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Prospect of Growing Energy Crops on Biosolids-Amended Marginal Soils in Ukraine

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Abstract. Ukraine is one of the largest countries in eastern Europe and a substantial area (> 70%) of its land is under conventional agriculture. Current high-energy input conventional farming practices are responsible for degrading once-productive lands in Ukraine. Effects of these farming practices, together with climate change effects, are adversely affecting crop yields, soil health, water quality, and ecosystem services. While the share of renewable energy within the total energy demand is small, the prospect for producing alternate energy especially biofuels in Ukraine is growing rapidly due to the abundance of marginal lands and unutilized nutrient-enriched biosolids. To alleviate the energy crisis, domestically produced biofuels, by recycling biosolids on vast areas of marginal lands to raise commercial plantations of bioenergy crops, such as Sweet sorghum (*Sorghum bicolor* (L.) Moench) Miscanthus x *giganteus*, and Poplar (*Populus*, L), could be a proactive energy independence approach in Ukraine.

Keywords. Sweet sorghum, biofeedstock, renewable energy, high-input agriculture, land degradation

1. Introduction

A lack of operational geothermal energy resources makes Ukraine completely dependent on imported energy [1]. Moreover, regional geopolitical instability and accelerated climate change effects are contributing to making imported geothermal energy riskier and more expensive. Recent advances in conversion technologies have suggested that biomass energy could be an important sector for investment and development in the future of Ukraine. Renewable energy sector is growing steadily and has the potential to become an economically viable, environmentally compatible, and

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socially acceptable source of energy alternative to geothermal energy-based power generation systems [2, 3].

Globally, total biofuel production from biomass and recyclables was 0.9 M tons of oil equivalent in 2010, and at a growth rate of around 35% per year, that number rise to 2.8 M tons in 2016. The projection for 2035 is asking for an increase of biomass production of up to five times to around 11 M tons of oil equivalent. Potential energy crops can replace around 20 billion m^3, or two-thirds, of natural gas supply needs in Ukraine [4, 5]. According to the Bioenergy Association, the share of renewable energy production in Ukraine in-creased by 1% annually (uabio.org; saf.org.ua/stakeholders/460/) [1]. Moreover, Ukrainian biofuel industries are aggressively looking to support, develop and maximize steady-source supply of feedstocks to address growing energy usage, provide cheap alternatives, improve farm economics, create green jobs, and expand business opportunities.

Using prime agricultural land for growing energy crops to produce ethanol, biodiesel, or bioenergy feedstock is not a logical choice [6]. A valid argument for biofuel development is that several designated energy crops (perennial vs. annual) can grow on marginal lands and do not create competition with agriculture. While the conventional farming practices are degrading once-productive lands, the domino effects of these farming practices together with climate change are responsible for accelerated ecosystem disservices in Ukraine. Today in Ukraine, about 25% of the once-productive agricultural lands are now marginal lands. Using the vast areas of marginal lands for raising energy crops will help to ensure a much-needed supply of biofeedstock for producing renewable energy. Currently, land area under energy crops is only 6,500 ha in Ukraine. According to the Ukrainian National Academy of Agrarian Sciences, raising perennial crops on about 2 M ha of existing marginal lands will allow replacing natural gas usage completely for heat generation during the winter months. This has a great potential for Ukraine in its quest to become energy in-dependent.

Most of the marginal lands in Ukraine could easily be put into production for growing highly adaptive and versatile energy crops, and this could be an ideal situation to di-versify and improve the farm economy. Currently, willow, poplar, and Miscanthus planted on about 4,000 ha of land are producing an annual yield of 12 to 20 tons/ha; however, these energy crops are poorly developed when compared to those in the United States and European countries.

