Biomass production by desert halophytes: Alleviating the pressure on food production

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Abstract:- Desert plants, i.e., plants that are adapted to grow under extreme desert conditions were studied with the aim of identifying new sources for energy crops. Such crops should not compete with conventional agriculture for valuable resources of fertile soil and fresh water. In order to obtain the high yields necessary for having an economically viable operation the plants must be amply irrigated, but can use reclaimed sewage and brackish water. Several types of salt cedar (*Tamarix spp.*) trees were grown in an experimental field at the Southern Arava Valley of Israel, under extreme desert conditions and were irrigated with reclaimed sewage and brackish water. Results have shown that such trees can be utilized under short-rotation type of agro-forestry to yield 26 to 52 tons/ha/y of organic biomass, that is not less then that obtained for common cash crops on arable land. An intensive screening of additional species of trees is under way with the aim to identifying more tolerant and faster growing lines. Another plant, the so called "pencil tree" (*Euphorbia tirucalli*), is being investigated as a possible source of secondary metabolites that can be converted into fuel substitutes.

Key-Words:- Biofuel, Biomass, Desert halophytes, *Euphorbia tirucalii,* Saline water, *Tamarix*

1 Introduction

Biofuel and biodiesel have become popular terms advertised and used by politicians, economists, scientists and by the industrial community. Altogether they refer to the production of high-energy organic liquids produced from plants that can replace, at least partially, fossil fuel, i.e., gasoline or diesel fuel [1]. The ecological rationale for using such "green" fuel substitutes is that such plants recycle the CO_2 of the current atmosphere, in contrast to fossil fuels that add to the CO_2 concentration of the atmosphere by burning organic matter that was produced millions of years ago.

The increase in atmospheric CO_2 has been implicated in global warming and global climate change. In an effort to curb these processes the governments of the U.S. [2] and of the European Union [3,4] announced ambitious programs for the increase of the production of plant-based fuels. Mainly this is based on the use of sunflower, maize, soybeans and rapeseeds. In Brazil some 20% of the gasoline for cars is made of bioethanol produced from sugarcane.

One of the most important issues, related to the production of biofuel is its competitive relationship with conventional agriculture. The rapidly increasing use of sugarcane of sunflower seeds and of maize grains for production of ethanol, or the use of soybeans and various other oil-crops for production of biodiesel has been met with mounting criticism [5,6,7] based on the fact that the resource allocation for biofuel production competes with production of food. Even perennial high biomass producing plants like switchgrass (*Panicum virgatum*) or elephant grass (*Miscanthus giganteus*) compete with "green fuel crops for the same scarce resources i.e., arable land and fresh water [8,9,10,11,12,13,14].

In order to be economically, environmentally and socially acceptable biofuel production should ideally co-exist and complement food and fiber production and not replace it. The purpose of our research is to test halophytic plant species that can cope with conditions considered stressful for food crops, but can be introduced into fuel production. Such plants should occupy a niche of unused marginal or saline lands where saline or recycled water are available and can be utilized for irrigation.

Water is a limiting factor for plant production. However, in many desert areas large quantities of brackish or saline water can be found either as surface water in marshes near sea coasts, lakes or oasis springs, or in deep wells. Such water are too saline for conventional agriculture or for human consumption and cannot be used for such purposes. Great efforts and large sums of money were invested in recent years in inland water desalination facilities that desalinize saline water of desert wells. However, there is no accepted solution to the large quantities of the highly saline brine that is discharged by such installations. Desalination facilities that are located near the sea coast discharge the brine into the sea without serious effects on the marine flora and fauna. In land-based desalination facilities, the discharge of the brine causes serious environmental problems; salinization of the soils and/or salinization of the ground water. The problem of brine discharge has worldwide implications. Hundreds of desalination plants in the USA and in Australia face the problem [15,16,17,18].

Amazingly, the solutions that one can find in the documents of the American Bureau of Reclamation and of the US-EPA, give only partial answers to the problem, and describe only some of the currently used solutions. These are: pumping of the brine into deep unused wells, discharge the brine concentrates on refuse disposal sites, precipitate the brine salts in evaporation ponds or use of some brines for irrigation after dilution with good potable water. Each solution has its weakness and negative effects. All of them involve large expenditures of money with no attempt to make use of such water resources [19,20,21].

