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NOTES ON NEGLECTED AND UNDERUTILIZED CROPS

Saccharum spontaneum: an underutilized tall grass for revegetation and restoration programs

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Abstract *Saccharum spontaneum* L. is a perennial tall grass and invades naturally abandoned and pastoral lands in many tropical countries. Although it is a potentially multiple-use and multifunctional species, it remains neglected and underutilized. It is commonly known as 'Wild cane' in English and 'Kans' in Hindi. In recent years, *S. spontaneum* has attracted serious attention for its potential in ecological restoration. The present paper deals with geographic distribution, ecology, morphological description, multiple uses, restoration potential, and propagation of this species. We also report the suitability of *S. spontaneum* for the restoration and stabilization of bare fly ash (FA) dumps. In this context, the highest importance value index, visual observations and practitioner insights reveal that *S. spontaneum* has great ability to grow on bare FA dumps and can be used as an ecological tool in restoration of vast tracts of fly ash dumps across the world. Besides grass vegetation study, we also report the change in physicochemical properties of abandoned site and compared with naturally colonized site with *S. spontaneum* of FA dumps to assess its ecological suitability for restoration of bare FA dump. Overall, the field results showed that *S. spontaneum* is a promising and potential tall grass for the restoration of FA dumps.

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Introduction

Growing waste dumps of a wide variety such as fly ash (FA) dumps, mine spoils, red mud disposals, sewage sludge and other wastes are worldwide ecological, economic and social challenges. These waste-dumps may cause heavy metals pollution, soil and water system degradation, and serious dust pollution to atmosphere. These waste-dumps pose adverse conditions for soil microbe and plant growth, due to its low organic matter and unfavourable substrate chemistry (Pandey and Singh 2012). The pollution and consequent human health risks from these dumps are indeed a large concern requiring holistic approach to remediation. The management of waste-dumps is a challenging geotechnical and ecological problem and a substantial issue for ecological, economic and social sustainability.

Revegetation is one of the most widely used approaches for controlling erosion and stabilisation of waste-dumps, and thereby maintaining ecological services and sustaining ecosystem functions (Tormo et al. 2007; Pandey and Singh 2011; Pandey et al. 2012; Pandey 2013; Pandey and Singh 2014). The role of vegetation growth upon waste-dumps can be variously described in terms of pollutants remediation, rehabilitation, substrate improvement, carbon sequestration, and creating a functional ecosystem on derelict lands (Pandey and Singh 2011; Pandey et al. 2012; Pandey 2013; Kumari et al. 2013; Verma et al. 2014). Additionally, the root system of growing vegetation play an important role in controlling the capture of rainwater and evapotranspiration and the resulting pore pressure reduction (Blight 1987; Hussain 1995). Ecological restoration is a potential approach of renewing degraded, damaged or derelict lands with afforestation and cropping through active human intervention (Pandey et al. 2011; Singh et al. 2012). Recent approaches have posited restoration as an activity also aimed at biodiversity enrichment and livelihoods improvement of local communities (Pandey et al. 2014a). Indeed, successful ecological restoration can create novel multifunctional ecosystem capable of generating ecosystem services such as improved water quality and increased carbon storage for the benefit of society.

Emerging recent research provides insightful knowledge and perspectives of *Saccharum spontaneum* L., such as development of *S. spontaneum* fibers (Kaith et al. 2010); revegetation of uranium tailings (Singh and Soni 2010); bioethanol production (Chaudary et al. 2012); and reclamation of coal mine dump (Chaulya et al. 2000). However, *S. spontaneum* based restoration is still poorly studied in various waste-dumps and the subject requires further exploration. The present study deals with the restoration of fly ash dumps through naturally colonizing *S. spontaneum* for long-term protection of environment and to develop a holistic approach for improving rural livelihoods and sustaining ecosystems (Fig. 1).

In the sections that follow, we discuss ecology of the species, geographic distribution, ecology, morphological description, various uses, and the suitability of the species for ecological restoration. We specifically report the suitability of *S. spontaneum* for the restoration and stabilization of bare fly ash (FA) dumps.

