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Biomass Production by Desert Halophytes: Alleviating the Pressure on the Scarce Resources of Arable Soil and Fresh Water

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ABSTRACT

The utilization of plants for mitigating carbon dioxide accumulation in the atmosphere in Clean Development Mechanism (CDM) projects and biofuel production causes a severe burden on the limited sources of arable land and fresh water. This research is aimed at finding alternative plant types for biomass and biofuel production among desert halophytes. Such plants have the advantages of being naturally adapted to grow under the harsh desert conditions, on non-arable soils irrigated with reclaimed sewage or other types of brackish water. Exceptionally fast growing salt-resistant genotypes were identified among native populations of *Tamarix* of Israel. These may serve for future CDM projects and short-rotation forestry for biomass production. Another plant that originated from East Africa, *Euphorbia tirucalli* was also shown to be able to grow under desert conditions and saline water irrigation. This plant has been named in the literature as a potential source of biofuel.

Keywords: biofuel, biomass, CDM, desert, *Euphorbia tirucalli*, halophytes, salt resistance, *Tamarix* spp.

INTRODUCTION

Plants were recognized as an important instrument in mitigating the global climate change by sequestering carbon dioxide in the context of CDM projects and biofuel production as outlined in The Marrakech Accords (2001), which was a result of the Kyoto Protocol (IPCC 2000; Ellis *et al.* 2006; Fargione *et al.* 2008). As a result, a worldwide movement of diverting common agricultural assets towards forestation and biofuel production took place. However, after the first surge of activities the economic realities of the effects of such activities on the scarce resources of arable soil and fresh water, and its inevitable effect on the agricultural product markets were realized (Dagoumas *et al.* 2006; Dalla Marta *et al*. 2010; Harto *et al.* 2010; Kullander 2010). This has become especially evident in developing countries where the ‘‘low carbon society’’ concept, promoted following the Kyoto Protocol, has become a difficult target to achieve. Utilization of edible feedstock such as palm oil and sugar cane for biofuel has disrupted the fragile industry due to the fluctuations of feedstock prices (Goh and Lee 2010).

The alternative proposed was the use of the, so called, ’second generation‘ crops which produce inedible products and were supposed to grow on marginal soils and saline water. Jatropha (*Jatropha curcas*) had a central position among these plants but a thorough study of its economic and environmental feasibility as an energy crop had not been performed beforehand. Later it was found that the salinity of soil and limited fresh water sources restricted the production of jatropha oil, which required large amounts of water during the cultivation of young plants (Maes *et al.* 2009; Goh and Lee 2010). Instead of the sugar and starch crops that were competing with food and feed crops for high-quality land, the cultivation of lignocellulosic crops on marginal and set-aside lands was considered a more environmentally sound and sustainable option for renewable energy production (Fargione *et al.* 2008; Carroll and Somerville 2009; Frigon and Guiot 2010).

In a previous article (Eshel *et al.* 2010) we have shown that desert halophytes, adapted to grow on non-arable soils under extreme desert conditions can be used as new sources for energy crops. Such uses of halophytes will not compete with conventional agriculture for valuable resources of fertile soil and fresh water (Ruan *et al.* 2010). In order to obtain the high yields necessary for an economically viable operation, the plants received plentiful amounts of reclaimed sewage and brackish water. Under such conditions the old-world desert trees *Tamarix* spp. yielded 52 to 26 ton/ha/y of organic biomass. Another desert plant, *Euphorbia tirucalli* was mentioned in the literature, as a potential biofuel plant about 30 years ago and was estimated then to be a highly economical source of biofuel (Nielsen *et al.* 1977; Calvin 1980; Duke 1983). The origin of *E. tirucalli* is the arid regions of East Africa yet it was grown as an ornamental plant in other parts of the world.

Here we report on a continuation of this research aimed at identifying salt-resistant *Tamarix* types that will be highly efficient as a source of biomass when grown under desert conditions and irrigated with saline water. We also include the first results of growing *E. tirucalli* under such non-agricultural environment.