Biosolids are organically-bound nutrient-enriched byproducts of wastewater treatment facilities that can be recycled as soil amendments to improve the soil health and productivity of the marginal lands [7]. City corporations or municipalities all over the world including Ukraine have an abundance of treated biosolids need to be recycled, land-filled, or discharged in the water systems. The proactive choice for recycling biosolids as organic amendments of the marginal lands is quite logical to support biofeedstock production, increase carbon sequestration, and improve soil health with enhanced ecosystem services. While bioenergy crops are not grown for food or feed, recycling biosolids for producing biofeedstock poses no danger to human or animal health.

2. Background Information

2.1. Energy Situation

By 2050, global population is projected to reach at least 9 billion people with an associated increase in food security and energy consumption. In response to projected energy usage, biofeedstock has the potential to become one of the steady-source of inputs to complement and/supplement for producing energy [4, 8, 9]. As energy consumption continues to rise, alternate energy use has also increased and now accounts for 18% of the worldwide total energy consumption [10]. While alternative energy comprised 8.72% of the total U.S. energy consumption in 2015, up from 4.18% in 1990, its use really began to take off in Ukraine, where consumption increased from just up from 0.65% in 1990 up to for 4.9% in 2018 [11]. Recently, the Ukrainian government has prioritized to derive a portion (11 to 25%) of its total energy usage from alternate sources between 2020 to 2035 [11]. The potential of alternative energy usage is expected to grow in Ukraine as the costs of building and maintaining geothermal and nuclear power plants increase [12].

2.2. Bioenergy Future

Energy securing is one of the primary challenges and goals in Ukraine [11, 13]. Domestically produced economically viable steady-source of biofeedstock is expected to be one of the complementary solutions of the overall energy strategy in Ukraine. Globally, a relatively small percentage of the corn and soybeans is being utilized for ethanol and biodiesel production; however, the demand for food and feed from these and other agronomic crops, which are usually grown on healthy fertile soils, will double by 2050 as global population increases [14]. In recent years, opportunities for marketing crop residues, especially corn stover, as bioenergy feedstocks have emerged; however, this poses challenges for farmers attempting to weigh the potential economic benefits and risks associated with removal of crop residue on soil organic matter, nutrients, and soil quality [15].

Bioenergy can be an eco-friendly means of supplementing Ukraine's growing energy needs; however, the impacts of growing crops for biofuels can be mixed depending on the feedstock amount and quality, cultural practices, land use change, supply and marketing, and conversion process [16]. By 2050, global agricultural production will need to double in order to provide food security [17]. The prospect of using existing healthy and fertile soils for growing corn and soybeans as commercial feedstock for ethanol and biodiesel conversion is highly debated [15, 18, 19]. Agronomic crops also require heavy doses of fertilizer and reactive agrochemicals that can accelerate greenhouse gas emissions and edge-of-field loss of reactive nutrients (especially phosphorus and nitrogen) and consequently, degrade water quality with harmful algal blooms and associated microcystin toxicity [20, 21]. So, while agronomic crops represent a steady-source of feedstock for biofuel production, it can also cause environmental degradation with reduced ecosystem services.

2.3. Bioenergy Crops

There is a great potential from low external input management of biologically diverse, highly adaptable, and versatile trees, shrubs, crops, and perennial grasses [6, 14, 22]. Plants that are already widely grown, or being developed for biofeedstock, including sunflower, switchgrass, big and little bluestem, Indian grass, Eastern Gamma grass, Sudan-sorghum, sweet sorghum, beet and potatoes, sugarcane, Miscanthus giganteus, Giant reed grass, dandelions, guayule, eucalyptus and acacia, hybrid willow, and poplar [14, 22-26]. Poplar, Miscanthus, and sweet sorghum are among the most dedicated ones which can be commercially raised as bioenergy plantations on marginal lands [22, 24]. These plants have the potential withstand diverse conditions due to their inherent adaptive characteristics, high biomass or fermentable sugar yield potential, increased water-use efficiency, and low nutrient requirements or nutrient remobilization properties when compared to other plants and crops [22, 24]. A critical water requirement period is less important for these crops because they are grown for total biomass or canes with minimal or no emphasis on nutrient-enriched grain production.