Ecology

Saccharum spontaneum L., a wasteland weed, is a tall perennial C4 grass with deep roots and rhizomes, growing up to 3–4 m in height. In the plains of north India, it is commonly known as “Kans” and “Kansa” (Hindi name) but the Tharu tribes of Himalayan Terai region (India and Nepal) also called it ‘Jhaksi’ as folk name (Dangol 2005). *S. spontaneum* L. grows in banks of water bodies (river, lakes and ponds), along roadsides and railway tracks, alluvial plains, damp depressions and swamps. It grows in lowland eco-region at the base of the Himalayan range in India, Nepal, China and Bhutan. It occurs at an altitude ranging from sea-level to 1,800 m (Holm et al. 1997). It belongs to Poaceae family with Magnoliophyta division. Genus *Saccharum* has five extant species, of which *S. spontaneum* L. is a wild species. It also grows very well on less nutritious sandy soils (Balyan et al. 1997). The species also shows some allelopathic effects by leachates from their

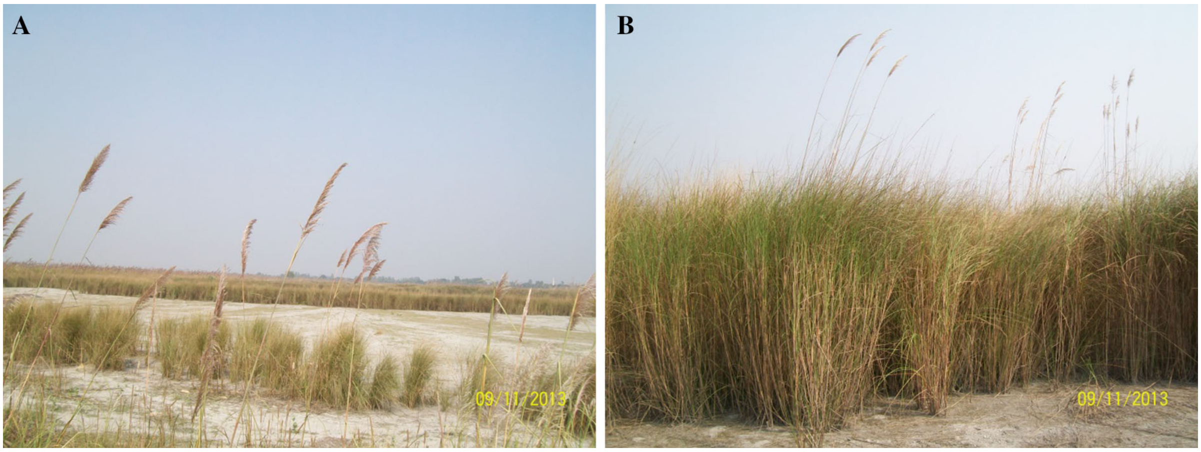

Fig. 1 **A** A landscape view of naturally colonizing *S. spontaneum* on fly ash dump; **B** Close view of naturally colonizing *S. spontaneum* on fly ash dump. Photographs by V.C. Pandey

rhizomes and roots on crops (Amritphale and Mall 1978). The grass lands of *S. spontaneum* L. in the Himalayan Terai and Duar, provide an important habitat for the Indian rhinoceros (*Rhinoceros unicornis* L.). The species is most commonly found in association with *Saccharum bengalense* Retz., *Cynodon dactylon* (L.) Pers., *Typha latifolia* L., *Dactyloctenium aegyptium* (L.) Willd., *Cyperus esculentus* L., *Eragrostis nutans* (Retz.) Nees ex Steud. and *Fimbristylis umbellata* Schrad. ex Nees. Its phenological behaviour (flowering and fruiting at the end of rains) make it capable to colonize very quickly on the bare sandy soils, and invades abandoned pastoral fields in many tropical countries.