Trees that grow naturally in saline habitats can serve as sources of cellulosic biomass to be used for syngas production, or for biofuel production following degradation into simple sugars and subsequent fermentation [22]. Various species of salt cedar (*Tamarix spp.*) trees are well known for their fast growth rates. This underlies their invasiveness in riparian habitat in the South Western U.S. However, in the Old World (Asia, Europe and Africa) these are native species that occupy saline habitats and are limited to such habitats.

Another desert plant, *Euphorbia tirucalli* was mentioned in the literature, as a potential biofuel plant about 30 years ago [23,24]. It was estimated then that the production of biofuel from this plant would be highly economical [24,25]. The origin of *E. tirucallii* is the arid regions of East Africa, but it is grown as an ornamental plant in other parts of the world. It was reported that the succulent stems of *E. tirucallii* show CAM metabolism whereas its leaves have an apparent C_3 metabolism [26]. Such plants are typical for desert environments and are naturally adapted to salinity and drought conditions. They have high water use efficiency.

We report here the results of preliminary experiments for high biomass production by these plants grown under extreme desert conditions and irrigated with saline water.

2 Materials and Methods

2.1 *Tamarix spp.*

Plants were propagated from cuttings, collected from trees of coastal and inland saline habitats, and from trees used as windbreaks in desert areas in Israel. Cuttings of four taxa, *T. aphylla*, *T. aphylla var. erecta*, *T. tetragyna* and *T. jordanis*, were planted directly in an 3.5 ha experimental field spaced 1.8 m between rows and 1 and 2 m along the row, yielding plant densities of 4800 and 2400 trees per ha.

The experimental field was located in the southern part of the Arava Valley in The Negev Desert of Israel (29°53'43.90" N 35°04'24.15" E). The air temperatures vary between monthly average of 40°C in the hot summer month (August) and 20°C in the winter (January). Average relative humidity is 20% and average annual rainfall is 25 mm. Average potential evapotranspiration is 11 mm/day. The soil is coarse alluvial aridisol.

Irrigation of subplots with either reclaimed sewage from the city of Elat (EC ~3 dS/m) or brine from a local desalination plant (EC 7-10 dS/m) was applied daily through drip irrigation systems at a rate that compensated for the ET. Soil water content, at 90 cm depth, was monitored continuously by buried tensiometers.

For dry matter determination,whole trees were felled, weighed fresh and shredded by timber shredder (AZ 35 Jenz, Petershagen, Germany). Samples of the shredded biomass were dried in an oven (80°C, 48h) and weighed to determine the dry matter. Sub-samples of the dried biomass were ground to fine powder and burnt in a furnace (500°C 4h) to determine inorganic material content. These data were used to estimate rates of organic biomass production by the trees.

2.2 *Euphorbia tirucalli*

Plants were propagated from cuttings, collected from trees of the Botanic Garden of Tel-Aviv University. The saplings were first grown in a nursery located in the Mediterranean coastal plane of Israel (29°22'58.00" N 34°52'24.00" E) on Xeralf soil irrigated with fresh water.

Propagation material from the nursery was used for the establishment of a 0.5 h experimental plot in the southern part of the Arava Valley, 10 km south of the plot that is used for the *Tamarix*. This plot was drip-irrigated daily with saline sewage water (EC 8-10 dS/m).

Plants were also grown in sand culture at Tel-Aviv University campus and irrigated with nutrient solutions containing up to 200 mM NaCl. The effect of the salt treatment on photosynthetic performance was tested using both PAM fluorometry and pH monitoring.

3 Results

3.1 *Tamarix spp.*

Growth of the trees under extreme desert conditions but with sufficient irrigation was very rapid. Records of height increase during the first 18 months of the experiment are shown in Fig. 1.

The maximal values of carbon sequestration in our experimental plot, expressed as organic biomass production, were record high. Net production of organic aboveground biomass reached 52 ton/ha/y under reclaimed sewage water irrigation and 26 ton/ha/y under saline water irrigation.

