USE OF SALINE LAND AND WASTEWATER FOR GROWING A POTENTIAL BIOFUEL CROP (*ARUNDO DONAX* L)

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ABSTRACT

Second generation biofuel crops (non food, cellulosic feedstock) or pulp/paper crops are needed that grow well on saline lands with wastewaters. This paper reports on the underutilised resources of saline water and land to grow a new second generation biofuel crop, namely *Arundo donax* (Adx). This crop together with other cellulose feedstocks could form the basis of a new biofuel or pulp/paper industry for Australia. Trial results are presented for Adx growing on saline soil and irrigated with saline winery wastewater for biomass production, nutrient removal, salt tolerance, weed risk and carbon sequestration. Benefit/cost analyses are also presented.

Arundo donax (giant reed) is a perennial, rhizomatous grass that has been grown in every state of Australia for over 150 years. Adx can invade riparian systems, but has rarely been targeted in weed control programs in Australia and is only declared noxious in the Sydney region of NSW. Because it does not produce viable seed, due to polyploidy and its clumping rhizome growth habit; its ability to spread from where it has been deliberately planted is limited. When grown in the saline conditions described above, *Arundo donax*, produced 45.2 tonnes of oven dry tops per hectare in the first year. This yield is over twice that reported for conventional crops such as forage sorghum, kenaf or lucerne, when grown on arable land with high rainfall or better quality water. Adx when irrigated with winery wastewater (salinity up to 9 dS/m) removed large amounts of N, P, and K at rates of 528, 22 and 664 kg/ha/year, respectively, while tolerating up to 25 dS/m salinity in the soil water extract for several months. After measuring high yield of Adx under extremely saline conditions, we class Adx as a halophyte.

Benefit/cost analyses showed that enterprises such as wastewater remediation, ethanol or pulp/paper production were highly viable with the proviso that Adx is not grown on the floodplains of riparian systems subject to torrential flooding and proper crop hygiene is practiced.

INTRODUCTION

More than 50 % of the cropped land in Australia is affected by soil acidity, sodicity and salinity problems with an estimated annual impact to the agriculture of A$2,559 million (NLWRA, 2002). Sustainable systems to use marginal land and waste waters for second generation biofuel or pulp/paper crops are urgently needed (Williams *et al.,* 2007). Introduction of high-yielding, non-food biomass crops to support the change to renewable energy policy is inevitable. *Arundo donax* L. (Adx), commonly known as giant reed, has many potential uses as feedstock for biofuel, pulp/paper or fodder production (Spafford, 1941; Lewandowski *et al.,* 2003; Paul and Williams, 2006; Williams *et al.,* 2006; 2008). It is a perennial rhizomatous grass that has persisted for over 150 years in Australia (Jessop *et al.,* 2006). Williams *et al.,* (2006; 2008) reported Adx produced exceptionally, high biomass yields, of 51 t/ha of total dry matter yield of tops when harvested 43 weeks after clearfell on arable land, irrigated with sewage effluent at Roseworthy, South Australia, and grown with no pesticides.

Giant reed is invasive in riparian systems of many regions of the world, particularly where stem and rhizome fragments are broken and dispersed by torrential floodwaters. The lack of fertile seed production limits establishment of new, distant colonies to those arising from spread of stem and rhizome fragments. However, its reputation as an invasive species in riparian systems has discouraged research to develop its full utilisation as a commercial crop. Based on appropriate selection of planting sites (eg. no plantations in riparian zones subject to flooding) and crop hygiene (eg. use of buffer areas, covered transport), Adx could be grown with a manageable level of risk (Williams *et al.,* 2006; 2008; Pollock, Czako and Marton, unpublished data).

This paper describes *Arundo donax* (Adx), which has potential to form the basis of a new biofuel and/or pulp paper industry using the *underutilised resources* of saline wastewater and saline/marginal lands in Australia.