MATERIALS AND METHODS

Tamarix collection and field experiment

In order to find salt-adapted trees of *Tamarix* spp. we collected cuttings from natural populations in salt-affected habitats along the Mediterranean coast of Israel and in inland habitats along the Jordan valley, by the Dead Sea and The Aravah desert (**Fig. 1**). They were grown in a common garden experimental field located in Yotvata at the southern part of the Arava Valley in The Negev Desert in Israel (29°53'43.90" N 35°04'24.15" E). The local air temperatures vary between a monthly average of 40°C in the hot summer month (August) and 20°C in the winter (January). Average relative humidity is 20% and annual rainfall 25 mm. Average

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Research Note

Fig. 1 A map of Israel showing the locations of *Tamarix* collection sites along the Mediterranean coast and inland saline and desert habitats. The field experiment is at Yotvata.

potential evapotranspiration is 11 mm/day. The soil is coarse alluvial aridisol. Irrigation with brine from a local desalination plant (EC 7-10 dS/m) was applied daily through drip irrigation system at a rate that compensated for evapotranspiration (average 10 mm/day).

Ten cuttings of each accession were planted directly to the field plot in the spring (February – March) of 2008. Tree height was measured every 6 months in order to identify the fastest growing trees. In August 2010 a single tree of 9 selected accessions was felled and its biomass was measured.

Tamarix sand culture experiment

A sand culture experiment was carried out at Tel-Aviv University campus. The sand culture experiment was designed to determine the comparative response of the tested lines to the salt treatments. Obviously other growth conditions were not equal to those in the Negev because of the differences of climatic conditions between the two locations.

Cuttings from both fast and slow growing accessions grown in the field experiment at Yotvata and were planted in 2-L plastic pots filled with coarse sand. For a 6-week period, all pots were irrigated with control solution (tap water + 0.75 g/L of combined fertilizer [20: 20: 20 Haifa Fertilizers, Haifa, Israel]). After this initial period three treatments were applied; fertilizers only (Control), 100 mM NaCl plus the fertilizers, and 200 mM NaCl plus the fertilizers. The pots were irrigated every other day by drip irrigation at a rate that prevented salt concentration build-up in the sand. The experiment was set up in 5 blocks and with a fully randomized design. Two months after beginning of the treatments pulse amplitude modulated (PAM) fluorometry measurements (PAM2000, Walz, Effeltrich, Germany) were taken on dark-adapted young twigs, since the leaves of the trees are scale like about 1 mm in size, appressed to the twigs. Four months after the beginning of treatments the plants were harvested, divided into green and woody material, rinsed by shaking each sample for 30 sec in a 0.5 L beaker of distilled water, dried (80°C for 48 h), and weighed. Sub-samples of dried green twigs were ashed (500°C), dissolved in 2M HNO_3, and diluted with distilled water. Extracts were analyzed for Na and K ion content by flame photometry (401 Flame Photometer, Corning Inc., Corning USA) and for chloride by a Chloride Analyzer (MKII, Sherwood Scientific, Cambridge, UK).

Three-way analysis of variance was used for data analysis with accession no., treatment and block no. as the main effects.

Euphorbia tirucalli field experiment

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

Propagated material from the nursery was used for establishment of a 0.5 ha experimental plot in the southern part of the Aravah Valley in The Negev Desert in Israel, 10 km south of the one used for the *Tamarix*. This plot was drip-irrigated daily with saline sewage (EC 8-10 dS/m).

RESULTS AND DISCUSSION

Tamarix spp. collection and field experiment

Our wide ranging sampling covered the six common *Tamarix* species growing in Israel: *T. aphylla*, *T. aravensis*, *T. jordanis*, *T. nilotica*, *T. palaestina*, *T. tetragyna*. Cuttings of 65 accessions were planted in a common garden in Yotvata under extreme desert conditions and irrigated with brine from a local desalination plant. This is the only use found for these waters which otherwise would cause severe salinization problems if poured at a nearby site or mixed with other effluents. Systematic identification of the species was based on microscopic examination of flowers collected in the garden, according to Zohary (1976).

In order to identify the fastest-growing types within our collection we measured tree heights every 6 months. As can be seen in **Fig. 2** the variability within the tested accessions was large. After six months, tree height varied between 30 and 180 cm. Height of the 15 best trees as measured one year after planting (**Fig. 3**) showed variation between 180 and 400 cm. These are extremely rapid growth rates comparable to fast growing *Eucalyptus* species in warm climates (cf. Callister *et al.* 2007; Calvo-Alvarado *et al.* 2007; Watanabe *et al.* 2009).

