Chapter 12
Bioenergy Crops: Recent Advances and Future Outlook

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Abstract Fossil fuels have solved our energy problems since the beginning of the industrial revolution that started in the eighteenth century. However, from past few decades, the world has seen an unprecedented and uncontrolled use of fossil fuels. In the current era, we heavily rely on fossil fuels for energy demands. It is undeniably true that fossil fuels hold the credit of shaping our world, but on the cost of environmental and related hazards. The negative environmental impacts of fossil usage are now being realized, and the search for alternative energy sources has begun. Bioenergy crops are one such energy source that could positively impact the environment to reduce the level of carbon dioxide, emission of greenhouse gases and soil erosion. The biofuel generation using fast growing and photosynthetically efficient bioenergy crops is emerging as a reliable alternative to fossil fuels. Bioenergy plants increase soil carbon and fix atmospheric carbon. In addition, bioenergy crops (miscanthus, sorghum and poplar) could also be used for the phytoremediation of heavy metal-contaminated soils. The bioenergy crops include specific plants that are grown and maintained at lower costs for biofuel production. The bioenergy crops are classified into five types namely, first-, second- and third-generation bioenergy crops, dedicated energy crops and halophytes. The first-generation bioenergy crops include corn, sorghum, rapeseed and sugarcane, whereas the second-generation bioenergy crops are comprised of switchgrass, miscanthus, alfalfa, reed canary grass, Napier grass and other plants. The third-generation bioenergy crops contain boreal plants, crassulacean acid metabolism (CAM) plants, eucalyptus and microalgae. Bioenergy halophytes are comprised of the genera *Acacia, Eucalyptus, Casuarina, Melaleuca, Prosopis, Rhizophora* and *Tamarix*. The dedicated energy crops include perennial herbaceous and woody plant species as giant miscanthus, switchgrass, jatropha and algae.

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12.1 Introduction

Due to the expanding population, the world has seen a steep surge in energy demands. Most of our current energy requirement is fulfiled by burning fossil fuels. However, the use of traditional fuels is associated with an environmental surge in the intensity of harmful gases like carbon dioxide, greenhouse gases and nitrogen oxide. For example, coal emits greenhouse gases like carbon dioxide, particulate soot and sulphur-containing compounds, leading to soil acidification. Electricity generated from nuclear fission requires huge infrastructure and imparts harmful effect on the environment and human health (Gresshoff et al. 2017). Use of fossil fuels is associated with long-term environmental impacts, which may contribute to degrading land and desertification of fertile soils (Karp and Shield 2008). The after effects of the surge in fossil fuel usage are now visible in the form of climate change, torrential rains and disease linked to environmental pollution.

Majority of countries are still using traditional fuels as a chief energy source. The negative impacts of fossil fuel burning have been recognized worldwide, and search for alternative fuel sources has begun. Several countries have shifted their priority for energy fulfilment from non-renewable to renewable energy resources. However, only a few energy sources are sustainable and have lesser environmental impact. The use of 'bioenergy crops' for energy generation is one such potential alternative with long-term positive future outcomes. The energy from bioenergy crops is obtained from biomass derived from plants and animals (Taylor 2008). Bioenergy crop products include ethanol, biodiesel, biogas etc. (Yuan et al. 2008). Bioenergy crops reduce the level of carbon dioxide, decrease the emission of greenhouse gases, increase soil carbon, reduce soil erosion, increase transpiration and could supply heat and electricity (Adler et al. 2007; Wang et al. 2012; Kim et al. 2013). The bioenergy crops also phytoremediate heavy metal-contaminated soil (Barbosa et al. 2015). Large-scale cultivation of bioenergy crops could also positively impact the wildlife.

The concept of bioenergy crops is drawing attention in the scientific community for its renewability and eco-friendly nature. However, bioenergy crops have more conventional use as food in the worldwide market, which raises food security issues for energy usage. In addition, bioenergy plants compete with food crops for agricultural land, water resources and nutrient requirement. Another negative impact linked with bioenergy crop usage includes wildlife habitat destruction and increased dispersion of invasive plant species (Dipti and Priyanka 2013). In this chapter, different types of bioenergy crops and their characteristics are described.

12.2 Types of Bioenergy Crops

To overcome the environmental and associated issues, the 'traditional biofuel' concept was introduced. Traditional biofuels were derived from vegetable crops. Their use in bioenergy is debatable due to food security issues. Bioenergy crops are

