum of pasture biomass of which only 200-400 kg is harvested by grazing cattle (Dutton *et.al.*, 1992).
***Drawback**: Prosopis* must not be grazed when pods are falling because of the spread of seeds through the faeces of cattle and other ruminants which might result in its spread as an unmanageable weed. However, within tree plantations Prosopis is rather easy to be managed (Dutton *et.al.*, 1992).

Prosopis cineraria (L.) Druce (Qureshi and Barrett-Lennard, 1998)
Salinity: Grows successfully in highly saline (ECe > 15 dS/m) and alkaline soils (pH values up to 9.8). It is highly drought tolerant; its taproot can reach groundwater at 20 meters depth.
Fuel: It is an excellent fuel (calorific value of sapwood: 20.9 MJ/kg), and also gives high-quality charcoal (5,000 kcal/kg).
Planting: Furrows 10 meter apart and distance between plants: in 20 year rotations 8 to10 meters apart (125-100 trees/ha) and in 7 to10 year rotations 3 to 5 meters apart (333-200 trees/ha). If not planted with the furrow method, initial spacing of 2 x 2 m is recommended. Annual yields of stacked firewood is 3 m^3/ha. The heartwood is very hard and heavy (769-945 kg m^3).
Production*:* Under favourable conditions trees can reach a height of 7 meters in 11 years time (60 cm/year). Yields of 3-5 m^3/ha per year are common.
Agroforestry: Due to its deep root system, mono-layered canopy and ability to fix atmospheric nitrogen P. cineraria is extensively used as an agro-forestry tree throughout arid and semi-arid India. The tree has a boosting effect on the yield of crops growing in its vicinity. The crops draw their moisture and nutrients from the top 50-60 cm of soil while the tree gets its nutrients from a deeper horizon. In addition, the tree provides shade to crops during summer (Dutton *et.al.*, 1992). The tree is favoured for agro-forestry as it fixes large amounts of nitrogen and does not affect growth of plants under the canopy. The tree coppices readily.

Prosopis juliflora (Swartz) D.C. (Qureshi and Barrett-Lennard, 1998)
Salinity: Grows under conditions of moderate to high salinity (ECe = 8 - >15 dS/m) and sodicity (SAR = 25 - >45), high alkality (pH values up to 9.8) and intermitted flooding. Singh and Singh (1992) report that *P. juliflora* still has a considerable height growth and survival on a slightly saline (EC = 0.89 and 2.84 dS/m) and very alkaline soil (pH 9.3 and 10.4 respectively).
It can be quite successful in lowering water tables on dense saline-sodic soils with shallow groundwater. Plantations can be grown with irrigation with saline groundwater or even sea water. However, under these conditions a 25% reduction in shoot extension and biomass production with irrigation water of EC 30 dS/m seems likely. Fagg and Steward (1994) report that the production is decreased by about 25% as the soil pH increases from 8 to 10.5.
Fuel: The generally crooked stems and branches make good firewood with a calorific value of: 18.9 to 19.9 MJ/kg and provide excellent charcoal. Charcoal from *P. juliflora* wood is used extensively in the

USA as barbecue fuel; about 30% of the charcoal sold for this purpose originates from *P. juliflora* from the Sonora Desert in northern Mexico.
Planting: Has a good capacity to regrow after coppicing. It also spreads by making suckers. Thinning and pruning of the trees is extremely important for obtaining a thick straight trunk and for developing shade trees. Next to this it is necessary to keep the stands accessible and to prevent it from becoming a weed. Spacing depends on the use intended for the trees. In South America when grown for fuelwood, a spacing of 2 x 2 m or wider is used. In agro-forestry systems in association with grasses and other crops, the spacing may be up to 10 x 10-15 m. When the emphasis is on seed pod production, the spacing used is usually 5 x 5-10 m.
Production: It yields about 5 kg of dry wood per plant per year. The density of this wood depends on plant age; it is initially relatively light (650 kg/m^3 in year 1) but increases in density with time (950 kg/m^3 in year 10). On a 15 year rotation the expected yield of fuelwood is 75-100 tons/ha (i.e. 5-7 odt/ha/year); on a 10 year rotation this may be 50-60 tons/ha (i.e. 5-6 odt/ha/year). In India a planting of 2500 plants/ha gave about 13 odt/ha from cut side-branches after 40 months of growth. Singh and Singh (1992) report the growth and biomass production of *P. juliflora* on a ten-year-old plantation in India (pH = 10.4). The tentative biomass production in ten years was 260 odt/ha. The height was 12.9 m, the DBH 12,5 cm, bole weight 112.6 kg/tree and the branches and leaves weight was 43.2 kg/tree. (In comparison: Acacia nilotica 215 odt, Eucalyptus tereticornis 188 odt and Casuarina equestifolia 148 odt/ha.). *P. juliflora* planted at 10,000 plants per hectare on a high alkaline soil resulted in an annual increment of 47 odt of biomass each year with a rotation of 7 years. The annual increment in a plantation with 5000 plants per ha under the same conditions was 28 tones per ha (Singh and Singh, 1992).
Drawback: *P. juliflora* is an aggressive species it is difficult to eradicate and because it may eliminate native species, it should be only sown or planted in arid problematic areas, where soils must be recovered or protected from erosion (Singh and Singh, 1992).