A year and a half after planting an average tree of each of 9 selected accessions was felled and its biomass was measured. The results (**Fig. 4**) show that tree weights at that stage varied between 30 and 80 kg. At a density of 2500 trees per ha this would translate to 75 to 200 ton/ha (FW), or 25 to 67 ton/ha/y (DM). Further evaluation of these trees under the conditions used in commercial plantations is

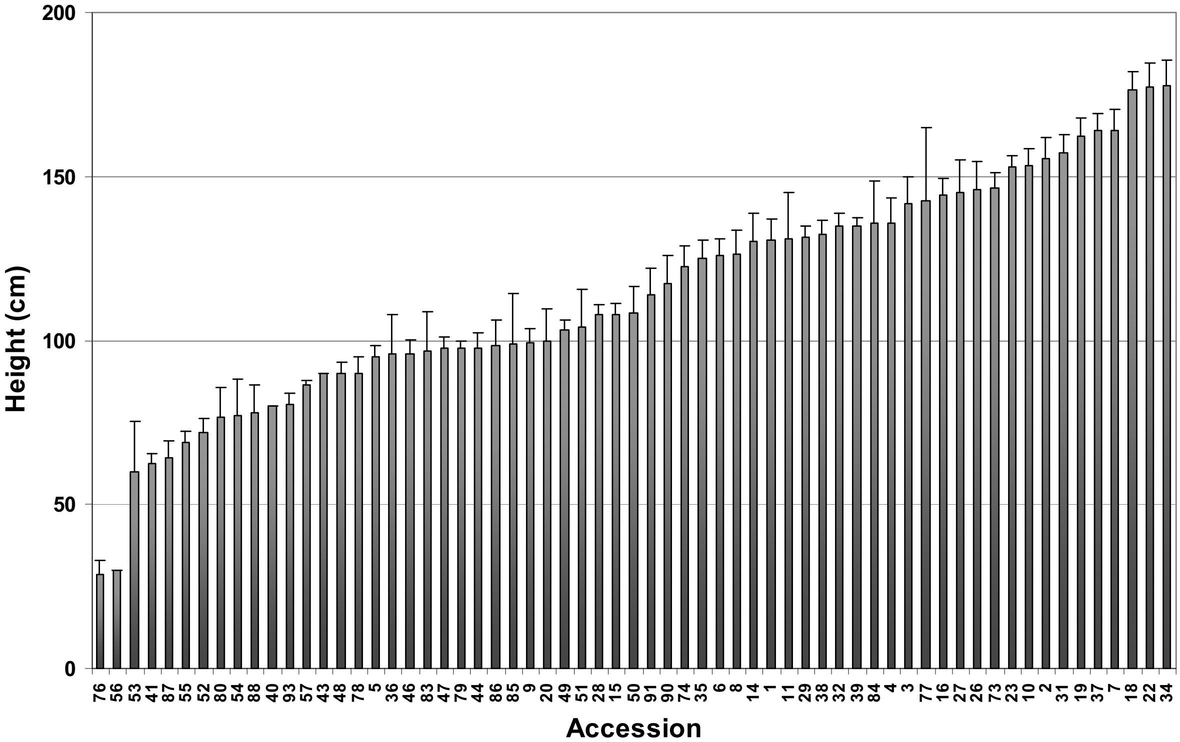

Fig. 2 Height (average + SEM of 3-10 replicates) of *Tamarix* spp. trees. Trees of various accessions were propagated from cuttings in the spring of 2008, irrigated with saline water under extreme desert conditions at Yotvata, Israel. Measured in Sept. 2008.