Morphological description

Saccharum spontaneum is a tall (100–600 cm) perennial grass with a creeping, tufted and rhizomatous rootstock. Stem 100 × 0.4–400 × 1.5 cm, solid above, fistular below (=Culm), serect, polished, robust; internodes solid; node 5–10, waxy. Leaves linear-lanceolate, involute, with long hairs at base, base rounded; ligule 2–8 mm long, ovate, brown, membranous, ciliolate; leafblade 45 × 0.2–200 × 1.5 cm, glabrous, apex accuminate, base simple or tapering to the white midrib, scabrid to serrate along margins; sheath longer than internode. Inflorescence plumose panicles; peduncle hirsute above; panicle 15–60 cm long, silky white, axis silky pilose or hirsute, open, ovate, dense; racemes 3–17 cm long; rachis internodes filiform; spikelets homomorphic, 2.5–5.0 (−7.0) mm long, lanceolate, reddish-brown, paired (one sessile and the other pedicelled), pilose with long silky hairs, awnless. Fertile spikelets sessile, 0.35–0.70 cm long, lanceolate, dorsally compressed, two in the cluster, subequal; pedicels filiform, ciliate. Glumes similar, membranous above, chartaceous below; lower glume 3–4 × 1 mm, ovate-lanceolate to elliptic, subcoriaceous to coriaceous, acuminate at apex, ciliate along margins, much thinner above, 2-keeled; upper glume 3–4 × 1 mm, ovate-lanceolate, coriaceous, acute at apex, ciliate along margins, mucronate, much thinner above, without keels. Florets basal sterile and upper fertile; sterile florets barren, without significant palea; lemma 1–2 × 1 mm, lanceolate, hyaline, 0-veined, without midvein, without lateral veins, acute at apex; fertile floret bisexual, first lemma 1–2 × 1 mm,linear, hyaline; second lemma 2–2.5 mm long, linear-lanceolate, hyaline; Palea absent or minute. Flower lodicules, cuneate, ciliate. Stamens three; anthers yellow or reddish, 1.5–2.0 mm. Ovary oblong; stigma white. Flowering and fruiting occurs from June to September. Flowers emerge just before rains and takes 1–2 months to produce seeds.

Geographic distribution

Saccharum spontaneum is native to South Asia (India) (Panje 1970). Globally, it is distributed throughout the tropical countries of Asia, Africa, America as well as in tropical Australia. It is often planted in Bangladesh, Sri Lanka, India, Nepal and Pakistan (Cook 1996).

Propagation

Saccharum spontaneum is propagated through seeds as well as vegetatively by creeping rhizomes and stem cuttings. The number of seeds produced per plant may vary as 3,042 seeds/plant in India (Datta and Banerjee 1973) to 12,800 seeds/plant in Philippines (Pancho 1964). Due to the presence of callus hairs seed dispersal occurs by wind. Occasionally few seeds get entwined to form a woolly mass, which increase its dispersal distance (Sharma and Tiagi 1979). The seeds germinate and emerge in July–August after the first rain of the season. Vegetative regeneration occurs by rhizomes and stem fragments (Artschwager 1942). Stem shows good regeneration potential even after 6 days of drying (Graham et al. 2014). *S. spontaneum* is cultivated around the barren lands as hedges and along the water canals to prevent soil erosion (Bhandari 1990; Sastri and Kavathekar 1990).

Multiple uses

Saccharum spontaneum is one of the important medicinal plants in traditional systems of medicine in India according to Ayurveda. The roots of the plant are sweet, astringent, emollient, refrigerant, diuretic, lithotriptic, purgative, tonic, aphrodisiac and used in the treatment of dyspepsia, burning sensation, piles, sexual weakness, gynecological troubles, respiratory troubles etc. (Kumar et al. 2010). Fresh juice of plant stem is also used in the treatment of mental illness and disturbances by different tribes in India. In Philippines, numerous medicinal uses have been described (Pancho and Obien 1983). In Indonesia, the young shoots are boiled and relished with rice (Uphof 1968). Culm of the species is a good source of pulp for the production of different grades of papers, especially the grease-proof paper. Leaves are good thatching material and used by local people in the making of ropes, mats, baskets, broom, huts, etc. to support their livelihood. It is reported as fodder for goats and camels (Thakur 1984) in juvenile stage and suitable for the production of silage (Komarov et al. 1963). Its slow rate of decomposition makes it an excellent mulching material (Wapakala 1966). *S. spontaneum* L. contains high levels of carbohydrates in its cell walls (67.85 % on a dry solid basis), which makes it novel and suitable substrate for ethanol production (Chandel et al. 2011; Scordia et al. 2010). It is a fast growing biomass with flowers containing fibers. These fibers are distinctly different in appearance from other type fibers such as cotton, jute, flax, ramie and hemp. These fibers are white/purplish silky and have better strength and fineness (Bhandari 1990; Sastri and Kavathekar 1990). Chemical modification of *S. spontaneum* fibers for enhancement of moisture retardance, chemical resistance and thermal stability through graft copolymerization with methyl methacrylate and study of morphological changes were studied by Kaith et al. (2009). Furthermore, Kaith et al. (2010) worked on development of corn starch based green composites reinforced with *Saccharum spontaneum* fiber and graft copolymers. From the perspective of ecological importance, the species is very effective against soil-erosion, due mainly its extensive rhizome network (Bor 1960). The species also acts as a valuable genetic resource containing various climatic stress tolerant genes especially for sugarcane (*Saccharum officinarum* L.) (Anonymous 1972). Beside all these uses, it also has religious importance in India.

