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Potential of *Eucalyptus* in the Remediation of Environmental Problems: A review

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ABSTRACT: Water logging, heavy metals contamination, energy crisis and pest control are some serious environmental problem that affects valuable agriculture lands, production and affect other organisms directly and indirectly. Many convention techniques are used to remediate pests, water logging and heavy metals pollution. However these techniques require extensive operation and management practices. Biotechnology and bioremediation provide some of the most economically and environmentally sound techniques for the environmental pollution. This review paper discusses the potential of *Eucalyptus* in the remediation of environmental problems.

KEYWORDS: Bio-drainage; *Eucalyptus*; water logging; water table; heavy metals.

1 INTRODUCTION

Eucalyptus has over 700 species distributed throughout the world [1]. *Eucalyptus* plants vary in size from small shrubs to giant trees. The growth of *Eucalyptus* species are quick and produce large quantities of wood when grown within or outside their natural range. Mostly *Eucalyptus* species are introduced to provide various products such as fuel wood, pulp and paper, sawn timber, essential oils e.g. for medicine and perfumes, and services including reclamation of degraded lands, saline areas and drainage of water-logged areas [2]. The aim of this review paper is to investigate the potential of *Eucalyptus* for environmental remediation.

1.1 ROOT SYSTEM OF *EUCALYPTUS*

Eucalyptus has a special rooting system. This rooting system consists of a shallow rooting system just beneath the soil surface, and deep tap roots that penetrate deep into the soil reaching the water table. The shallow roots extend horizontally to more than three to five meters, these roots are used to absorb surface soil moisture but they are not very dense. The tap roots can grow up to 9 meters into deeper soil layers. They are used to take up groundwater from aquifers that are more permanently available than surface soil moisture. In dry times *Eucalyptus* shift their water uptake to the deep roots. This roots system makes them able to survive and even grow during dry periods [3]. In an impressive review of measurements from a wide range of sites with stands at different stages of development, Knight [4] showed that roots of *Eucalyptus* trees are consistently dimorphic, comprising a widely spreading lateral system just below the soil surface and a deep tap root system in young trees that develops deep sinker roots as trees mature. Dawson and Pate [5] present an elegant demonstration of the adaptation of deep-rooted trees to access different sources of water from within the soil profile in relation to seasonal water availability. They used measurements of the natural abundance of hydrogen stable isotopes to detect seasonal changes in the sources of water for plantation stands of *E. globulus* and *E. camaldulensis* at Mount Barker, Western Australia. Both species accessed ground water using sinker roots in the summer, but the proportion of ground water in stems in the more opportunistic *E. camaldulensis* (26–47%) was much higher than that for *E. globulus* (9–15%).

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1.2 *EUCALYPTUS* AND WATER

Eucalyptus species use more water than native species of trees [6]. Soil moisture depletion rates were higher under *Eucalyptus* trees in dry season and were lower under the teak and jackfruit. The roots of *Eucalyptus camaldulensis* penetrate in the soil at 2.5 meters per year and absorb water from ground reservoir. *Eucalyptus* utilizes ground water as well as water from upper vadose zone [7]. When roots of *E. camaldulensis* and *E. platypus* grow through layers of soil with different water contents, they are able to redistribute water between the layers by transferring significant quantities along gradients of water potential [8]. The direction of the movement of water, termed 'hydraulic lift' may be upwards or downwards depending on the timing of rainfall and availability of water stored in different layers. Soares and Almeida [9] used a hydrological model to estimate water movement in five layers in the soil profile for *E. grandis* plantation in Brazil. Water was supplied from the root zone for transpiration during the wet period. In the dry period, rates of transpiration fell but water was supplied from soil below the root zone. At the end of the dry season this upward movement of water amounted to 1 mm per day and was sufficient to balance transpiration rate and maintain water potential in the trees above the critical limit for stomata closure. The trees growth causes an increase in the depth of the water table. The rate of fall of the water table doubled with the development of the trees [10]. Ahmad et al., [11] studied the *Eucalyptus* plantation for intercepting canal seepage and controlling water table. White et al., [12] showed that transpiration and evaporation for four species of *Eucalyptus* planted in contour belts were effective at reducing groundwater recharge with minimal competition with adjacent crops for water.

The high growth rate of *Eucalyptus* by utilizing more water makes it a water pumper in marshy lands. *Eucalyptus* has an inbuilt mechanism to utilize water luxuriously in marshy areas [13]. Among the different *Eucalyptus* introduced, *Eucalyptus camaldulensis* and *Eucalyptus tereticornis* are found to be grown extensively [14]. Depending upon the genetic makeup, *Eucalyptus* are showing good tolerance to salinity, water logging etc. Utilizing these variations, benefit capturing through selection of tolerant genotypes to abiotic stresses must be exploited in *Eucalyptus* [15].