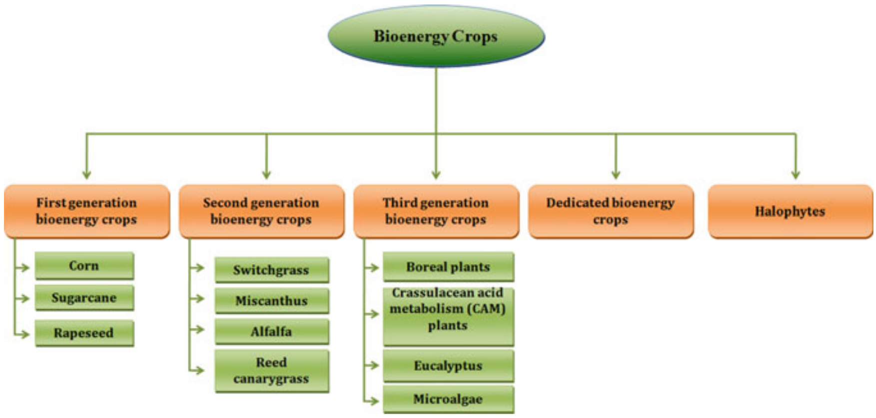

Fig. 12.1 Different types of bioenergy crops

screened on the basis of specific characters like oil yields, oil quality and global climate change mitigation. Cultivation of traditional bioenergy crops could improve food and fodder production, with the additional advantage of mitigation of global climate change (Singh 2008). They are mainly classified into five groups, namely, first-generation, second-generation and third-generation, dedicated energy crops and halophytes (Fig. 12.1).

12.2.1 First-Generation Bioenergy Crops

The programme of biofuel generation was initiated with first-generation bioenergy crops (FGECs). These crops are also local or global common food source. FGECs like sweet sorghum, corn, sugarcane, oil palm and rapeseed were initially used for preparing biofuel (Lobell et al. 2008). However, first-generation bioenergy crops have limited ability to replace petrol-oil products (Chhetri et al. 2008; Carroll and Somerville 2009; Lorenz et al. 2009) due to the higher cost of production (Wang and Yan 2008). These limitations have been removed in the second-generation bioenergy processing concept by using lignocellulosic materials from crop residues (Eisenbies et al. 2009) in fuel extraction process. Some of the common first-generation bioenergy crops are discussed below.

12.2.1.1 Sweet Sorghum

Sweet sorghum (*Sorghum bicolour* L.) consists of several varieties of grasses with high sugar content. It accumulates a large amount of fermented sugars in stems to yield higher biomass. The plant requires lesser fertilizer and therefore easily cultivable on marginal lands. Agronomic characteristics of sorghum include high drought tolerance and C_4 photosynthesis. Less scientific efforts were done for genetic and molecular characterization of sorghum features, compared to crops like corn and sugarcane. The sweet sorghum is a model bioenergy crop to understand the complex genomes of other bioenergy crops (maize, sugarcane, miscanthus and switchgrass) (Paterson et al. 2009). Sweet sorghum contains high sugar content in stems, and therefore higher activity of sugar metabolizing enzymes is observed during stem development (Qazi et al. 2012). Sorghum crop possesses good nitrogen use efficiency. It accumulates sugar in higher amount in stem during drought (Thomas and Howarth 2000; Harris et al. 2006). Crops of sorghum and sweet sorghum could be crossbred for better crop productivity and desirable characters could be detected by genetic mapping (Okada et al. 2010; Swaminathan et al. 2010).

12.2.1.2 Corn

Corn (*Zea mays*) is an important feedstock crop due to high grain yield and better rate of starch accumulation in grains (Mabee et al. 2011). The high percentage of volatiles and easy conversion process makes it a preferable crop for bioconversion. Corn is used for ethanol production in the United States and other countries. However, the main limitation of corn feedstock is its primary use as a staple food in several countries. Corn use in bioenergy fuel production could increase worldwide food prices, leading to poverty and hunger. To combat the problem, sweet corn variety of corn was developed through spontaneous recessive mutations in genes controlling sugars to starch in the endosperm of the corn kernel. The use of dual-purpose and photosynthetically efficient sweet corn hybrids could benefit farmers in contributing towards energy generation without affecting the environment and food supply (Takamizawa et al. 2010; Zhao et al. 2010).

12.2.1.3 Oil Crops

Oil crops include oilseed rape, linseed, field mustard, hemp, sunflower, safflower, castor oil, olive, palm, coconut and groundnut. Vegetable oils could be refined to generate transport biofuels or utilized directly as heating fuels (Sims et al. 2006).

12.2.1.4 Sugarcane

Sugarcane (*Saccharum officinarum* L.) is the major sugar-producing plant adapted to warm temperate or tropical climates. Contrary to annual crops, sugarcane is a perennial plant that grows throughout the year. Henceforth, sugarcane feedstock remains available year-long at comparatively lower costs than other bioenergy crops (Yuan et al. 2008). Sugarcane is chiefly grown for obtaining sugars from the sugarcane juice. The sugarcane juice contains a high percentage of sucrose, a substrate for biofuel production. Several breeding programmes are running for improving the sugarcane germplasm, enhancing sucrose yield and cellulosic biomass. The commercial bioethanol is produced from molasses, a by-product of the sugar industry.