Use of *S. spontaneum* in ecological restoration programs

Ecologically, *S. spontaneum* is recognized as a good colonizer of wastelands and marginal lands. The ecological significance in terms of high biomass productivity and good root system indicates that *S. spontaneum* is a promising tall grass for restoring disturbed soils and colonization of wastelands. *S. spontaneum* is considered as a weed or the invasive grass in some countries like the Republic of Panama as it interferes with the natural vegetation over the landscape (Park et al. 2010). *S. spontaneum* can be used for restoration programs because of its ability to grow on various waste-dumps where other plants are unable to grow. It can survive on various types of degraded lands like fly ash basins, mine spoils, red mud disposals and other industrial disposals. Thus, it contributes to enhance the productivity of underutilized land resources. Interestingly, *S. spontaneum* dominate the spoil-vegetation with a very high value of prevalence (80 %) of over-burdens (Das et al. 2013). In a case study, *S. spontaneum* has been identified in eco-restoration of a high-sulphur coal mine overburden dumping site in northeast India (Dowarah et al. 2009). *S. spontaneum* has been planted in the initial phase of restoration of rock phosphate mine (Bhatt 1990). *S. spontaneum* has reported for restoration of sponge iron solid waste dumps (Kullu and Behera 2011) and biostabilization for a coal mine overburden dump slope (Chaulya et al. 1999). However, being invasive species, the control of spreading of *S. spontaneum* is an important issue regarding biodiversity loss. For this, Doren et al. (2009) proposed a comprehensive ecological model to control spreading of invasive species. Thus, we can follow this ecological model to stop the spreading of *S. spontaneum* during the revegetation and restoration programs and to allow native species to become established.

The fly ash dumps and its remediation

FA is a coal combustion residue of thermal power stations and its disposal as FA dumps are serious problems across the world (Pandey et al. 2009; Pandey and Singh 2012). FA contains plant's micro- and macro-nutrients (Pandey and Singh 2010; Ram and Masto 2014), and 10 % FA amended sand has been recommended as a suitable rooting media for vegetative propagation of *Leucaena leucocephala* (Pandey and Kumar 2013). Besides these nutrients, FA is also a source of toxic metals, radioactive elements and organic pollutants (Pandey et al. 2009, 2011; Ribeiro et al. 2014). Therefore, FA dump's remediation is urgently needed worldwide. Phytoremediation is a holistic approach and has been found suitable for the remediation of FA dumps (Ram et al. 2008; Pandey et al. 2009; Maiti and Jaiswal 2008). Furthermore, naturally colonizing and socio-economically valuable plants based phytoremediation has been explored well for the phytomanagement of FA basins and obtaining self-sustainable FA ecosystem (Maiti and Nandhini 2006; Pandey et al. 2009; Pandey 2012a, b; Pandey

2013; Pandey and Singh 2011). In the present study, we now assess the restoration ability of naturally colonizing *S. spontaneum* of FA basin in the next section.

