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SURVIVAL, GROWTH AND BIOMASS PRODUCTION OF *Pennisetum purpureum* Schum IN A CLOSED LANDFILL

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Abstract

A phytocapping experience with elephant grass, *P. purpureum*, was carried out in a closed landfill in Buenos Aires province, Argentina, to evaluate survival, growth and biomass production. In spring of 2015 (November), 240 plants were planted in three lines of 80 plants, the distance between plants and lines was 1 m in both cases. The planting was done directly in the topsoil layer of the landfill capping system. The average height of the planted plants was 80.3 ± 24.5 cm. In the next 6 months after planting, elephant grass showed exponential growth with 33.3% of the plants exceeding 260 cm in height. Four harvests were made in winter, the first one, 10 months after planting, August 2016 and the remaining ones in September 2017, August 2018 and August 2019. In each one of them the plants survival and biomass production were evaluated. Survival was 100%, 100%, 87.1% and 82.9%, while the dry biomass production was 9.27, 16.96, 13.24 and 18.15 t / ha for the years 2016, 2017, 2018 and 2019, respectively. The elephant grass adapted to the conditions of the final cover of the sanitary landfill, showed high survival rates, good development of the specimens and a biomass production within the ranges observed in other works on natural soil.

Key words: biomass production, closed landfill, *Pennisetum pupureum*, phytocapping

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1. Introduction

Sanitary landfills continue to be the most widely used method of waste disposal in developed and developing countries (Ashwath and Venkatraman, 2010; Lamb et al., 2014; Nochian et al., 2016). When sanitary landfills are closed, the final coverage system must ensure to protect human health and the environment primarily through minimizing infiltration of precipitation, resist erosion and control gas migration considering the end use for the closed landfill (EPA, 2000).

There are different landfill capping alternatives, the most common are constructed with inorganic compounds that involve one or more layers: topsoil, compacted native soil, compacted clay, drainage layers, geomembranes, geosynthetic clay liners, geotextile filter fabric, compacted bentonite etc. (Albright et al., 2006; EPA, 2000; Lamb et al., 2014). However, the use of alternative cover systems such as phytocaps are being studied, either directly into the landfill cover material (without topsoil), into a layer of topsoil above the landfill cover or replacing the traditional layer of compacted clay (Bolan et al., 2013; Lamb et al., 2014; Phillips et al., 2004; Vaverková and Adamcová, 2018).

Phytocapping, as a subdiscipline for phytoremediation, was initially designed to mitigate the environmental impact resulting from leachate generation, preventing rainwater into contact with waste, but also was observed that it can reduce greenhouse gas emissions through carbon

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sequestration and methane oxidation, reduce soil erosion, remove contaminants, improve the aesthetics of the landfill, increase biological diversity, by using endemic plant species for the creation of wildlife corridors or habitats for local fauna and to establish plantations of high biomass production and eventually generate energy (Bolan et al., 2013; Lamb et al., 2014; Vaverková and Adamcová, 2018).

Landfill phytocapping experiences involve tree, shrub, and grass species, however, there are not many publications since most landfill recovery projects are not research oriented. Venkatraman and Ashwath (2009) worked with 19 tree species, Lamb et al. (2014) with *Arundo donax*, *Brasica juncea*, *Helianthus annuus*, Pierini et al. (2018) with *Pennisetum purpureum* and *Miscanthus giganteus*.

Determining a suitable strategy of revegetation for either restoration or production purposes is a very complex issue, since conditions usually prevailing at landfill sites have negative consequences on plants. In this sense perennial herbaceous species such as *P. purpureum* are of increasing interest, especially for its high photosynthetic efficiency (C4 plants), rapid growth, low nutrient requirements and high biomass production and potential energy generation (Lamb et al., 2014; Tao et al., 2011).

P. purpureum (elephant grass), family Poaceae, is a native species of Africa that was introduced into most tropical and subtropical countries. It is a robust herb with perennial stems reaching over 3 m high, due to its great production of lignocellulosic biomass, it is considered as a potential alternative raw material for biofuels production (Somerville et al., 2010).

The cultivation of perennials plants emerges as a viable alternative to generate lignocellulosic biomass. In general, sanitary landfills are accessible sites, which represent an attraction for biomass production, although the area they occupy is much smaller than other marginal or degraded lands of potential use, for example mines. On the other hand, the trend is to obtain additional benefits from landfill waste sites, at low cost (Bolan et al., 2013; Lamb et al., 2014).

The objective of this work is to carry out a phytocapping experience with *Pennisetum purpureum* Schum directly in the topsoil layer of the capping system of a closed landfill to evaluate survival, growth and biomass production.