Prosopis flexuosa (D.C.) is regarded as an especially attractive species for the productive recovery of arid and salt-affected areas. The study of Catalán *et.al.* (1994) has shown that seedlings of this species could be used for afforestation of salt-affected areas, because the salt tolerance at seedling stage appeared to be greater than at germination stage. (Seeds from 2 areas 1700 and 900 m above sea level) Salt concentrations ranged from 0 to 0.4 M NaCl.

Casuarina

Casuarina equisetifolia Forst. (Qureshi and Barrett-Lennard, 1998, Vimal and Tyagi, 1986, Midgley *et.al.*, 1983)
Salinity: Grows in calcareous and slightly alkaline soils (pH values up to 10), where it withstands salinity but not waterlogging. It can survive salinities of 56 dS/m under drained but not waterlogged conditions this salinity level equals that of sea water. A decrease in height and diameter of 16-18% is reported if irrigated with saline water EC = 9-10. It can tolerate drought for 3 months. It grows well on sandy soils near the coast where it can withstand salt-laden wind.
Fuel: The wood ignites readily even when green, and ashes retain heat for long periods. It has been called ‘the best firewood in the world’ and also produces high-quality charcoal. The calorific value of sapwood is 20950 kJ/kg and that of the charcoal exceeds 7 000 kcal/kg. Density 1000 kg/m^3.
Planting: Plantations of 2000 trees/ha are commonly used but some farmers plant up to 8 000-10 000 stems/ha when fuelwood and small poles are the required product. Pruning is necessary up to 2 m to make plantations accessible for maintenance.
Production: Volume yield is maximum with a rotation of 15 to 20 year (7-10 m^3/ha per year) or 30 years (6-18 m^3/ha/year). Plantations are usually managed on a rotation of 7-15 years.
In India, a 6-8 year old plantation of C. *equisetifolia* on a saline soil produced about 15 tons of fuelwood and small timber per hectare.
On this same soil *Acacia nilotica* produced about 20 tons of wood and *Prosopis juliflora* produced 25-30 tons of wood. It coppices only to a limited extent and best results are obtained when cut young. Under favourable conditions, early growth rates are about 2 m/year in height and the trees have good form in cultivation. On favourable sites, it can yield an annual increment of 15 m^3/ha of wood in 10

years. In India, plantations using 1 x 1 m or 2 x 2 m spacing on 6-15 year rotations yield 8-13 tons/ha/year. Dry weight per tree ranges from 15 to 25 kg at 3 years of age, depending on site quality. In South China, where an estimated 1 million hectares in shelterbelts along the coastal dunes have been established since 1954, heights of 7-8 m and diameters of 5-7 cm are achieved in about 4 years. The rotation length ranges from 4-5 years for fuelwood and 10-15 years for poles. Mean annual increments usually fall in the range of 4-5 m^3/ha per year.

Casuarina glauca (Sieb.) (Midgley *et.al.*, 1983)
Irrigation is required to establish trees in desert areas. Moderately fast growing: at the age of 7 years, the tree reaches an average height of 5 m with a 72% survival rate.
Fuel: The wood has a calorific value of 4 700 kcal/kg, splits easily, and burns slowly with little smoke or ash. Can also be burned when green. Produces excellent charcoal. After 4 years, trees begin to shed about 4 t of cones/year.
Production: By the age of 12 years, a yield of 295 m^3/ha of wood and 34 tons/ha of green foliage is expected. This corresponds with a biomass production of 24 odt/ha/year. In Israel, *C. glauca* outperforms other casuarinas, reaching 20 m in 12-14 years, even on saline water tables. Coppices easily and produces root suckers vigorously. Inoculation of seedlings with symbiotic nitrogen-fixing bacteria is recommended when introducing the species to new areas.

