Promising resources for bioenergy: shrub willows of Turkey

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Abstract

Salix L. species are economically excellent candidates for sustainable bioenergy production. Especially, shrubs of Salix L. are used in agroforestry for their characteristics of quick growth, wide distribution and resistance to disease and stress. The shrubs of subgenera Salix and Vetrix under Salix L. commonly found in riparian or wetland habitats of Turkey have great potential as bioenergy crops with high biomass yield. This review study will provide information to determine the potential of willows species native to Turkey for bioenergy and to contribute to energy production by using the biomass of fast-growing shrub willows as renewable energy resources. Firstly, botanical description, habitat, growth, traditional breeding efforts and genetic composition were summarized concerning about the bioenergy potential of willows from results of existing studies. Secondly, the titles, establishing willow plantations, biomass reducing the greenhouse gas emissions responsible for climate change and development of willow as bioenergy crop in worldwide and Turkey were reviewed. Lastly, the future of bioenergy potential estimation of willows was proposed to provide some instructions for bioenergy development in Turkey.

Introduction

Botanical Description of Salix L.

Turkey is a rich of biodiversity including trees and shrubs (Kaya and Raynal, 2001). One of the most significant member of the Anatolian forest is Salicaceae members (Skvortsov, 1999). The genus Salix is very diverse, representing from 350 (Skvortsov, 1999) to over 500 species (Wu et al., 2015) in the world. They are growing in the form of trees, shrubs or dwarf shrubs (Argus, 1997). In Salicaceae family, Salix are more adaptable when it is compared with Populus regarding to ecology. The traditional morphological characters used to characterize members of most plant genera are not reliable in Salix due to introgressive hybridization, polyploidy and complex phenotypic characterization. In world, the genus is divided into five subgenera: Salix L. subg. Salix, Longifoliae (Andersson) Argus, Protitae Kimura, Chamaetia (Dumort). Nasarov in Kom. and Vetrix Dumort. (Wu et al., 2015). Many shrubs in Vetrix subgenus have great potential to be cultivated as bioenergy crops with high biomass yield and good coppicing ability (Kuzovkina et al., 2008).

Willow Habitat and Growth

Willows have a wide distribution and can thrive in different climate zones and soil types such as arctic, temperate, sub-tropical and tropical regions of Europe, Asia and North America (Smart & Cameron, 2008). The species habitats vary in much wider ranges. They can
survive from arid areas to wetlands, from beaches to high mountains. They are also pioneer species that are shade-intolerant and capable of colonizing disturbed sites (Newsholme, 1992). This adaptable characteristic of the genus comes from minute features of the seeds. And also, most willow species easily propagated and self-dispersed by rooting of wind-broken branches (Skvortsov, 1999). Thus, the genotype can hypothetically continue to live in a population for a much longer period of time from branches. By the help of this characteristic, the new and superior varieties can be grown rapidly by forming roots and shoots. Salix species as clones are more preferred in forest biotechnology for their quick growth, wide distribution and resistance to disease (Herrera, 2006; Vermerris, n.b.).

Figure 1

Today, the genus is consisted of 27 willow species naturally found in Turkey (Acar et al., 2020), divided into two subgenera (Salix and Vetrix) and 13 sections (Skovortsov, 1999). Numerical taxonomic methods and molecular approaches (Acar, 2017) were used to comprehend the complex relations of Salix genus in Turkey (subgenera Salix and Vetrix). The subgenus Salix includes species that display traits considered to be more primitive including medium to large sized trees or large shrubs (Smart and Cameron, 2008). The species in subgenus Salix are Salix alba, S. excelsa, S. fragilis, S. acmophylla, S. pentandra, S. pentadoides, S. trubzonica and S. triandra and the exotic species, S. babylonica. The subgenus Vetrix including mostly shrubs and small trees is classified into many sections. Subg. Vetrix is characterized by evolutionary advanced traits such as pubescence on bud scale (Acar et al., 2020). The subgenus Vetrix is consisted of S. elbursensis, S. apoda, S. pseudodepressa, S. aegyptiaca, S. eulaegnos, S. pseudomedemii, S. purpurea subsp. leucodermis, S. armenorossica, S. cinerea, S. caprea, S. pedicellata subsp. pedicellata, S. myrinfolia, S. caucasia, S. wilhelmsiana, S. amplexicusalis, S. rizeensis, S. viminalis and S. anatolica in Turkey. Other subgenera of Salix L. found in world such as Longifoliae and Chamaeta are dwarfs with root suckers in alpine habitats thus not suitable as potential bioenergy crops. The richest region of Turkey for Salix species is Northern Anatolia. It is followed by the Eastern Anatolia and Southeast Anatolia regions (Arhan & Güvenç, 2009). Shrub willows (23 taxa) mainly located in Central Anatolia and Black Sea regions are shown in Table 1. One of the shrub willow species, Salix cinerea from Ankara province can be seen in the Figure 1.

