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Spartina argentinensis as feedstock for bioethanol

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This paper describes the possibility of producing bioethanol and/or electricity using pellets from natural rangelands in the Bajos Submeridionales (Submeridional Lowlands) of the province of Santa Fe, Argentina, where the dominant species is Spartina argentinensis, a C4 perennial grass with high photosynthetic rate, which tolerates the conditions of alkalinity and the recurrent droughts and floods that shape the region. According to our estimates, enough ethanol could be produced in this region to satisfy the energy demand of vehicles with Otto combustion cycle in several Argentine provinces. Pellets production would allow electricity generation via syngas and power turbines. This would allow the production of liquid fuel and/or electricity with sustainability criteria, reducing the emission of GHG and generating jobs, economical growth and development in a depopulated region.

Keywords: Biomass, biofuels, electricity, greenhouse gases (GHG) emissions, lignocellulose, sustainability

Introduction

Biofuels are liquid fuels made from renewable materials that can be used pure or in mixtures. Several countries have passed laws stipulating mandatory replacements of gasoline and diesel in different proportions with bioethanol and biodiesel respectively, with the goal of reducing oil dependence and emission of greenhouse gases (GHG), but there are some concerns related with the use of food raw materials for their production (Rathmann, Szklo, and Schaeffer, 2010; Tilman, Socolow, Foley et al., 2009). A promising alternative is obtaining second generation bioethanol from lignocellulosic materials, a complex mixture of cellulose, hemicelluloses and lignin. These lignocellulosic materials could also be pelleted and used for electricity generation (Rodriguez, Mayb, Herr, and O'Connell, 2011).

The different kinds of lignocellulosic materials are: (*i*) energy crops (*Panicum virgatum* and *Miscanthus sinensis*) and high-growing rate trees (*Populus* spp., *Salix* spp.,); (*ii*) crop residues, such as stubble of wheat, corn, rice, sugar cane; (*iii*) industrial wastes (grinding, juice extraction, wine), and pruning of trees; and (*iv*)

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rangelands with dominance of perennials grasses. Energy crops require energy inputs for sowing and fertilizing, and removing crop residues has the disadvantage that soil would remain with reduced stubble on surface, thereby increasing water loss by evaporation, wind and water erosion, decreasing organic matter inputs to soil (Lal, 2007) or affecting its use as livestock feed (Nonhebel, 2007). Therefore we consider that using native perennial grasses is a better option for biofuels.

Fernández (Fernández, 2003) has proposed the following guidelines to produce second generation biofuels: (*i*) source of biomass should have a high aboveground net primary productivity (ANPP); (*ii*) land used for biofuels production should not be suitable for crop production; (*iii*) inputs requirements should be as low as possible; (*iv*) it should use machinery already available; and (*v*) it should have high Net Energy Ratio (NER) and neutral or negative carbon balance. We sustain that some of the Argentinean rangelands fulfill all these requirements and some authors agree with us (Tilman, Socolow, Foley et al., 2009; Gonzalez Hernández, Sarath, Stein, Owens, Gedye, and Boe, 2009).

Rangelands occupy 35 million km^2 all over the world, 22.5 million km^2 tropical savannas, and 12.5 million km^2 temperate grasslands with cattle, sheep and goats raising as their main activity (IPCC, 2000). In Argentina, almost one third of the 2.80 million km^2 land area of the country are rangelands (INDEC, 2002). Many of these are on agriculture unsuitable land and cattle raising presents low productivity due to low quality forage species, i.e. *Panicum prionitis* Ness, *Paspalum intermedium* Munro ex Morong & Britton, *Paspalum quadrifarium* Lam, *Elionurus muticus* (Spreng.) Kuntze, and *Spartina argentinensis* Parodi.

