Efficiency of Bioenergy Plant in Phytoremediation of Saline and Sodic Soil

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Abstract

Saline and sodic soils are distributed all over the world and are continuously increasing with a rapid rate and hence considered as one of the serious problems of land degradation. Land degradation is directly affecting the agricultural production. Due to limited availability of agricultural land/soil and poor soil physical and chemical characteristics, there is scarcity of food supply for the increasing population. Hence, the sodic and saline soil can be considered as an important land resource and can be utilized for economic development of the country. Several methods have been applied to restore the saline and sodic land. Chemical methods, such as using gypsum cause dissolution of calcium ion by replacing Na^+ ion through cation exchange processes. This process works efficiently but is cost intensive and not feasible for farmers as well as natural ecosystems. There is a need of sustainable and cost-effective process/technology that can help in reclamation of saline and sodic soil. In this respect, phytoremediation has emerged as a versatile technology towards the reclamation of degraded land. The purpose of phytoremediation using bioenergy crops is to obtain resources that can sustain the increasing population and simultaneously can be used for oil production. Adopting phytoremediation using energy crops also sequesters car-

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bon, fixes atmospheric nitrogen in the soil, and produces oil and biomass that can be utilized as feedstock for biofuels.

Keywords
Saline soil • Sodic soil • Microbial fuel cell • Bioenergy crops • Phytoremediation

14.1 Introduction

Soil salinity and sodicity is a serious issue of land degradation worldwide and is predicted to become more of a problem in the future (Wong et al. 2008). Soil salinity refers to the high salt concentration in the soil, and sodicity is the presence of high concentration of just sodium ions (Na^+) among all of the other cations present in the soil such as magnesium (Mg^{2+}), calcium (Ca^{2+}), etc. (Bernstein 1975). Saline soil is one of the important soil resources in the world, and coastal saline soil is one of the main types of saline soil. Sandy loam and silt soil are examples of soil types present in coastal saline region (Li et al. 2016). Salt-affected soil is distributed in 831 million hectares of land worldwide including 397 and 434 million hectares of saline and sodic soil, respectively (FAO 2000). The characteristic features and principles involved in the identification, reclamation, and management of salt-affected soil are similar throughout the world. Some of the factors vary regionally such as soil characteristics, climatic condition, water availability, farm management efficiency, available resources, and economic status that lead to differences in methods and reclamation potential (Abrol et al. 1988). Various methods have been established for reclamation purposes but are associated with certain limitations. In this regard, phytoremediation can be seen as an effective, low-cost, and environmentally safe technology. It is a plant-based technology which enhances soil quality and productivity potential, thereby reducing pollutants or contaminants responsible for impaired plant growth. Some plants have more capacity to remediate degraded sodic or saline soil. It is important that the plants that are selected possess the highest potential of phytoremediation. If those plants also have the potential for high biomass production, they can be used for bioenergy generation. Bioenergy is a renewable source of energy from biological materials that produces heat, electricity, and fuel and their coproducts (Yuan et al. 2008). Among various energy sources, bioenergy is the most abundant and versatile renewable energy in the world (Zhuang et al. 2011; Edrisi and Abhilash 2016). Bioenergy is termed as the conversion of biomass into energy (McKendry 2002a). Biomass is the typical form of renewable energy that has been widely utilized as source of energy for domestic purposes since quite long ago (McKendry 2002b). Biomass can be produced by growing dedicated energy crops such as short rotation coppice (SRC), perennial grasses, forest residues, sludge from organic industrial wastes, and organic domestic wastes (McKendry 2002a). According to Ni et al. (2006), resources produced from biomass used to convert into energy have been classified into four categories:

- Energy crops: herbaceous energy crops, woody energy crops, industrial crops, agricultural crops, and aquatic crops.
- Agricultural residues and end products: crops waste and animal-produced waste.
- Forests wastes and leftover: mill wood, logging residues, trees, and shrubs residues.
- Industrial and municipal wastes: municipal solid waste, sewage sludge, and industrial effluent waste.

Biomass is used for the purpose of heating, cooling, and producing electricity and liquid biofuels. Burning fossil fuels, deforestation, and human activities have led to the emission of greenhouse gases into the atmosphere. The usage of biomass for biofuel reduces greenhouse gas emissions, making it carbon neutral (Kraxner et al. 2013). Energy produced from biomass has been categorized into two groups: biomass produced from food crops such as corn grain, sugarcane, soybean, oil seed, etc.; and biomass produced from cellulosic feedstock such as starch, sugar, fatty acid, or cellulose (Ghosh 2016). The physical quantity of biomass has enough potential for worldwide bioenergy production (Altman et al. 2015). The new renewable energy obtained through wind, solar, and biofuel is growing fast continuously and contributing to global renewable energy supply. Bioenergy is one of the alternative sources for fossil fuel, particularly for those used in transportation. Presently, commercially available biofuels are produced from starch or sugar-rich crops for bioethanol and from oilseeds for biodiesel production (Popp et al. 2014).

There are numerous plant species that are capable of cleaning up the soil. These plants are also used to obtain useful by-products such as biofuel (biodiesel or bioethanol), fiber, wood, charcoal, alkaloid, bioplastic, etc. (Tripathi et al. 2016). In India, the 1970 oil crisis has led to the establishment of bioenergy promotion (Rabindranath et al. 2010; Edrisi and Abhilash 2016).

14.1.1 Saline and Sodic Soil: Origin, Characteristics, Distribution, and Parameters for Salinity/Sodicity Measurement

14.1.1.1 Origin of Saline and Sodic Soil

Salinity is caused by natural weathering of parent material, deposition of sea salt carried by wind and rain, inundation of coastal land by tidal water, and anthropogenic activities such as excessive irrigation by underground water resulting in a rise of the water table, irrigation by salt-containing water, poor drainage, etc. (Munns 2005; Manchanda and Garg 2008; Hasanuzzaman et al. 2013; Hasanuzzaman et al. 2014). Salts present in the upper surface of the soil profile undergo hydration, hydrolysis, oxidation, solubilization, and carbonization through chemical weathering. The salts solubilize and are transported away from the origin sites through soil surfaces or groundwater. Salts in the groundwater are gradually concentrated when the water moves to more arid areas (Abrol et al. 1988).