Sweet sorghum is one of the multipurpose crops that withstand diverse conditions due to its high abiotic stress tolerance (drought), photosynthesis and biomass yield potential (C_4 pathway), and water- and nutrient-use efficiency than other bioenergy crops [27, 28]. Furthermore, it has the advantage of tolerating delayed planting over corn, soybeans, or edible sorghums while still producing acceptable juicy cane yields. Sweet sorghum has a higher fermentable sugar concentration in its cane juice, so a complex conversion step of biomass (carbohydrates) into fermentable sugar is not necessary and can easily be fermented to produce first-generation commercial bioethanol with more than 90% efficiency [27, 28]. Sweet sorghum residues (bagasse and leaf biomass) have also been considered as one of the potential lignocellulosic materials that could further serve as feedstock for second-generation biofuels production [29]. Alike sugarcane, this gives sorghum an economic advantage over totally biomass-based energy crops [30].

Miscanthus x. *giganteus* is a perennial C_4 hybrid which is more productive at cool temperatures than any other C_4 agronomic crops or grasses and has remarkable potential for enhanced ecosystem services [24, 31, 32]. Miscanthus, as a sterile triploid, cannot produce viable seeds and must be planted vegetative from rhizome pieces or transplants [33]. Results of the trial at Piketon, U.S. indicate annual harvestable Miscanthus biomass yields ranging from 12 to 25 tons/ha [15, 22].

Poplar is one of the dedicated bioenergy crops which can be raised commercially in short- and medium rotation systems. With both rotation systems, the first coppice harvests take place 4-5 years after planting and subsequently in 2-3-year intervals. The poplar biomass productivity can reach a maximum of 20 tons/ha over a period of 15-20 years [25].

Expected environmental benefits associated with raising these energy plantations on marginal lands include the potential for biodiversity, compaction and drainage alleviation, efficient nutrient recycling, phytoremediation, soil carbon sequestration, and improved soil health with enhanced ecosystem services. Moreover, these plantations provide a very effective ground cover, thus reducing soil erosion and edge-of-filed loss of reactive nutrients via this pathway. This is especially important if more sloping and vulnerable marginal lands are to be used for biofeedstock production. However, this has yet to be well documented.

2.4. Marginal Lands for Bioenergy

Marginal lands include eroded agricultural fields, reclaimed or abandoned mine lands, degraded pasture and grass fields, and shrubby and degraded forest lands those are still relatively low priced, abandoned, or underutilized and can be the “proactive solution” for raising commercial plantations as feedstock for biofuel and value-added bio-based products in Ukraine [34-36]. Currently, out of 32 million ha of agricultural lands, about 8 million ha are economically unproductive, abandoned, or partially out of production. While the energy crops are not grown for food or feed production on marginal lands, efficient recycling of carbon- and nutrient-enriched biosolids to improve soil health would be sustainable for commercial biofeedstock production [22]. However, marginal lands are often associated with accelerated erosion, poor fertility, drought or waterlogging, acidity or salinity, heavy metals contamination, and organic pollutant toxicities. Raising bioenergy plantations on marginal lands will require nutrient inputs or amendments that if provided chemical fertilizer and lime sources, will add to overall costs as well as require large inputs of energy (i.e. high C inputs) for production, collection, and transportation.

A novel and integrated nutrient management approach is needed for sustainable biofeedstock production by utilizing marginal lands that will control erosion, increase soil carbon sequestration, reduce greenhouse gas emissions, improve soil health, and enhance ecosystem services. Reducing total or partial dependency on expensive commercial sources of nutrients and reactive chemicals and replacing them with regional "waste or recyclable nutrients" is a proactive approach for creating both sustainable environmental and economic systems. Therefore, it is logical to evaluate the proactive recycling of biosolids what we often called "waste nutrients" that are locally or regionally available to support for raising commercial biofeedstock plantations [7, 15, 37]. Commercial recycling of waste nutrients can also contribute to the overall economic activity in Ukraine [38-40].