MATERIALS AND METHODS

Field studies were conducted on a former salt evaporation basin near Barmera, SA (34° 14' S, 140° 35' E). Soil at the site was a loamy sand overlying a sandy clay loam. The 1:5 soil:water Electrical Conductivity (EC) in the top 90 cm of soil ranged from 0.62 to 1.53 dS/m (saline soils). Adx plantings were established by planting rhizome clusters from a nearby wild Adx stand at Loveday, SA (Loveday rootstock) and from sandhills at Henley Beach, (Henley Beach rootstock), both at 2-4 per linear metre in furrows 1 m apart (Williams *et al.,* 2008).

Four harvests of plant tops and rhizomes were conducted to measure dry matter production, nutrient uptake and major salt elements, eg., sodium (Na) and potassium (K). Salinity and nutrient concentrations of the soil water within a 1m depth of the soil profile were monitored using replicated sets of SoluSAMPLER^{TM} (Biswas, 2006) installed at 30, 60 and 90 cm soil depths. Plant, soil and water samples were analysed as per Williams et al. (2004).

RESULTS AND DISCUSSION

Saline water and soil resources

In addition to 1824 GL of wastewater produced annually, of which approximately 156 GL is reused (Boland *et al.,* 2006). Australia has large reserves of saline (> 5001 mg/L of total soluble salts) ground water (Figure 1), with 3,434 GL/yr of sustainable groundwater (Ball *et al.,* 2001) unsuitable for drinking or irrigation of traditional crops. Along the lower part of the Murray River there are about 124 Salt Interception Scheme (SIS) bores that yield over 10 GL/year of highly saline water (mostly 20 to 50 dS/m, Figure 2) by intercepting the ground water flow into the River. Similarly, there are also large quantities produced from mining and intensive primary industries (abattoirs, wool scouring).

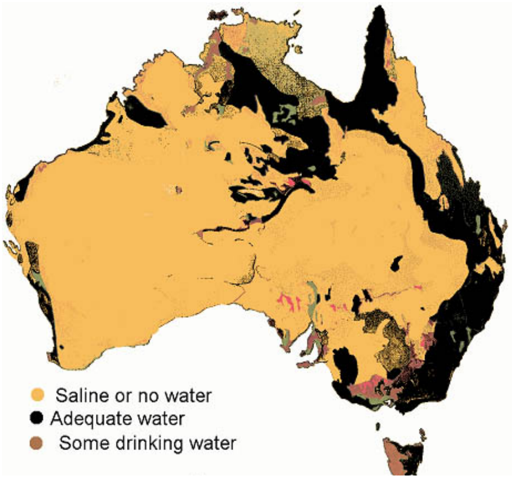

Figure 1: Saline water resources in Australia (source NLWRA, 2008).

Figure 2: Salt Interception Scheme (SIS) in South Australia, to collect highly saline ground water before entering into the Murray River (source DWLBC, 2008).

Saline soils in Australia and South Australia are estimated to cover 2.6 and 1.4 million ha, respectively (DWLBC, 2007). In many situations large areas of saline, marginal soils exist adjacent to the highly saline water resources (Figure 3). For example, at Bolivar; South Australian water agencies could treat sewage to a low quality (e.g. class D, high salinity) and use or sell such wastewaters to grow salt tolerant biofuel crops on nearby saline, marginal lands. This would be preferable to discharging to the sea or to evaporation basins.

Biofuel crops could be grown as a dryland crop on thousands of hectares of saline soils with moderate rainfall (>400 mm) in the south east of SA (Figure 3). Significant areas of saline soils are located close to the Salt Interception Scheme (SIS) areas in the South Australian Riverland (Figure 3). These areas may be suitable for Adx production for biofuels or pulp/paper.