2. Material and methods

The experience was carried out in the Villa Domínico sanitary landfill, managed by a state company called CEAMSE (Coordinación Ecológica Área Metropolitana Sociedad del Estado). This landfill is in Buenos Aires province (34 ° 41' 33.92´´ S - 58 ° 16' 29. 41´´ W), being one of the largest in Argentina. Between 1979 and 2004, when it was definitively closed, 47,659,178 t of municipal solid waste (MSW) were disposed in 487 ha. Waste disposal was carried out in operating units called modules. The modules had different height and surface but the same type of capping, a 40 cm layer of compacted clay and a thin layer of natural soil at the top (20 cm). This capping is called technosol by the World Reference Base for Soil Resources as it assembles a soil but was created by men (Pierini et al., 2018).

In all the modules the grass cutting is done at least quarterly. Vegetation cover is practically 100%, the most abundant herbaceous species are *Cynodon dactylon*, *Lolium perenne*, *Cirsium vulgare*, *Festuca arundinacea*, *Bromus catharticus*, *Pascalia glauca* and *Paspalum sp*.

Between November 3rd and 5th, 2015, 240 plants of elephant grass, *P. purpureum*, with average height of 80.3 ± 24.5 cm were manually planted in one of the modules of Villa Domínico´s landfill. This module was active from November 1986 to April 1987, when 464,990 t of MSW were disposed in approximately 11.7 ha.

The plants used were produced in a nursery from single node cuts, they were developed in 20 l plastic pots using compost produced with green pruning residues as substrate. For planting in the module, holes of the same volume as the pots were made, introducing the plant with the substrate in which they grew. They were arranged in three parallel lines of 80 plants each. The distance between plants and lines was 1 m in both cases. They were watered only twice, once at planting and the other one week later. No amendments or pesticides were used.

Four harvests were made, the first one, 10 months after planting, on August 22, 2016 and the remaining ones on September 8, 2017, August 27, 2018 and August 20, 2019. The harvests were carried out manually with electric scythe cutting approximately 15 cm above the ground level. The plants were weighed *in situ* at the time of harvest with an electrical balance of 250 kg of maximum capacity in raffia bags with capacity for approximately 50 kg of plants.

2.1. P. purpureum survival and number of tillers

The survival of *P. pupureum* was evaluated weekly until the first harvest and annually after each harvest. The survival rate was calculated as (Eq. 1):

$$SR = \frac{Number\ of\ surviving\ plants}{Total\ number\ of\ plants\ planted} \quad (1)$$

where: *SR*: survival rate; *Total number of plants planted*: 240

The average number of tillers per plant was estimated at 48 randomly chosen plants (16 from each of the 3 planting lines) at 60 and 90 days after planting (January 4 and February 5, 2016 respectively) and at the time of the first harvest.

2.2. Height and growth of P. purpureum

For each plant, height was measured extending their leaves approximately every two weeks until June

23, 2016, 15 measurements in total. Heights above 260 cm were difficult to survey, therefore they were recorded as > 260 cm, and for statistical calculations, this height was taken. The measurements did not continue beyond June 23, since the plants began to dry with the arrival of winter, almost 40% of them had exceeded 260 cm in height (specifically 38.3%) and the averages were kept almost constant. Exponential, logistic and Gompertz distributions were evaluated to describe the growth of *P. purpureum.*

2.3. Moisture percentage and biomass production

The moisture percentage of *P. purpureum* was calculated with 20% of the biomass harvested the first year. On August 22, 2016, 131 kg of plants without chipping were dried in a greenhouse made of transparent plastic film (4m long by 2 m wide and 1.2 m high vaulted ceiling). The floor of this greenhouse was located at 0.8 m from the ground and built with a plastic mesh with openings of 0.1 x 0.1 m to favor aeration and prevent plant rot. The plants were weighed approximately every 2 weeks until reaching constant weight in two consecutive measurements. The moisture percentage was calculated as (Eq. 2):

$$MP = \frac{(Initial\ biomass - Final\ biomass)}{Initial\ biomass} * 100 \qquad (2)$$

where: *MP: moisture percentage*

The dry biomass production was calculated in t / ha for each harvest considering a planted area of 0.024 ha and the moisture percentage previously mentioned.

3. Results and discussion

The survival rate was 100% during the first two years (2016, 2017), even though in the first two weeks after planting, some plants with signs of browsing were observed, probably due to hares. The survival rates of 2018 and 2019 were 87.1% and 82.9% respectively. The average number of tillers was 14.4 ± 6.3 and 18.0 ± 8.7 at 60 and 90 days after planting respectively. At the time of the first harvest (292 days after planting) the average was 20.4 ± 8.3.

