mechanical behaviour combining the self-centering and energy-dissipation capability, permit calibration of the desired features to fit specific needs. The availability of these features opens considerable room for improvement of the structural system design. They can be fitted into structures as diagonal braces or seismic dampers, as shown in Figure 11.

A variety of hysteretic behaviour can be obtained from the material tested and its application can be made suitable for seismic devices like re-centering, supplemental re-centering and non re-centering devices. The orthodontic wires tested showed excellent fatigue resistance. Cyclic behaviour of the wires, especially energy-dissipation capability, equivalent viscous damping and secant stiffness were not sensitive to the number of cycles in the frequency range of interest (0.5–3 Hz). The stiffening observed in the wires for higher amplitude loading ensures a good control of displacements in case of strong seismic events. The re-centering capability is an added advantage. Pre-strained super-elastic wires show higher energy-dissipation capability and equivalent damping over the available strain range of 2–10%. Among the various types of devices, the wire under tension mode can be selected between pre-strained and non pre-strained wires for possible application in various kinds of vibration control devices in structural systems. One such device fabricated and tested in the Structural Engineering Research Centre, Chennai renders promising applications for seismic response reduction/retrofit measures in structures, including bridges.

1. Pelton, A., DiCello, J. and Miyazaki, S., Optimisation of processing and properties of medical grade Nitinol wire. *Min. Invas. Ther. Allied Technol.*, 2000, **9**, 107–118.
2. Stöckel, D. and Melzer, A., *Materials in Clinical Applications* (ed. Vincentini, P.), Techna Srl., 1995, pp. 791–798.
3. Duerig, T., Tolomeo, D. and Wholey, M., An overview of superelastic stent design. *Min. Invas. Ther. Allied Technol.*, 2000, **9**, 235–246.
4. Duerig, D. and Tolomeo, D., In Proceedings of the International Conference on Shape Memory and Superelastic Technologies SMST-2000 (eds Russell, S. M. and Pelton, A. R.), International Organization on SMST, Pacific Grove, California, 2001, pp. 353–358.
5. Andreasen, U.S. patent number 4037324.
6. Birman, V., Review of mechanics of shape memory alloy structures. *Appl. Mech. Rev.*, 1997, **50**, 629–645.
7. Humbeeck, J. V., Shape memory alloys: A material and a technology. *Adv. Eng. Mater*, 2001, **3**, 837–850.
8. Savi, M. A. and Mamiya, E. N., Passive vibration control using pseudoelastic materials DINAME. In Proceedings of 4th symposium On Dynamic Problems of Mechanics, Caxambu, Brazil, 1995, pp. 230–233.
9. Cardone, D., Dolce, M., Bixio, A. and Nigro, D., Experimental tests on SMA elements MANSIDE Project, Italian Department for National Technical Services, Rome, 1999, II85–104.
10. IS 1893–2002, Indian standard criteria for earthquake resistant design of structures, Part 1: General provisions and buildings, Bureau of Indian Standards, New Delhi, 2002.
11. Sreekala, R., Avinash, S., Gopala Krishnan, N. and Muthumani, K., Development of seismic isolators and dampers using shape memory alloys – a critical review. In Proceedings of National Seminar on Smart Materials, Intelligent Structures and Systems in Civil Engineering, Bangalore, 20–21 June 2003.
12. Sreekala, R., Avinash, S., Gopalakrishnan, N. and Muthumani, K., Energy dissipation and pseudo elasticity in NiTi alloy wires. SERC Research Report MLP 9641/19, October 2004.
13. MANSIDE Project, Italian Department for National Technical Services, Rome, 1999.
14. Sreekala, R., Arvind, V., Sathish Kumar, K., Gopalakrishnan, N. and Muthumani, K., Experimental study on passive energy dissipation device using NiTi wires. SERC Research Report MLP 12041//2, May 2006.

ACKNOWLEDGEMENTS. We thank the Director, Structural Engineering Research Centre, Chennai for permission to publish this paper, and also for his encouragement and support. The help and assistance provided by the staff of the Structural Dynamics Laboratory in carrying out the experimental work is acknowledged.