12.2.2 Second-Generation Bioenergy Crops

The second-generation bioenergy crops (SGECs) include perennial forage crops (switchgrass, reed canary grass, alfalfa, Napier grass and Bermuda grass) (Sanderson and Adler 2008; Oliver et al. 2009). The second-generation bioenergy generation adopts the milder approach of utilizing crop remains as feedstock. The SGECs generate biofuel from cellulosic biomass and are more energy efficient than first-generation bioenergy crops (FGECs). Second-generation biofuel is non-oxygenated and pure hydrocarbon fuel (Oliver et al. 2009). SGECs avoid many of the environmental problems and involve lower cost of biofuel production. Biofuels from SGECs are produced from lingo-cellulosic crop wastes, thermo-chemically or biochemically (Petersen 2008; Wang and Yan 2008). The annual grain crops and perennial biomass crops are the backbones of second-generation biofuel (Adler et al. 2007).

The SGECs need least processing, produce high energy with reduced greenhouse gas emissions compared to FGECs. Growing SGECs produce appreciable biomass for bioenergy generation (Kotchoni and Gachomo 2008). The sugarcane industry finds huge potential as second-generation bioenergy crop because currently the remains of sugarcane stalks (bagasse) are burned in sugarcane factories for producing steam and electricity. Bagasse is enriched with cellulosic biomass, which is a linear chain of thousands of β (1 → 4) linked D-glucose units. Cellulolytic bacterial fermentation releases cellulose residues from bagasse, which could be used for producing bioenergy using latest technologies (Waclawovsky et al. 2010). However, the second-generation ethanol production from sugarcane remains has not yet been commercialized due to the lower sugar conversion percentage from bagasse. Nevertheless, countries like Brazil fulfil their energy requirements from bioethanol generated from sugarcane. Some of the main second-generation bioenergy crops are as follows.

12.2.2.1 Switchgrass

Switchgrass (*Panicum virgatum* L.) is a warm-season perennial C_4 grass cultivated on marginal and erosive lands. The grass requires fewer nutrients and water for growth, making it an environmentally friendly crop for large-scale biofuel production (McLaughlin et al. 2006; Vogel and Mitchell 2008). However, switchgrass has slow establishing time that requires approximately two years (McLaughlin et al. 2006). The plant has received less attention from the scientific community, especially in the field of plant breeding (Bouton 2007). As a result, the germplasm of most cultivars of switchgrass is not far away from native genomes. Based on genetic make-up, few varieties of switchgrass are non-differentiable from natural populations. Therefore, switchgrass holds huge potential for genetic improvement (Casler et al. 2007; Rose IV et al. 2008) for efficient biomass production.

12.2.2.2 Miscanthus

The *Miscanthus* genus contains 14–20 species of tall, perennial grasses native of Asia that are grown as ornamental plants (Heaton et al. 2010). The plant's morphology restricts its usage as a forage crop. The plant is a model herbaceous biomass feedstock in Europe. The miscanthus plant performs C_4 photosynthesis, possesses high carbon dioxide fixation rate and requires less water and nitrogen than C_3 plants (Villaverde et al. 2009). This grass is considered a dedicated energy crop due to its fast growth, resistance to disease, high productivity and comparatively longer productive life of 10–15 years (Villaverde et al. 2010). The biomass yield of miscanthus was reported 33% higher than switchgrass (Heaton et al. 2004). One good example of *Miscanthus* genus is *M. giganteus* L. which requires 87% lesser land compared to prairie species to produce equivalent biomass (Heaton et al. 2010). The drawback of growing miscanthus crop includes the longer propagation time of 2–3 years for rhizome cuttings, higher irrigation and energy requirement during greenhouse propagation.

12.2.2.3 *Alfalfa*

Alfalfa (*Medicago sativa* L.) is the oldest forage crop cultivated in North America (Russelle 2001). The stems of alfalfa are fibrous and combusted in the gasification cycle for electricity production. The leaves contain high protein contents (Lamb et al. 2003). The plant is a feedstock for biofuel production and also a high-quality feed for animals (Delong et al. 1995). Alfalfa has greater polysaccharide and lignin concentrations in stem cell walls that contribute to a higher yield of stem dry matter and theoretical ethanol yields (Lamb et al. 2007).

12.2.2.4 Reed Canary Grass

Reed canary grass (*Phalaris arundinacea* L.) is a C_3 grass found in North America. It is tall-growing perennial grass which is efficient in internal nitrogen recycling from shoots to roots. Several features of reed canary grass are common with switchgrass such as slow growth and low yields. It is an invasive species in wetlands (Merigliano and Lesica 1998). The grass yields relatively higher biomass (Tahir et al. 2011) and thus could yield fair amount of biofuel.