The observed survival rates show that elephant grass was able to survive and grow on the final cover of the landfill. The plant losses observed in the last two years of the experience were not due to diseases, they occurred in two well identified sectors of the plantation, low sectors that remained flooded after the rains, where the plants grew visibly less. Probably, the observed survival is associated with the fact that the plants were well developed at planting time, with an average height of 80.3 ± 24.5 cm, in this sense Ramadhan et al. (2015) evaluated the survival of three varieties of elephant grass, observing that the survival of cuttings of two and three nodes was 37% higher than those of a single node.

Until the 27th day after planting (November 11, 2015), the height averages of *P. purpureum* did not register increases. On March 31, 2016 (148 days after planting) the first plants with heights greater than 260 cm were recorded, 13 in total. For April 21, 2016 (169 after planting) the average was 218.7 ± 41.3 cm with 80 plants that exceeded 260 cm. The averages calculated from this date to June 23, 2016, were most likely underestimated, Fig. 1.

From planting until day 169, the average height of *P. pupureum* shows a good fit to the exponential model according to (Eq. 3):

$$Average\ \ height = 65.23 * e^{(0.0071 * days)} \qquad (3)$$

with a *MSerror* = 60.31 and *AIC* = 87.06 both resulting less what than those calculated for the logistic and Gompertz distributions.

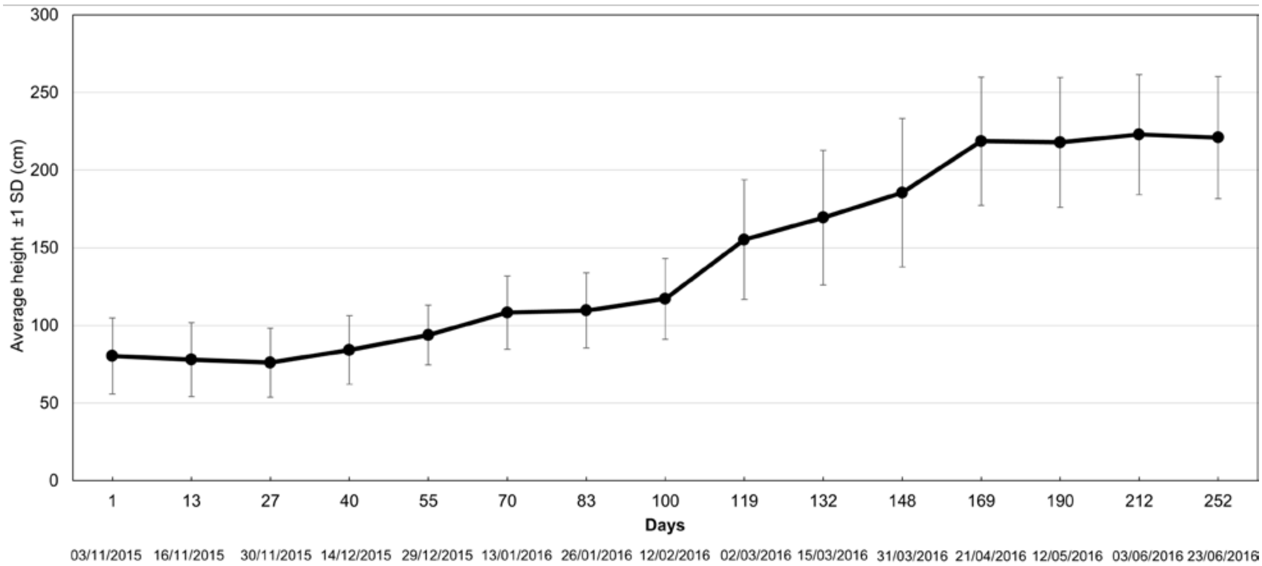

Fig. 1. Average height of *P. purpureum* ±1 standard deviation in cm *versus* days elapsed after planting, November 6, 2015 to June 23, 2016

The observed exponential growth of *P. purpureum* is like the same one obtained by Rodríguez et al. (2011), however there are records of a higher growth rate and higher heights, especially in tropical climates (Barrón et al., 2009; Wijitphan et al., 2009), but it must be considered that this experience was developed on the final coverage of a sanitary landfill consisting mainly of compacted clay, in a temperate climate without the addition of amendments or fertilizers and without irrigation.