S. argentinensis is a halophyte grass with C4 photosynthetic metabolism, adapted to drought, and occupies large areas in Argentina, named "espartillares". The biggest "espartillares" are in the Bajos Submeridionales (Submeridional Lowlands, mostly within the Santa Fe province of Argentina), that covers 33,000 km^2, and the "Mar Chiquita" salt lake, with a total lake and surroundings area of 10,000 km^2 (Figure 1), both depressed areas frequently subjected to late summer floods. Towards the south of the Bajos Submeridionales, the "espartillares" can be found in flooded areas along river valleys and although there are no precise data of the area they cover, they probably account for not more 2,000 km^2, because most of these "espartillares" have been replaced by grasslands with exotic species (i.e. *Chloris gayana*) or low intensity agriculture. The "espartillares" are characterized by a dense upper layer of the strong dominant *S. argentinensis,* with 30- 90% ground cover and very few or no individuals of other species, most of them C4 grasses, such as *Chloris halophyla*, *C. ciliate*, *Diplachne uninervia*, *Distichlis spicata*, *Leptochloa chloridiformis* and, *Paspalum* spp., and C3 grasses with very low density (i.e.: *Chaetotropis chilensis, Hordeum euclastum* and *H. stenostachys*), as well as some C3 forbs (i.e.: *Eryngium coronatum, Pluchea sagittalis*, *Pterocaulum virgatum*, and *Iresine diffusa*). All these species have scattered distribution within *S. argentinensis* plants, which can be more than a meter in height and diameter (Lewis, Stofella, Prado, Pire, Franceschi, and Carnevale, 1990; Lewis, Pire, Prado, Stofella, Franceschi, and Carnevale, 1990).

Lewis et al. (Lewis et al., 1990) stated that fire is a disturbance factor that determines community structure in these tall grasslands, but Feldman & Lewis (Feldman and Lewis, 2005) concluded that fire should be considered an intrinsic factor of their dynamics because after the entire removal of the aboveground biomass by fire, the "espartillares" community as a whole returns to its initial state after an initial mild depression of *S. argentinensis* dominance. The photosynthetic rates of leaves emerging after disturbance (fire or clipping) were higher than those of the control plants even under severe drought conditions (31.98 ± 0.63 and 30.02 ± 0.73 vs. 23.20 ± 1.94 µmol CO_2 $m^{-2}s^{-1}$, respectively), determining higher rates of leaf expansion and tiller recruitment than in controls (Feldman, Bisaro, and Lewis, 2004). Analyzing field experimental data, Feldman & Lewis (2007) reported that in *S. argentinensisis* plants leaf and tiller emergence were promoted by fire treatments and tiller recruitment, and survival were higher in burnt plants than in control plants. All these ecological experiments here quoted (Feldman and Lewis, 2005; Feldman, Bisaro, and Lewis, 2004; Feldman and Lewis, 2007) conclude that while fire can be considered disturbance in other plant communities, it seems to be a regular component of the *S. argentinensis* habitat, among the South American grasslands and their experimental data sustains there's no difference among fire and clipping effects.

The Bajos Submeridionalaes have a temperate humid climate with rainfall decreasing westward, from 1380 mm per year with zero water deficit, to 900 mm per year with *circa* 200 mm water deficit (Servicio Metereológico Nacional, 2012). However, drought and floods are recurrent in the whole region. Soils of the espartillares area are Natracualfs and Natracuols with an A horizon of 10-17 cm with silt-loam texture and, 3.4-4.6% organic mater. B horizon is natric with high content of salt and a pH from 7.3 to 8.1. These soils have more than 15% of exchangeable sodium percentage in the 0-25 cm layers and these figures are higher in deeper layers (Espino, Seveso, and Sabatier, 1983).

Weather and soil characteristics make this region unsuitable for crop production. The main activity is cattle production characterized by a low stocking rate. Average beef production is low (approximately 35 kg ha^{-1} $year^{-1}$), with a stocking rate of 0.25 cow * ha^{-1}. The region is almost uninhabited, as soil and climate characteristics mentioned do not allow the development of profitable activities, resulting in a low quality of life for its inhabitants (FVSA, 2007).

A widespread practice among farmers is burning *circa* 100 ha rangelands plots when high amount of low digestibility biomass accumulates (mostly leaves of *S. argentinensis*), in order to stimulate the emergence of new leaves of higher palatability and digestibility. Period between burnings for the same plot ranges from 1.5 to 3 years depending on weather conditions.