12.2.2.5 Other Plants

Some other plants also contribute to bioenergy due to associated advantages. For example, a tall, perennial and tropical grass, called Napier grass (*Pennisetum purpureum* Schumach) is preferred bioenergy crop due to ease of establishment, persistent and drought tolerant capacity. The grass is tasteful and nutritious (Schmer et al. 2008). The potential of Napier grass as bioenergy crop was recognized due to its low-lignin content and higher biomass yield per acre (Yasuda et al. 2014). The Napier grass biomass contains higher volatile matter, carbon content, lower ash, nitrogen and sulphur values (Mohammed et al. 2015). The simultaneous saccharification and fermentation (SSF) of Napier grass reportedly yielded 74.1% ethanol. Another plant used in bioenergy is Bermuda grass (*Cynodon dactylon* L.). It is highly diverse, short-lived perennial grass, mostly used as warm-season forage. Bermuda grass works as soil binder in sand dams of riverbanks or sea coast due to its pioneering nature and salinity tolerance. It is a valuable crop in irrigated lands (Grassland 2011). Eastern gamagrass (*Tripsacum dactyloides* L.) and prairie cordgrass (*Spartina pectinata* Link.) are also potential perennial grass feedstocks (Springer and Dewald 2004).

12.2.3 Third-Generation Bioenergy Crops

The third-generation bioenergy crops (TGECs) include boreal plants, crassulacean acid metabolism (CAM) plants, eucalyptus and microalgae. CAM and boreal plants are feedstock for direct fermentation of cellulosic biomass (Patil et al. 2008; Schenk et al. 2008). Eucalyptus is used in bioenergy production via thermo-conversion (Carere et al. 2008; Wang and Yan 2008). Some microalgae are good feedstock for biodiesel production. The TGECs success as a reliable biofuel source depends on the efficient metabolisms of cellulolytic bacteria during the fuel conversion process. In the aerobic system, cellulose is broken down into water and carbon dioxide. However, in anaerobic systems, cellulose degrades into CH_4 and H_2. Newer methodologies like genomics, biodiversity studies, system biology and metabolic engineering are improving biofuel yields. TGECs are introduced to develop a renewable and non-polluting energy source that could reduce global climate change (Bush and Leach 2007; Ehrlich and Pringle 2008; Rubin 2008).

12.2.3.1 Boreal Plants

Perennial grasses like *Phleum pratense* and *Phalari sarundinacea* are examples of boreal plants. Under boreal conditions, perennial grasses are major producers of herbaceous biomass. Boreal plants could be easily grown, harvested, stored and are used for CH_4 production. The plants are tolerant to most of the phytopathogenic diseases, drought and frost. Boreal plants can withstand cold winters and could grow on soils with low nutrition (Finckh 2008). Few boreal plants like *Ananas comosus*, *Opuntia ficus-indica*, *Agave sisalana* and *Agave tequilana* are commonly utilized for bioenergy production (Lehtomäki et al. 2008).

12.2.3.2 Crassulacean Acid Metabolism (CAM) Plants

Plants having CAM adapts well to photosynthesis. These plants help in the uptake of carbon dioxide at night. In arid habitats, CAM plants improve the efficiency of water use and carbon assimilation. The CAM plants are tolerant to drought and are used as bioenergy crop (Fraiture et al. 2008). The water use efficiency of CAM plants is 3–6-fold higher than C_3 and C_4 plants. CAM plants like cardoon are multifunctional bioenergy crops. These plants are used to produce solid and liquid biofuels (Grammelis et al. 2008; Borland et al. 2009).

12.2.3.3 *Eucalyptus*

Eucalyptus (*Eucalyptus* sp.) is a native plant of Australia. The plant grows faster with indefinite growth and holds a large genetic resource base. The plant is resistant to drought, fire, insects, acidic soils, low fertile soils and other harsh conditions. Eucalyptus is cultivated in tropical countries due to faster growth and higher yield (70 m^3/ha/year). The plant has a rotation period as short as 5 years. Only four species and their hybrids (*E. grandis, E. urophylla, E. camaldulensis* and *E. globulus*) contribute to 80% plantations worldwide. Of the four species, *E. globulus* is widely adapted plant that is used in breeding programmes due to faster growth rate. The eucalyptus oil extracted via thermo-conversion from plant parts holds huge potential in biofuel and bioenergy production (Rockwood et al. 2008; Wang and Yan 2008).

12.2.3.4 *Agave*

Agave (*Agave* sp.) is a monocot plant native to hot and arid regions of Mexico. A plant species, *Agave tequilana*, is used for producing tequila. The agave nectar is used as a sugar alternate in cooking. The plant grows in arid regions and possess thick fleshy leaves ending with a sharp point. Agave uses the CAM pathway for photosynthesis. It opens stomata for CO_2 uptake during the night, causing less water loss during transpiration. The plant is used for making alcoholic beverages, sweeteners and fibers. Agave is preferred feedstock for biofuels as it has minimal water requirement, could easily grow on wastelands and does not compete with food crop feedstocks (Escamilla-Treviño 2012).