Review of Results

Willows as a Sustainable Bioenergy Crop

Evidence suggests that people living along the rivers in the Middle East over 10,000 years used poplars and willows for cooking and heating and for the construction of their dwellings (Stettler, 2009). Ancient civilizations used willows for many necessities such as furniture, snowshoes, arrow shafts, fish traps, nets, shelter, fences and medicinal remedies (Kuzovkina et al., 2008). In energy forestry fast growing willow trees and shrubs are widely used. In northern temperate areas, woody crop development has focused on willow shrubs of Salix L. (Volk et al., 2004). These shrubs can grow under quite different climatic, soil conditions and their growth rate is 10-20 times higher than other trees. Willows, especially those that grow as shrubs with multiple small stems, have many of the characteristics desired in dedicated energy crops, including high yields obtained in a few years, ease of vegetative propagation, a broad genetic base and a short breeding cycle (Volk et al., 2004). Those traits are used as advantages in bioenergy plantations. When the stem biomass is harvested by cutting the stems near to the ground, shrubs produce new shoots from the root system called coppicing in bioenergy (Smart & Cameron, 2008). Fast-growing shrub willows can be cultivated in short-rotation coppice (SRC) which is a traditional practice in willow (Sennenby-Forsse, 1995; Karp & Shield, 2008). Hybrid productivity called hybrid vigour is used to increase the yield of willow with high coppice response (shoots) (Larsson, 1998; McCracken & Dawson, 2001). Salix sachalinensis × S. miyabeana, S. viminalis × S. miyabeana and S. purpurea × S. miyabeana are the hybrids in U.S. used for increasing cellulose content of stem biomass and disease resistance through breeding efforts (Serapiglia et al., 2013).

Biomass obtained from the energy forest does not provide as much energy as wood obtained from traditional forestry. Wood density, moisture content and shell amount vary depending on the rotation period and change the calories of the wood in energy forestry. As the rotation period increases, the quality of the wood increases (General Directorate of Forestry Bioenergy Commission, 2009). As known, wood willows have caloric value as bioenergy. For example, the higher calorific value of wood willows is obtained from stem of 2-year-old shrub (Klasnja et al., 2002). Biomass from woody crop was previously not cost-competitive with fossil fuels such as coal (Tharakan et al., 2005) but today wood-based bioenergy plantations become an important issue as far as climate change is concerned and emerge as a renewable energy source in abandoned agricultural lands (FAO, 2016).
<table>
<thead>
<tr>
<th>Subgenus</th>
<th>#</th>
<th>Species name</th>
<th>Life form</th>
<th>Location (Region)</th>
</tr>
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<tr>
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<td><em>S. excelsa</em></td>
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<td></td>
<td><em>S. trabzonica</em> (endemic)</td>
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<td>VETRIX</td>
<td>9</td>
<td><em>S. apoda</em></td>
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<td><em>S. myrsinifolia</em></td>
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<td>Black Sea Region</td>
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<td>24</td>
<td>*S. purpurea subsp. <em>leucodermis</em> (endemic)</td>
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<td>Aegean Region</td>
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<td>Black Sea and Eastern Anatolia Regions</td>
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<tr>
<td></td>
<td>26</td>
<td><em>S. anatolica</em> (endemic)</td>
<td>Shrub</td>
<td>Mediterranean Region</td>
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</table>
Traditional Breeding Efforts on Willows as Bioenergy Crops