2 WATER LOGGING

Water logging is the condition of the soil in which excess water limits gas diffusion [16]. Presently about one third of the world's irrigated area faces the threat of water logging and 60 Mha is already waterlogged and 20 Mha salt affected [17]. A soil is said to be water logged when the ground water table gets linked to soil water in the crop root zone and remains like this for the remaining period in a year [18]. In other words water logging is the condition when the soil becomes 100% saturated with water and becomes unfit for the growth of plants. In such soils, the space between the soil particles is occupied by water instead of air. Water logging occurs whenever water enters the soil at a faster rate than it can drain away. The duration and severity of the water logging event is influenced by the amount of water entering the system, the topography of the site, soil structure and the water absorbing capacity of the soil. The soil is made up of different sized soil particles with different sized spaces or pores. The smaller pores (less than 0.5 mm wide) are usually filled with water while the larger pores are usually filled with air. Good horticultural soils normally have between 10 to 30% of their volume composed of larger pores that are filled with air and 10% is considered the minimum air content for healthy root growth depending on plant species [19]. Rise in groundwater level followed by water logging and secondary Stalinization has become a serious problem in canal irrigated areas located in arid and semi-arid regions of the world [20].

The causes of water logging can be natural and anthropogenic. Main causes are heavy rainfall, poor water management system, high water table, floods, over irrigation, seepage from the canals, dams, and other construction activities like railways and roads. Water logging and salinity has adverse impact on crop productivity [21], [22], [23]. The principal cause of damage to plants grown in waterlogged soil is inadequate supply of oxygen to the submerged tissues as a result of slow diffusion of gases in water and rapid consumption of O_2 by soil microorganisms. Oxygen deficiency in waterlogged soil occurs within a few hours under some conditions. In addition to the O_2 deficiency, production of toxic substances such as Fe^{2+}, Mn^{2+}, and H_2S by reduction of redox potential causes severe damage to plants under waterlogged conditions [24].

Suitable water management strategies such as conjunctive use of groundwater and canal water and changes in crop patterns by reducing rice crop areas against of other low-water crops such as sorghum are suggested to bring the groundwater table down to a safe limit and prevent further rise of the groundwater table [25].

2.1 CONVENTIONAL DRAINAGE TECHNIQUES

The conventional techniques for recovery of waterlogged areas are the engineering based sub-surface horizontal drainage and sub-surface vertical drainage. These techniques are quite effective provided these are properly designed, installed, maintained and operated [17].

2.1.1 SURFACE DRAINAGE

According to American Society of Agricultural Engineers surface drainage is the removal of excess water from the soil surface in time to prevent damage to crops and to keep water from ponding on the surface. The term surface drainage applies to situations where overland flow is the major component of the excess water movement to major drains or natural streams. The technique normally involves the excavation of open trenches/drains. It could also include the construction of broad-based ridges or beds, as grassed waterways, with the water being discharged through the depressions between ridges. Surface drainage is most commonly applied on heavier soils where infiltration is slow and excess rainfall cannot percolate freely through the soil profile to the water table [17].

2.1.2 HORIZONTAL SUBSURFACE DRAINAGE

Horizontal subsurface drainage involves the removal of water from below the surface. The field drains can either be open ditches, or more commonly a network of pipes installed horizontally below the ground surface. These pipes used to be manufactured of clay tiles, with the water entering the pipes through the leaky joints [17].

Horizontal subsurface drainage has been found to be an effective technique. It controls the rise of groundwater tables and enables productive agriculture. However it is relatively expensive to install, operate and maintain. Also the disposal of drainage water that can contain high concentrations of pollutants (nutrients and/or toxic elements such as boron) can create problems [17].

2.1.3 VERTICAL SUBSURFACE DRAINAGE

Vertical subsurface drainage involves the removal of groundwater through pumped boreholes or tube wells, either in single or multiple well configurations. The common problem with this technique is that deeper, often more saline water can be mobilized which can cause disposal problems. Also, as the water is commonly used for irrigation rather than disposal, salt is recycled through the soil profile and inevitably groundwater salinities will increase over time.

Conventional physical drainage works require expensive capital investment, operation and maintenance. Physical drainage measures also generate drainage effluent. Bio-drainage is the use of vegetation to manage water fluxes in the landscape, is one such technique that has recently attracted interest in drainage and environmental management circles [17].

2.2 BIO-DRAINAGE

Bio-drainage is the pumping of excess soil water by deep rooted plants using their bio-energy [26]. Bio-drainage is the use of vegetation to manage water fluxes through evapotranspiration [27]. The Bio-drainage system consists of fast growing tree species, which absorb water from the capillary fringe located above the ground water table. It is an alternative technique that has recently attracted interest in drainage and environmental management. The absorbed water is transported to different parts of plants and finally more than 98% of the absorbed water is transpired into the atmosphere by stomata. This combined process of absorption, translocation and transpiration of excess ground water into the atmosphere by the deep rooted vegetation conceptualizes Bio-drainage.