12.2.3.5 Microalgae

Microalgae are an important feedstock for producing biodiesel, bioethanol, biomethane and biohydrogen (Ahmad et al. 2011). They are photosynthetically more efficient than terrestrial plants. Microalgae decrease greenhouse gases emission by absorbing carbon dioxide released from plants. They produce huge biomass in short span through efficient photosynthesis (Schenk et al. 2008). Microalgae reduce the carbon dioxide of the atmosphere through carbon sequestration. Compared to conventional biofuel-producing crops, microalgal biofuels have lesser impact on the environment and world's food supply (Patil et al. 2008; Schenk et al. 2008; Tilman et al. 2009). Microalgae hold huge potential in mitigating global climate change (Patil et al. 2008) as they have efficient rate of photon conversion to photosynthates. In addition, they could be harvested throughout the year (Williams et al. 2007). Microalgae provide non-toxic and highly biodegradable biofuels. Several programmes are running to improve the biofuel production rate by enhancing the efficiency of strains through genetic engineering. Compared to other bioenergy crops, the microalgae-derived fuel is considered greener due to the higher conversion rate into biofuels.

12.2.4 Dedicated Bioenergy Crops

Perennial herbaceous and woody plant species are the example of dedicated energy crops. They require lesser biological, chemical or physical treatments for biomass generation. These crops are considered environmentally friendly and could be helpful in controlling global climate change (Petersen 2008; Taherzadeh and Karimi 2008). These crops could remediate several environmental problems by reducing salinity, carbon sequestration, biodiversity enrichment and by improving the soil and water quality (Ehrlich and Pringle 2008; Lal 2008). The dedicated bioenergy crops include cellulosic plants (eucalyptus, poplar, willow, birch, etc.), perennial grasses (giant reed, reed canary grass, switchgrass, elephant grass, etc.), non-edible oil crops (castor bean, physic nut, oil radish, pongamia, etc.) and oil plants (*Jatropha curcas, Pistacia chinensis, Sapium sebiferum* and *Vernicia fordii*). Such crops have shorter life cycle and therefore could be harvested several times in a year with long period of harvesting (Boe and Lee 2007; Ranade et al. 2008). Short rotation coppice (SRC) is among the most potential dedicated crop for bioenergy (Rae et al. 2009). Countries like Sweden and the UK are pioneers in the large-scale plantation of dedicated bioenergy crops (Mola-Yudego and González-Olabarria 2010).

12.2.5 Halophytes

Halophytes are specific plants that grow in saline, semi-deserted and marshy soils. They generally inhabit coastal regions, mangrove swamps and estuaries (Glenn et al.

1999). These plants grow and reproduce better at higher salt concentrations (Ventura et al. 2014). Halophytes help in carbon sequestration and rehabilitation of degraded land, stabilizing ecosystems by providing ecological niches necessary for reducing global climate change. Moreover, they protect the associated flora and fauna from environment and pathogens (Jaradat 2010). Under saline conditions, frost-sensitive *Eucalyptus* spp. and the frost-tolerant *Populus* spp. are the best genetic resources for biomass generation (Rockwood et al. 2008). Halophytes easily establish in salt-degraded lands and could also phytoremediate soils polluted with heavy metals (Hasanuzzaman et al. 2014; Panta et al. 2014). It has been shown that dicot halophytes are more tolerant to saline conditions than monocots (Flowers and Colmer 2008). Halophytes could be used for food, medicine and ornamental landscaping. Moreover, they protect the environment by supporting wildlife (Cassaniti et al. 2013; Panta et al. 2014). Halophytes of the genera *Acacia, Eucalyptus, Casuarina, Melaleuca, Prosopis, Rhizophora* and *Tamarix* are commonly used in the biofuel production. It has been demonstrated that perennial halophyte (*Kosteletzkya pentacarpos*) seeds can be used to produce biodiesel (Moser et al. 2013). Halophytes hold higher efficiency rate of biofuel conversion due to greater amounts of secondary metabolites (Hastilestari et al. 2013).

12.3 Characteristics of Bioenergy Crops

Bioenergy crops protect the environment in multiple ways (Boehmel et al. 2008). They are resistant to diseases and pests due to perennial nature (Finckh 2008). Bioenergy plans have improved phenotypic, architectural, biochemical and physiological characters which are desirable traits in biofuel production. Moreover, bioenergy crop cultivars are tolerant to biotic and abiotic stresses which grow faster than other crops. Additionally, bioenergy crops require less biological, chemical or physical pretreatments, thus reducing the cost involved in biomass processing. There is a need to introduce new high-yielding energy crop varieties for fulfilling energy needs which could be accomplished by wide-scale screening of efficient botanical plants across the globe.

12.3.1 Agronomic and Metabolic Traits

Bioenergy crops require low energy for the establishment, possess good adaptation to marginal lands and hold higher biomass. These plants decrease global warming and mitigate the effect of global climate change. As per agronomic characters, the bioenergy crop should hold traits of long canopy duration, perennial growth, sterility, lesser dry matter to reproductive structures and lesser moisture content at harvest. A C_4 perennial grass, *Miscanthus* spp., holds most such agronomic traits (Lewandowski et al. 2000; Jakob et al. 2009; Leakey 2009). The metabolic architecture of dedicated energy crop decreases 'plant-to-plant' and 'weed' competition. The plant metabolic change also reduces radiation interception, enhances the efficiency of water use and accelerates field drying. Such plants are straight, thick with upright stem branching and are resistant to waterlogging.