The plant breeding has long history in agricultural crops but shrub willow production for bioenergy is relatively a new area. The actual aim of breeding and selection in propagated vegetatively shrub willows is to identify clones through replicated trials. The clones are selected from first generation, from F1 hybrids produced by interspecific crosses. Interspecific hybridization can be done by controlled pollination. Many willow species are capable of hybridization. However, there can be barriers based on incompatibility between tetraploid and diploid species. In traditional breeding, mechanical pollination of willows can also be done by viable pollen extracted from male flowers using toluene and stored at −20°C for several years (Kopp et al., 2002). Female flowers can be pollinated by mechanical application of stored pollen by using a fine paintbrush (Kopp et al., 2002). After successful pollination, the seeds can be collected per catkin and the mature seed should be sown to moist or fine potting mix. After a few weeks in greenhouse, they can be transplanted to the field (Mosseler, 1989). The crosses within subgenera are more likely to succeed than crosses between different subgenera (Smart & Cameron, 2008). Besides, the crosses between species in the same section are being the most likely to produce viable seed (Kopp, 2000). Molecular systematic and phylogenetic information showing the sectional and subgenus level position of species provide unique information for the breeding system (Kadam et al., 2016). Studies based on this subject of Turkey (Acar et al., 2020) may lead to the development of new willow varieties from shrubs by the improvement of the new breeding technologies.

Genetic Composition of Willows In Bioenergy

Today, the growth rate of energy shrubs can be increased even more by using breeding and also genetic methods. Variation in gene content, gene expression and gene functionality can be used to understand traits of interest (Carlson et al., 2019). The traits such as vigor, cold tolerance, disease resistance, biomass composition have a genetic basis and the high performance are related with specific genetic variations (Vermerris, 2008). Crossing programmes and the identification of molecular markers for marker-assisted selection such as Amplified Fragment Length Polymorphism (AFLP), Simple Sequence Repeat (SSR), Restriction Fragment Length Polymorphism (RFLP) and Single Nucleotide Polymorphism (SNP)s can enhanced through improved knowledge of the genetic basis of the traits (Sorrells, 2007). The genetic studies generally and potentially reduce the time of selection for new willow genotypes. The AFLP and RFLP markers were used in 87 progeny of a cross of S. viminalis × S. schwerinii with S. viminalis to identify the quantitative trait loci (QTL) for height growth, stem diameter, height, diameter ratio, number of vegetative buds and number of stems (Tsarouhas et al., 2003). The large population was crossed between two S. viminalis × (S. viminalis × S. schwerinii) hybrid by using AFLP and SNPs (Hanley et al., 2006). In Turkey the microsatellite markers (SSR) were used to determine the genetic variation of Salix alba (Değirmenci et al., 2019). Molecular breeding tools are important to provide powerful approaches for gene discovery, however, genetic linkage maps with technology of mapping of QTL have greater impact on bioenergy (Brunner et al., 2007).

The plant cell wall is a dynamic composite network of complex polymers of four major wood component: hemicellulose, pectin, cellulose and lignin as far as composition of biomass is concerned (Joshi and Mansfield, 2007). Compared with annual and perennial grasses, wood biomass in general has a higher content of lignin, lower cellulose and hemicelluloses contents (Serapiglia et al., 2009). The genetic and biochemical regulation of cellulose biosynthesis remains to be resolved and the dynamic complexity of cell wall composition presents some significant challenges (Rose et al., 2004; Joshi & Mansfield, 2007). The cell wall gene expression was tested whether it can be correlated with genetic variation in biomass composition on Salix sacholinensis and Salix miyabeana (Serapiglia et al., 2012). Some other techniques such high-resolution
thermogravimetric analysis (HR-TGA) was developed as a rapid and low-cost method for analyzing large numbers of willow biomass samples (Serapiglia et al., 2009). Variation in hemicellulose content was found as genetically controlled while cellulose and lignin content were influenced by environmental effects (Fabio et al., 2017). The genetics studies showed that there is considerable genotype × environment interactions for traits important for yield (Tahvanainen & Rytkonen, 1999). New genetic techniques, QTL, Genome-wide association (GWAS), Genotyping-by-sequencing (GBS) with genome-wide SNP discovery by next generation sequencing (NGS) technologies reduce sequencing cost compared to whole-genome sequencing (Allwright & Taylor, 2015). Important marker–trait associations identified in GWAS and linkage mapping were successfully done in large S. purpurea populations of North America (Carlson et al., 2019). In Salix, bi-parental QTL mapping populations studies are the other important studies to indetify the genetic markers for key traits such as wood composition (Berereton et al., 2010; Pawar et al., 2018), phenology (Tsarouhas et al., 2003), drought tolerance (Berlin et al., 2014) and leaf rust (Hanley et al., 2011; Samils et al., 2011). CRISPR/Cas (clustered regularly interspaced short palindromic repeat/ CRISPR-associated) technology in poplar can also be promising for genome editing in willow (Allwright & Taylor, 2015). The genetic modification of plant cell wall was tested to enchance the biomass yield on naturalized S. purpurea accessions of North America (Wang et al., 2016). Transformation protocols for the genetic modification policy are established for poplar and are now emerging in willow (Yang et al., 2013).