Fast growing *Eucalyptus* species are known for luxurious water consumption under excess soil moisture conditions is suitable for Bio-drainage. These species can be planted in blocks in the form of farm forestry or along the field boundary in the form of agroforestry [28]. Bio-drainage can be a feasible option for controlling water logging and salinity in irrigated lands [29]. So far *Eucalyptus* species has a higher Bio-drainage potential as compared to relatively slow bio-drainers like *T. aphylla* and *P. pinnata* [30]. The growth behavior, biomass accumulation by the plants and physiological parameters suggests that *Eucalyptus* has high potential to be used as an efficient Bio-drainage species [31]. *Eucalyptus tereticornis* and *Eucalyptus* hybrid are fast bio-drainers primarily due to their ability to display large leaf area [32]. Cloned *Eucalyptus tereticornis* (Mysure gum) is fast growing, goes straight and thus has low shading effect and has luxurious water consumption where excess soil moisture conditions exist. It grows well under a wide range of climatic conditions. In waterlogged areas, it can be successfully grown by ridge planting. The world's *Eucalyptus* plantation area has increased to 19 Mha because of its fast growth rate, good wood properties, carbon sequestration, and thus seems to be a good option for Bio-drainage [33]. In a study conducted by Ram et al., [34] the annual rate of transpiration by *Eucalyptus* plantations was 268 mm against the mean annual rainfall of 212 mm. These plantations generated 46.6 tons ha^{-1} fresh biomass with benefit cost ratio of 3:5 and also sequestered 15.5 tons carbon ha^{-1}. Lowering of water table and associated soil improvement by *Eucalyptus* plantations increased the wheat grain yield by 3.4 times and resulted in reclamation of waterlogged areas.

3 HEAVY METALS

The problem of heavy metals getting worse in the environment from year to year [35]. Therefore heavy metal problem must be handled to ensure maintenance of environmental and ecological restoration. Conventional methods are generally considered as destructive, expensive, labor intensive and causing secondary problems [36]. Phytoremediation is a new, economical, efficient, environmentally friendly remediation strategy with social acceptance [37], [38], [39].

3.1 HEAVY METALS REMEDIATION BY EUCALYPTUS

Woody vegetations are advantageous for phytoremediation as they produce large amounts of biomass, which can be used an energy source [40]. *Eucalyptus* has a huge shoot system which should be able to bioaccumulate large concentrations of heavy metals from the soil [41]. *Eucalyptus* species are effective accumulators of both organic and inorganic compounds, which may be due to the leaf geometry and to the possession of epidermal features that include the excretion of sticky secondary compounds, thus promoting the adsorption of particulates [42]. Although *Eucalyptus* accumulates lower levels of heavy metals compared to hyper accumulating but using *Eucalyptus* as bioaccumulator for heavy metals is the low risk of entering the food chain because this plant is not consumed by humans and hardly ever used by mammals [43]. For the phytostabilisation of arsenic (As) contaminated land and mine tailings E. cladocalyx is an effective species [43]. *Eucalyptus* species are effective in the bioaccumulation of Pb, Zn and Cr in its tissues. However the bioaccumulation can be improved by the addition of biodegradable chelating agents such as methylglycine diacetate (MGDA), ethylene succinic acid (EDTS), L-glutamic acid diacetate (GLDA), L-aspartic acid diacetate (ASDA) [44]. The efficiency of phytoremediation can also be enhanced by rhizospheric bacteria [45] and saprophytic fungi [46]. Arriagada et al., [47] reported that *Glomus deserticola* enhances the amount of Pb absorbed by *Eucalyptus* plants.

3.2 SORPTION OF HEAVY METALS BY EUCALYPTUS BARK

On the other hand *Eucalyptus* bark has the ability to remove Hg [48], Cu and Pb [49] and Cr [50] from contaminated water. *Eucalyptus* bark is an economic sorbent for removal of cadmium ions from aqueous solution [51]. The bark of *Eucalyptus tereticornis* can remove about 96% of Fe, 75% of Zn, 92% of Cu and 41% of sulphate from the acid mine water [52]. Kongsuwan et al., [53] demonstrated the use of *Eucalyptus* bark in the binary component sorption for Cu and Pb. The maximum sorption capacities for Cu and Pb were 0.45 and 0.53 mmol/g.

4 *EUCALYPTUS* OIL

Apart from the direct services provided by *Eucalyptus* specie like biomass production and sink for atmospheric carbon dioxide [54], it also has indirect services through their essential oil used as insect/pest repellent and as a pesticidal agent [55]. Widespread oil yielding *Eucalyptus* species are *E. citriodora, E. globulus, E. polybractea, E.* camaldulensis and *E. grandis, E. citriodora. Eucalyptus* species are among the world's top traded oils and oil extracted from *E. citriodora* is one of the world's major oil in terms of trade volume [56]. Under Food and Drug Authority of USA *Eucalyptus* oil is GRAS (Generally Regarded as Safe) category by and classified as non-toxic [57]. Council of Europe has also approved the use of *Eucalyptus* oil as a flavoring agent in foods (≤5 mg/kg) and candies and confectionery items (≤15 mg/kg) [58]. *Eucalyptus* essential oils and their major constituents possess toxicity against a wide range of microbes including bacteria and fungi, both soil borne and post harvest pathogens.