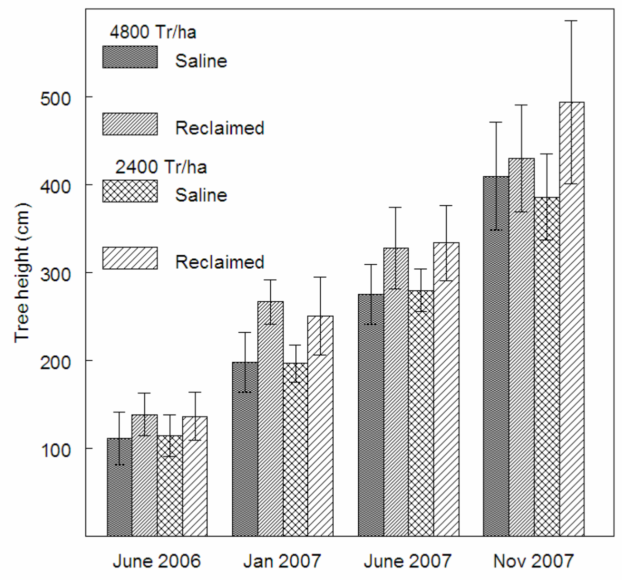

Figure 1. Time course of height increase of *Tamarix aphylla* (erect type) trees in the experimental plot at Yotvata, planted in January 2006, in two densities (2400 and 4800 trees / ha) and treated by saline and reclaimed water.

The rates of biomass production were determined using a simple protocol that was developed for that purpose. It was aimed at measuring wood production but also all parts of the trees including small twigs, green matter as well as the main roots. Special attention was given to the fact that salt treated trees contain significant quantities of inorganic materials, "ash", derived from the soil and the irrigation water.. The net organic matter content was derived from the weight of harvested fresh biomass followed by the laboratory analyses of water and ash content.

3.2 *Euphorbia tirucalli*

Plants that were sampled in the nursery located in a Mediterranean Coastal Plain and irrigated with fresh water. During the winter months (eight months after planting) the plants have increased their fresh biomass on the average by approximately 3.7 times. Plants that were sampled 12 months after planting increased their fresh biomass by some 37 times, and those that were sampled 18 months after planting increased their weight over 60 times since planting.

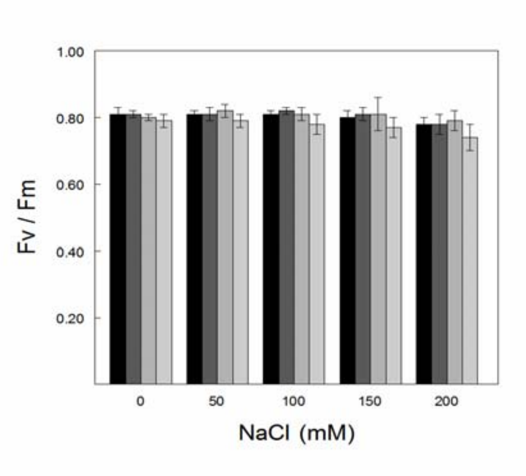

Fig. 2. PAM measurements of *E. tirucalli* plants under increasing salinity from zero to 200 mM NaCl. Columns represent four different plants. Error bars are SD. of 12 measurements taken during 4 consecutive days.

Irrigation of the plants with salt solutions, up to 200 mM NaCl, did not affect the performance of the photosynthetic system. Samples of plant biomass were collected at the desert experimental field 8 months after planting. The increase of the plants' weight indicated that they grew rather fast, and reached a weight of 3 ton, per hectare, i.e., an average of 6 time increase of the initial weight planted. It should be kept in mind that during these first months growth of plants is normally slower than average due to lag time needed for establishment of new root systems.