Genetic improvement of shrub willow has also been associated with species hybridization and poliploidy mechanisms (Serapiglia et al., 2014). Three years post coppice performance on height, stem diameter, stem area, stem number and specific gravity values were tested on diploid, triploid and tetraploid genotypes of S. purpurea, S. eriocephala, S. suchowensis and S. miyabeana species to detect the genetic improvements in the study of Serapiglia et al. (2014). It was found that triploid willows had high stem area and height across all three years of growth. Among the species, Salix miyabeana, S. purpurea and S. viminalis triploid hybrids have shown the greatest aboveground biomass compared to diploid and tetraploids and greater biomass with high biomass on leaf traits and rapid early stem elongation (Fabio & Smart, 2018a). The triploid progeny can generate cultivars with trials of genotype environment interactions and with improved growth traits and wood composition (Serapiglia et al., 2015; Fabio et al., 2017).

Establishing Willow Plantations

In northern temperate countries, the agriculture regions (cultivation and livestock grazing) have left important areas of arable land available for the production of energy crops (Smart & Cameron, 2008). Although field crop and vegetables are not cultivated in these areas due to the limited fertilizers, willows can be planted as a bioenergy product. Proper site preparation, the mechanical planter, elimination of weed competition, the best possible soil structure and composition are the important criteria for the successful establishment (Isebrands & Richardson, 2014). Equipment are needed for the cultivation of shrub willow such as the willow planter and coppice forage harvester (Smart & Cameron, 2008). Recently published paper showed the effects of planting design and advantages of harvest rotation on shrub willow bioenergy crops with a double-row design (Gouker et al., 2021). In the last 10 years, Short-Rotation Coppice (SRC) as harvesting method on willow shrubs was established in many European countries (FAO, 2016). Willow has higher demand for nutrients than many tree or shrub species, yet lower than most agricultural crops (Stanfurt & Oosten, 2014). The irrigation and annual nutrient fertilization increase willow productivity in many sites. However the effects of fertilization were observed on shrub willows by Fabio & Smart (2018b) and they concluded that the results of yield response was correlated with geographic and climatic variables rather than nitrogen dosage. Thus, the highest yields are generally achieved in trials with supplemental irrigation and/or fertilizer application on second generation biomass of willows (Allwright & Taylor, 2015).

Weed competition, drought and disease are the greatest threats to willow plantation for the crop management. The primary concern rust disease is caused by fungus Melampsora epitea Thüm. The insects are the beetles, Phratora vitellinae L. and Phratora vulgatissima L. in the U.K. (Kendall & Wiltshire, 1998) and the beetles (Popillia japonica Newman and Plagiodera versicolora Laicharting) (Nordman et al., 2005) in the U.S. To establish succesful and long term willow plantation path (Figure 2), it is advised to plant a genetically diverse mixture of varities.

For the harvest of shrub willow biomass, the production of wood chips during harvesting is the best way when the biomass will be used soon after delivery or when the chips will be stored in a chip pile to avoid significant decay (Jirjis, 2005). There are some options to make conversion of willow chips to the energy. The wood chips of willows are most commonly burned in district heating plants that distribute hot water or steam among the buildings of a small town. Commercial willow chips are important for producing 10% of electricity in the U.K to reduce carbon emissions by 2010 (Wright, 2006). And also, willow biomass has potential as a feedstock for biochemical conversion to ethanol when the wood chips are subjected to steam pretreatment with dilute sulfuric acid (Sassner et al., 2006).

In woody energy, it is known that it is necessary to use more biomass than fossil fuels in order to obtain the same amount of heat. Since this will increase the costs of collection, storage and transportation, the most...
economic solution is to use biomass at its location (General Directorate of Forestry Bioenergy Commission, 2009). Thus wood biomass need to be generated according to national willow plantations strategies (Klasnja et al., 2013).