Table 1. Eucalyptus oil used as pesticide

***Eucalyptus* Species**	**Extracted constituent**	**Reference**
E. citriodora	Citronellal	Ramezani et al., [65]
E. globules	1,8-Cineole	Yang et al., [61]
E. urophylla *E. camaldulensis, E. grandis*	γ-Terpinene, 1,8-Cineole	Su et al., [62]
E. grandis	α-Pinene, 1,8-cineole	Lucia et al.,[66]
E. grandis, *E. urophylla*	Alloocimene, α-pinene	Liu et al., [67]
Eucalyptus oleosa	1,8-cineole	Naceur et al., [68]
Eucalyptus camaldulensis, Eucalyptus astringens, Eucalyptus leucoxylon, Eucalyptus lehmannii and Eucalyptus rudis	1,8-cineole, α-pinene, and α-terpineol	Mediouni et al., [69]
Eucalyptus camaldulensis	1,8-Cineole	Cruz-galvez et al., [70]

They have been found to reduce mycelial growth and inhibit spore production and germination [59], [60]. *E. globules* and its major monoterpene 1,8-cineole showed toxicity against human head lice, *Pediculus humanus capitis* [61]. The essential oil from E. Citriodora could be an excellent choice as a wood preservative and preservation of leather goods and wood artifacts [62]. *Eucalyptus* oil is toxic for weeds and has a great potential for weed management [63], [64].

Table 2. Eucalyptus oil used as insecticide

***Eucalyptus* Species**	**Used for**	**Reference**
Eucalyptus camaldulensis	*Tribolium confusum* and *Ephestia kuehniella*	Tunc et al., [71]
Eucalyptus spp.	*Sitophilus oryzae*	Lee et al., [72]
Eucalyptus spp.	*Thaumetopoea pityocampa*	Kanat and Alma [73]
E. globules	*Pediculus humanus capitis*	Yang et al., [61]
E. globules	*Musca domestica*	Abdel Halim and Morsy [74]
Eucalyptus spp.	*Lycoriella mali*	Choi et al., [75]
E. tereticornis	*Anopheles stephensi*	Nathan, [76]
Eucalyptus spp.	*Tribolium castaneum, Rhyzopertha dominica, Sitophilus oryzae* and *Sitophilus zeamais, Corcyra cephalonica* and *Sitotroga cerealella*	Rajendran and Sriranjini [77]
Eucalyptus leucoxylon	*C. maculates, S. oryzae* and *T. castaneum.*	Kambouzia et al.,[78]
Eucalyptus globulus	*Trogoderma granarium*	Tayoub et al., [79]
E. camaldulensis	*Ectomyelois ceratoniae*	Mediouni et al., [69]

5 BIO-ENERGY FROM *EUCALYPTUS*

Eucalyptus is among the fastest growing hardwood plantation genus in the world. In addition, *Eucalyptus* has been used for bio-energy production in many countries. *Eucalyptus* species have potential for high biomass production and they tolerate a wide range of soils and climatic conditions. High productivity can provide substantial yields of biomass reduce greenhouse gas emissions from fossil fuel consumption and can also reduce operational fossil fuel use by replacement of more energy intensive forms of land use [80]. Annual stem growth rate vary with soil, climate, biotic influences and genetic factors. *Eucalyptus* yields $18m^3ha^{-1}$ $year^{-1}$ over a 12 year rotation with single species clones [81] and up to $35m^3$ ha^{-1} $year^{-1}$

with hybrid clones [82]. Cold tolerant species like *E. gunnii* have yielded annual stem growth rate of 25m^3 ha^{-1} $year^{-1}$ at 11 years old [83]. Faster growing species such as *E. nitens* may yield mean annual increments of over 25m^3ha^{-1} $year^{-1}$ [84].

6 CONCLUSION

This was concluded that *Eucalyptus* species are effective in combating water logging, heavy metals remediation and as natural pest control. *Eucalyptus* can provide substantial yields of biomass can reduce greenhouse gas emissions from fossil fuel consumption. *Eucalyptus* in remediated water logging, pest control and heavy metal pollution is economically feasible, socially acceptable and ecologically viable as compared to conventional techniques. Bio-drainage is a viable alternative of conventional engineering-based techniques could be bio-drainage by high water uptake trees like *Eucalyptus* species. Bio-drainage is economical because it requires only initial investment for planting the vegetation, and when established, the system provides economic returns by means of fodder, wood or fiber harvested and additionally sequesters carbon in the timber. However the salts extraction ability of *Eucalyptus* needs to be improved to make these species more effective for water logging.

REFERENCES

[1] M.I.H. Brooker, and D.A. Kleinig, Field Guide to *Eucalyptus*. vol. 1. South-eastern Australia, Third edition. Bloomings, Melbourne.

[2] Munishi PKT. The *Eucalyptus* Controversy in Tanzania. Department of Forest Biology, Sokoine University of Agriculture; Morogoro, Tanzania, 2006.

[3] F. Fritzsche, A. Abate, M. Fetene, E. Beck, S. Weise, and G. Guggenberger, "Soil-plant hydrology of indigenous and exotic trees in an Ethiopian montane forest." Tree Physiology 26(8): pp. 1043-1054, 2006.