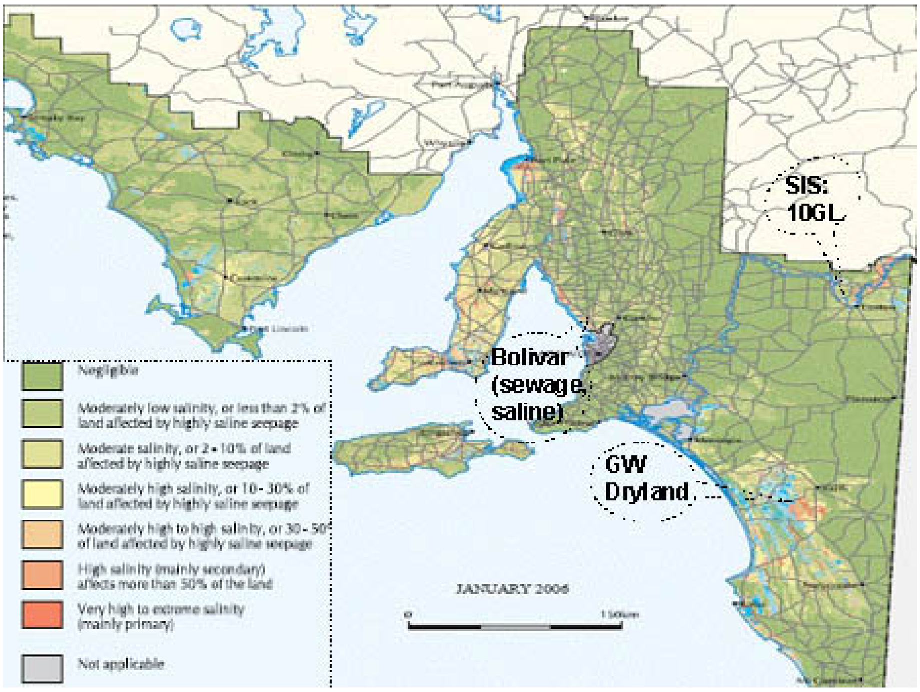

Figure 3: Saline soil areas in South Australia (source: DWLBC, 2008). Note: SIS = Salt Interception Scheme, GW = Ground Water

Biomass yields and nutrient uptake

The flood irrigated Loveday rootstock of Adx which received 21 ML/ha of winery wastewater, produced the highest biomass yields of 45.2 t/ha of dry tops including 35.9 t/ha of dry, bare stems in the first year (Table 1). The Henley Beach rootstock produced 29 t/ha of dry tops including 17.7 t/ha of dry, bare stems. These high biomass yields were similar to those reported as the highest yield study in Spain (Lewandowski *et al.,* 2003) and at Roseworthy, SA (Williams *et al.,* 2006). The latter studies were conducted on arable land with good quality irrigation water.

The exceptional yields of the irrigated Loveday rootstock, at Barmera far exceed those expected from traditional biomass crops grown on arable land with *ad lib* irrigation (Biswas *et al.,* 2002). For example, Biswas *et al.,* (2002) reported 15 t/ha of total tops dry matter per season for forage sorghum grown on arable land and irrigated *ad lib* with secondary treated sewage near Griffith, NSW.

Photosynthesis by Adx during the first year was likely to be the main mechanism for the large amount of organic carbon (20.6 t/ha) accumulated in the dry tops for the Loveday rootstock (Table 1). Adx crops could qualify for carbon (C) credit programs if introduced in Australia (annual sequestration of carbon). Uptake of nitrogen (N), phosphorus (P) and potassium (K) to the above-ground biomass of Adx from the Loveday rootstock was 528, 22 and 664 kg/ha, respectively, during the first year of growth (Table 1).

Table 1. Biomass yield and nutrient removal by *Arundo donax* in South Australia

Adx Rootstock/ land type	Biomass yield (t/ha/year)			Nutrients removed in Adx tops (kg/ha/year)			
	Leaf	Stem	Tops	Org C [1]	N	P	K
Barmera (saline soil) irrigated							
Loveday	9.3	35.9	45.2	20577	528	22	664
Henley Beach	11.3	17.7	29.0	13698	448	19	472
Roseworthy (arable land)							
Irrigated	10.3	40.7	51.0	22200	773	40	832
Dryland[2]	4.0	11.4	15.4	6500	282	17	331