Experimental design

The field study was conducted at coal fly ash (FA) dump of Unchahar thermal power station (25°53′59″ N 81°17′59″ E), Raebareli, Uttar Pradesh (Pandey et al. 2014b). For the study of grass diversity, we surveyed vegetation colonizing on FA dump. Several naturally colonizing grasses were noticed on coal FA dump. *S. spontaneum* is one of the most abundantly colonized grasses on this FA dump, and has been reported from other FA dumps of India. For testing the restoration ability of *S. spontaneum* grass on FA basin, we took soil samples from the abandoned site and naturally revegetated site with *S. spontaneum* grass. Five 5 × 5 m quadrates were laid out at five different points of FA dump, one in each direction (North, East, West and South) and one in the centre of the FA dumping site to cover the maximum range of variations in the vegetation as well as FA sampling.

Materials and methods

Twenty-five observations for quantitative assessment of ecological data were done by laying quadrates. In each quadrate number of individuals of each grass species have been counted, and this information was used to calculate frequency, density and abundance (Curtis and McIntosh 1950). This was further used in the calculation of relative frequency, density and abundance and finally importance value index (IVI) by adding them (Cootam and Curtis 1956). IVI represents to the sum of relative frequency, relative density and relative abundance to show the importance of a species in the location (Singh et al. 2013). The details regarding the definitions and calculation formulas of others vegetation indices are presented in our earlier work (Singh et al. 2013). All grasses were identified with the help of pertinent floras and literature (Duthie 1960; Mishra and Verma 1992). At the same time, twenty-five random composite samples of FA were collected from the rhizosphere of dominant species *S. spontaneum* colonizing naturally on FA dump to reduce the spatial heterogeneity of the FA, if any. All the FA samples were taken up to a 30 cm during the digging of plant's rhizosphere. Same process was also done during the collection of soil samples from abandoned site. The samples were air-dried and ground to pass through a 2.0 mm sieve, homogenized and analyzed for physicochemical characteristics. The pH and electrical conductivity (EC) of FA were analyzed by using a pH meter and a conductivity meter, respectively. Organic carbon (OC) was analyzed by using the method of Walkley and Black (1934). Available phosphorus was estimated by Olsen et al. (1954). Potassium was determined by flame photometric method. Nitrogen was estimated by the micro-Kjeldhal method.

Results and discussion

Relative Frequency (R.F.), Relative density (R.D.), Relative Abundance (R.Ab.) and importance value index (IVI) of naturally growing grasses on fly ash basin is presented in Table 1. The IVI calculated for the individual grass species encountered on fly ash basin revealed *S. spontaneum* L. was the most important grass species followed by the *Cynodon dactylon* (L.) Pers., *Saccharum bengalense* Retz., *Dactyloctenium aegyptium* (L.) Willd., *Cyperus esculentus* L., *Typha latifolia* L., *Fimbristylis bisumbellata* (Forssk.) Bubani and *Eragrostis nutans* (Retz.) Nees ex Steud. This indicates the ability of *S. spontaneum* to compete with stressful conditions and survive on fly ash basin. *S. spontaneum* appeared as a pioneer grass species in abandoned fly ash landfill with an IVI about 146 %. This is consistent with our previous study (Singh et al. 2013; Pandey et al. 2014a). We reported 91–182 % IVI of dominant grass *S. spontaneum* in inner and outer sides of two fly ash dumps when other grasses became an important companion species (Pandey et al. 2014a). This indicates that most adaptable species, *S. spontaneum*, created suitable micro-climatic conditions for less adaptable species towards succession. Indeed, several plants are able to survive in hostile and nutrient poor soil conditions due to their interactions with rhizosphere and root associated efficient microbes (Singh et al. 2011).

The physicochemical properties of abandoned and naturally revegetated site with *S. spontaneum* of coal FA dump is given in Table 2. In this study, the porosity of abandoned site was higher (48.75 %)

Table 1 Relative Frequency (R.F.), Relative density (R.D.), Relative Abundance (R.Ab.) and importance value index (IVI) of naturally growing grasses on fly ash dump (n = 25)