Tamarix

Salt cedar (Tamarix spp.) is a deep-rooting deciduous shrub/tree that is easily propagated from cuttings. Over 50 salt-tolerant species found on seacoasts and inland deserts throughout the world show considerable promise for shelterbelts, hedgerows and erosion control as well as the rehabilitation of saline wastelands (reducing saline water tables) and sand dune stabilization. T. ramosissima (tolerates up to 20-25 dS/m) and related species are being used in northwestern China to stop desert expansion and increase agricultural productivity with direct economic benefits from much-needed timber and fuel in these low-vegetative environments. Field tests suggest that some of the more productive species, T. aphylla, T. chinensis and T. nilotica, can be irrigated with seawater. T. stricta, native to the Middle East, has the desirable qualities of rapid growth and uniform branching with the formation of dense canopies (weedy tendencies) (Biosaline awareness project, 2005; Hoek, 2004).

Tamarix aphylla(L.) Karsten (Qureshi and Barrett-Lennard, 1998).
General: Also known as Tamarix articulata or Tamarix orientalis. It is a small coniferous-looking tree, which grows to a height of 10-15 meters.
Salinity: It can tolerate high levels of salinity and sodicity. It is a common tree of salt-affected wastelands. It tolerates waterlogging.
Fuel: Tamarix is slow to catch fire but has good burning quality. The wood can be used to prepare charcoal (calorific value, 4835 kcal/kg).
Planting: Plants are established in rows 3 meters apart , with plants at 2 meters apart within the rows. Under natural conditions, the crop is harvested in a 20-year rotation. However, under irrigated conditions, this time can be reduced to 10-12 years. Weeding is necessary to facilitate proper growth at the early stages of establishment but eventually its litter suppresses the weeds. Drastic thinning is done when the plants have grown for over 2 years to get 37-50 trees/ha. Pruning is necessary to prevent development into a shrubby habitus with many weak main stems which are subject to splitting and breaking off at ground level.
Production: Wood production of 5-10 cubic meters per hectare per year have been reported.
Drawback: Salt drip from the leaves kills all ground vegetation beneath the tree and together with its salt litter it increases the salt concentration in the soil. For this reason planting op the trees under natural circumstances may result in a decrease in biodiversity in the area where it is planted. It can act as a aggressive weed.
The species has extensive surface roots which makes it unpopular for intercropping due to excessive competition for water and nutrients with crops.

Leucaena

Leucaena leucocephala (Lam.) de Wit (Qureshi and Barrett-Lennard, 1998)
General: *L. leucocephala* is a fast growing, tropical leguminous tree that originated from central America. The species is planted for soil improvement, reforestation, fire breaks wood and animal feed. The tree as a whole is used in alley cropping, as an over storey plant for shade loving crops and in reforestation. The foliage is used as mulch or is incorporated as green manure. *L. leucocephala* is also a prime candidate for various reforestation programs because it not only encourages growth of hardwoods, but it can also be used to choke out agressive grasses like *Imperato* that take over barren lands left behind by slash and burn cultivation. The species is also highly valuable as fodder for ruminants (Anthraper and DuBois, 2003).
Salinity: Grows well on light textured saline soils that are well drained. However, it is sensitive to waterlogging. In irrigated sand and gravel cultures, water with EC 9-10 dS/m did nod adversely affect growth. It grows on soils with a pH of 5.5 to 8.
Fuel: calorific value of sapwood: 18855 to 19903 kJ/kg.
Planting: Plantations of 2500 to 5000 trees/ha are commonly used.
Production: In general yields of less than 15 m^3/ha per year are considered poor. For fuelwood plantations a short rotation of 2-3 years is practiced. In general yields will be greater for coppice regrowth where weed competition no longer exists and existing root systems are well established. Coppice shoots in 1.5 year grow equal to 3 year old original trees (Vimal and Tyagi, 1986). One ha of *L. leucocephala* foliage can produce about 500 kg of nitrogen roughly equivalent to 2500 kg ammonium sulfate.