[1] Org C: Organic Carbon

[2] Dryland grown at Roseworthy, South Australia with 450 mm rainfall

Second generation biofuel crops to use saline lands and waters

First generation biofuels are made from edible components of food crops. Second generation biofuels are processed from dedicated non-food cellulosic biomass crops and agriculture and forestry wastes. Demand for food crops (cereal grains, oilseeds, sugarcane) grown on arable lands for first generation biofuels in America and elsewhere is outstripping supply. This has led to high global food prices, low world grain reserves and increased risks of pending famine. Second generation biofuels could reduce well-to-wheels carbon dioxide production by up to 90% (Shell, 2007) compared to fossil fuels. Such biofuels may be the most cost-effective route to renewable, low-carbon energy for road transport (Shell 2007). Although costs of production are comparable for grain ethanol and cellulosic biofuels, the current higher capital costs of factories processing cellulose may be a barrier to their commercialisation (Wright and Brown 2007). However, biomass-to-liquid (BTL) fuel technologies are advancing rapidly for second generation biofuels. For example, a biofuel company recently processed (in laboratory scale systems in Norway), samples of Australian grown, giant reed (*Arundo donax* L.) into BTL ethanol. *Arundo donax* produced 299 litres of ethanol per tonne of stem dry matter biomass, in a process time of less than 24 hours. This equates to 11,000 L/ha of bioethanol from Adx from 40 t/ha of dry tops per year, compared to 4,400 L/ha from corn kernels (*Zea mays*), 4,600 L/ha from switch grass (*Panicum virgatum*) and 8,800 L/ha from sugarcane (*Saccharum officinarum*) as shown in Figure 4.

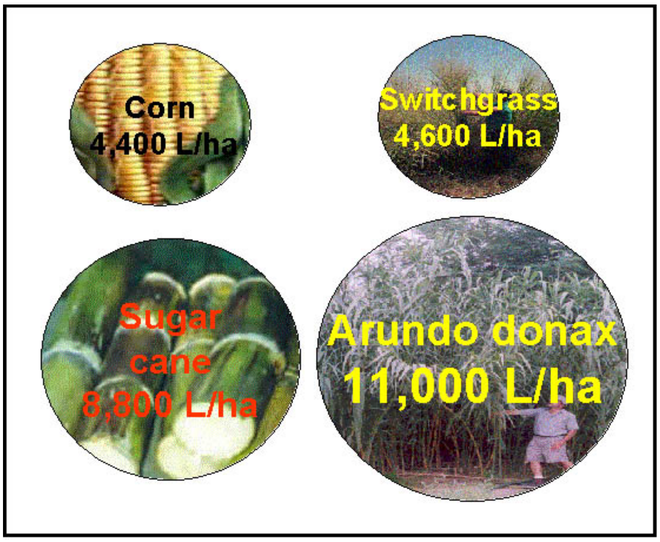

Figure 4: Comparative bioethanol production (L/ha) from food and non-food crops. (source: Bourne 2007 and for *Arundo donax* Williams *et al.,* 2008)

The calorific value of 19 MJ/kg of dry Adx biomass burnt (Williams *et al.,* submitted), is equivalent to 75% of that from combusted coal per kg. This equates to 1 t of Adx dry biomass combustion generating 19 GJ or 5320 kWh (electricity for 266 homes for 1 day).

Temporal changes of soil water salinity and the salt tolerance of Adx

Periodic measurement of soil water salinity by SoluSAMPLER, expressed as EC and ECswe were conducted within the Loveday stand. The ECswe readings increased from 5 dS/m in January to 18 - 50 dS/m by April, 2007 (Figure 4). In comparison, salinity of ocean water is approximately 55 dS/m. Winter rainfall, which was associated with salt dilution and leaching, reduced ECswe to 17-33 dS/m by end of June, 2007.