There is very little information on productive management of *S. argentinensis,* mainly technical reports in Spanish. Bissio and Luisoni (Bissio and Luisoni, 1989) studied the effects of frequency and number of clipping after burning in the digestibility, protein content and biomass yield of *S. argentinensis* in Fortín Chilcas (29° 7' S; 60° 40' 60" W). They concluded that higher clipping frequency (clipped at 7-10 cm when the plants achieved 10-15 cm of height) and intensity affected negatively biomass yield. However the biomass showed higher digestibility and protein content with high clipping frequency.

There are some reports about *S. spartinae*, a closely related species (some authors even sustain that *S. argentinensis* and *S. spartinae* are the same species (Mobberly, 1956)). Garza et al. (Garza, Mclendon, and Drawe, 1994) presented data of monthly clipping at 10 and 20 cm stubble heights: biomass yield, and protein content were higher in plants clipped at 10 cm. Total non structural carbohydrates in stem bases and roots were also grater in plants clipped at the lower stubble height. These data suggest that *S. spartinae* can withstand monthly removal of herbage to a height of 10 cm for a period of 18 month without adverse effect.

Herrera et al. (Herrera, Torrella, and Adámoli, 2003) estimated that in the "Humid Chaco" region, where the Bajos Submeridionales are included, 2-4 million hectares of grasslands and savannas are annually burned. Considering an average of 10 Mg ha^{-1} $year^{-1}$, burning releases between 36 and 72 million Mg of CO2 every year. Therefore, it would be appropriate to consider the possibility of using this biomass to produce bioethanol or electricity generation via pellets instead of just burning it (Verón, Jobbágy, Di Bella, Paruelo, and Jackson, 2012). As the "espartillares" recover fast after a disturbance, using them as bioenergy crops could be sustainable, not affecting biodiversity (Feldman and Lewis, 2005; Anderson, Haskins, and Nelson, 2004). Furthermore, Verón et al. (2012) claim that Argentina is a moderately developed country where electricity generation using fire-prone biomass shows big potential.

Materials and methods

Estimation of the area covered by S. argentinensis and its ANPP (aboveground net primary productivity)

The area occupied by "espartillares" was calculated using maps of the Bajos Submeridionales (FVSA, 2007). Areas where *S. argentinensis* accounted for at least 37.5% of plant cover, according to the Braun Blanquet (Braun-Blanquet, 1979 cover-abundance scale, were classified as "espartillar". The ANPP was estimated based on average of 2000-2006 ANPP maps (NTSG, 2012), validated with information obtained under experimental conditions (Feldman, Permingeat, Ortiz et al., 2011). Harvest efficiency considered was 70% of the standing biomass.

Fraction of Cellulose and hemicellulose and bioethanol yield potential

Percentages of cellulose and hemicellulose in leaves of *S. argentinensis* were obtained according to Van Soest (1963). Potential bioethanol yield per Mg of dry matter was calculated (United States Department of Energy, 2009), considering two scenarios of cellulose and hemicellulose hydrolysis efficiencies of (60% and 90%).

Gasoline demand

Annual average gasoline energy demand (average 2009-2011) of Santa Fe province and Argentina were obtained and compared to the energy that could be produced as bioethanol. Lower heating value for bioethanol (21.26 MJ * L^{-1}) was considered for calculus (SERA, 2013).

Results

Estimation of the area covered by S. argentinensis and its ANPP

The espartillares occupy 16,500 km^2 of 33,000 km^2 in the Bajos Submeridionales' area and the ANPP average of the period 2000-2006 is 10 Mg*ha^{-1}. Considering a harvest efficiency of 70% of, 7 Mg*ha^{-1} could be harvested.

Fraction of Cellulose and hemicellulose and bioethanol yield potential

S. argentinensis cellulose and hemicelluloses percentages are 37.99% and 22.96%, respectively. Thus, one Mg could yield between 240-360 liters of bioethanol, depending on the hydrolysis efficiency, hence producing 1,690 to *circa* 2,500 L* ha^{-1} (Table 1).

TABLE 1. BIOETHANOL YIELD POTENTIAL ACCORDING TO DIFFERENT HYDROLYSIS EFFICIENCIES

Hydrolysis efficiency (%)	Bioethanol yield	
	L*Mg^{-1}	L*ha^{-1}
100	402.38	2816.66
90	362.14	2534.98
60	241.43	1690.01

Gasoline demand

Bioethanol has a lower heating of 21.26 MJ * L^{-1}, therefore one hectare would be able to produce 35.93-53.89 GJ (60 and 90% hydrolysis efficiency, respectively). We propose integrating one year of biomass accumulation for bioenergy with two years of cattle grazing. Therefore 33% of the "espartillares" in the Bajos Submeridionales, could annually produce 19.76-29.63 PJ of bioethanol derived energy.