Parkinsonia aculeata L. (Qureshi and Barrett-Lennard, 1998)
Salinity: Grows well under conditions of high salinity, but is sensitive to waterlogged conditions.
Fuel: The wood is considered moderately hard, heavy and brittle and is used especially for fuelwood.
Production: It is a relatively fast growing tree.

Annex 2: Salinity measures, units and classes

Most salinity measures use electrical conductivity to estimate salinity of soil and water. These measures are cheap and easy to do, and can even be done (with some care) in the field.
To understand the 'saltiness' of a salinity reading, it makes a big difference to measure soil or water properties, the way in which it was measured (or estimated in most cases), and the units which were used. For example, moderately salty soil could be presented as 600 mS/m (ECe), 125 mS/m (EM-38 hor), or 60 mS/m (EC1:5 (w/v) loam).

- Salinity measures include electrical conductivity of a solution or soil and water mix, weight of salts in a given amount of water, and the quantity of molecules of salts in a solution. Each of these measures have particular uses. A popular measuring tool is the EM[3]8 (ElectroMagnetic Induction Metre).
- Units includes grains per gallon, milligrams per litre, milliSiemens per meter, deciSiemens per centimetre and many more.
- Classes range from non-saline to extremely saline. In the Australian standards which are described here and which are often used or referred to in international publications, the salinity classes refer to plant tolerances to salt.

Note that the salt tolerance of plants is affected too by factors other than the salinity reading: e.g. by waterlogging, soil type, sodicity, depth to water table, salinity of the water table, rainfall and other factors. Waterlogging interacting with salinity is probably the most important influencing factor on most sites.

Soil Salinity

EC 1:5
Soil samples can be measured by the '1:5' w/v method : one part by weight (g) air dried soil to five parts by volume (ml) distilled water, which is agitated then allowed to settle. The solution is measured for Electrical Conductivity (EC 1:5). This measure is used to allow for soil texture differences. Sand particles will not hold as much salt from the soil water as will clay. Therefore, sand will give apparently lower readings than from clay, even though the salt concentration in the soil water is the same.[6]

ECe
The Electrical Conductivity of a saturated soil extract (ECe) is the most useful and most reliable measure of salinity for comparing between soil types. The 1:5 reading can be used to estimate the ECe. Conversion factors from EC 1:5 to ECe are given in table 4. Note that these are guidelines - the actual conversion figure can vary quite widely for particular soils. Note also, that proper measurement of the ECe is a laboratory technique, and an expensive one.
A technique for converting reported ECe to EC 1:5 can be used in the reverse direction for converting EC1:5 (less than 350 mS/m) to ECe. The technique is based on a limited data set, and care should be taken extrapolating the technique.

[6] Some field surveys estimate an EC 1:5 based on volume: volume (v/v). That is, one scoop of soil to five scoops of water. This can lead to large errors in reporting in comparison with the w/v method and between samples from the same site, especially for clay soils. It is important to 'calibrate' any EC 1:5 estimated from the v/v technique against the w/v estimated technique. Unfortunately, this is often not the case. The technique is not recommended for critical measurements.

Table 4
Conversion factors to estimate ECe from EC 1:5 (w/v) in relation to soil texture

Soil texture	*Multiply EC 1:5 (w/v) by factor*	*Example*
Sand	15	10 mS/m (EC1:5) = 150 mS/m (ECe)
sandy loam	12	10 mS/m (EC1:5) = 120 mS/m (ECe)
loam	10	10 mS/m (EC1:5) = 100 mS/m (ECe)
clay loam	9	10 mS/m (EC1:5) = 90 mS/m (ECe)
light/medium clay	8	10 mS/m (EC1:5) = 80 mS/m (ECe)
heavy clay	6	10 mS/m (EC1:5) = 60 mS/m (ECe)

EM38
Another measure, which is increasingly becoming common, is the EM 38 or EM 31 using Electro-Magnetic induction. EM readings are useful to compare within and between similar sites, but use EM readings with caution unless they are calibrated against soil salinities (ECe for preference) and other influencing factors. The EM38 is quite an expensive unit, but relatively easy to use in the field, and gives estimates of salt concentrations at the root zone.