The moisture percentage calculated was 65.5%. The greenhouse-dried plants showed a constant weight towards the end of October, 45.3 kg on day 12 and 45.2 kg on day 27. Dry biomass production varied between 9.27 and 18.15 t / ha year, the lowest production was obtained in the first harvest (year 2016) while the highest production was obtained in the last harvest (year 2019), Table 1.

Table 1. Biomass production of *P. purpureum* at time of harvested

Harvest	*Green Biomass Weight (t/ha year)*	*Dry Biomass Weight (t/ha year)*
2016	26.86	9.27
2017	49.17	16.96
2018	38.67	13.34
2019	52.60	18.15

Elephant grass yields are known to increase with plants age (Bodgan, 1997). On the other hand, the highest yield was obtained with the least number of plants, this implies that the plants that survived achieved greater development. We only surveyed the number of tillers in the first year of the experience, which were 3 or 4 times lower than those observed in other works (Barrón et al., 2009; Wijitphan et al., 2009).

It must also be considered that the dry matter yields were always calculated with the same moisture percentage of 65.5%, although it is within those described for this species, there are works where the humidity percentage is higher than 80% (Barron et al., 2009; Ohimain et al., 2014; Okaraonye and Ikewuchibuscar, 2009; Salazar-Zeledón et al., 2015).

The observed dry matter yields for elephant grass vary widely from 7 t / ha year to more than 80 t / ha year (Barrón et al., 2009; De Morais et al., 2009; Ohimain et al., 2014; Ramadhan et al., 2015; Somerville, 2010; Wijitphan et al., 2009; Zewdu et al., 2003), the conditions in which they are obtained are also highly variable, different climates, temperatures and daylight hours, soils, irrigation, use of fertilizers or amendments. The yields obtained in this experience fall within the described range, but again not on a floor but on the capping system of a closed sanitary landfill without the use of amendments.

Landfills sites can be an attractive option for biomass production, obtaining additional benefits from areas whose uses are limited. Furthermore, there is a promising future to produce bioethanol from lignocellulosic material, including *P. purpureum* (Angelini et al., 2009; Bolan et al., 2013; Lamb et al., 2014; Ohimain et al., 2014; Salazar-Zeledón et al., 2015; Somerville et al., 2010; Yasuda et al., 2014), but direct combustion of elephant grass to generate energy should not be discarded (Samson et al., 2005).

4. Conclusions

The elephant grass adapted to the conditions of the final coverage of the sanitary landfill, showed survival rates higher than 82%, an exponential growth in the first months of development and good state the specimens in the five years of experience, with heights greater than 2.6 m. Dry biomass production varied between 9.27 and 18.15 t / ha year, this production is within the ranges observed in other works but in natural soils, not in the topsoil layer of the capping system of a closed landfill.

Assessing the advantages and disadvantages of this type of phytocapping for landfills as well as economic analyses on the use of amendments or irrigation to increase production are future research topics.

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References

Albright W.H., Benson C., Gee G.W., Abichou T., Tyler S.W., Rock S.A., (2006), Field performance of three compacted clay landfill covers, *Vadose Zone Journal*, **5**, 1157-1171.

Angelini L.G., Ceccarini L., Nassi o Di Nasso N., Bonari E., (2009), Comparison of *Arundo donax* L. and *Miscanthus x giganteus* in a long-term field experiment in Central Italy: Analysis of productive characteristics and energy balance, *Biomass and Bioenergy*, **33**, 635-643.

Ashwath N., Venkatraman K., (2010), Phytocapping: an alternative technique for landfill remediation, *International Journal of Environment and Waste Management*, **6**, 51-70.

Barrón J.L., Velásquez M.G., Echevarria M.R., Basurco V.T., (2009), Effect of age and cutting season on the yield and nutritional value of purple elephant grass (*Pennisetum purpureum*, Schum) in the Central Coast *Anales Científicos UNALM* (in Spanish), **70**, 51-57.

Bogdan A., (1997), *Tropical Grasses and Forage Plants* (in Spanish), AGT Editor S.A., México.

Bolan N.S., Thangarajan R., Seshadri B., Jena U., Das H., Wang K.C., Naidu R., (2013), Landfills as a biorefinery to produce biomass and capture biogas, *Bioresource Technology*, **135**, 578-587.

de Morais R.F., de Souza B.J., Leite J.M., de Barros Soares L.H., Rodriguez Alves B.J., Boddey R.M., Urquiaga S., (2009), Elephant grass genotypes for bioenergy production by direct biomass combustion, *Brazilian Journal of Agricultural Research*, **44**, 133-140.

EPA, (2000), Landfill site design, Environmental Protection Agency, Ireland, 154, On line at: https://www.epa.ie/pubs/advice/waste/waste/EPA_landfill_site_design_guide.pdf.