TABLE 2. PERCENTAGE OF ARGENTINEAN AND SANTA FE GASOLINE DEMAND

Bioethanol (PJ $year^{-1}$)	Percentage of Argentinean gasoline demand	Percentage of Santa Fe gasoline demand
19.76	8.81	96.3
29.63	13.22	144.4

It Table 2 we present percentage of Argentinean and Santa Fe province gasoline demand (224.17 PJ and 20.52 PJ respectively (SERA, 2013) that could be covered with *S. argentinensis* bioethanol.

Conclusion

According to these estimates, the "Submeridional Lowlands" region has the potential to produce enough bioethanol derived energy to supply the whole Santa Fe province gasoline demand. This could be accomplished in a sustainable manner, hence stimulating growth and development of this depopulated region.

There is no carbon balance analysis for bioethanol production using *S. argentinensis*, but considering (*i*) its high growth rate (Feldman, Bisaro, and Lewis, 2004), (*ii*) the ability of C4 grasses to maintain high growth rates even under drought conditions (Oliver, Finch, and Taylor, 2009); and (*iii*) the fact that there are only harvest and transport energy costs but no agricultural energy costs, the balance might be close to neutrality. We support this hypothesis comparing our situation with Tilman and Hill (2006) data: our ANPP figures are twice higher than those in their experimental plots and besides we do not have to consider seeding costs. However, the land we are considering is not degraded so its organic carbon might not increase as in Tilman´s proposal and either would do roots biomass

According to Smith and Searchinger (2012), biofuels Life Cycle Analysis underestimate emissions of N_2O from nitrogen fertilizer use. No nitrogen fertilizer would be needed in our approach due to: (*i*) as a C4 plant, *S. argentinensis* has a high nitrogen use efficiency; (*ii*) there's a high density of nitrogen fixing cyanobacteria in the "espartillares" (personal obs.); and (*iii*) we do not consider transforming the whole area to a crop system but rather integrating biomass removal for bioethanol or electricity production with 2 - 3 years of cattle raising.

They also sustain that "first generation biofuels can not claim a credit for plant growth that would occur anyway" and that "biofuels can only reduce CO_2 in the atmosphere if their use result either in more CO_2 absorbed from the atmosphere, or less CO_2 emitted to it in some other way". A proper estimation of GHG emissions reduction should consider and compare two scenarios: with and without biofuels production. In our proposal the scenarios are: 2-4 million hectares of rangelands in the Humid Chaco being burnt per year vs. using the biomass produced there either for electricity or bioethanol production therefore avoiding considerably GHG emitted by fossil fuels.

Getting bioethanol from species like *S. argentinensis* would promote the transformation of rural areas, generating jobs and goods required for development, in a context of biodiversity conservation. Firstly, it is expected that rural workers and their families will benefit directly from this activity. But meanwhile, and indirectly, other beneficiaries would be: (*i)* livestock producers, for an extra source of income (hays of lignocelluloses) and the emergency of tender leaves after mowing the old ones (Garza, Mclendon, and Drawe, 1994), (*ii*) service companies in these regions, and (*iii*) the Government, for the generation of a new productive activity generating a renewable energy source, environmentally friendly, hence reducing GHG emissions.

Considering that cattle raisers burn plots at least once every three years, we propose that one third of the area covered by *S. argentinensis* could be used annually to produce bioethanol. Biomass accumulation during this period may not be much higher than the annual ANPP as the old leaves decompose being probably difficult to harvest while new ones would compensate this losses.