[4] J.H. Knight, Root distributions and water uptake patterns in *Eucalyptus* and other species. In: Landsberg, J.J. (Ed.), The Ways Trees use Water. Water and Salinity Issues in Agroforestry No. 5. Rural Industries Research and Development Corporation Publication Number 99/37, Barton, ACT, pp. 55– 85, 1999.

[5] T.E. Dawson, J.S. Pate, Seasonal water uptake and movement in root systems of Australian phraeatophytic plants of dimorphic root morphology: a stable isotope investigation. Oecologia 107:pp. 13–20, 1996.

[6] D. M. Zahid, F. R. Shah, and A. Majeed, Planting *Eucalyptus* camaldulensis in arid environment is it useful species under water deficit system. J. Bot., 42(3): pp. 1733-1744, 2010.

[7] Calder, Ian. R., Paul, T.W., Roiser, Prasanna, K.T and Parameswarappa, *Eucalyptus* water use greater than rainfall input, Hydrology and earth system sciences, 1(2), pp. 249-256, 1997.

[8] S.S.O. Burgess, Adams, M.A., Turner, N.C., White, D.A., and C.K., Ong, Tree roots: conduits for deep recharge of soil water. Oecologia 126: pp. 158–165, 2001.

[9] J. V Soares, and A.C. Almeida, Modeling the water balance and soil water uses in a fast growing *Eucalyptus* plantation in Brazil. , 253, pp.130–147, 2001.

[10] Rodríguez-suárez, J.A. Influence of *Eucalyptus* globulus plantation growth on water table levels and low flows in a small catchment. , 396, pp.321–326, 2011.

[11] S. Ahmad, Mohyuddin. J, Siddiqui. S.M. and Bhutta. M. N, Tree Plantation for Intercepting Canal Seepage and Controlling Watertable, Pakistan Journal of Water Resources, Vol.11(2) July-December 2007 / 35.

[12] D.A. White, Water use by contour-planted belts of trees comprised of four *Eucalyptus* species. , 53, pp.133–152, 2002.

[13] Tushar, *Eucalyptus* – falsely cursed. Farmers Eorums, 2(3): 17, 2002.

[14] Mohan Varghese., A. Nicodemus, B. Nagarajan, N. Ravi and R. Hedge, A breeding Programmed for improving productivity of *Eucalyptus* camaldulensis and *Eucalyptus* tereticornis in India. Recent *Eucalyptus* research in India (eds) Bagshi, S.K., M.Varghese and Siddappa. pp.19-28, 2002.

[15] K.V. D. Chaitanya, Sunfar, M.V., and Ramachandra R.A, Variation in photosynthesis and drought tolerance among eight open pollinated families of *Eucalyptus* camaldulensis and E. tereticornis. In: Recent Eucalypt research in India (Eds. S.K.Bagchi., M. Varghese and Siddappa). pp. 83-93, 2002.

[16] Setter TL, Waters I, Sharma SK, Singh KN, Kulshreshtha N, Yaduvanshi NPS, Ram PC, Singh BN, Rane J, McDonald G, Khabaz-Saveri H, Biddulph TB, Wilson R, Barclay I, McLean R, White, D.A., Dunin, F.X., Turner, N.C., Ward, B.H., Galbraith, J.H, Water use by contour-planted belts of trees comprised of four *Eucalyptus* species. Agric. Water Manage. 53: 133–152, 2002.

[17] A. F. Heuperman, and Kapoor, A. S., Bio- drainage: Principal Experiences and Applications, IPTRID, FAO, Rome, pp. 1–79, 2002.

[18] A.M. Michael, and Ojha, T.P., Principles of agricultural engineering. vol. II, 5th ed., pp. 391-457, M/S Jain Brothers, New Delhi, India, 2006.

[19] Hardy, Sandra, Pat Barkley, and Andrew Creek. "Impacts and management of flooding and waterlogging in citrus orchards." Published by the Department of Primary Industries, a part of the Department of Trade and Investment,