14.1.1.2 Characteristics

Saline and sodic soil bears several features which make them unsuitable for agricultural practices. Saline and sodic soil possesses poor physical properties and fertility problem that adversely affect the growth and yield of various crops (Sumner 1993; Naidu and Rengasamy 1993; Qadir and Schubert 2002; Qadir et al. 2005). It has been reported that saline soil has electrical conductivity with value ranging from 2 to more than 32 dS/m (Richards 1954; Farifteh et al. 2008). Saline soil consists of many ions like chlorides, sulfates, nitrates and bicarbonates of sodium, calcium, magnesium, and potassium (Bul 2013). Most of saline soil also consists of some proportion of gypsum ($CaSO_4$) (Abrol et al. 1988). Sodic soil consists of sodium carbonate, sodium bicarbonate, and sodium chloride as dominating components. The physicochemical characteristics of saline and sodic soil has been depicted in Table 14.1.

14.1.1.3 Distribution of Saline and Sodic Soils

According to Szabolcs (1974), salt-affected soils can be found in North America, Mexico, Central America, South America, Africa, Southern Asia, North and Central Asia, Southeast Asia, Australia, and Europe. Several states of India such as Uttar Pradesh, West Bengal, and Gujarat are largely salt affected (Edrisi and Abhilash 2016).

Table 14.1 Physicochemical characteristic of saline and sodic soil

Parameter	Value	References
pH	>8.5	Bul (2013)
Electrical conductivity (dS/m)	>4.0	US Salinity Laboratory (1969) and Bul (2013)
Sodium absorption ratio	~13	Qadir et al. (2007)
Exchangeable sodium percentage	>15	Qadir et al. (2007)
Calcium carbonate (%)	0.80–1.05	Garg (2000), Tripathi and Singh (2005), and Singh et al. (2016)
Total soluble salts (%)	0.14–0.22	Garg (2000), Tripathi and Singh (2005), and Singh et al. (2016)
Sand (%)	43	Garg (2000); Tripathi and Singh (2005), and Singh et al. (2016)
Clay (%)	27	Garg (2000); Tripathi and Singh (2005), and Singh et al. (2016)
Silt (%)	30	Garg (2000); Tripathi and Singh (2005), and Singh et al. (2016)
Water holding capacity (%)	32–35	Garg (2000); Tripathi and Singh (2005), and Singh et al. (2016)
Cation exchange capacity (cmole$_{(+)}$kg^{-1})	47.9	Gharaibeh et al. (2011)
Organic matter (%)	<0.1	Singh et al. (2016)

14.1.1.4 Parameters for Salinity/Sodicity Measurement

Sodium absorption ratio (SAR) is the ratio of soluble sodium to the sum of the square root of divalent cations, usually calcium (Ca^{++}) and magnesium (Mg^{++}), divided by 2:

$$SAR = \frac{Na}{\sqrt{(Ca + Mg)/2}} \text{ (Harron et al. 1983)} \tag{14.1}$$

An equivalent proportion of sodium remaining present in the cation exchange complex when expressed in terms of percentage is referred to as exchangeable sodium percentage (ESP) (Mau and Porporato 2015):

$$ESP = \frac{100(E_{Na})}{CEC} \text{ (Qadir et al. 2007)} \tag{14.2}$$

Cation exchange capacity (CEC) is the quantity of adsorbed cations on the unit mass of soil (Sposito 2008). Cation exchange capacity of a saturated saline soil paste can be analyzed by the sodium acetate method (Harron et al. 1983).

14.2 Methods for Bioenergy Generation

Biomass can be converted into bioenergy by different processes associated with various sources of biomass, conversion processes, their application, and infrastructure used (Mckendry 2002a). Biomass can be converted into bioenergy by means of producing three types of products: electrical/heat energy, transportation fuel, and chemical feedstock (Mckendry 2002b).

Biomass-based energy production processes are divided into two categories (Ni et al. 2006): thermochemical conversion and biochemical conversion. A third technology for bioenergy generation is mechanical extraction (with esterification) that produces biodiesel (McKendry 2002a).

There are three thermochemical processes (Ni et al. 2006):

- *Combustion*: Biomass burnt in air is combustion. Equipment includes stoves, furnaces, boilers, steam turbines, and turbogenerators used for the conversion of chemical energy stored in biomass into heat, mechanical power, or electricity. At a temperature range from 800 to 1000 °C, hot gases are produced by combustion of biomass. Bioenergy production efficiency by power plant is 20–40% produced mainly by pyrolysis (Verma et al. 2011). Temperature ranging from 650 to 800 K is used to convert biomass heated in the absence of air at a pressure of 0.1–0.5 Pa into biofuel such as liquid oil, charcoal, and gaseous compounds (Ni et al. 2006).
- *Liquefaction*: Biomass is converted to liquid hydrocarbon under low temperature and at higher hydrogen pressure (Warren Spring Laboratory 1993).
- *Gasification*: The gasification process is suitable for producing fuel and electricity using gas engines by gasification of biomass. This is operated either by simple technology based on a fixed-bed gasifier or fluidized bed technology.

Biochemical conversion processes are of two main types (Mckendry 2002a):

- *Anaerobic digestion*: This is the direct conversion of biomass into gas through anaerobic digestion. Biogas products are methane and carbon dioxide, along with a few other gases in smaller quantities such as hydrogen sulfide (EU 1999). Biogas is used in spark-ignition gas engines and gas turbines and can be upgraded to finer quality gases by removing carbon dioxide (Mckendry 2002a).
- *Fermentation*: In the process of fermentation, ethanol is produced from sugar crops such as sugarcane, sugar beet, and starch crops (maize and wheat). The material biomass is crushed, and starch is converted to sugar by enzymatic activities using yeast, and finally sugar is converted to ethanol (Mckendry 2002a).

Microbial fuel cell is another emerging technology where microorganisms are placed in an electro-biochemical chamber without air to oxidize organic matter and release electrons and protons, thus producing electricity (Pant et al. 2010; Hernandez-Fernandez et al. 2015) (Fig. 14.1).