This proposal could be adapted perfectly to farming systems currently practiced in the region and would replace the practice of burning, therefore improving carbon balance. The extraction of nutrients should be taken into account since part of them (*i.e*: K_2O, P_2O_5, CaO, and MgO (Schmer, Liebig, Vogel et al., 2011) remain in ashes after fire, but this could be solved by fertilizing with these nutrients after two or three cycles of biomass extraction. However, some authors claim that nutrient removal by mowing of perennial grasses is significantly lower than removal by crops (Propheter and Staggenberg, 2010). We sustain that in a rotation scheme of two years of cattle raising after and before mowing and removing the biomass for energy production, soil nutrients extraction should be negligible. Tilman and Hill (2006) also sustain that 7.4 $kg*ha^{-1}$ $year^{-1}$ of phosphorous should be enough to compensate the extraction of biomass removal.

Tilman et al. (Tilman, Socolow, Foley et al., 2009) has argued that it is urgent to solve the trilemma which humanity faces today- disputes between food, energy and environment. The use for biofuel production of land unsuitable for crop production, such as the "espartillares" of the Bajos Submeridionales would contribute to the solution of this trilemma, improving life quality of its inhabitants.

Conclusion

The developed algorithms of the threshold control, control on time sequences increments and on the basis of statistical prediction allowed to receive toolkit for extraction and use the statistical parameters and dynamic properties of the data, which then use at adaptive control of information authenticity during transfer in systems of technological processes control. It is established, that in conditions, close to practical, the increase of information authenticity is reached in comparison with existing methods of the threshold control on two-three order.

As result of identification of neuro-fuzzy system intended to data processing of non-stationary processes for the control of data transfer authenticity authors of paper constructed base of fuzzy sets, rules and knowledge allowing to decide the task of approximation for nonlinear dependences.

References

Anderson, GQA, Haskins, LP, Nelson, SH, 2004. "The effects of bioenergy crops on farmland birds in the United Kingdom: a review of current knowledge and future predictions," OCED Pub Services: 199-218

Bissio, JC, Luisoni, LH, 1989. Producción y calidad de forraje de un pajonal de Spartina argentinensis (Trin.) Parodi luego de la quema. http://www.produccion-animal.com.ar Accessed 13 March 2013

Braun-Blanquet, J., 1979. Fitosociología. Madrid, Espa-a

Espino, LM, Seveso, MA, Sabatier, MA, 1983. Mapa de suelos de la Provincia de Santa Fe. Tomo II. Ministerio de Agricultura y Ganadería de la Provincia de Santa Fe, INTA EEA Rafaela

Feldman, SR, Bisaro, V., Lewis, JP, 2004. "Photosynthetic and growth responses to fire of the subtropical-temperate grass Spartina argentinensis Parodi," Flora, 199 (6): 491-499. http://dx.doi.org/10.1078/0367-2530-00177

Feldman, SR, Lewis, JP, 2005. "Effect of fire on the structure and diversity of a Spartina argentinensis tall grassland," Applied Vegetation Science 8: 77-84

Feldman, SR, Lewis, JP, 2007. "Effect of fire on Spartina argentinensis Parodi demographic characteristics," Wetlands, 27: 785-793. http://dx.doi.org/10.1672/0277-5212(2007)27[785:DRTFOS]2.0.CO;2

Feldman, SR, Permingeat, H., Ortiz, JP et al., 2011. "Preliminary results of bioethanol production potentialities of Spartina argentinensis," In: IX International Rangeland Congress

Fernández, J., 2003. "Energía de la biomasa," In: Juana JM (ed) Energías renovables para el desarrollo. Thompson-Paraninfo, Madrid, pp.187-260

FVSA, 2007. Fundación Vida Silvestre Argentina (FVSA) y Fundación para el Desarrollo en Justicia y Paz (FUNDAPAZ) (2007) Zonificación de los Bajos Submeridionales del norte santafesino

Garza, AJ, Mclendon, T, Drawe, DL, 1994. Herbage yield, protein content, and carbohydrate reserves in gulf cordgrass (Spartina spartinae). Journal of Range Management 47:16-21. http://dx.doi.org/10.2307/4002834

Gonzalez Hernández, JL, Sarath, G., Stein, JM, Owens, V., Gedye, K., Boe, A., 2009. "A multiple species approach to biomass production from native herbaceous perennial feedstocks," In Vitro Cellular & Developmental Biology - Plant, 45: 267-281. http://dx.doi.org/10.1007/s11627-009-9215-9

