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Research paper

On the issue of halophytes as energy plants in saline environment

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ABSTRACT

Presented paper describes findings of original researches on assessment of halophytes in Uzbekistan for biogas production. A range of wild and cultivated plants was investigated. Their development and chemical composition was observed. Good yield of halophytes in marginal environment with low-fertile sandy soils and warm mineralized irrigated water was recognized (14–44 t/ha of green biomass). Chemical content of the biomass was analyzed. Highest total salt accumulation was revealed for *Salicornia, Halostachys, Kallidium* and *Climacoptera* (35–50%DM). *Suaeda, Atriplex, Kochia, Karelinia* and *Glycyrrhiza* accumulated less amounts of mineral ions (9–26%DM). Plants grown in farm trial contained less mineral compounds as compared with the same species from solonchak (for instance, 31.6% ash versus 46.9% for *Climacoptera*). Na^+; Cl^-; SO_4^{2-} was mainly accumulated in green biomass of halophytes. High nutritional value of the biomass was confirmed. Halophytes contained a big amounts of crude protein (5–13 mg/g DM); cellulose (10.38–20.54 mg/g DM); and lipids (0.5–5.06 mg/g DM). *Atriplex*, *Suaeda* and *Kochia* are recognized as the most nutritional valuable plants. Anaerobic digestion of halophytic biomass was studied in batch-test and continuous mode experiments; 130–366 mL of biogas was produced from 1 g DM of various halophytes at 35 °C; and 269–480 mL – at 55 °C. Taking into consideration current use of different plants, biomass yield and biogas production it is recommended to admit *Karelinia caspia* as the most promising source of biogas. AD-reactor daily fed by mixture of *Karelinia* + vegetables/fruit waste (1:1) can produce about 500 mL CH_4/day from 1 L of volume (35 °C; HRT = 20; OLR = 2.65 gVS/L/day).

1. Introduction

Energy supply is crucial question for sustainability of world development. Exhaustibility of carbon based energy sources is immediate cause to seek for new sources of energy. Renewable resources of energy will in the longer term have to replace the non-renewable ones. The replacement of fossil fuels is all-embracing project for the near future in many modern societies.

Presented study is dedicated to exploration of halophyte biomass potential for biogas production and assessment of some widespread halophytes as energy plants. It is suggested to use halophytic biomass (unusable and inedible) as renewable feedstock for alternative energy production. It is promissory idea from economical, technical and environmental points of view.

Generally halophytic biomasses could be used in different ways. Some of them can be used for food, fodder or forage production in marginal environments [1–4]. There are a number of annual and perennial species among halophytes that are able to uptake significant amounts of salts in biomass and remove them from saline soils. Thus, cultivation and sustainable utilization of wild or domesticated halophytic plants could play an important role for salinity control, melioration of saline lands and improvement of livelihoods of rural communities in Central Asian region. In addition, they may be useful as sources of renewable energy [1,5,6]. More than half of irrigated lands of Uzbekistan are salt-effected (State Committee for Nature Protection of Uzbekistan, 2013), their productivity is being decreased or almost lost; that's why they are being eliminated from agricultural use and becoming abandoned for several reasons. Halophytes unlike conventional plants are able to develop and produce good yield in saline environment; therefore cultivation of halophytic plants in marginal (saline) environment could bring multiple positive effects to local communities and environment:

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Halophytes + saline environment →

biomass/grain yield + improvement of saline soils →

income (from food, fodder, energy, etc.) + nature conservation

Moreover, there is no any competition for land or water use between conventional profitable crops and salt tolerant plants in saline environment. Here is a range of important questions: *How to introduce halophytes into current agricultural system? How to cultivate halophytes? What halophytes could be used? How to use halophytic biomass sustainably?*

This paper presents original work focused on assessment of biogas potential of some halophytes in Uzbekistan, Central Asia, including an assessment and identification of the most promising species as energy crops.

2. Materials and methods

Biomasses of wild or cultivated plants were sampled for the study on desert salt-affected sand-loamy soils in the Karakata saline depression, 80–100 m above sea level, Central Kyzylkum, Uzbekistan, 2012–2014. The predominant soil salinity was sulfate-chloride. Only warm artesian water (EC about 4 mS/cm; TDS 2.5 g/L) was used for irrigation; Na^+ and Mg^{2+} were the dominant cations.

A range of halophytic plants (*Kalidium capsicum, Halostachys belangeriana, Salicornia europaea, Climacoptera lanata, Climacoptera brachiata, Suaeda paradoxa, Atriplex nitens, Karelinia caspia, Glycyrrhiza glabra*) were investigated. Conventional grasses *Panicum coloratum* and *Cynodon dactilon* were taken for comparison with halophytes. Plant biomass was dried, well-milled and sifted through wire sieve with an aperture of 1.00 mm before the study.

Chemical composition of the biomass was partly identified. First of all, water content, total mineral compounds (ash) and organic fractions (VS, volatile solids) were measured by the gravimetric method after drying (at 105 °C, 24 h) and burning of dried biomass in melt pots (at 605 °C, 1 h) [7]. Concentrations of main mineral ions were determined in water extracts of the biomass (0.2 g DM/100 mL deionized water, shaken 1 h and filtered). Sodium, potassium and chloride ions were measured in the extracts using a pH/ion meter ("Expert-001.3") in accordance with standard electrometric methods of measurement for ion-selective electrodes (Elit-031 (K^+); Elit-261 (Cl^-), Elis-112Na (Na^+)). Sulfate-ion concentrations were measured in the same water extracts using UV/VIS Spectrophotometer V-530 ("Jasco") by standard method with $BaCl_2$ [7]. Total organic carbon (TOC) was also measured by spectrophotometric method with preliminary wet process of biomass by 0.4 M chrome mixture ($K_2Cr_2O_7 + H_2SO_4$) [7]. Crude protein, cellulose and fat were measured by standard analytical methods for nutritional value evaluation of fodders described in practical book [8].