12.3.2 Physiological and Ecophysiological Traits

Bioenergy plants store thermo-chemical and solar energy in several biochemical forms. Such plants need various physiological and ecophysiological traits to maximize radiation absorption, water efficiency, nutrient-use and environmental sustainability (Boe and Lee 2007; McLaughlin et al. 2006). These physiological traits include efficient nutrient cycling, low nutrient requirement, carbon sequestration, low competition among plan groups, long canopy duration, efficient C_4 or CAM photosynthetic pathway and effective light capturing. All of these physiological traits assist plants in growth season to increase above-ground biomass (Lal 2008; Jakob et al. 2009).

The ecophysiological traits in germplasm of perennial short rotation coppice and lignocellulosic grasses show great diversity (Carroll and Somerville 2009; Tharakan et al. 2001). Bioenergy crops possess vegetative storage organs to store food reserve for longer periods. The vegetative storage structures are reported to decrease environmental stress and minimize metabolic loss (Wang and Yan 2008). Carbon and nitrogen ratio is the deciding factor in bioenergy production from plant biomass. Higher C:N ratio of bioenergy crops yields more bioenergy in the form of methane from bioenergy crops (Long et al. 2006).

12.3.3 Biochemical Composition and Caloric Content

Plants differ in the biochemical composition of carbohydrates, proteins, lipids and organic acids. Their use in the bioenergy sector depends on the uniqueness of biochemical composition. Bioenergy crops are a good energy source, hold low production cost and mitigate greenhouse gas emissions (Monti et al. 2008). The plant bioenergy is measured in terms of calorific value, which is defined as the expression of released heat value and energy content during the burning of material in air. Each bioenergy plant type has its merits and demerits in terms of calorific value. For example, more energy is obtained from poplar plant than switchgrass and reed canary grass, whereas reed canary grass emits more greenhouse gases compared to switchgrass and hybrid poplar (Ferré et al. 2005; Boe and Beck 2008). The issues of plant growth energetics and crop suitability are critical and related to bioenergy and food production (Lobell et al. 2008). Improvement in biochemical composition and structure of bioenergy crop enhances its caloric value, thus generating higher energy per tonne of biomass (Sticklen 2006). The accumulated plant biomass is not proportional to energy absorbed during photosynthesis because the magnitude of accumulated chemical forms differs in their energy densities. This difference depends on the species and developmental stage of the plant. Carbohydrate generation is a valuable trait in bioenergy crops. The carbon hydrates are utilized in the fermentation process for biofuel generation. Cellulosic crops bear more potential in bioenergy generation since their degradation releases a vast amount of glucose units. The higher yields of biofuel from cellulosic crops correspond with decreased greenhouse gas emissions per hectare and per unit biofuel produced, compared to FGECs (Carroll and Somerville 2009).

12.4 Genetic Improvement of Bioenergy Crops

Plants are commonly grown for obtaining food and feed. Traditional breeding techniques of genetic modification have aided in developing plant varieties with desired morphological, phenotypic and biochemical characters (Lee 1998; Baenziger et al. 2006). The prime focus of such efforts involve improvements in crop productivity and quality. In addition, food crops could be modified for bioenergy generation through genotype alteration to yield more starch and higher C:N ratio. Such modification could alter the lignin biosynthesis pathway for better preprocessing via cellulases and cellulosomes expression. Bioenergy crop characters can be improved by identifying natural variations and genetic alteration to produce transgenic plants (Gressel 2008; Ortiz 2008). Genetically altered bioenergy crops hold better adaptability to unfavourable environment, higher growth rate and caloric value. The high degree of similarity found among the genomes of grass or *Poplar* spp. could facilitate the translation of gene function in such species to more genetically recalcitrant grass species like switchgrass, miscanthus and short rotation coppice. Willow was identified as a promising biomass crop due to easy propagation and faster growth in short rotation coppice cycles with lesser fertilizer requirement. For better yield, willow plants need to be kept free from pests and diseases. The yields of willow can be improved without significantly increasing the need for fertilizers and water through genetic engineering (Karp et al. 2011).

12.5 Environmental Impacts of Bioenergy Crops

Bioenergy crops provide multi-fold benefit to the environment and humans. The positive environmental impacts of bioenergy crop production can be evaluated through sustainability indicator analysis (McBride et al. 2011), risk–vulnerability–reliability assessment (Hoque et al. 2014) and absolute or percentage change impact assessment with baseline reference (Feng et al. 2015; Cibin et al. 2016). Various environmental impacts of bioenergy crop production are shown in Fig. 12.2 and thoroughly described below.