14.3 Phytoremediation Potential of Energy Crops

Jatropha curcas has the potential to phytoremediate lindane and fly ash-contaminated sites by accumulating these contaminants in root followed by stem and leaf (Abhilash et al. 2013; Jamil et al. 2009). There are some species and their hybrids such as *Populus* and *Salix* known for their phytoremediation potential of contaminated sites (Zalesny et al. 2007). *Populus* is known to remediate the landfill sites, petroleum sludge, salts, heavy metals, pesticides, solvent, explosives, and radionucleotides (Burken 2001; Erdman and Christenson 2000; Gordon et al. 1997; Neill and Gordon 1994; Thompson et al. 1998; Zalesny et al. 2007). *Salix* is known to phytoremediate dairy effluent, wastewater sludge, municipal wastes, and cadmium from the contaminated sites. Plants such as *Pistacia chinensis*, *Sapium sebiferum*, and *Xanthoceras sorbifolium* are distributed in different parts of China and considered as oil-yielding plant cultivated under different range of environmental conditions (Shaoa and Chu 2008). In Greece, experimentation with *Eucalyptus* was done for wood and biomass production (Panetsos and Alizoti 1996). The result indicated that six species of *Eucalyptus*, namely, *E. bicostata*, *E. cladocalyx*, *E. viminalis*, *E. saligna*, *E. camaldulensis*, and *E. dalrympleana* are considered as dedicated energy crops (Panetsos et al. 1981). *Pinus taeda* has rapid growth on soil that is poorly or moderately drained (Coyle et al. 2008). *Liquidambar styraciflua* has potential to remediate soil contaminated with uranium (U) and thorium (Th) (Saritz 2005). *Glycine max*, *Panicum virgatum*, and *Helianthus annuus* are considered as biofuel crops grown on marginal soils such as brownfield sites (Smith et al. 2013). A study on legumes and trees for fuelwood production on sodic wasteland has been reported by Goel and Behl (2001). The legumes referred were *Acacia auriculiformis*,

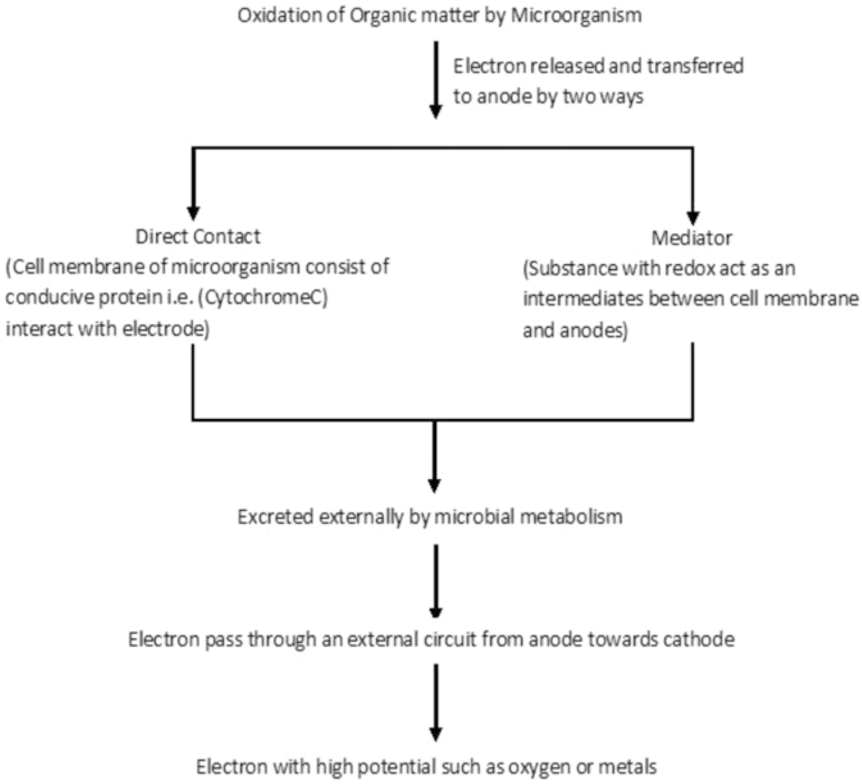

Fig. 14.1 Procedure for conversion of chemical energy of substrate into electrical energy by bacteria through microbial fuel cells (Hernandez-Fernandez et al. 2015)

A. nilotica, *Albizia lebbeck*, *A. procera*, *Dalbergia sissoo*, *Leucaena leucocephala*, *Pongamia pinnata*, *Prosopis juliflora*, and *Pithecellobium dulce.* The trees studied were *Azadirachta indica*, *Eucalyptus tereticornis*, and *Terminalia arjuna*. Among the species studied, *P. juliflora* ranked first as the most promising species for biomass production, and *Acacia nilotica* ranked second most promising species for biomass production on degraded sodic land (Goel and Behl 2001). Table 14.2 depicts the potential of pollution remediation and bioenergy production.

14.4 Reclamation of Saline and Sodic Soil

Reclamation of sodic and saline soils requires removal of most of the exchangeable cations and its replacement by Ca^{2+} ions and solubilized salts from the root zone, which can be done by various methods (Abrol et al. 1988). Before amelioration of a specific site, important factors should be considered such as soil depth to be ameliorated, presence of a dense solid layer in the subsoil, salt constituent in the soil,

Table 14.2 Pollution remediation and bioenergy potential of energy crop

Species	Remediation of particular pollutants by the plant species	Product(s)	Reference(s)
Jatropha curcas	Lindane, Fe, Al, Cr, Cu, and Mn	Biodiesel and biofertilizer	Abhilash et al. (2013) and Jamil et al. (2009)
Populus deltoids, *P. trichocarpa*, *P. nigra*, *P. maximowiczii*, *P. tremula*, *P. tremuloides*, *P. deltoids*, *P. nigra*	Explosive nitrate esters and nitro aromatics	Biomass, biogas, plywood, charcoal	Fortier et al. (2010) and Doty et al. (2007)
Salix alba, *S. viminalis*, *S. schwerinii*, *S. viminalis*	Zn, Cd, Cu, Hg, Pb, Cd	Biomass, biogas, plywood, charcoal	Delplanque et al. (2013) and Mleczek et al. (2010)
Xanthoceras sorbifolium	Not reported	Biomass, biodiesel, charcoal	Shaoa and Chu (2008)
Sapium sebiferum	Not reported	Biomass, charcoal	Shaoa and Chu (2008)
Pistacia chinensis	Not reported	Biomass, charcoal	Shaoa and Chu (2008)
Eucalyptus grandis, *E. bicostata*, *E. dalrympleana*, *E. viminalis*	PO_4^{3-}	Biomass, biogas, plywood, charcoal	Aravanopoulos (2010) and Panetsos (1988)
Pinus taeda L.	PO_4^{3-}	Biomass, biogas, plywood, charcoal	Kline and Coleman (2010) and Panetsos (1988)
Liquidambar styraciflua	Not Reported	Bioenergy, paper and pulp	Kline and Coleman (2010)
Glycine max	Cd, Cr, Ni, As, Fe, poly-aromatic hydrocarbon, atrazine	Bioenergy, bioethanol, charcoal	Smith et al. (2013) and Cutright et al. (2010)
Panicum virgatum	Cd, Cr, Ni, As, Fe, poly-aromatic hydrocarbon (PAH), atrazine	Bioethanol	Fairley (2011) and Graham Rowe (2011)
Helianthus annuus	Cd, Cr, Ni, As, Fe, poly-aromatic hydrocarbon (PAH), atrazine	Bioenergy, bioethanol, charcoal	Smith et al. (2013) and Cutright et al. (2010)
Miscanthus sinensis	Nutrients, Zn, Cd, and Pb	Bioethanol, biogas	St. Clair et al. (2008) and Zhao et al. (2012)