Regional Infrastructure and Services, ISSN 1832-6668, 2012.
[20] A. Singh, Groundwater modelling for the assessment of water management alternatives. Journal of Hydrology, 481: pp.220–229, 2013.
[21] A.A.M. Mohamedin, M.S. Awaad and Azza R. Ahmed, Research Journal of Agriculture and Biological Sciences, 6(4): pp.378-385, 2010.
[22] C. Zheng, Jiang, D., Dai, T., Jing, Q., Cao, W., Liu, F., plant Science 176: pp.575 – 582, 2009.
[23] Zhen Luo, Hezhong Dong, Weijiang Li, Zhao Ming, Yuqing Zhu, Crop Protection 27: pp.1485–1490, 2008.
[24] T.L. Setter, Review of wheat improvement for waterlogging tolerance in Australia and India : the importance of anaerobiosis and element toxicities associated with different soils. , pp.221–235, 2009.
[25] Singh, Ajay, Sudhindra Nath Panda, Wolfgang-albert Flugel, and Peter Krause,"Waterlogging And Farmland Salinisation: Causes And Remedial Measures In An Irrigated Semi-Arid Region Of India, Irrigation And Drainage Irrig. and Drain. (2012) Published online in Wiley Online Library (wileyonlinelibrary.com) DOI: 10.1002/ird.651, 2012
[26] J. Ram, Dagar, J.C, Singh, G, Lal, K, Tanwar, V.S, Shoeran, S.S, Kaledhonkar, M.J, Dar, S.R and Kumar, M, Bio-drainage: Eco-friendly technique for combating waterlogging and salinity. Technical Bulletin: pp.24, 2008.
[27] S. Akram, Abkavosh, S., Liaghat, H., and Abureyhan, World Congress of the International Commission of Agricultural and Biosystems Engineering (CIGR). 1–9, 2010.
[28] J. C. Dagar, G. Singh, and J. Ram, "Bio-drainage: an eco-friendly technique for combating water logging and salinity." (December):6–11. 60th 5 th International Executive Council Meeting & Asian Regional Conference, 6-11 December 2009, New Delhi, India, 2009.
[29] A.S. Kapoor, Bio-drainage: A Biological Option for Controlling Water Logging and Salinity (Tata McGraw Hill, New Delhi) 2002, 1-332,2002.
[30] O.P. Toky, R Angrish, K S Datta, V Arora, C Rani, P Vasudevan, and P J C Harris, "Bio-drainage for preventing water logging and concomitant wood yields in arid agro-ecosystems in North-Western India." 70(August): 639–644, 2011.
[31] N.G. Bala, N.K. Singh, Bohra, and N.K. Limba, "Increasing Productivity of Waterlogged Zone Of Canal Command Area In Indian Desert." (December):6–11. 60th 5 th International Executive Council Meeting & Asian Regional Conference, 6-11 December 2009, New Delhi, India, 2009.
[32] R. K. S. Angrish, Datta, C., V.S. Rani, and S.M. Chawla, 'Comparative Bio-drainage Potential Of Some Tree Species',, 6–11, 5 Asian Regional Conference, 6-11 December 2009, New Delhi, India, 2009.
[33] T. G. Iglesias, and Wilstermann, D., *Eucalyptus* universalis. Global cultivated eucalypt forests map, In GIT forestry consulting's eucalyptologics: information resources on *Eucalyptus* cultivation worldwide. Retrieved from http://www.git-forestry. com/; 19 January 2009.
[34] J. Ram, Dagar, Khajanchi Lal, G Singh, O P Toky, V S Tanwar, S R Dar, and M K Chauhan, "Bio-drainage to combat waterlogging , increase farm productivity and sequester carbon in canal command areas of northwest India." Pp. 1673–1680, 2011.
[35] C. Govindasamy, M. Arulpriya , P. Ruban, L.J.Francisca, and A. Ilayaraja, "Concentration of heavy metals in sea grasses tissue of the Palk Strait, Bay of Bengal", International Journal of Environmental Sciences, 2 (1):pp.145-153, 2011.
[36] G. Wu, H. Kang, Zhang, X., Shao, H., Chu, L., and Ruan, C., "A critical review on the bio-removal of hazardous heavy metals from contaminated soils: Issues, progress, eco-environmental concerns and opportunities", Journal of Hazardous Materials, 174:pp. 1-8, 2010.
[37] Singh, A., Eapen, S., and Fulekar M.H., (2009) "Potential of Medicago sativa for uptake of cadmium from contaminated environment", Romanian Biotechnology Letters, 14: 4164-4169.
[38] Saier, J.M.H., and Trevors, J.T. (2010) "Phytoremediation", Water, Air and Soil Pollution, 205 (Suppl 1), pp S61-S63.
[39] Revathi, K., Harbabu, T.E., and Sudha, P.N. (2011) "Phytoremediation of chromium contaminated soil using sorghum plant", International Journal of Environmental Sciences, 2 (2):417-428.
[40] French CJ, Dickinson NM, Putwain PD. Woody biomass phytoremediation of contaminated brownfield land. Environ Pollut 2006;141: 387–95.
[41] T. Martha, Flowers in Isreal. http//isreal1234wordpress.com *Eucalyptus* camaldulensis,2006.
[42] Q.D. Goodger, Cao, B., Jayali, I., Williams, S.J., & Woodraw, I.E., Non-volatile components of the essential oil secretory cavities of *Eucalyptus* leaves: discovery of two glucose monoterpene esters, cuniloside B and froggattiside A. Phytochemistry 70: pp.1187-1194,2009.
[43] D. J. King, Doronila, A. I., Feenstra, C., Baker, A. J. M., & Woodrow, I. E., Phytostabilisation of arsenical gold mine tailings using four *Eucalyptus* species: Growth , arsenic uptake and availability after five years, science of the total environment, 40: pp.35 – 42, 2008.
[44] V. Nenman, N.D. Nimyel, I. Ezekiel, Journal, I., Nenman, V., Nimyel, N. D., and I. Ezekiel, The Potentials of *Eucalyptus* camaldulensis for the Phytoextraction of Six Heavy Metals in Tin – mined Soils of Barkin Ladi L . G . A . of Plateau State , Nigeria, 2(2): pp.346–349, 2012.
[45] X. Zhuang, J. Chen, H. Shim, Z. Bai, New advances in plant growth-promoting rhizobacteria for bioremediation. Environ. Int. 33: pp.406–413,2007.