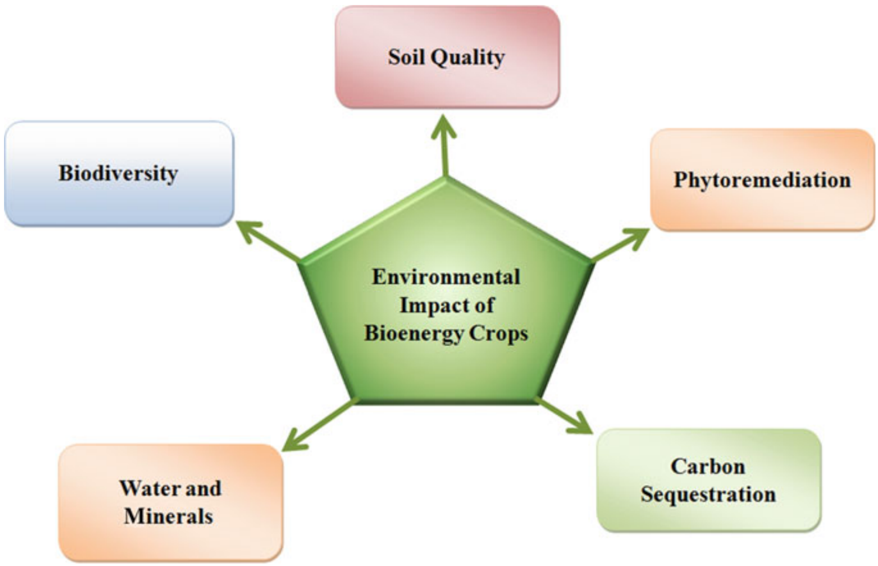

Fig. 12.2 Different environmental impacts of bioenergy crops

12.5.1 Phytoremediation

Phytoremediation involves the use of plants to remediate contaminated soil, sediments and groundwater by removing or degrading contaminants (EPA 1999). This technology is innovative, cost-effective and holds long-term applicability (Oh et al. 2013). Phytoremediation of bioenergy plants could remove heavy metals from soil to improve the soil quality. The method has an additional advantage of treating contaminated site without excavation (Vaněk et al. 2010; Zhu et al. 2010). The chief phytoremediation methods used to remediate heavy metal-contaminated land involve phytostabilization and phytoextraction. Phytostabilization involves the use of root-accumulating plants which reduces the bioavailability of metals stabilized in the substrate (Salt et al. 1995). Phytoextraction includes the use of plants with the ability of high shoot accumulation of heavy metals from soils, sediments and water. This method seems economically viable in treating metal-polluted land (Fritioff and Greger 2003).

The phytoremediation phenomenon is common to many plant genera. However, effective phytoremediation needs a selection of appropriate plant. The selection of plant depends on its availability, adaptation to specific climate, heavy metals extraction ability, biomass production rate and economic values (Oh et al. 2015). A study on *Sorghum bicolor* for phytoremediation of heavy metals showed that the plant is efficient in the uptake of metals due to the high biomass. The plant accumulates high concentration of metal in shoots. Sorghum plants were able to efficiently uptake metals such as Ni, Pb and Zn (Al Chami et al. 2015).

A major source of water pollution in agricultural lands is the wide-scale and indiscriminate fertilizer application in fields. The high amount of nitrate fertilizers is applied in fields to increase crop yield. The use of nitrate fertilizers in high amount creates surface and groundwater nitrate pollution. Few bioenergy plants hold the potential to remediate contaminants from soil or water. Poplar plant is known to accumulate high level of nitrate from water streams draining from agricultural lands (Rennenberg et al. 2010). This plant filters out nitrate from water bodies, thus reducing its concentration in contaminated water (O'Neill and Gordon 1994). Poplar is well adapted to grow in nitrate-rich soil through high- and low-affinity nitrate transporter proteins (Bai et al. 2013). The miscanthus crops are also used in phytoremediation (Xie et al. 2008; Masarovičová et al. 2009). The crop is preferred in phytoremediation due to perennial nature, high productivity, better growth rate, efficient CO_2 sequestration, higher water utilization efficiency and ability to protect soil erosion. However, the use of miscanthus has associated disadvantage of lower numbers of viable seeds for oil extraction (Masarovičová et al. 2009; Miller and Gage 2011), rendering it unsuitable for biofuel extraction.

12.5.2 Carbon Sequestration

Carbon sequestration involves plant-mediated removal of CO_2 from the atmosphere. Bioenergy crops decrease the atmospheric CO_2 through high biomass accumulation. The use of perennial crops could improve the quality of soil by increasing carbon sequestration by high biomass production and deep root systems (Ma et al. 2000). Henceforth, bioenergy crops could be used to sequester atmospheric CO_2 and enhance biomass productivity for bioenergy generation (Lemus and Lal 2005).