(continued)

Table 14.2 (continued)

Species	Remediation of particular pollutants by the plant species	Product(s)	Reference(s)
Madhuca indica	Dye removal from wastewater, fly ash	Biodiesel, biomass, charcoal	Ghadge and Raheman (2005)
Prosopis juliflora	Fly ash	Biomass, charcoal	Goel and Behl (2001)
Acacia nilotica	Not reported	Biomass, charcoal	Goel and Behl (2001)
Ricinus communis	Cd, DDT	High biomass	Huang et al. (2011)
Camelina sativa	Poly-aromatic hydrocarbon (PAH), atrazine	Biofuel	Fairley (2011) and Graham Rowe (2011)
Phragmites australis	Lindane, monochlorobenzene (MCB), dichlorobenzene (DCB), trichlorobenzene (TCB)	Bioethanol, charcoal	Sathitsuksanoh et al. (2009)
Pongamia pinnata/ Pongamia glabra	Cr, Mn, Fe, Ni, Cu, Zn, Pb, Rb, Sr, Ti, Co	Biomass, biodiesel, charcoal	Reddy et al. (2008) and Ravikumar et al. (2013)
Azadirachta indica	Cr, Mn, Fe, Ni, Cu, Zn, and Pb	Biomass, biodiesel, charcoal	Reddy et al. (2008) and Ravikumar et al. (2013)
Arundo donax	Nutrients, Cd, As, and Ni	Bioethanol, charcoal	Liu et al. (2012)
Pennisetum purpureum	Nutrients	Bioethanol	Liu et al. (2012)

availability of water for leaching, nature and depth of groundwater, topography of land, type of crops to be grown after amelioration, and climatic condition of the region (Qadir et al. 2000). Chemical amelioration of sodic land for their reclamation can be divided into three categories: gypsum and calcium chloride as a soluble calcium salt; acid-forming compounds such as sulfuric acid, iron sulfate, aluminum sulfate, lime sulfur, and pyrite; and less soluble calcium salts such as limestone (Abrol et al. 1988). Chemical amelioration using gypsum provides a source of Ca^{2+} ions directly to the soil that replaces excess Na^{+} ions while dissoluting calcite ($CaCO_3$) in the soil (Shainberg et al. 1989; Gupta and Abrol 1990; Oster et al. 1999; Qadir and Oster 2002 and Qadir et al. 2002). Methods to ameliorate saline/sodic soils include leaching salts from the upper surface of the soil and transporting them to lower depths, flushing of salts from the salt crusts at the surface and also in the shallow water table, etc. Biological amelioration involves sequestration of salts by the aerial (i.e., completely exposed in air) or shallow depth parts of plants that can be harvested and thus removes the salts from the soil (Qadir et al. 2000). Plants can improve chemical properties of soils, decrease soil pH, add organic matter, and dissolute lime (Ilyas et al. 1997). Remediation of saline soil is a critical global issue that requires multidisciplinary ways to remediate salt-affected land including agricultural practices, varieties of salt-tolerant crops, and phytoremediation.

14.5 Phytoremediation of Saline and Sodic Soil by Energy Crops

Phytoremediation is considered a cost-effective and environmentally safe technology for saline soil remediation (Hasanuzzaman et al. 2014). Phytoremediation involves various processes such as phytoextraction, phytodegradation, rhizofiltration, phytostabilization, and phytovolatilization (Fletcher 2006). According to Qadir et al. (2005), the two main advantages of phytoremediation are: i. no financial outlay needed for purchase of chemicals (for chemical amendment), and ii. salt-resistant crops generate high-value by-products. Roots of plants maintain soil structure and enhance drainage through the formation of macropores (pores greater than 0.08 mm in diameter) at deeper depths (Czarnes et al. 2000). Phytoremediation utilizing bioenergy crops/plants is one of the best technologies for remediation of saline and sodic soil because the harvested biomass can be used to produce biofuel or other commercial by-products while ameliorating the soil. The best bioenergy crops for soil amelioration should have high biomass production, be cost effective, have low contaminant content, have less nutrient and water requirements, be carbon neutral for the whole life cycle, and do not lead to the “food versus fuel” issue (Singh and Singh 2016).

Lal and Pimentel (2007) reported that several species of plant can produce abundant, good quality forage during summer, including warm season grasses such as switchgrass (*Panicum virgatum*), big bluestem (*Andropogon gerardii vitman*), and Indian grass (*Sorghastrum nutans*). Salt-tolerant grasses include Guinea grass (*Panicum maximum*), elephant grass (*Pennisetum purpureum*), and Kallar (also called Karnal) grass (*Leptochloa fusca*). Some of the short rotation woody perennials such as poplar (*Populus* spp.), willow (*Salix* spp.), and black locust (*Robinia pseudoacacia* L.) produce 10–20 tons of dry weight of biomass per hectare. Some important halophytes that grow in brackish water containing salt concentrations up to 30,000 ppm include pickle weed (*Salicornia bigelovii*), salt grass (*Distichlis palmeri*), salt brushes (*Atriplex* spp.), and few algae (e.g., *Spirulina geitleri*). Some non-edible oil-yielding plants include *Jatropha* (*Jatropha curcas*), *Pongamia* (*Millettia pinnata*), and *Madhua* (*Madhuca longifolia*). There are few energy crops in the world (*Miscanthus*, *Ricinus*, *Jatropha*, *and Populus*) that possess phytoremediation potential and act as carbon sinks, thus contributing profit through carbon tax credits (Bauddh and Singh 2012a, b; Bauddh and Singh 2015a, b; Bauddh et al. 2015a, b; 2016a, b; Pandey et al. 2016). Vetiver (*Chrysopogon zizanioides*) and lemongrass can tolerate and grow in saline soil. Live and dry biomass of vetiver and lemongrass has economic importance through their oil production (Maiti and Kumar 2016). India is the largest producer of lemongrass oil with production of 300–350 tons year^{-1}, of which 80% is exported to developed countries of the world (Lal et al. 2013). Mesquite (*Prosopis juliflora*) grows in Africa, Argentina, Australia, Brazil, Cameroon, Caribbean, Central America, Egypt, Ethiopia, Hawaii, India, Kenya, Nigeria, Pakistan, Paraguay, Peru, Ecuador, Portugal, Senegal, Spain, Sri Lanka, Sudan, Uganda, the United States, and Yemen. Mesquite is known to rehabilitate degraded saline and sodic land and concomitantly increases soil fertility by adding soil organic carbon, nitrogen, and phosphorus and decreases exchangeable Na^+ levels, pH, and electrical conductivity (Prasad and Tewari 2016). It can also be used for the production of charcoal, bioethanol, timber, fuelwood, and antibiotics (Prasad and Tewari 2016). It is estimated that crop residues and lignocellulosic residues from cereals can produce 4 billion Kg and 3 billion Kg of ethanol per year, respectively. One Mg (megagram) of corn stover can produce 280 L of ethanol, and 1 Mg of corn grains can produce 400 L of ethanol. One Mg of biomass produces about 18.5 GJ of energy. Three billion Mg of residue can produce 840 billion L of ethanol or about 56×10^9 GJ of energy (Lal 2008). Presently, global bioenergy consumption is 50 EJ yr.$^{-1}$ and is expected to reach to 80–160 EJ yr.$^{-1}$ (Pandey et al. 2016). The total biofuel production in India increased from 27.3 million L in 2007 to 46.4 million L in 2011, including 34.8 million L for bioethanol and 11.6 million L for biodiesel (Edrisi and Abhilash 2016). Marrison and Larson (1996) estimated that total bioenergy production from Africa by 2025 will be 18 EJ per year on the basis of planting crops on 10% of available land except forest, agricultural, and wilderness areas. Halophytes are being considered as potential new agricultural crops to reclaim salt-affected land. A species of halophyte (*Salicornia bigelovii*) can withstand high salinity and produce biomass and seeds of 2 tons hectare^{-1}, yielding 28% oil, 31% protein, 5% fiber, and 5% ash (Glenn et al. 1999).