Received 25 May 2007; revised accepted 8 October 2008

Wild cane as a renewable source for fuel and fibre in the paper industry

V. A. Amalraj[1,*], P. Rakkiyappan[1], D. Neelamathi[1], S. Chinnaraj[2] and S. Subramanian[2]

[1]Sugarcane Breeding Institute (ICAR), Coimbatore 641 007, India
[2]Tamil Nadu Newsprint and Papers Limited, Pugalur 639 136, India

The Sugarcane Breeding Institute, Coimbatore in collaboration with Tamil Nadu Newsprint and Papers Limited (a bagasse-based paper mill), is exploring the utilization of wild cane in energy generation and as an alternate source of raw material for the paper industry. The germplasm collection of the wild cane species, *Erianthus arundinaceus*, was evaluated for its performance under cultivation, biomass production, stalk yield, fibre content and juice quality. Out of 88 clones evaluated, 23 with high fibre–pith ratio were selected. Based on proximate analysis, six clones were selected for further tests and trials. This species has the potential to yield high biomass for the production of energy through cogeneration, alcohol through bio-fermentation of its juice and bagasse (stalks after extraction of juice) as raw material for paper manufacture. Energy content of biomass was assessed by estimation of the calorific value. Studies on fibre content, bagasse yield, biomass yield and pulping showed that this species is superior to sugarcane as a source of energy and fibre. So far no systematic evaluation of this naturally growing species has been done for its biomass production, energy content, fibre yield and juice quality, and no commercial cultivation for its co-products has been attempted.

Keywords: Bagasse, energy, fibre, fuel, wild cane.

*For correspondence. (e-mail: vaamalraj@yahoo.co.in)

SUGARCANE bagasse is one of the major by-products generated from the sugar industry, utilized as fibrous raw material for manufacturing pulp and paper along with other non-wood fibrous raw materials like rice straw, wheat straw, bamboo, cotton waste and reed. The various grasses and their by-products have been used in pulp and papermaking ever since paper was invented. The production of non-wood pulp and paper has a long tradition in Asian countries, particularly China and India. Until now, paper consumption in these countries has remained at a relatively low level. Moreover, the rapid growth in the Asian economies is increasing paper consumption rapidly compared to the Western countries. This growth, together with the steady acceleration in paper consumption worldwide, diminishing forest resources, and the enormous economic and environmental problems associated with the existing process presently adopted in the mills, represent major challenges for the pulp and paper industry.

Apart from the above, nonavailability of raw material such as bagasse, due to its alternative uses for other purposes like fuel for power generation, reduced sugarcane acreage due to continuous drought, technological difficulties in raw-material handling and storage, and inherent quality drawbacks associated with pulp produced from sugarcane bagasse fibres, are becoming a major hurdle for bagasse-based pulp and paper mills.

Almazan *et al.*[1] reported that 1 ha of cane can produce 100 t of green matter every year, which is more than twice the yield of most other commercial crops. One hectare of sugarcane can produce about 5 t of fibre for paper production every year. Sugarcane bagasse is generally utilized as fuel in sugar mills for power generation and the surplus is used as raw material for production of pulp and paper. Bagasse lends itself to the manufacture of all grades of paper, and several mills have started using sugarcane bagasse as a raw material. The cane bagasse comprises of fibre, pith, nonsoluble solids and water. Fibre represents about half of all components and includes cellulose, hemicellulose and lignin. Since several mills in India have started consuming bagasse for cogeneration, surplus bagasse is not available and the paper industry has been forced to explore alternate sources of raw material. Several farmers are known to face problems in sugarcane cultivation (due to drought, poor marginal lands, input costs) and supply to sugar mills. Wild cane with high fibre content and low sugar has the potential to be an attractive alternative crop for the paper industry as well as for those small farmers who face difficulties in commercial cane cultivation.