12.5.3 Soil Quality

Common cropping systems and crop characteristics affect soil quality by influencing nutrient supply, organic matter availability, soil structure and pH. For example, miscanthus, switchgrass and other fiber crops are mild on nutrient requirements while giant reed and cardoon heavily deplete nutrient resources. Soil supplementation with proper nutrients is necessary for maintaining soil quality. In addition, nutrient supplementation needs careful adjustment with concentration. For example, comparatively lower phosphorus concentration is required by sweet sorghum and potato crops. Moderate concentrations of nitrogen and potassium application are needed by crops to prevent the plant malnutrition. Lack of proper nutrition reduces plant biomass and nutrient deficiency becomes visible in the form of external symptoms. Deeper nitrogen deficits are observed in sunflower, giant reed and cardoon. Giant reed, cardoon, sugar beet, sweet sorghum, reed canary grass and wheat also exhibit high potassium deficiencies (Fernando et al. 2010).

12.5.4 Biodiversity

Biodiversity describes the range of organisms living on earth. It enhances ecosystem productivity where each species contributes in its own way. Thus, maintenance of biodiversity is important for a healthy ecosystem. Several environmental factors reduce the biodiversity of nature, among which land conversions, deforestation and grassland conversions contribute to great length. Most such environment-linked factors could be controlled by growing bioenergy crops. Bioenergy crops preserve biodiversity by reducing greenhouse gases emission and mitigating global climate change (Boehmel et al. 2008). In addition, the blossoming period of biodiversity and other crops also increase the abundance and diversity of bird or insects, especially in the fields of sunflower (Jones and Sieving 2006; Fernando et al. 2010). However, cultivation of annual crops reduces biodiversity due to short impact on soil and demanding growth requirements.

The development of lignocellulose-based biofuel systems that use a range of feedstock could increase agricultural landscapes diversity and increase arthropod-mediated ecosystem services (Landis et al. 2008). For example, perennial grasses with high lignocellulose content reduce soil tillage and agrochemical use, yield high above and below ground biomass, favour soil micro-fauna and provide shelter to invertebrates as well as birds (Börjesson 1999; Boehmel et al. 2008). Willow and poplar plants sustain more biodiversity compared to perennial grasses due to longer life cycles and creation of habitat for birds, vertebrates and flora. However, the overall effect of these crops on biodiversity may be negligible or not even positive (Berg 2002; Paine et al. 1996). Bioenergy plants like eucalyptus do not support biodiversity due to more aggressive management involved in cultivation.

12.5.5 Water and Minerals

Cultivation of bioenergy crops could be water demanding to the point of compromising natural water resource availability. Therefore, the water requirement of the crop should be taken into consideration before planting bioenergy crops. Water scarcity could hinder the successful establishment of bioenergy crops as a biofuel resource. Careful selection of bioenergy crops with water stress tolerance is required for arid and semi-arid regions. Some deep-rooted bioenergy crops are drought tolerant and capable of efficient carbon sequestering. However, such crops modify the water and nutrient dynamics in soils to negatively impact biodiversity (Ehrlich and Pringle 2008).

The crops of corn, sugar cane and oil palm require more water for yield and are best suited to grow in high-rainfall tropical areas (Fraiture et al. 2008). Also, sugar beet, hemp and potato heavily impact water resources (Fernando et al., 2010). However, plants of miscanthus and eucalyptus have an overall lower impact on water resources.

Bioenergy crops are known to affect soil minerals. For example, the sorghum plant accumulates Pb, Ni and Cu in roots and shoots. The application of phosphorus and potassium on bioenergy crop fields reduce soil mineral ore depletion to some extent. Perennial crops are less macronutrient demanding, and their nutrient utilization pattern is not significantly different from annual crops. The eucalyptus and willow plants affect mineral resources at lower rates, whereas sweet sorghum and potato present the higher risks of nutrient depletion (Fernando et al. 2010).

12.6 Conclusion and Future Prospect

Plants grow by absorbing CO_2 liberated during biomass combustion. By using crop biomass for energy generation, no net CO_2 is generated as the amount emitted during use has previously been fixed during plant growth. Use of bioenergy crops for energy generation could aid in utilizing this alternative source of renewable energy. The commercial production of bioenergy fuels could reduce our dependency on fossil transportation fuels using existing engine technologies. Bioenergy crop feedstocks (cellulose or sugar, starch plants) can play major in ethanol and biodiesel generation to boost the rural economy, provide greater energy efficiency and productively use environmentally damaged lands. Bioenergy crops are drought tolerant and capable of carbon sequestration. Energy crops that can be grown on the farm may also protect natural forests by providing an alternative source of wood. Biodiversity of the region decreases due to land conversions, deforestation and grassland conversions. Such environmental factors could be regulated by a large-scale plantation of bioenergy crops. Since bioenergy crops could modify the water and nutrient dynamics of soils, their water usage pattern should also be taken into consideration before field plantation. Depending on the land type, a suitable bioenergy crop should be recommended.

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