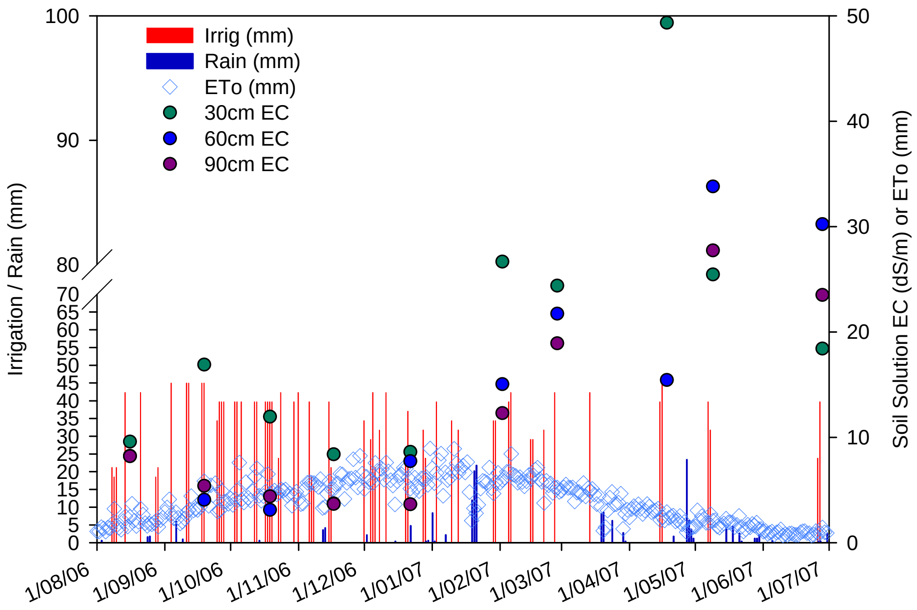

Figure 4: Changes in soil water salinity (soil solution EC) over time at 30, 60, and 90 cm soil depths and other variables for first year growth of *Arundo donax* at Barmera, SA for the Loveday rootstock irrigated with winery wastewater.

Accordingly, Adx Loveday rootstock was exposed to ECswe of 18-50 dS/m, almost half to full sea water, from February to June 2007. This coincided with the time of maximum growth rate and very high biomass yields of Adx at Barmera (Table 1). According to Flowers *et al.,* (1986), halophytes are those plants that can complete their normal annual life cycle under conditions of over 150 mM (15 dS/m) rootzone salinity. Due to its tolerance to prolonged periods of extreme salinity, we class Adx as a halophyte. To further assess the salt tolerance of Adx, ratios of K:Na in plant parts were calculated. For Adx Loveday rootstock, K:Na ratios for leaf, stem and rhizomes of 62:1, 15:1, and 8:1, respectively were recorded. The high K:Na ratios of Adx leaves and stems were most likely associated with sodium exclusion through a preference for potassium. This is a mechanism for salt tolerance used by halophytes (Flowers *et al.,* 1986).

Weed risk assessment and biosecurity

A major barrier to the use of Adx as a biomass crop is its invasive properties in riparian ecosystems. Especially vulnerable are those areas subject to torrential flooding, with occurrences in all inhabited continents (Randall, 2002). Adx is likely to be invasive only when planted in these riparian and floodplain systems, particularly those subject to torrential flooding such as arise from annual snow melts in California. Away from such aquatic systems, there is limited potential for rhizome and stem fragments to be broken off and spread. Adx is limited in its dispersal ability. Unlike some invasive bamboos, Adx rhizomes have a limited spreading growth habit, with plants forming well defined clumps (Lewandowski *et al.,* 2003). Most significantly, no fertile seed production has been reported for Adx in the USA (DiTomaso and Healy, 2007) or Australia. Williams *et al.,* (2008) found no fertile seeds when 400 seeds per stand were tested from five wild stands in South Australia.

Adx is currently a declared noxious weed in South Africa, parts of the USA (California, Texas and Nevada) and in the Sydney region of New South Wales, Australia. Despite being widely grown in Australia for over 150 years, it has not posed a significant threat in comparison to other grass or aquatic/riparian weeds. Given its international invasion history, however (Randall, 2002), potential expansion in the cultivation of Adx is of significant concern to some conservationists.