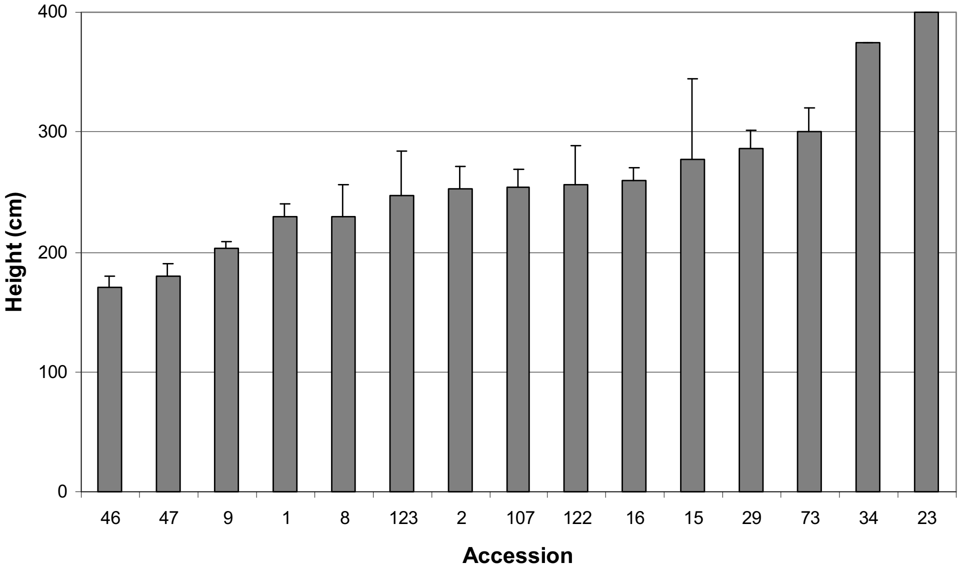

Fig. 3 Height (average + SD of 3replicates) of *Tamarix* spp. trees. Trees of selected accessions propagated from cuttings in the spring of 2008, irrigated with saline water under extreme desert conditions at Yotvata, Israel. Measured in Feb. 2009.

underway.

The response of selected accessions to salinity was tested in a sand-culture experiment. The accessions were chosen so they would include both fast and slow growing genotypes in order to see whether salt response is associated with growth rate. As can be seen from the data presented in **Fig. 5** the slow growers (#46, #47, #48) were most salt sensitive and exhibited reduced growth under the salt treatments as compared with the control. The other accessions showed a small decrease or even a slight increase under the 100 mM treatment and a relatively small decrease under 200 mM salt.

The decrease in growth under the salt treatment was not associated with reduction in the efficiency of the photosynthetic system as indicated by the PAM measurements of Fv/Fm (**Fig. 6**). On the contrary, even the species that showed a marked decrease in growth rate under salt did not exhibit reduction in this photosynthetic efficiency parameter.

As these plants rely on salt secretion (Waisel 1972) as a major adaptation mechanism, Na content did not increase very much under the 100 and 200 mM treatments (**Fig. 7**). Even the slow growing lines that were affected severely by the salt did not show excessive Na accumulation. The main difference between the salt sensitive and the more tolerant lines was in the Na/K ratio. Apparently inhibition of K uptake by the presence of NaCl was stronger in the slow growing, more sensitive accessions.

Euphorbia tirucalli growth

Cuttings taken from our nursery plantation were planted (500 plants/ha; average cutting weight 0.08 ± 0.01 kg) in the extreme desert condition at the Southern Aravah Valley in May 2009. These plants are amenable to *in vitro* mass