Plant species	R.F.	R.D.	R.Ab.	IVI
Saccharum spontaneum L.	16.41	68.03	61.98	146.41
Cynodon dactylon (L.) Pers.	13.28	14.68	16.52	44.49
Saccharum bengalense Retz.	14.84	4.70	4.73	24.27
Dactyloctenium aegyptium (L.) Willd.	10.94	4.45	6.08	21.47
Cyperus esculentus L.	10.94	3.98	5.43	20.35
Typha latifolia L.	13.28	2.78	3.13	19.19
Fimbristylis bisumbellata (Forssk.) Bubani	9.38	1.01	1.62	12.01
Eragrostis nutans (Retz.) Nees ex Steud.	10.94	0.37	0.51	11.82
Total	100.00	100.00	100.00	300.00

Table 2 Physicochemical properties of abandoned and naturally revegetated site with *S. spontaneum* of coal FA dump; Values are mean ± standard deviation (n = 25)

Parameter	Coal FA dump	
	Abandoned site	Naturally revegetated site
Porosity (%)	48.75	46.50*
WHC (%)	68.50 ± 2.00	65.45 ± 1.50*
pH	9.45 ± 0.10	8.50 ± 0.08*
EC (μS cm^{-1})	145 ± 4.50	110.5 ± 6.50*
OC (%)	0.00 ± 0.00	1.10 ± 0.05*
Available N (%)	0.00 ± 0.00	0.03 ± 0.01*
Available *P* (μg g^{-1})	6.75 ± 0.25	25.45 ± 0.09*
Available K (μg g^{-1})	37.50 ± 2.5	77.65 ± 6.5*

* Indicates significance difference between abandoned and revegetated site (paired *t* test, $P < 0.05$)

compared to naturally revegetated site with *S. spontaneum* (46.50 %). The water holding capacity (WHC) of abandoned site was also highest (68.50 ± 2.00 %) than naturally revegetated site with *S. spontaneum* (65.45 ± 1.50 %). The pH and EC were higher in abandoned site than the naturally revegetated site. The reason of high pH in abandoned site may be due to the alkaline nature of fly ash, because of the presence of low sulphur content, hydroxides, carbonates of calcium and magnesium in coal (Pandey and Singh 2010; Pandey et al. 2009). Organic acids produced by root associated microbes and present in root exudates may play a significant role in the reduction of soil pH (Babu and Reddy 2011; Koranda et al. 2011). Thus, it seems that the lower pH in naturally revegetated site might be due to the growth of *S. spontaneum* and root associated microbes and also due to the accumulation of OC in naturally revegetated FA basin. On the other hand, OC, available N, available *P*, and available K were significantly ($P < 0.05$) higher in naturally revegetated FA dump with *S. spontaneum* than the abandoned site. This was most likely due to the poor OC, N and *P* in ash substrate of FA dump (Pandey and Singh 2010). Increased level of OC was noticed in naturally revegetated FA dump, and it may be due to fine root decay of *S. spontaneum*. Because it is reported that vegetation cover can restore soil organic matter (Ruiz-Sinoga et al. 2012) and stabilize FA substrate (Pandey et al. 2012) in degraded lands and FA dumps, respectively. Available *P* content was found to be significantly higher ($P < 0.05$) in naturally revegetated FA dump in comparison to abandoned site due to the presence of phosphate solubilizing bacteria or mycorrhizal associations in revegetated site. This seems clearly that *S. spontaneum* has potential to ameliorate the substrate of FA basins (decrease in pH as well as increase in OC, available N, available *P*, and available K). Overall, *S. spontaneum* has remarkable potential for ecological restoration of FA dump and thus convert these unproductive tracts into functional ecosystems.

Conclusion and future perspective

The present study concludes that unfavourable physicochemical properties of FA inhibit the vegetation establishment and growth on freshly laid FA dump. While some naturally colonizing grass species are present on FA dump, the *S. spontaneum* is one of the most abundantly colonized grasses. The highest importance value index, visual observations, practitioner insights and analytical results presented in this study demonstrated that *S. spontaneum* has great ability to colonize on bare FA dumps and thus can be used as a valuable genetic resource for ecological restoration.

We believe that our research has world-wide relevance from the perspective of restoration of waste-dumps, particularly in countries that are facing serious waste dump problems due to industrial activities. The knowledge and insights we provided here can be linked to action on the ground by practitioners for revegetation and restoration programs of a variety of waste-dumps.

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