The most effective treatment to control unwanted Adx plants as reported in the USA is foliar application of a 1-3% solution of glyphosate (with a non-ionic surfactant) applied post flowering and pre-dormancy. This can give up to 100% control in one application (Bell 1997). The SARDI research team on Adx, is working with SA weed experts, to further investigate and develop a strategy from which potential 'weed risk' from current and future plantings of Adx can be readily managed. The bases of this strategy are: (a) appropriate geographical placements of plantings in the landscape therefore avoid plantings in floodplains (1 in 50 year flood risk), especially along riverbanks subject to torrential flooding. A preliminary buffer distance of 500m is suggested for Australia; and (b) crop hygiene protocols to contain Adx at the planting sites (secure transport protocols, soil buffer strips of 50 m width from adjacent properties).

Work has begun to refine the weed risk assessment and to produce a management guideline handbook for Australia (project funded by RIRDC). The rate of spread and incidence of running rhizomes will be quantified in plots in joint trials in Australia and the USA. The lack of viable seed and the absence of rapid lateral root expansion means that Adx is likely to be a manageable new biomass crop under the conditions outlined above.

Benefit-cost analysis of Adx grown for industry

Benefit:cost analyses were carried out on two potential Adx growing enterprises (Black and Williams, unpublished report). Based on the results shown in Table 2, these two enterprises were profitable in Australia. Secondly, benefit:cost analyses were conducted for these enterprises based on levying the enterprises at 50 c/t dry matter to perform, survey and control any escaped Adx that might establish on roadside shoulders as a result of transporting Adx tops (Black and Williams, unpublished report). Based on results in Table 2 and the fact that Adx does not produce viable seed together with the restriction that Adx should not be planted on floodplains near riparian systems, we concluded that the benefits of the Adx enterprises at Barmera and South East of SA far exceeded the costs of survey and control of any volunteer Adx stands.

Table 2. Profit and benefit:cost analyses (BCA) for potential Adx enterprises in South Australia (Aust$) (Modified from Williams *et al.,* 2008)

Enterprise	Pre tax $ profit/ha at crop maturity	BCA for volunteer Adx control[1]
Barmera winery wastewater (40 dry t/ha yield)		
(a) savings from processing wastewater	3,490	175:1
(b) a + carbon credit @ $30/t dry matter	4,090	205:1
(c) b + ethanol price @ $50/t dry matter	6,090	305:1
South-East SA dryland[2] (20 dry t/ha yield)		
(a) ethanol or paper pulp @ $50/t dry matter	400	40:1
(b) a + carbon credit @ $30/t dry matter	700	70:1

[1] 50 c/t dry matter levy; BCA based on profit/ha vs. levy cost/ha

[2] Dryland SE of SA is a warm, temperate climate of c. 500mm rainfall.

CONCLUSIONS

- *Arundo donax* (Adx), a second generation biofuel crop, produced high biomass yields (45.2 t/ha of dry tops) per annum on saline land using low quality, saline wastewater without pesticides.
- These biomass yields are greater than any other crop reported in the literature for Mediterranean to sub-tropical environments.
- Due to its high biomass yield, Adx removed large amounts of N, P and K (528, 22 and 664 kg/ha, respectively). Adx is an ideal interceptor crop to prevent certain pollutants entry into riparian and groundwater systems.
- Adx qualified as a valuable carbon credit crop (eg within a year, it produced 20.6 t of organic carbon per hectare of tops). If each tonne of C sequestered is valued at Au$25, this would generate Au$515 /ha/yr in carbon credits.
- Initial economic analysis of Adx enterprises indicated they were viable options for cost saving measures of wastewater remediation; for ethanol or pulp/paper production at Barmera and for ethanol production from dryland systems in the South East of South Australia.
- As Adx can produce high yields under conditions of high salinity, we classified it as a halophyte. However, further research is planned to define the upper limits of salt tolerance of Adx. .
- Our work has shown the potential for Adx to treat saline wastewaters, P-, and N- rich wastewaters (e.g. sewage or winery wastewaters) and to produce high biomass yields. This biomass can be used for feedstock for combined heat and power factories (to run pumps and other equipment) or to produce ethanol.
- The lack of pollen formation and the absence of fertile seed exclude the danger of seed-based spread of Adx.
- Future research in Australia will include development of a weed risk management handbook. The yield and energy efficiency of conversion of Adx biomass to biofuels (ethanol or heat and power) or pulp/paper will also be assessed.

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