Biomass Reducing the Greenhouse Gas Emissions Responsible for Climate Change

Today, climate change is a serious threat on the global scale and the use of fossil fuels is one of the most important causes of global warming (Zengin et al., 2020). The progressive depletion of fossil energy sources and the growing concerns about global climate have made the importance of renewable energy sources increase even more (Rubin et al., 1992). Mitigation of climate change by increasing carbon sinks through afforestation and reforestation provides good opportunities for the use of fast growing species for carbon reduction (FAO, 2016). According to FAO, depending on the use of wood biomass in electricity generation facilities instead of coal or natural gas, CO₂ emissions and energy consumption can be reduced.

Wood-based bioenergy often compares with fossil fuels because of caloric value or smaller carbon footprint. Biomass from willow crops can be used to produce energy with no net addition of CO₂ to the atmosphere (Volk et al., 2004). In other words, the amount of CO₂ produced during production, transportation and use of willow biomass is offset by the CO₂ taken up during photosynthesis by its’ growing (Volk et al., 2004). The United Nations Framework Convention on Climate Change has recognized the importance of plantation forestry as a greenhouse gas mitigation option (Arora et al., 2014). The cultivation and conversion of willow biomass to bioenergy or biofuels has many positive environmental benefits. For example, increasing net energy ratios (Heller et al., 2003), lower greenhouse gas emissions than fossil fuels (Keoleian & Volk, 2005), improved soil conservation (Volk et al., 2004), greater agricultural landscape diversity, raising bird biodiversity and improved nutrient (Kuzovkina & Quigley, 2005; Volk et al., 2004). Willow plantations also mitigate erosion and have a significant impact on afforestation (Isebrands & Richardson, 2014).

There are also some disadvantages of wood plantations as renewable energy: 1) Availability of plantation area to harvest (the public, private sectors or forest area), 2) Maintaining nutrient cycling processes imposes restrictions, 3) Willow biomass with having low heat value will increase the costs (Kukrety et al., 2015). Although woody biomass has uncertainty with described criteria above, the activities on willows and the production of short rotation woody crops on marginal land are still promising bioenergy option with high yields and less CO₂ emissions (Volk et al., 2011).

Development of Willow as an Energy Crop in Worldwide and Turkey

The increasing worldwide demand for wood products after rising world population growth accelerated the spread of fast-growing hybrids (poplar and willows) to all corners of the world (Schreiner, 1959). China is recognized as the country with one of the richest resources of natural poplar and willow forests in the world. Generally, the native willows are primarily used for environmental protection (78%) or for multi-purposes (21%) (FAO, 2016). In agroforestry system, willows are for multi-purposes (59%), biomass for fuelwood production (24%), industrial roundwood production (12%) and environmental protection (5%) (FAO, 2016).

An estimated 70 countries grow poplars and willows in mixtures with other natural forest species in planted area. According to the country reports, it was indicated that poplars and willows area exceeds 80 million hectares globally. The Russian Federation,
Canada and the United States have the largest reported areas of naturally occurring poplar and willows, while China, India and Pakistan have the largest planted areas (Ball et al., 2005). The total area of planted poplars and willows were 31.8 million ha, of which, 31.4 million ha were planted poplars (99%) and planted willows, only 0.4 million ha (FAO, 2016). Globally, 94 percent of willows grow in natural forests, 5 percent in plantations and 1 percent in agroforestry systems (Ball et al., 2005). China accounted for 0.3 million ha of planted willow (71% of global total), followed by Argentina with 56.400 ha. (FAO, 2016). In the light of new information (FAO, 2020), the overall area of poplars, willows and other fast-growing species reported by 17 countries is estimated as 71.803.129 ha. The biggest area covered by fast-growing species is reported in China, Sweden, Canada and Turkey (FAO, 2020).

Interest in willow breeding has grown dramatically, particularly in Sweden, due to the energy crisis in the 1970s. Willow cultivation has expanded from a few hectares to about 17,000 ha (Verwijst, 2001). Willow varieties of Sweden were produced that displayed improvements in important traits called as ‘Orm’, ‘Rapp’, ‘Jorr’, ‘Jorunn’, ‘Björn’, ‘Tora’ and ‘Loden’ (Åhman & Larsson, 1994; Larsson, 1997). Breeding of willow bioenergy crops in the U.K. was initiated in 1996 and the new varieties were produced from the hybrids such as ‘Endeavour’ S. viminalis × S. schwerinii, ‘Discovery’ S. schwerinii × S. schwerinii × S. viminalis (Smart and Cameron, 2008). Willow breeding in North America was started at Toronto by investigating the native willows including S. eriocephala, S. exigua, S. lucida, S. amygdaloides, S. bebbiana, S. pelletia, S. petiolaris and S. discolor (Mosseler, 1989; Lin, 2006).

