CEST 2019

16th International Conference on Environmental Science and Technology

Rhodes, Greece, 4 to 7 September 2019

Combining phytoremediation with bioenergy production: Developing a multi-criteria decision matrix for species selection

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Abstract
Plant species required for both phytoremediation and bioenergy generation needs to satisfy certain important criteria such as translocation index, metal and drought tolerance, fast growth rate, high lignocellulosic content, good biomass production, adequate calorific value, and a good rooting system. It is therefore necessary to develop a set of comprehensive selection criteria to select the most appropriate plant species suited to attaining desired outcomes. In this study, we used a systematic review approach to develop a multicriteria decision matrix for species selection. Eight species (sunflower, Indian mustard, soybean, willow, poplar, Typha, Miscanthus, switch grass) were selected. Data from the literature relating to relevant species suitability criteria were aggregated, normalized and their suitability was analyzed and compared. Utility scores were assigned after criteria were weighted according to stipulated research objectives. The results showed that soybean has the best translocation index rate; silvergrass and switchgrass were the fastest growers; switchgrass, willow and poplar have better metal tolerance. On their bioenergy potentials, the lignocellulosic biomass percentage of poplar and sunflower scored the highest; with sunflower having the highest biomass production and poplar having the best calorific value among the species. These results are subject to differing priority ratings according to user preference.

Keywords: bioenergy, heavy metals, phytoremediation, multicriteria matrix, decision making

1. Introduction

Generating some form of energy from a phytoremediation process by utilizing energy crops for heavy metal extraction can be a useful way of gaining added value from the process (Jiang et al., 2015; Tripathi et al., 2016). To achieve the desired outcomes in this regard, identifying and selecting the best plant species is critical. The process of selecting plant species must consider all the underlying suitability criteria for the plant species and their suitability duly evaluated to determine the most suitable fit (Tangahu et al., 2011). A multicriteria decision analysis (MCDA) tool satisfy this requirement. It provides a platform to evaluate all the complex suitability criteria for different plant species in a comprehensive and verifiable manner and allows for informed decision making given the outcomes of the assessments (Ellis and Garelick, 2009). The study therefore is designed to recognize the complex nature of decision making as it relates to desired outcomes of multiple stakeholders and also to develop a multi-criteria analysis matrix based on a number of established criteria to determine which phytoremediation species is (are) best suited for the purpose of phytoremediation and bioenergy generation.

2. Methodology

The study used a systematic review approach to develop a MCDA matrix for species selection. Eight species (sunflower, Indian mustard, soybean, willow, poplar, cattail, silvergrass, switchgrass) were selected on the basis of number of hits on a range of scientific search databases. The relevant criteria required for these species were identified, their key indicators (measure for criteria evaluation) were determined and corresponding data from the literature were obtained (See Table 1). These raw data were aggregated, normalized by estimating their Z-score values (standard deviation above/below the group means) and their suitability was analyzed and compared. These criteria/indicators were weighted based on stipulated research objectives/priorities to form the basis of a final overall utility scoring.

Table 1. Suitability criteria and key performance indices

Criteria	Key performances indices
Pollutant accumulation	Translocation index
Growth rate	Crop growth rate (CGR)
Root system	Root depth
Heavy metal tolerance	Metal tolerance index
Biochemical composition	Lignocellulosic biomass
Second generation attribute	Competition with food uses
Biomass production	Total dry biomass yield
Thermal energy potential	Calorific value in MJ per kg
Drought tolerance	Drought tolerance index

3. Results

The results in Table 2 showed that soybean has the best translocation index rate; Miscanthus and switchgrass were the fastest growers; switchgrass, willow and poplar have a significantly higher metal tolerance index compared to the others. Sunflower and switchgrass has very deep root system at maximum levels even though they are not tree crops. On their bioenergy potentials, the results showed the lignocellulosic biomass percentage of poplar and sunflower are highest; with sunflower having the highest biomass production in tons per acre and poplar having the best calorific value among the species. We applied our subjective priority weightings (which may be adjusted according to stakeholder priorities) to these values, and sunflower and Miscanthus emerged the top two.

Table 2. Phytoremediation/bioenergy multicriteria decision matrix

Criteria	Key indicator	Plant species								Weight
		Sunflower	Brassica	Soybean	Miscanthus	Poplar	Salix	Switch grass	Typha	
Pollutant accumulation	Translocation index	0.28	0.43	1.88	-0.22	0.44	-0.48	-1.05	-1.28	0.15
Growth rate (Short rotation)	Crop growth rate (CGR)	-0.29	-0.47	-0.06	1.63	-0.98	-0.99	1.42	-0.25	0.30
Root system	Root depth	1.23	-1.19	-0.22	0.10	-0.06	0.42	1.23	-1.52	0.05
Heavy metal tolerance	Metal tolerance index	-0.93	-1.05	-1.07	0.08	0.78	1.19	1.32	-0.32	0.10
Biochemical composition	Lignocellulosic biomass	1.28	-1.02	-0.88	-0.16	1.29	0.85	-1.00	-0.36	0.05
Biomass production (tons per acre)	Total dry biomass (matter) yield	2.04	-0.86	-0.25	0.44	-0.90	-0.92	0.02	0.43	0.25
Thermal energy potential	Calorific value in MJ per kg	0.07	0.06	-1.39	0.09	1.60	0.96	-1.25	-0.15	0.05
Drought tolerance	Drought tolerance index	0.71	0.91	0.70	0.40	0.19	-0.21	-0.55	-2.15	0.05
	Weighted scores	0.564	-0.459	-0.005	0.596	-0.224	-0.379	0.327	-0.401	1

The cells in the matrix contains species Z-score values and gives an indication of species performance in relation to each individually defined criterion. Weighted scores were determined by the formula:

Weighted average = $W_1X_{1\,+}\,W_2X_{2\ldots}WnXn_{.}$ where W = relative weight and X = Z-score value

4. Conclusion.

These species will be further explored as candidates for phytoextraction of metals and energy recovery via pyrolysis and the findings will further seek to validate the multicriteria decision matrix

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