In terms of the secondary metabolite content of the biomass our preliminary results indicate that the yield of organic crude extract of *E. tirucalli* surpasses the yields of most other euphorbs as reported in the literature [27] and reached ~24% w/w extract of the total dry biomass. Removal of water from the original extracted aqueous phase by distillation resulted in a brown sticky organic material that burns like a candle when ignited. This material was analyzed by elemental analysis and was found to contain 57.91% carbon and 9.10% hydrogen and only traces of nitrogen (<0.3%). This corresponds to C:H:O ratio of 5:9:2. From NMR analyses of the materials separated by extraction procedures it was determined that the majority of the latex was composed of hydrocarbons, most likely tri-terpens. The material that was extracted in the organic phase contained a small fraction of aromatics.

4 Discussion

4.1 *Tamarix spp.*

It is generally accepted that the next generation of biofuel will be based on cellulose degradation [22]. Halophytic desert trees, such as the *Tamarix* species that we have tested in this study are capable of very high biomass production rates. We should bear in mind that such production is in desert areas on non-arable soils and under extremely hot, dry and saline conditions. As in all desert systems, water will be the limiting factor of plant productivity. However, reclaimed sewage and saline effluents of inland desalination plants can be used for irrigating such trees that are naturally adapted to saline conditions.

Tamarix trees have a high capacity for regeneration after harvesting the aboveground biomass and are therefore highly suitable for rotation forestry management without repeated planting. Salt extraction by the roots and its secretion from the leaves, through special salt glands decreases the danger of long term salt accumulation within the rooting zone [28].

4.2 *Euphorbia tirucalli*

Having CAM metabolism makes this species a promising candidate for bioenergy production on marginal lands [29]. In addition to the high rate of biomass production under desert conditions and with saline water irrigation these plants produce high amounts of secondary metabolites that have the potential of being directly converted to biofuel by simple chemical processes [30]. It was shown that *E. tirucalli* is adapted to large areas in the arid regions of Africa and South Asia [31].

5 Conclusion

Highly productive desert plants that will be grown on dry and saline land may contribute, at least a partially to the badly needed additional sources for biomass. A great advantage of utilization of such plants is by replacing the current use of the traditional food crops for fuel production and providing the biodiesel industry with a more consistent "green" supply. This will be absolutely essential for the continued economic viability of biofuel production while alleviating the economic and ethical pressure that this industry exerts on the food markets. Another important aspect in the use of such plants is the small amount of green-house gases emission due to land use change of non-arable desert soils [32].

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References:

[1] Gomez LD, Steele-King CG, McQueen-Mason SJ, Sustainable liquid biofuels from biomass: The writing's on the walls. *New Phytologist* Vol.178, 2008, pp.473–485.

[2] DOE, Biomass – Multiyear Program Plan. Avilable at: *http://www1.eere.energy.gov/biomass/pdfs/biomass_program_mypp.pdf*, 2007.

[3] Directive 2003/30/Ec of the European Parliament and of the Council on the promotion of the use of biofuels or other renewable fuels for transport. Available at: *http://ec.europa.eu/energy/res/legislation/doc/biofuels/en_final.pdf*

[4] Directive, 2008/0016 (COD) of the European Parliament and of the Council on the Promotion of The Use Of Energy From Renewable Sources. Brussels:European Commission; 2008. Available On-Line At: *http://Ec.Europa.Eu/Energy/Res/Legislation/Doc/Strategy/Res_Directive.Pdf, 2008.*

[5] Albiac J, Playan E, Martinez Y Instruments for water quantity and quality management in the agriculture of Aragon. *International Journal of Water Resources Development* Vol.23, 2007, pp.147-164.

[6] Brahic C, Biofuels demands eating into US corn stockpiles. *New Scientist – Environment*,2007. Available on-line: *http://environment.newscientist.com/channel/earth/energy-fuels/dn11849-biofuels-demands-eating-into-us-corn-stockpiles.html*

[7] Editorial, Biofuel production may raise price of food. New Scientist – Environment. Available on-line: *http://www.newscientist.com/article/dn11811-biofuel-production-may-raise-price-of-food--.html*, 2007.

[8] Foley JA et al. Global consequences of land use. *Science* Vol.309, 2005, pp.570-573.

[9] Farrell AE, Plevin RJ, Turner BT, Jones AD, O'Hare M, Kammen DM, Ethanol can contribute to energy and environmental goals. *Science* Vol.311, 2006, pp.506-508.