Herrera, P, Torrella, S, Adámoli, J., 2003. Los incendios forestales como modeladores del paisaje en la región chaque-a. Fuego en los ecosistemas argentinos. Santiago del Estero. INTA, Buenos Aires, Argentina

IPCC, 2000. Land-use, land-use change, and forestry. Intergovernmental Panel on Climate Change. Special Report . Cambridge University Press

INDEC, 2002. Instituto Nacional de Estadísticas y Censos, Censo Nacional Agropecuario

Lal, R., 2007. "Biofuels from crop residues," Soil & Tillage Research, 93: 237-238. http://dx.doi.org/10.1016/j.still.2006.11.007

Lewis, JP, Pire, EF, Prado, DE, Stofella, SL, Franceschi, EA, Carnevale, NJ, 1990. "Plant communities and phytogeographical position of a large depression in the Great Chaco, Argentina," Vegetatio, 86: 25-38. http://dx.doi.org/10.1007/BF00045133

Lewis, JP, Stofella, SL, Prado, DE, Pire, EF, Franceschi, EA, Carnevale, NJ, 1990. "Dynamics and development of floristic richness in the vegetation of a large depressed area of the Great Chaco," Flora, 184: 63-77

Mobberly, DG., 1956. "Taxonomy and distribution of the genus Spartina," Iowa St. College J. of Sci.: 471-574

Nonhebel, S., 2007. "Energy from agricultural residues and consequences for land requirements for food production," Agricultural Systems, 94:586-592. http://dx.doi.org/10.1016/j.agsy.2007.02.004

NTSG, 2012. Numerical Terradynamic Simulation Group, MOD17: Vegetation Production MOD16: Evapotranspiration, MODIS Land Science Team.http://www.ntsg.umt.edu/modis accessed 15 May 2013

Oliver, RJ, Finch, JW, Taylor, G., 2009. "Second generation bioenergy crops and climate change: A review of the effects of elevated atmospheric CO2 and drought on water use and the implications for yield," GCB Bioenergy, 1: 97-114. http://dx.doi.org/10.1111/j.1757-1707.2009.01011.x

Propheter, JL, Staggenberg, S., 2010. "Perfomance of annual and perennial biofuel crops: Nutrient removal during first 2 years," Agronomy Journal, 102: 798-805. http://dx.doi.org/10.2134/agronj2009.0462

Rathmann, R, Szklo, A, Schaeffer, R., 2010. "Land use competition for production of food and liquid biofuels: An analysis of the arguments in the current debate," Renewable Energy, 35: 14-22. http://dx.doi.org/10.1016/j.renene.2009.02.025

Rodriguez, LC, Mayb, B., Herr, A., O'Connell, D., 2011. "Biomass assessment and small scale biomass fired electricity generation in the Green Triangle, Australia," Biomass and Bioenergy, 35: 2598-2599. http://dx.doi.org/10.1016/j.biombioe.2011.02.030

Schmer, MR, Liebig, MA, Vogel, KP et al., 2011. "Field-scale soil property changes under switchgrass managed for bioenergy," GCB Bioenergy, 3(6): 439-448. http://dx.doi.org/10.1111/j.1757-1707.2011.01099.x

SERA, 2013. Secretaría de Energía, República Argentina, http://www.energia.gov.ar/home/ accessed 15 April 2013

Smith, KA, Searchinger, TD, 2012. "Crop-based biofuels and associated environmental concerns," GCB Bioenergy, 4 (5): 479-484. http://dx.doi.org/10.1111/j.1757-1707.2012.01182.x

Tilman, D., Hill, JC., 2006. "Carbon-negative biofuels from low-input high-diversity grassland biomass," Science 314:1598-1600. http://dx.doi.org/10.1126/science.1133306

Tilman, D., Socolow, R., Foley, JA et al., 2009. "Beneficial biofuels - The food, energy, and environment trilemma," Science, 325(5938): 270-271. http://dx.doi.org/10.1126/science.1177970

United States Department of Energy, 2009. Biomass program, energy efficiency & renewable energy

Verón, SR, Jobbágy, EG, Di Bella, CM, Paruelo, JM, Jackson, RB, 2012. "Assessing the potential of wildfires as a sustainable bioenergy opportunity," Global Change Biology - Bioenergy, 4: 634-641