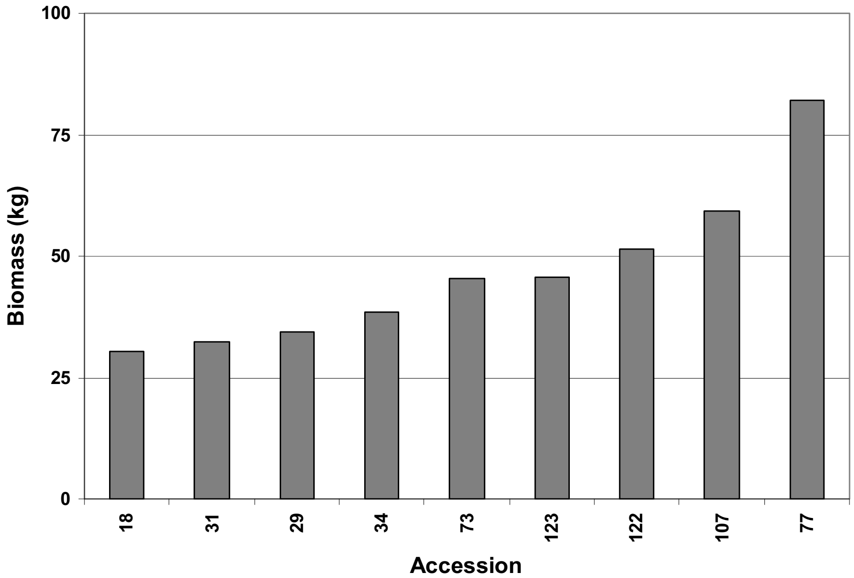

Fig. 4 Biomass of single *Tamarix* spp. trees. Trees of selected accessions propagated from cuttings in the spring of 2008, irrigated with saline water under extreme desert conditions at Yotvata, Israel. Measured in August 2010.

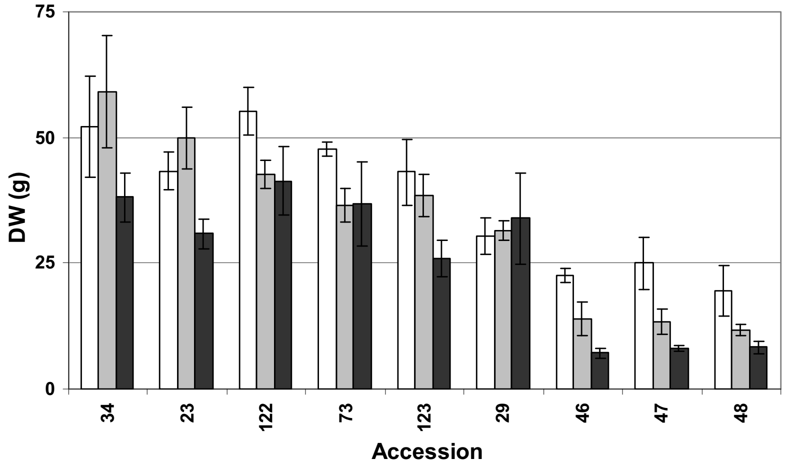

Fig. 5 Dry weight per plant (average ± SEM of 5 replicates) of selected *Tamarix* accessions. Plants were grown in sand culture for four months under: tap water with no added salt [open bars], tap water + 100 mM NaCl [gray bars], and tap water + 200 mM NaCl [black bars].

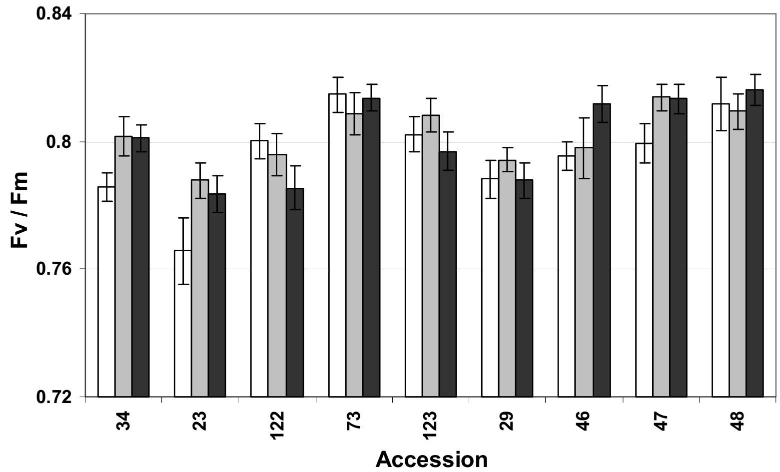

Fig. 6 PAM measurements (average ± SEM of 5 replicates) of selected *Tamarix* accessions. Plants were grown in sand culture for four months under: tap water with no added salt [open bars], tap water + 100 mM NaCl [gray bars], and tap water + 200 mM NaCl [black bars].

vegetative propagation (Ma *et al.* 2011). The plot was irrigated with saline sewage from a local cowshed after a primary treatment in a constructed wetland. The salinity of the water was too high for any common agricultural use, and was dispersed in the area to evaporate, causing salinization and pollution. The *Euphorbia* bushes grew well under these conditions and at a sampling in June 2010, a year after planting, average plant weight was 2.3 ± 1.6 kg, showing an average increase in FW of almost 30 fold. This would correspond to a yield of ca 11 ton/ha/y FW or 2.2 ton/ha/y DW. The content of latex and potential biofuel precursors in these desert-grown plants will be determined in the future.