Gharaibeh et al. (2011) assessed the potential of *Atriplex halimus* in reclamation of calcareous saline sodic soil. Cultivation of this plant significantly increased soil properties. The electrical conductivity (ECe) was reduced from 5.8 to 3.7 dSm^{-1} (Fig. 14.2); however, ESP was found to be decreased. ECe value after plantation of *Atriplex halimus* in salt-contaminated areas was the indication of removal of Na^+ ions from the soil.

Plantations of some plant species on degraded sodic land (D-SL) with rehabilitated *Terminalia arjuna* (R-TA), rehabilitated *Prosopis juliflora* (R-PJ), reference *Tectona grandis* (Ref-TG), rehabilitated mixed forest (R-MF), and reference mixed forest (Ref-MF) improved soil physicochemical characteristics and soil particle distribution, exchangeable sodium percentage, and microbial enzyme concentration (Singh et al. 2012). Bulk density for D-SL was 1.62 g cm^{-3}. After rehabilitation with R-TA, the bulk density reduced to 1.24 g cm^{-3} (29% decrease). With rehabilitated *Prosopis juliflora* (R-PJ), it showed a 24% decrease, and with R-MF, a 21% decrease in bulk density has been reported. Water holding capacity

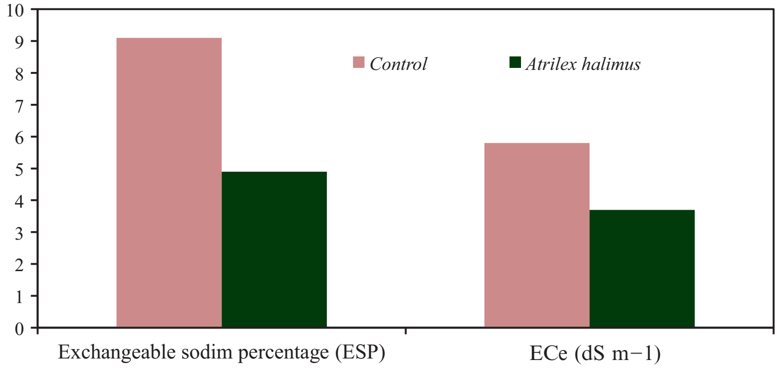

Fig. 14.2 Effect of plantation of *Atriplex halimus* in salt-contaminated areas (Gharaibeh et al. 2011)

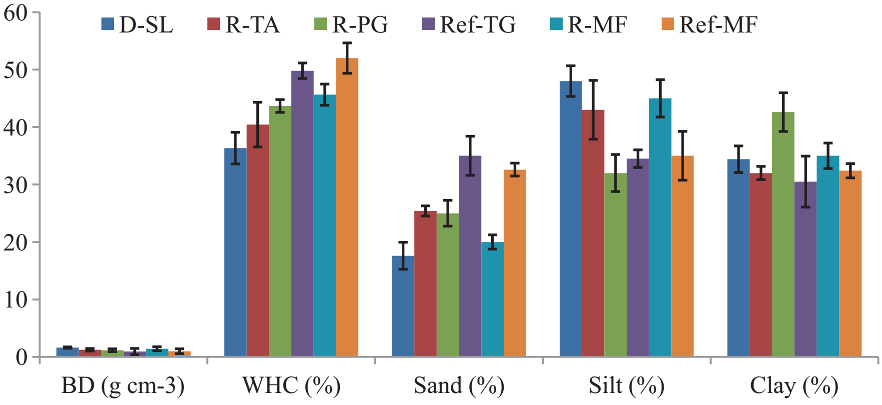

Fig. 14.3 Effect of plantation on bulk density (BD), water holding capacity (WHC), and soil particle distribution of degraded sodic land, rehabilitated land uses, and reference plantation and forest (Singh et al. 2012)

(WHC) percentage increased to 52.00 ± 2.75% in Ref-MF as compared to D-SL having WHC of 36.33±2.65%. Na^+ ion concentration decreased in the following order: R-TA (3.45 cmol kg^{-1}) <R-PJ (3.43 cmol kg^{-1}) <Ref-MF (1.96 cmol kg^{-1}) <R-MF (1.47 cmol kg^{-1}) <Ref-TG (0.80 cmol kg^{-1}). The mean values of K^+, Ca^{2+} and Mg^{2+} ion increased to 2.48, 20.35, and 5.50 cmol kg^{-1} respectively in Ref-MF. Figure 14.3 depicts the role of afforestation in improvement of physico-chemical characteristics of soil.