2.5. Biosolids Role

Biosolids are carbon- and nutrient-enriched byproducts of municipal wastewater treatment facilities that can be proactively recycled to rejuvenate the soil health of marginal lands for raising bioenergy plantations [15, 17, 26]. According to U.S. EPA [41], biosolids that meet environmental compatibility can be recycled as fertilizing amendments for improving or maintaining soil health to support plant growth. These biosolids are an excellent choice for providing home-grown nutrients for raising large-scale bioenergy plantations which contain about 3% N, 1.5% P, 0.3% K, 4% Ca, and 0.4% Mg on a dry weight basis [41]. It is worthwhile to mention that every 1,000 m^3 of biosolids (with 60 to 86% water) produced in Ukraine contains about 20-150 kg of Ca and Mg, 15-88 kg of total N, 16-18 kg of K, and 12-16 kg of P with a pH of around 8.

Average across Ukrainian municipalities, the heavy metals and trace elements content are 56-681 mg Pb, 500-752 mg Mn, 662-1500 mg Cr, 30-150 mg Ni, 200-583 mg Cu, 700-1149 mg Zn, 10-46 mg Cd, 2.7-6.6 mg Co, and 220-380 mg Sr per kg dry biosolids [38-40, 42]. The heavy metals content in Ukrainian biosolids is below maximum permissible limits except for Cr.

Therefore, the impact biosolids recycling, especially lime-stabilized biosolids, is expected to (1) provide liming materials to increase pH; (2) increase availability of essential nutrients and labile organic matter to improve biology; (3) reduce heavy metals toxicities due to rise in pH; (4) increase aggregate formation and structural stability; (5) improve porosity and hydrological properties; and (5) regenerate soil health of marginal lands to sustain bioenergy plantations. Moreover, the impact of biosolids amendments under relatively underutilized or undisturbed lands will (1) support biodiversity and efficiency (anabolism); (2) improve chemical equilibrium, stability and buffering, and (3) physical stability of soil properties. As biosolids recycling will not be associated with food crops or livestock, there could be minimal or no risk of contaminating ecosystems. While city corporations or municipalities nationwide face increasing growing population growth (meaning more waste) and environmental contaminations, any opportunities for proactive recycling of biosolids in a positive, environmentally friendly, and productive way will be highly strategic in Ukraine. The recycling of biosolids for bioenergy feedstock production on marginal lands have not been investigated in Ukraine.

2.6. Bioenergy Prospects in Ukraine

The bioenergy market has been developing quite dynamically in Ukraine over the last few years. All of them require a steady-state source of feedstocks to produce biofuel and bio-based products. Ukrainian farmers are eagerly looking for alternate ways, means, technologies, and opportunities to utilize their marginal lands for new and productive purposes. However, the bioenergy industry has been limited in its interactions with farmers and researchers, or has missed opportunities to develop steady-sourced economic bio-feedstock production as required for their operations. Likewise, farmers are not getting enough of the required evidence-based knowledge on how to raise energy crops on their marginal lands by recycling biosolids. There is a disconnect among different sectors. That is why it is essential to establish applied research with diverse energy crops with the active collaboration among farmers, researchers, government policy makers, and industry leaders to address the energy independence of Ukraine.

3. Conclusions

Considering the current trend in increasing energy needs, climate change and land degradation, the prospect of growing energy crops is immense. By recycling biosolids for energy feedstock production will be a proactive strategy for Ukraine. Applied research work based on integrating holistic and novel approaches is expected to proactively foster biosolids amendments on marginal lands for producing bioenergy feedstocks and creating much-need economic opportunities in Ukraine.

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Conflicts of Interest

Authors have no conflicting interests.

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