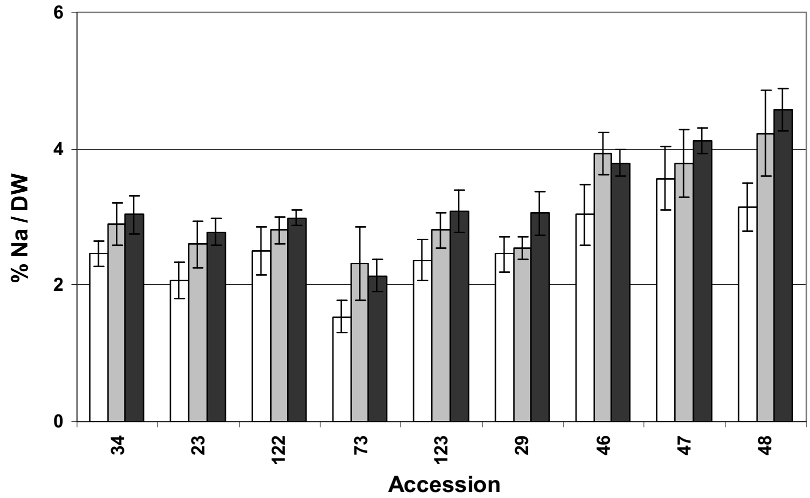

Fig. 7 Na ion content (average ± SEM of 5 replicates) of selected *Tamarix* accessions. Plants were grown in sand culture for four months under: tap water with no added salt [open bars], tap water + 100 mM NaCl [gray bars], and tap water + 200 mM NaCl [black bars].

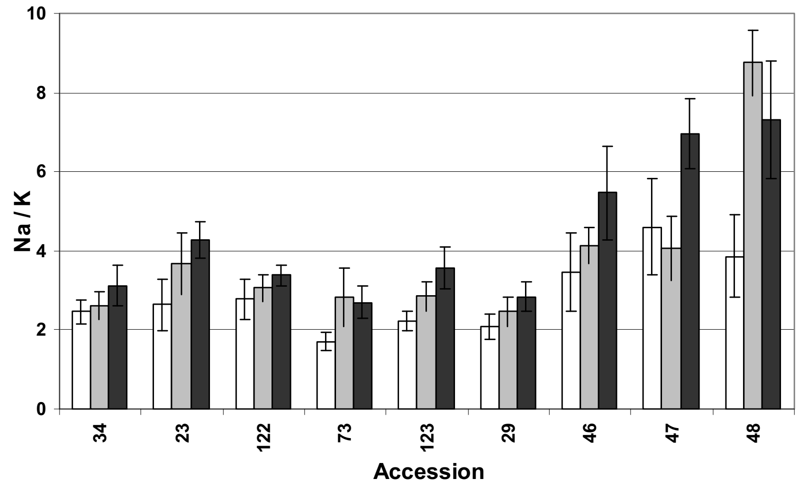

Fig. 8 Na/K ion ratio (average ± SEM of 5 replicates) of selected *Tamarix* accessions. Plants were grown in sand culture for four months under: tap water with no added salt [open bars], tap water + 100 mM NaCl [gray bars], and tap water + 200 mM NaCl [black bars].

CONCLUSIONS

The utilization of desert halophytes as energy crops can alleviate the pressure on the scarce resources of arable soil and fresh water. Such plants have the advantages of being naturally adapted to grow under the harsh desert climatic conditions of high temperature, low humidity, and high radiation intensity, on non-arable soils. Their growth is enhanced when irrigated with reclaimed sewage or other types of brackish water. Intensive studies can reveal, as we have demonstrated here, highly resistant and fast growing genotypes (Ruan and Teixeira da Silva 2011).

The desert environment is characterized by high radiation intensities and high temperatures throughout most of the year; such conditions are conducive for high biomass production. Another benefit of utilizing non-arable desert soils for biomass production is the low amounts of carbon dioxide and nitrogen compounds that will be released factors that threaten to offset the benefits of such operation in tropical rainforests, peat lands savannas, or grasslands (Fargione *et al.* 2008).

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