14.6 Conclusion

Saline and sodic soils are distributed in around 831 million hectares of land worldwide and possess various adverse features such as high pH, high exchangeable sodium percentage, high sodium adsorption ratio, and low cation exchange capacity that make a soil infertile. At the same time, fuel and energy needs are increasing globally, leading to greater emissions of greenhouse gases which results changes in climate. Chemical treatment using gypsum shows rapid amelioration of saline and sodic soil, but is a costly and non-eco-friendly approach. The emerging technology of phytoremediation using specific plants that reclaim sodic and saline land may be used to produce energy. Some of the energy crops like *Miscanthus*, *Ricinus*, *Jatropha*, and *Populus* are extensively used worldwide. Reclamation of saline and sodic soils utilizing such plants is preferable because of its applicability and sustainability. Phytoremediation using bioenergy crops could be adopted as a better approach for mitigation of major environmental concerns like land degradation, pollution, energy crisis, and climate change.

References

Abhilash PC, Singh B, Srivastava P, Schaeffer A, Singh N (2013) Remediation of lindane by *Jatropha curcas* L: utilization of multipurpose species for rhizoremediation. Biomass Bioenergy 51:160–170

Abrol IP, Yadav JSP, Massoud FI (1988) Salt-affected soils and their management, FAO soils bulletin 39. Food & Agriculture Organization, Rome

Altman I, Bergtold J, Sanders D, Johnson T (2015) Willingness to supply biomass for bioenergy production: a random parameter truncated analysis. Energy Econ 47:1–10

Aravanopoulos F (2010) Breeding of fast growing forest tree species for biomass production in Greece. Biomass Bioenergy 34:1531–1537

Bauddh K, Singh RP (2012a) Cadmium tolerance and its phytoremediation by two oil yielding plants *Ricinus communis* (L) and *Brassica juncea* (L) from the contaminated soil. Int J Phytoremed 14:772–785

Bauddh K, Singh RP (2012b) Growth, tolerance efficiency and phytoremediation potential of *Ricinus communis* (L) and *Brassica juncea* (L) in salinity and drought affected cadmium contaminated soil. Ecotoxicol Environ Saf 85:13–22

Bauddh K, Singh RP (2015a) Effects of organic and inorganic amendments on bio-accumulation and partitioning of Cd in *Brassica juncea* and *Ricinus communis*. Ecol Eng 74:93–100

Bauddh K, Singh RP (2015b) Assessment of metal uptake capacity of castor bean and mustard for phytoremediation of nickel from contaminated soil. Bioremed J 19(2):124–138

Bauddh K, Singh K, Singh B, Singh RP (2015a) *Ricinus communis*: a robust plant for bio-energy and phytoremediation of toxic metals from contaminated soil. Ecol Eng 84:640–652

Bauddh K, Singh K, Singh RP (2015b) *Ricinus communis* L a value added crop for remediation of cadmium contaminated soil. Bull Environ Contam Toxicol 96:265–269. doi:10.1007/s00128-015-1669-3

Bauddh K, Kumar A, Srivastava S, Singh RP, Tripathi RD (2016a) A study on the effect of cadmium on the antioxidative defense system and alteration in different functional groups in castor bean and Indian mustard. Arch Agron Soil Sci 62(6):877–891

Bauddh K, Singh B, Singh RP (2016b) *Ricinus communis* L. as a value added alternative for restoration of cadmium contaminated and degraded agricultural ecosystem. Bull Environ Contam Toxicol 96(2):265–269

Bernstein L (1975) Effects of salinity and sodicity on plant growth. Annu Rev Phytopathol 13(1):295–312

Bul EN (2013) Soil salinity: a neglected factor in plant ecology and biogeography. J Arid Environ 92:14–25

Burken, Joel G. (2001) Uptake and volatilization of chlorinated solvents by poplars at field-scale. In: Sixth international in situ and on site bioremediation symposium

Clair SS, Hillier J, Smith P (2008) Estimating the pre-harvest greenhouse gas costs of energy crop production. Biomass Bioenergy 32(5):442–452

Coyle DR, Coleman MD, Aubrey D (2008) Above and below ground biomass accumulation, production, and distribution of Sweetgum and Loblolly pine grown with irrigation and fertilization. Can J Res 38:1335–1348

Cutright T, Gunda N, Kurt F (2010) Simultaneous hyperaccumulation of multiple heavy metals by *Helianthus annus* grown in a contaminated sandy loam soil. Int J Phytoremed 12(6):562–573

Delplanque M, Collet S, Gratta FD, Schnuriger B, Gaucher R, Robinson B, Bert V (2013) Combustion of *Salix* used for phytoextraction: the fate of metals and viability of the processes. Biomass Bioenerg 49:160–170

Doty SL, Shang TQ, Wilson AM, Tangen J, Westergreen AD, Newman AL, Stuart SE, Gordon MP (2007) Enhanced metabolism of halogenated hydrocarbons in transgenic plants contain mammalian P450 2E.1. Proc Natl Acad Sci 97:6287–6291

Edrisi SA, Abhilash PC (2016) Exploring marginal and degraded lands for biomass and bioenergy production: an Indian scenario. Renew Sust Energ Rev 54:1537–1551

Erdman JA, Christenson S (2000) Elements in cottonwood trees as an indicator of ground water contaminated by landfill leachate. Ground Water Monit Remediat 20:120–126

EU (1999) Biomass conversion technologies. EU 18029 EN. ISBN:92-828-5363-3

Farifteh J, Van Der Meer F, Van Der Meijde M, Atzberger C (2008) Spectral characteristics of salt-affected soils: a laboratory experiment. Geoderma 145:196–206

FAO (2000) Global network as integrated soil management for sustainable use of salt-affected soils. http://www.fao.org/ag/agl/agll/spush

Fairley P (2011) Next generation biofuels. Nature 474:S2–S5

Fletcher J (2006) Introduction. In: Mackova M, Dowling D, Macek T (eds) Phytoremediation Rhizoremediation. Springer, Dordrecht

Fortier J, Gagnon D, Truax B, Lambert F (2010) Biomass and volume yield after 6 years in multiclonal hybrid poplar riparian buffer strips. Biomass Bioenerg 34(7):1028–1040

Garg VK (2000) Bioreclamation of sodic waste land - a case study. Land Degrad Dev 11:487–498

Ghadge SV, Raheman H (2005) Biodiesel production from mahua (*Madhuca indica*) oil having high free fatty acids. Biomass Bioenerg 28(6):601–605

Gharaibeh MA, Eltaif NI, Albalasmeh AA (2011) Reclamation of highly calcareous saline sodic soil using *Atriplex halimus* and by-product gypsum. Int J Phytoremed 13(9):873–883

Ghosh SK (2016) Biomass & biowaste supply chain sustainability for bioenergy and bio – fuel production. Procedia Environ Sci 3:31–39

Glenn EP, Jed Brown J, Blumwald E (1999) Salt tolerance and Crop potential of halophytes. Crit Rev Plant Sci 18(2):227–255