Lab-scale experiments on anaerobic degradation of plant biomass were conducted in batch and continuous modes. Water bathes were used as heaters with automatic control. Batch-reactors (1 L glass vessels with magnet stirring; F/M ratio of 0.2) were operated in mesophilic (35 °C) and thermophilic (55 °C) conditions. Continuous mode anaerobic reactors (2.5 L glass vessels with stirring) were used at 35 °C; they were fed by air-dried, milled and sifted biomass every day. Operational data: HRT 20 days; co-digestion of mixed substrate – mixture *Karelinia* + vegetables/fruits waste (1:1); OLR = 2.65 gVS/L (or 1 gTOC/L); TS = 18 g/L; TVS = 13 g/L; SS = 6 g/L; VSS = 1.8 g/L; adds were given once in a week – Fe^{3+} (10 ppm); Ni and Co (1 ppm). Produced biogas was purified by passing through distill water and 5% sodium hydroxide solution in turn. Everyday biogas (or methane gas) production was evaluated in each anaerobic reactor by measurement of displaced water volume in measurement cylinders placed in the end of lab-scale biogas system.

Anaerobic sludge was taken from Salar Waste Water Treatment Plant in Tashkent and Institute of Microbiology of Academy of Science of Uzbekistan.

OriginPro7.5 was used for statistical analysis of the data.

3. Results and discussion

Growth and development of salt-tolerant and halophytic plants were observed in the study. It was shown that it is possible to get high yield of halophytic biomass using warm mineralized water and low-fertile soils. For instance, green biomass yield of *Salsola sclerantha* was about 18.95 t/ha; *Climacoptera lanata* – 23.10 t/ha, *Suaeda paradoxa* – 25.45 t/ha, *Kochia scoparia* – 44.10 t/ha, *Glycyrrhiza glabra* – 13.84 t/ha, and *Atriplex nitens* – 42.05 t/ha. Dry biomass yields were 4.3; 5.75; 5.33; 11.3; 5.55 and 10.55 t/ha respectively.

Mineral content and organic matter was evaluated in the biomass. It was revealed that some halophytes contained very high concentrations of mineral compounds (about 40–50% of DM) as contrasted with conventional grasses (5–10% of DM). It confirms that they could remove significant amounts of various salts from soils/water and accumulate them in plant tissues. It should be noted that ash contents of some halophytes had been changed differently during the year (Table 1). Highest total salt accumulation among investigated plants was revealed for *Salicornia, Climacoptera* and *Halostachys*. Salt tolerant and halophytic plants grown in farm trial contained less mineral compounds in comparison with species from very saline environment. For instance, 35% ash was revealed in farm trial versus 46% in solonchak for *Climacoptera*. Ash content in aboveground biomass of some plants wasn't been changed significantly during the year (*Climacoptera lanata, Glycyrrhiza glabra, Karelinia caspia*); the other plants, such as *Atriplex, Salicornia* and *Kochia* contained the most amount of ash in the spring and less – in the autumn.

It is significant that *Suaeda, Kochia, Atriplex* and *Glycyrrhiza* accumulated less amounts of mineral ions in their biomass; it was 20.49; 6.39; 10.56 and 10.45% DM accordingly (autumn data). Water content in all plant biomass was decreased gradually during vegetation because of aridity, high temperature and water scarcity.

The plants under the study can be ranged in ascending order of mineral content: Pan < Cyn < Glyc < Koch < Kar < Atr < Sua < Cli l. < Cli b. < Kal < Hal(sol) < Cli l.(sol) < Sal (sol) (Table 2).

It is evidently that the less ash contents the more biogas production by the biomass. Organic fractions of any biomass are a food for anaerobic bacteria, and it could be decomposed by anaerobic digestion to simple inorganic substances as CO_2 and CH_4 (and H_2, H_2O, H_2S) which are considered as biogas.

The highest organic fractions were identified in biomass of *Suaeda, Atriplex, Karelinia, Glycyrrhiza* and in conventional grasses also; they were from 736 to 900 mgVS/g DM. Total organic carbon concentrations were measured as 243.9 (Sua), 348 (Atr), 348.72 (Kar), 395.64 (Cyn), 457.9 (Gly) mg/g DM; and the lowest TOC content (about 200 mg/g DM) was observed in biomasses of *Salicornia*, *Halostachys* and *Climacoptera* from very saline area. Water soluble organic carbon in investigated plant biomasses fluctuated approximately from 50 to 100 mg/g DM. A completely unexpected result was that two fold soluble organic carbon concentrations in comparison with other plants were determined in DM of *Kalidium capspicum* from solonchak (about 166 mg/g DM) (Table 2).

Analysis of water extracts of the biomass has shown high content of chlorides and sulphates in the halophytes; up to 150 and 100 mg/g DM respectively (Table 3). Low concentrations of phosphorus and traces of ammonium (which are essential nutrients for