[10] Hill J, Nelson E, Tilman D, Polasky S, Tiffany D, Environmental, economic, and energetic costs and benefits of biodiesel and ethanol biofuels. *Proccedings of the US National Academy of Science* Vol.103, 2006, pp.11206–11210.

[11] Koonin SE, Getting serious about biofuels. *Science* Vol.311, 2006, p.435.

[12] Ragauskas AJ et al. The path forward for biofuels and biomaterials. *Science* Vol.311, 2006, pp.484-489.

[13] Tilman D, Hill J, Lehman C, Carbon-negative biofuels from low-input high-diversity grassland biomass. *Science* Vol.314, 2006, pp.1598-1600.

[14] Kennedy D, The biofuels conundrum. *Science* Vol.315 2007, p.515.

[15]Ahmed M, Shayya WH, Hoey D, Al-Handaly J, Brine disposal from reverse osmosis desalination plants in Oman and the United Arab Emirates. *Desalination* Vol.133, 2001, pp.135-147

[16] Martin-Lagardette JL, Desalination of seawater - Helps meet fresh water demand. *Water-Engineering & Management* Vol.148, 2001, p.18-20.

[17] Dreizin Y, The impact of desalination. *2nd coference on Water for the life in the Middle East. Antalya*, *Turkey*, 2004.

[18] Zoller U, Water reuse/recycling and reclamation in semiarid zones: The Israeli case of salination and "hard" surfactants pollution of aquifers. *Journal of Environmental Engineering-ASCE* Vol.132, 2006, pp.683-688.

[19] Glater J, Cohen Y, Brine disposal from land based desalination plants. *Report for the Water district of Southern California*, 2003.

[20] Mace RE, Nicot J-P, Chowdhury A, Dutton AR, Kalaswad S, Please pass the salt: Using oil fields for the disposal of concentrate from desalination plants. *U.S. Bureau of Reclamation, Bureau of the Interior, Desalination and Water Purification Research and Development Program Report* 2004.

[21] Von Medeazza GLM, "Direct" and socially induced environmental impacts of desalination. *Desalination* Vol. 185, 2005, 57-70.

[22] Carroll A, Somerville C, Cellulosic biofuels. *Annual Review of Plant Biology* Vol.60, 2009, pp.165–182.

[23] Nielsen PE, Nishimura H, Otvos JW, Calvin M, Plant crops as a source of fuel and hydrocarbon-like materials. *Science* Vol.198, 1977, pp.942-944.
[24] Duke JK, Handbook of Energy Crops. Available at: *http://www.hort.purdue.edu/newcrop/duke_energy/Euphorbia_tirucalli.html*, 1983.
[25] Calvin M, Hydrocarbons from plants: Analytical methods and observations. *Naturwissenschaften* Vol.67, 1980, pp.525-533.
[26] Winter K, Aranda J, Holtum JAM, Carbon isotope composition and water-use efficiency in plants with crassulacean acid metabolism. *Functional Plant Biology* Vol.32, 2005, pp.381-388.
[27] Shi Q-W, Su X-H, Kiyota H, Chemical and pharmacological research of the plants in genus *Euphorbia. Chemical Review* Vol.108, 2008, pp.4295–4327.
[28] Waisel Y, Biology of halophytes. Academic press, 1972.
[29] Borland AM, Griffiths H, Hartwell J, Smith JAC, Exploiting the potential of plants with crassulacean acid metabolism for bioenergy production on marginal lands. *Journal of Experimental Botany* Vol.60, 2009, pp.2879–2896.
[30] Bohlmann J, Keeling CI, Harnessing plant biomass for biofuels and biomaterials: Terpenoid biomaterials. *The Plant Journal* Vol.54, 2008, pp.656–669.
[31] Kumar L, Dhavala P, Goswami A, Maithel S, Liquid biofuels in South Asia: Resources and technologies. *Asian Biotechnology and Development Review* Vol.8, 2006, pp.31-49.
[32] Kim H , Kim S, Dale BE, Biofuels, land use change, and greenhouse gas emissions: Some unexplored variables. *Environmental Science and Technology* Vol.43, 2009, pp.961-967.