Goel VL, Behl HM (2001) Genetic selection and improvement of hard wood tree species for fuelwood production on sodic soil with particular reference to *Prosopis juliflora*. Biomass Bioenergy 20:9–15

Gordon M, Choe N, Duffy J, Ekuan G, Heilman P, Muiznieks I, Newman L, Ruszaj M, Shurtleff BB, Strand S, Wilmouth J (1997) Phytoremediation of trichloroethylene with hybrid poplars. In: Kruger EL, Anderson TA, Coats JR (eds) Phytoremediation of soil and water contaminants. American Chemical Society, Washington DC, pp 177–185

Graham Rowe D (2011) Beyond food versus fuel. Nature 474:S6–S8

Harron WRA, Webster GR, Cairns RR (1983) Relationship between exchangeable sodium and sodium absorbtion ratio in a solonetzic soil association. Can J Soil Sci 63(3):461–467

Hasanuzzaman M, Nahar K, Fujita M (2013) Plant response to salt stress and role of exogenous protectants to mitigate salt induced damages. In: Ahmad P, Azooz MM, MNV P (eds) Ecophysiology and responses of plants under salt stress. Springer, New York, pp 25–87

Hasanuzzaman M, Nahar K, Bhowmik PC, Ahmad Hossain M, Rahman MM, Prasad MNV, Ozturk M and Fujita M (2014) Potential use of halophytes to remediate saline soils. Biomed Res Int. http://dx.doi.org/10.1155/2014/589341

Hernandez-Fernandez FJ, Perez de los Rios A, Salar-Garcia MJ, Ortiz-Martinez VM, Lozano-Blanco LJ, Godinez C, Tomas-Alonso F, Quesada-Medina J (2015) Recent progress and perspectives in microbial fuel cells for bioenergy generation and waste water treatment. Fuel Process Technol 138:284–297

Huang H, Yu N, Wang L, Gupta DK, He Z, Wang K, Zhu Z, Yan X, Li T, Yang X (2011) The phytoremediation potential of bioenergy crop Ricinus communis for DDTs and cadmium co-contaminated soil. Bioresour Technol 102:11034–11038

Ilyas M, Qureshi RH, Qadir MA (1997) Chemical changes in a saline-sodic soil after gypsum application and cropping. Soil Technol 10:247–260

Jamil S, Abhilash PC, Sharma PN (2009) *Jatropha curcas*: a potential crop for phytoremediation of coal fly ash. J Hazard Mater 172(1):269–275

Kline KL, Coleman MD (2010) Woody energy crops in the southeastern United States: two centuries of practitioner experience. Biomass Bioenerg 34(12):1655–1666

Kraxner F, Nordstrom EM, Havlik P, Gusti M, Mosnier A, Frank S, Valin H, Fritz S, Fuss S, Kindermann G, McCallum I, Khabarov N, Bottcher H, See L, Aoki K, Schmid E, Mathe L, Obersteinner M (2013) Global bioenergy scenarios – future forest development, land – use implications, and trade offs. Biomass Bioenerg 57:86–96

Lal R, Pimentel D (2007) Biofuels from crop residues. Soil Tillage Res 93(2):237–238

Lal R (2008) Crop residues as soil amendments and feedstock for bioethanol production. Waste Manage 28:747–758

Lal K, Yadav RK, Kaur R, Bundela DS, Khan Inayat M, Chaudhary M, Meena RL, Dar SR, Singh G (2013) Productivity, essential oil yield, and heavy metal accumulation in lemon grass (*Cymbopogon flexuosus*) under varied wastewater – groundwater irrigation regimes. Ind Crop Prod 45:270–278

Li X, Kang Y, Wan S, Chen X, Liu S, Xu J (2016) Response of a salt-sensitive plant to processes of soil reclamation in two saline–sodic, coastal soils using drip irrigation with saline water. Agric Water Manag 164:223–234

Liu B, Wu X, Chang J, Gu B, Min Y, Ge Y, Shi Y, Xue H, Peng C, Wu J (2012) Constructed wetland as biofuel production systems. Nat Clim Chang 2:190–194

Maiti SK, Kumar A (2016) Energy plantation, medicinal and aromatic plants in contaminated soil. In: Bioremediation & bioeconomy. Elsevier, Amsterdam, pp 29–40

Manchanda G, Garg N (2008) Salinity and its effects on the functional biology of legumes. Acta Physiol Plant Manchanda G (eds) Springer 30(5):595–618

Marrison CI, Larson ED (1996) A preliminary analysis of the biomass energy production potential in Africa in 2025 considering projected land needs for food production. Biomass Bioenergy 10:337–351

Mau Y, Porporato A (2015) A dynamic system approach to soil salinity and sodicity. Adv Water Resour 83:68–76

McKendry P (2002a) Energy production from biomass (part 2): conversion technologies. Bioresour Technol 83:47–54

McKendry P (2002b) Energy production from biomass (part 1): overview of biomass. Bioresour Technol 83:37–46

Mleczek M, Rutkowski P, Rissmann I, Kaczmarek Z, Golinski P, Szentner K, Strazynska K, Stachowiak A (2010) Biomass productivity and phytoremediation potential of Salix alba and *Salix viminalis*. Biomass Bioenergy 34(9):1410–1418

Munns R (2005) Genes and salt tolerance: bringing them together. New Phytol 167(3):645–663

Naidu R, Rengasamy P (1993) Ion interactions and constraints to plant nutrition in Australian sodic soils. Aust J Soil Res 31:801–819

Neill OGJ, Gordon AM (1994) The nitrogen filtering capability of Carolina poplar in an artificial riparian zone. J Environ Qual 23:1218–1223

Ni M, Leung YC, Leung MKH, Sumathy K (2006) An overview of hydrogen production from biomass. Fuel Process Technol 87(5):461–472

Oster JD, Shainberg I, Abrol IP (1999) Reclamation of salt affected soils. In: Skaggs RW, van Schilfgaarde J (eds) Agricultural drainage. ASA-CSSASSSA, Madison

Pandey VC, Bajpai O, Singh N (2016) Energy crops in sustainable phytoremediation. Renew Sust Energ Rev 54:58–73

Panetsos KP, Alizoti PG (1996) Biomass production from monoclonal and mixed clonal plantations. In: Proceedings 5th national renewable energy conference, vol 3. National Research Centre Democritus, Athens, pp 201–204

Panetsos KP (1981) Biomass yield of short rotation Platanus species in Greece. In: Commercialization of production of Mediterranean climatic regions. W. Junk Publications, The Hague, pp 235–238