[46] C. Arriagada, Restauraci ogico, pesados: Uso de hongos saprobios y micorricicos como herramienta de mejora medioambiental. PhD thesis, Universidad de on forestal de suelos contaminados por metales ordoba, Espana, 2001.
[47] C. A. Arriagada, M. A. Herrera, and J. A. Ocampo, Beneficial effect of saprobe and arbuscular mycorrhizal fungi on growth of *Eucalyptus* globulus co-cultured with Glycine max in soil contaminated with heavy metals, 84, pp.93–99,2007.
[48] I. Ghodbane, and O. Hamdaoui, Removal of mercury (II) from aqueous media using *Eucalyptus* bark : Kinetic and equilibrium studies, 160: pp.301–309, 2008.
[49] P. Patnukao, A. Kongsuwan, and P. Pavasant, Batch studies of adsorption of copper and lead on activated carbon from *Eucalyptus* camaldulensis Dehn . bark, 20: pp.1028–1034, 2008.
[50] V. Sarin, and K.K. Pant, Removal of chromium from industrial waste by using *Eucalyptus* bark, 97: pp.15–20, 2006.
[51] I. Ghodbane, L. Nouri, O. Hamdaoui, and M. Chiha, Kinetic and equilibrium study for the sorption of cadmium (II) ions from aqueous phase by *Eucalyptus* bark, 152: pp.148–158,2008.
[52] E. Chockalingam, and S. Subramanian, Bioresource Technology Utility of *Eucalyptus* tereticornis (Smith) bark and Desulfotomaculum nigrificans for the remediation of acid mine drainage. Bioresource Technology, 100(2): pp.615–621, 2009.
[53] A. Kongsuwan, P. Patnukao, P. Pavasant, Binary component sorption of Cu(II) and Pb(II) with activated carbon from *Eucalyptus* camaldulensis Dehn bark. J. Ind. Eng. Chem. 15: pp.465-470, 2009.
[54] B. Martin, *Eucalyptus*: A strategic forest tree. In: Wei, R.-P., Xu, D. (Eds.), *Eucalyptus* Plantations: Research, Management and Development. Proceedings of the International Symposium, Guangzhou, China, 1–6 September 2002. World Scientific Publishing Co. Pte. Ltd., Singapore, pp. 3–18, 2002.
[55] A.F.M. Barton, The oil mallee project, a multifaceted industrial ecology case study. J. Ind. Ecol. 3: 161–176, 2000.
[56] C. Green, Export Development of Essential Oils and Spices by Cambodia. C.L. Green Consultancy Services, Kent, UK, 2002.
[57] USEPA (United States Environment Protection Agency), 1993. R.E.D. FACTS. Flower and Vegetable Oils. Available online at http://www.epa.gov/oppsrrd1/REDs/ factsheets/4097fact.pdf (accessed on February 02, 2013).
[58] Council of Europe, Flavouring substances and natural sources of flavourings. Volume I, 4th Edition: Chemically-Defined Flavouring Substances, 1992.
[59] A.C.G. Fiori, Schwan-Estrada, K.R.F., Stangarlin, J.R., Vida, J.B., Scapim, C.A., Cruz, M.E.S., S.F. Pascholati, , Antifungal activity of leaf extracts and essential oils of some medicinal plants against Didymella bryoniae. J. Phytopathol. 148: pp. 483–487, 2002.
[60] H.O.A. Oluma, I.U. Garba, Screening of *Eucalyptus* globulus and Ocimum gratissimum against Pythium aphanidermatum. Nigerian J. Plant Prot. 21: 109–114, 2004.
[61] Y.C. Yang, H.C. Choi, W.S. Choi, J.M. Clark, and Y.J. Ahn, Ovicidal and adulti- cidal activity of *Eucalyptus* globulus leaf oil terpenoids against Pediculus humanus capitis (Anoplura: Pediculidae). J. Agric. Food Chem. 52: pp. 2507–2511, 2004.
[62] Y.C. Su, C.L. Ho, I.C. Wang, S.T. Chang, Antifungal activities and chemical compositions of essential oils from leaves of four *Eucalyptus*. Taiwan J. For. Sci. 21: 49–61, 2006.
[63] R.D. Batish, H.P. Singh, N. Setia, R.K. Kohli, S. Kaur, S.S. Yadav, Alternative control of littleseed canary grass using eucalypt oil. Agron. Sust. Dev. 27: 171– 177, 2007.
[64] N. Setia, D.R. Batish, H.P. Singh, R.K. Kohli, Phytotoxicity of volatile oil from *Eucalyptus* citriodora against some weedy species. J. Environ. Biol. 28: pp.63–66, 2007.
[65] H. Ramezani, H.P. Singh, D.R. Batish, and R.K. Kohli, Antifungal activity of the volatile oil of *Eucalyptus* citriodora. Fitoterapia 73: pp.261–262, 2002a.
[66] A. Lucia, P.G. Audino, E. Seccacini, S. Licastro, E. Zerba, and H. Masuh, Larvicidal effect of *Eucalyptus* grandis essential oil and turpentine and their major components on Aedes aegypti larvae.J.Am. Mosq.Control Assoc. 23: pp.299–303, 2007.
[67] X. Liu, Q. Chen, Z. Wang, L. Xie, Z. Xu, Allelopathic effects of essential oil from *Eucalyptus* grandis X E. urophylla on pathogenic fungi and pest insects. Frontiers of Forestry in China 3: pp.232-236, 2008.
[68] H. Naceur, B. Marzoug, M. Romdhane, A. Lebrihi, F. Mathieu, F. Couderc, and M. Abderraba, *Eucalyptus* oleosa Essential Oils: Chemical Composition and Antimicrobial and Antioxidant Activities of the Oils from Different Plant Parts (Stems, Leaves, Flowers and Fruits), pp.1695–1709, 2011.
[69] J.B.J. ediouni, H. Soumaya, B. Mohamed, and L. Mohamed, Seasonal variations in chemical composition and fumigant activity of five *Eucalyptus* essential oils against three moth pests of stored dates in Tunisia. J. Stored Products Research., 48: pp.61–67, 2012.
[70] A.M. Cruz-galvez, C.A. Gómez-aldapa, J.R. Villagómez-ibarra, N. Chavarría-hernández,J. Rodríguez-baños, Rangel-vargas, and J. Castro-rosas, Antibacterial effect against foodborne bacteria of plants used in traditional medicine in central Mexico: Studies in vitro and in raw beef. Food Control, 32(1) pp. 289-295, 2013.
[71] I. Tunc, B.M. Berger, F. Erler, and F. Dag, Ovicidal activity of essential oils from five plants against two stored-product insects. J. Stored Prod. Res. 36, pp.161– 168, 2000.
[72] S.E. Lee, B.H. Lee, W.S. Choi, B.S. Park, J.G. Kim, and B.C. Campbell, Fumigant toxicity of volatile natural products from Korean spices and medicinal plants towards the rice weevil, Sitophilus oryzae (L). Pest Manag. Sci. 57: pp.548–553, 2001.