Lamb D.T., Venkatraman K., Bolan N., Ashwath N., Choppala G., Naidu R., (2014), Phytocapping: An Alternative Technology for the Sustainable Management of Landfill Sites. *Critical Reviews in Environmental Science and Technology*, **44**, 561-637.

Nochian A., Tahir O.M., Maulan S., Mikaeili A.R., (2016), A review of systematic approach for sustainable redevelopment of a closed landfill site, *Journal Teknologi*, **78**, 299-307.

Ohimain E.I., Kendabie P., Nwachukwu R.E.S., (2014), Bioenergy Potentials of Elephant Grass, *Pennisetum purpureum* Schumach. *Annual Research and Review in Biology*, **4**, 2215-2227.

Okaraonye C.C., Ikewuchi J.C., (2009), Nutritional and Antinutritional Components of Pennisetum purpureum (Schumach), *Pakistan Journal of Nutrition*, **8**, 32-34.

Phillips I., Greenway M., Robertson S., (2004), Use of phytocaps in remediation of closed landfills-correct selection of soil materials, *Land Contamination and Reclamation*, **12**, 339-348.

Pierini V.I., Bartoloni N., Ratto S.E., (2018), Greenhouse gases emissions from a closed old landfill cultivated with biomass crops, *Environment, Development and Sustainability*, **20**, 2795-2809.

Ramadhan A., Njunie M.N., Lewa K.K., (2015), Effect of Planting Material and Variety on Productivity and Survival of Napier Grass (*Pennisetum purpureum* Schumach) in the Coastal Lowlands of Kenya, *East African Agricultural and Forestry Journal*, **81**, 40-45.

Rodríguez L., Torres V., Martínez R.O., Jay O., Noda A.C., Herrera M., (2011), Models to estimate the growth dynamics of *Pennisetum purpureum* vc (Modelos para estimar la dinámica de crecimiento de *Pennisetum purpureum* vc), *Revista Cubana de Ciencia Agrícola*, **45**, 349-354.

Salazar-Zeledón E., Moya R., Valaert J., (2015), Biomass and Bioenergy Production of *Arundo donax* L., *Pennisetum purpureum* Schum. and *Pennisetum purpureum* Schumack.× *Pennisetum glaucum* L. in Short Rotation Cropping System in Costa Rica, *Journal of Biobased Materials and Bioenergy*, **9**, 1-8.

Samson R., Mani S., Boddey R., Sokhansanj S., Quesada D., Urquiaga S., Reis V., Ho Lem C., (2005), The potential of C4 perennial grasses for developing a global BIOHEAT industry, *Critical Reviews in Plant Sciences*, **24**, 461-495.

Somerville C., Youngs H., Taylor C., Davis S.C., Long S.P., (2010), Feedstocks for lignocellulosic biofuels, *Science*, **329**, 790-792.

Tao L., Aden A., Elander R.T., Ramesh Pallapolu V., Lee Y.Y., Garlock R.J., Balan V., Dale B.E., Kim Y., Mosier N.S., Ladisch M.R., Falls M., Holtzapple M.T., Sierra R., Shi J., Ebrik M.A., Redmond T., Yang B., Wyman C.E., Hames B., Thomas S., Warner R.E., (2011), Process and technoeconomic analysis of leading pretreatment technologies for lignocellulosic ethanol production using switchgrass, *Bioresource Technology*, **102**, 11105-11114.

Vaverková M.D., Adamcová D., (2018), Case study of landfill reclamation at Czech landfill site. *Environmental Engineering and Management Journal*, **17**, 641-648.

Venkatraman K., Ashwath N., (2009), Phytocapping: importance of tree selection and soil thickness, *Water, Air, Soil Pollution*, **9**, 421-430.

Wijitphan S., Lorwilai P., Arkaseang C., (2009), Effect of Cutting Heights on Productivity and Quality of King Napier Grass (*Pennisetum purpureum* cv. King Grass) under Irrigation, *Pakistan Journal of Nutrition*, **8**, 1244-1250.

Yasuda M., Ishii Y., Ohta K., (2014), Napier Grass (*Pennisetum purpureum* Schumach) as Raw Material for Bioethanol Production: Pretreatment, Saccharification, and Fermentation. *Biotechnology and Bioprocess Engineering*, **19**, 943-950.

Zewdu T., Baars R.M.T., Yami A., (2003), Effect of plant height at cutting and fertilizer on growth of Napier grass (*Pennisetum purpureum*), *Tropical Science*, **42**, 57-61.