Panetsos KP (1988) Biomass production from fast growing forest tree species. In: Proceedings 3rd national conference of renewable energy, vol 2. Greek Productivity Centre, Thessaloniki, pp 29–36

Pant D, Van Bogaert G, Diels L, Vanbroekhoven K (2010) A review of the substrates used in microbial fuel cells (MFCs) for sustainable energy production. Bioresour Technol 101:1533–1543

Popp J, Lakner Z, Rakos MH (2014) The effect of Bioenergy expansion: food, energy and environment. Renew Sust Energ Rev 32:559–578

Prasad MNV, Tewari JC (2016) *Prosopis juliflora* (Sw) DC: potential for bioremediation and bioeconomy. In: MNV P (ed) Bioremediation & bioeconomy. Elsevier, Amsterdam, pp 49–68

Qadir M, Ghafoor A, Murtaza G (2000) Amelioration strategies for saline soils: a review. Land Degrad Dev 11:501–521

Qadir M, Schubert S (2002) Degradation processes and nutrient constraints in sodic soils. Land Degrad Dev 13:275–294

Qadir M, Oster JD (2002) Vegetative bioremediation of calcareous sodic soils: history, mechanisms, and evaluation. Irrig Sci 21:91–101

Qadir M, Qureshi RH, Ahmad N (2002) Amelioration of calcareous saline sodic soils through phytoremediation and chemical strategies. Soil Use Manag 18:381–385

Qadir M, Noble AD, Oster JD, Schubert S, Ghafoor A (2005) Driving forces for sodium removal during phytoremediation of calcareous sodic and saline–sodic. Soil Use Manag 21:173–180

Qadir M, Oster JD, Schubert S, Noble AD, Sahrawat KL (2007) Phytoremediation of sodic and saline sodic soil. Adv Agron 96:197–247

Ravikumar M, Sarita P, Naga Raju GJ, Bhuloka Reddy S (2013) Trace element accumulation in the leaves of *Azadirachta indica* and *Pongamia glabra* collected from different environmental sites. J Environ Res Dev 7(3):S410–S414

Rabindranath D, Shroff S, Rao N (2010) Bioenergy in India: barriers and policy options. United Nations Development Programme, New Delhi

Reddy BVS, Ramesh S, Kumar AA, Wani SP, Ortiz R, Ceballos H, Sreedevi TK (2008) Biofuel crops research for energy security and rural development in developing countries. Bioenergy Resour 1:248–258

Richards LA (1954) Diagnosis and improvement of saline and alkali soils. Soil Sci 78(2):154

Saritz R (2005) Phytoextraction of uranium and thorium by native trees in a contaminated wetland. J Radioanal Nucl Chem 264:417–422

Sathitsuksanoh N, Zhu Z, Templeton N, Rollin JA, Harvey SP, Zhang Y-H (2009) Saccharification of a potential bioenergy crop, *Phragmites australis* (Common Reed), by lignocellulose fractionation followed by enzymatic activities at decreased cellulase loading. Ind Eng Chem Res 48:6441–6447

Shainberg I, Sumner ME, Miller WP, Farina MPW, Pavan MA, Fey MV (1989) Use of gypsum on soils: a review. Adv Soil Sci 9:1–111

Shaoa H, Chu L (2008) Resource evaluation of typical energy plants and possible functional zone planning in China. Biomass Bioenergy 32:283–288

Singh K, Singh B, Singh RR (2012) Changes in physico-chemical, microbial and enzymatic activities during restoration of degraded sodic land: ecological suitability of mixed forest over monoculture plantation. Catena 96:57–67

Singh SP, Singh V (2016) Addressing rural decline by valuing agricultural ecosystem services and treating food production as a social and treating food production as a social contribution. Trop Ecol 57(3):381–392

Singh YP, Mishra VK, Singh S, Sharma DK, Singh D, Singh US, Singh RK, Haefele SM, Ismail AM (2016) Productivity of sodic soils can be enhanced through the use of salt tolerant rice varities and proper agronomic practices. Field Crop Res 190:82–90

Smith L, Thelen D, MacDonald J (2013) Yield and quality analyses of bioenergy crops grown on a regulatory brownfield. Biomass Bioenergy 49:123–130

Sposito G (2008) The chemistry of soils. Oxford University Press, New York

Sumner ME (1993) Sodic soils: new perspectives. Aust J Soil Res 31(6):683–750

Szabolcs I (1974) Salt affected soils in Europe. Martinus Nijhoff, The Hague, p 63

Thompson PL, Ramer LA, Schnoor JL (1998) Uptake and transformation of TNT by hybrid poplar trees. Environ Sci Technol 32(7):975–980

Tripathi KP, Singh B (2005) The role of revegetation for rehabilitation of sodic soils in semiarid subtropical forest, India. Restor Ecol 13:29–38

Tripathi V, Edrisi SA, Abhilash PC (2016) Towards the coupling of phytoremediation with bioenergy production. Renew Sust Energ Rev 57:1386–1389

United States Salinity Laboratory Staff (1969) Diagnosis and improvement of saline and alkali soils, Agriculture handbook no 60, Revised edn. United States Department of Agriculture, Washington DC

Verma M, Godbout S, Brar SK, Solomatnikova O, Lemnay SP, Larouche JP (2011). Biofuels production from biomass by thermochemical conversion technologies. Int J Chem Eng 2012:1–8 http://dx.doi.org/10.1155/2012/542426

Warren Spring Laboratory (1993) Fundamental research on the thermal treatment of wastes and biomass: literature review of part research on thermal treatment of biomass and waste ETSU, B/T1/00208/Rep/1

Wong L, Dalal C, Greene B (2008) Salinity and sodicity effects on respiration and microbial biomass of soil. Biol Fertil Soils 44:943–953

Yuan JS, Tiller KH, Ahmad HA, Stewart NR, Stewart CN Jr (2008) Plants to power: bioenergy to fuel the future. Trends Plant Sci 13(8):421–429

Zalesny RS, Bauer EO, Hall RB, Zalesny JA, Kunzman J, Rog CJ, Riemenschneider DE (2007) Clonal variation in survival and growth of hybrid poplar and willow in an IN SITU Trialon soils heavily contaminated with petroleum hydrocarbons. Int J Phytoremed 7(3):177–197

Zhao F, Yang W, Zeng Z, Li H, Yang X, He Z, Gu B, Rafiq MT, Peng H (2012) Nutrient removal efficiency and biomass production of different bioenergy plants in hypereutropic water. Biomass Bioenergy 42:212–218

Zhuang D, Jiang D, Liu L, Huang Y (2011) Assessment of bioenergy potential on marginal land in China. Renew Sust Energ Rev 15(2):1050–1056