[73] M. Kanat, and M.H. Alma, Insecticidal effects of essential oils from various plants against larvae of pine processionary moth (Thaumetopoea pityocampa Schiff) (Lepidoptera: Thaumetopoeidae). Pest Manage. Sci. 60:pp.173–177, 2003.

[74] A.S. Abdel Halim, and T.A. Morsy, The insecticidal activity of *Eucalyptus* globulus oil on the development of Musca domestica third stage larvae. J. Egypt. Soc. Parasitol. 35 (2), pp.631–636, 2005.

[75] W.S. Choi, B.S. Park, Y.H. Lee, D.Y. Jang, H.Y. Yoon, S.E. and Lee, Fumigant toxicities of essential oils and monoterpenes against Lycoriella mali adults. Crop Prot. 25, pp.398–401, 2006.

[76] S.S. Nathan, The use of *Eucalyptus* tereticornis Sm. (Myrtaceae) oil (leaf extract) as a natural larvicidal agent against the malaria vector Anopheles stephensi Liston (Diptera: Culicidae). Biores. Tech. 98: pp.1856–1860, 2007.

[77] S. Rajendran, and V. Sriranjini, Plant products as fumigants for stored-product insect control. J. Stored Prod. Res. 44:pp. 126–135, 2008.

[78] J. Kambouzia, M. Negahban, and S. Moharramipour, Fumigant Toxicity of *Eucalyptus* Leucoxylon Against Stored Product Insects. American-Eurasian Journal of Sustainable Agriculture, 3(2): pp.229-233, 2009.

[79] G. Tayoub, A.A. Alnaser, and I. Ghanem, Toxicity of two essential oils from *Eucalyptus* globulus Labail and Origanum syriacum L . on Larvae of Khapra beetle, 2(2):pp. 240–245, 2012.

[80] A.D. Leslie, M. Mencuccini, and M. Perks, The potential for *Eucalyptus* as a wood fuel in the UK. Applied Energy, 89(1), pp. 176–182, 2012.

[81] AFOCEL. Itineraire technique et production. Lettre d'information semestrielle *Eucalyptus*. Numero 2 Avril 2003, AFOCEL, France; Pp.4, 2003.

[82] AFOCEL. Fiches clonales *Eucalyptus*, *Eucalyptus* gundal AFOCEL, France; Pp. 4, 2006.

[83] J.G. Purse, and K.E. Richardson, Short rotation single stem tree crops for energy in the UK – an examination with *Eucalyptus*. Aspects of applied biology, No. 65, Biomass and nergy Crops II; pp. 1–8, 2001.

[84] J. Neilan, and D. Thompson, *Eucalyptus* as a potential biomass species for Ireland. COFORD connects, reproductive material no. 15. COFORD, Ireland; pp. 8, 2008.