The history of wood biomass as an energy source in Turkey was started in 1868-1893 by forest rights including collection of wood, charcoal and other forest products. Sixty-four percentages of the wood produced between 1925 and 1937 was firewood and 60% of the primary energy consumed was from the wood (General Directorate of Forestry, 2007). In addition, with the simulations that facilitate the use of solar heating systems in rural areas, the share of wood in consumption of primary energy resources have decreased significantly in 2007 (General Directorate of Forestry, 2007). Willows are traditionally planted in rows around the margins of damp meadows, fields and used as fuel in Turkey. In addition, basket willow (Salix viminalis) is used as an important value in Anatolian villages in making baskets due to its flexible branches (Velioglu & Akgul, 2016). While 30% of the production obtained from the natural stands of willows is used in the fiber-chip industry, the remaining production is preferred by the pallet and packaging industries (Velioglu et al., 2020). However, willow does not have an extraordinary economic input due to its commercial production in Turkey up to now (Velioglu & Akgul, 2016). Unfortunately, the number of studied willow clones are limited and not as many as poplar plantations in Turkey (Akgul & Tunctaner, 2011). Recently, willow plantations have been started with the increase in the demand for wood raw materials and many trials are being considered for willow cultivation (Velioglu et al., 2020).

With an agreement between Turkish Government and the Food and Agriculture Organization (FAO), Poplar and Fast Growing Forest Trees Research Institute was established at Izmit/Kocaeli in 1962. Mainly, ex-situ Populus nigra conservation programme has been carried out by Izmit institute in which over 1,000 genotypes have been archived in clonal nursery plantings at Behicbey in Ankara (Toplu, 2005). Furthermore, the geographical information system based application showing Biomass Energy Potential Atlas of Turkey (BEPA) includes knowledge about poplar (https://bepa.enerji.gov.tr/). But there is no records showing the range of product as fuelwood production or industrial roundwood production by willow species according to forestry data. Most of conservation and domestication willow efforts were investigated genetically by Acar (2017), Tokdemir (2017) and Değirmenci et al. (2019) reported in the Poplars and Willows in Turkey: Country Progress Report of the National Poplar Commission, Period: 2016-2019.

Turkey has decided to reduce greenhouse gas emissions by up to 21% in 2030 within the framework of the decision taken by the Climate Change and Air Management Coordination Board (Zengin et al., 2020). Willow plantation activities is an alternative way for decreasing effects of climate change. The bioenergy potentials and plantations of desired crops can be determined according to the data from geographic information system and statistic (Long et al., 2013). In Turkey, the previous study (Acar & Usta Baykal, 2020) showing 2050 climate scenario of willow habitat offered possible clone plantations for both conservation and bioenergy purposes (Figure 3). The certain conservation priority areas for willows in Turkey were determined as Western and Eastern Black Sea Region by species distribution modeling (SDM) approach in the study. It is also reported in Country Progress Report of the National Poplar Commission, Period: 2016-2019 and Değirmenci et al. (2019) that Marmara and Middle Black Sea regions have a great potential to produce Salicaceae hybrids for plantation (Velioglu et al., 2020).

Conclusion

With rising prices of fossil fuel and green gas emission, interests in expanding the use of renewable and sustainable sources of energy have been accelerated. Those criteria will increase the efforts on production areas of fast growing perennial bioenergy crops, including shrub willow. Shrub willow species from subgenera Vetrix in Turkey have tremendous potential to generate new varieties with improved yield, pest and disease resistance, water and nutrient use efficiency through conventional breeding. New DNA based molecular breeding techniques and crosses between
indigenous species are the excellent prospect for bioenergy to increase the yield and to produce new varieties in Turkey. Small scale willow plantations (Western-Eastern Black Sea region and Central Anatolia) can provide cost-effective alternatives for mitigating climate change, increasing and conserving the willow species in Turkey. Willow wood chips can be consumed in its production location or they can be transported only to short distances for collection, storage and transportation of biomass. The use of wood, which is a very old fuel known to mankind, is one of the best solutions as regard to rural development and environmental benefits for future bioenergy strategies. The willow as a reliable bioenergy crop needs to be investigated and evaluated in detail as a part of bioenergy policies in Turkey.

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