Water Salinity

Nearly all testing methods use electrical conductivity. The results are reported in various units, although the official standard is *milli-Siemens per meter (mS/m)*. Other units, which are still used are: deci-Siemens per meter(dS/m); 'parts per million' (ppm), which can be thought of as the same as milligrams per litre (mg/L); osmotic potential (OP); Percentage of Total Soluble Salts and grains per gallon (gpg).

Conversion factors:

- mS/m x 0.01 = dS/m (deci-Siemens per metre). For soil or water measures
- mS/m x 5.5 = mg/L = ppm (assuming sodium chloride is the only salt present; this figure increases with other common salts and may be as high as 6). For water.
- mS/m x 0.42 = gpg (Grains per Gallon. This conversion is rough, and the factor depends on salts present). For water.
- mS/m x 0.0034 = % TSS in soil from a EC1:5 (w:v) measure (conversion varies based on salts present). For soil.
- mS/m x 0.00055 = % TSS in water from an ECw (conversion varies based on salts present). For water.
- mS/m x 10 = mmol/dm^3 NaCl = mmol/litre NaCl. For water.

All these salinity measures are trying to relate plant growth to a certain salinity level. Some of these measures are more useful in predicting plant growth (for instance EM38), others are cheap and easy (eg EC 1:5 v/v). The ECe figures are widely accepted by research and are 'standards', but the groundwater, EM38 and EC 1:5 measures can vary between sites for the same apparent salinity.

Table 5
Salinity classes for plants. Note these are specific to soil or water measures.

Class	**ECe (dS/m)**	**ECe (mS/m)**	**ECgw (mS/m)**	**EM-38 hor (mS/m)**	**NaCl (sol. mmol/l)**	**EC 1:5 (w/v) loam (mS/m) approx**	**EC 1:5 (v/v) loam (mS/m) approx**	**Total Dissolved Solids (TDS %)**
	Soil (a)	Soil (b)	Water (c)	'Soil' (d)	Water (e)	Soil (f)	Soil (g)	Water

Non-saline	<2	<200	<500	<50	<20	<20	<40	<0.275%
Slightly	2-4	200-400	500-1000	50-100	20-40	20-40	40-80	0.275-0.55%
Moderately	4-8	400-800	1000-2000	100-150	40-80	40-80	80-160	0.55-1.1%
Very	8-16	800-1600	2000-3000	150-200	80-160	80-160	160-320	1.1-1.65%
Extremely	>16	>1600	>3000	>200	>160	>160	>320	>1.65%

(a) Based on USDA 1954 categories: Used by CSIRO Canberra and others in Australia.
(b) Units used in Western Australia
(c) Groundwater from within potential rooting distance of plant (bores). Suitability for 'tree' growth.
(d) From D Bennett and R George, DAWA Bunbury.
(e) 'Irrigation' water used in pot trials.

Note that the tree species mentioned in table 3 under the category "species moderately sensitive to salt" fall in the salinity class "Extremely saline" (dS/m > 16). For tree species a further classification can be useful, e.g. into moderate salt tolerant species (16 –25 dS/m); and salt tolerant species (dS/m > 25). Seawater has an electrical conductivity of >45 dS/m.

Soil texture effects on ECw/v measures and salinity class
Because ECw/v measures are very commonly used to estimate salinity from field samples, an additional table 5 is included. These measures are usually done in a laboratory.
Note that these values are estimates of salinity in the plant root zone. When salinity is measured from the surface layer, the estimate of salinity at the root zone may be incorrect. Note also, that the EC1:5 is one part soil by *weight* to five parts of water by *volume*. When the EC1:5 volume:volume technique is used in the field, it is prone to large errors.

Table 6
Soil salinity measurements using EC1:5(w/v) in mS/m

Salinity Rating	Sand	Sandy loam	Loam	Clay loam	L/Med Clay	Heavy Clay
Non-saline	<13	<17	<20	<22	<25	<33
Slightly	13-26	17-33	20-40	22-44	25-50	33-67
Moderately	26-52	33-67	40-80	44-89	50-100	67-133
Very	52-106	67-133	80-160	89-178	100-200	133-267
Extremely	>106	>133	>160	>178	>200	>267

Source:
http://agspsrv34.agric.wa.gov.au/environment/salinity/measurement/salinity_levels_for_revegetation.htm