Wild sugarcane species, particularly *Saccharum spontaneum* L. and *Erianthus* (Old World) species are native to India and occur naturally in many parts of the country. They belong to the tribe Andropogoneae, under the grass family Poaceae[2]. These species have high fibre, low sucrose content in their stalks and *Erianthus* in particular, has a high biomass production. Among the Indian *Erianthus* species, only *E. arundinaceus* can be vegetatively propagated by setts (stem cuttings). It has been reported[3] that *E. arundinaceus* yields pulp which is suitable for writing and printing papers. The juice contains brix (total soluble solids) up to 13% and can be fermented to produce alcohol. *E. arundinaceus* (wild cane), often found growing on river and canal banks, is known for its high biomass, high tillering, good ratooning ability, drought tolerance, disease/pest resistance, low input requirement and shy flowering[4]. It has the potential as a renewable source of (i) fibre from bagasse after extraction of juice, and (ii) fuel as energy from burning dry leaf trash, tops and bagasse; as alcohol from bio-fermentation of juice.

Results of proximate analysis conducted on some raw materials are given in Table 1, showing the superiority of *E. arundinaceus*.

Hence, an investigation was made to study the feasibility of utilizing the wild cane species, especially *E. arundinaceus* as a source of fibre and fuel, and to screen and select suitable clones from the germplasm collection.

The Sugarcane Breeding Institute maintains a large collection of variable forms of *Erianthus* sp. collected from different parts of the country and South East Asia. A majority of these entries have been described and documented in detail for 66 vegetative and floral characters and documented[4]. In order to select superior clones which combine high yield of stalks and fibre with good paper-making quality, 88 one-year-old clones of *E. arundinaceus* were screened and evaluated for characters such as stalk length, stalk diameter, single stalk weight, number of tillers, number of internodes, internode length, pithiness, brix %, sucrose %, purity %, extraction % and fibre content (Table 2). Proximate analysis was also done in selected clones that had high fibre–pith ratio. For fibre and sucrose content, fresh stalks were cut, weighed and fibre extracted in a mechanical fiberizer. For energy estimation, dry leaves, tops and bagasse were used.

After drying, the energy content of whole-plant biomass was estimated. The moisture content of cane was 72.5% and leaves was 45%. The gross calorific value was 4200 kcal/kg, the ash content was 5.6% and volatile matter constituted 74.6%. The moisture content and calorific value of *Erianthus* bagasse were 52% and 4550 kcal/kg respectively. In comparison, sugarcane bagasse has an average moisture content of 48% and calorific value of 4400 kcal/kg. A tonne of bagasse generates about 2.5 t of steam. With relatively low capital requirements, this wild cane can become a renewable indigenous raw material for supplemental power production.

The pulping results of *Erianthus* indicated that pulp properties are superior to those of sugarcane bagasse (Table 3). It may be noted that *Erianthus* fibre is stronger due to higher values of breaking length, and tear and burst factors.

Out of 88 clones screened for the characters as mentioned earlier, 23 which had high fibre–pith ratio were sele-

Table 1. Comparative proximate analysis of some raw materials

Parameter	Sugarcane stalk	*Erianthus arundinaceus* stalk	*Saccharum spontaneum* stalk	Bamboo stem
Fiber (%) (OD basis)	14.0	31.0	22.0	40.0
Hot-water solubles (%)	3.7	7.2	11.6	9.4
1% NaOH solubles	29.1	32.0	24.2	27.3
AB extractives (%)	2.7	3.6	4.2	–
Pentosans (%)	23.5	23.9	22.0	18.4
Acid insoluble lignin (%)	20.4	18.0	18.7	28.0
Holocellulose (%)	70.5	69.4	63.2	75.5
Ash (%)	1.8	1.8	3.3	2.5

Table 2. Evaluation of *E. arundinaceus* germplasm

Character	Range
Stalk length (cm)	150–350
Stalk diameter (mm)	14–25
Single stalk weight (g)	130–1100
No. of tillers	12–44
No. of internodes	15–32
Internodal length (cm)	6.2–19.7
Pithiness ratio	1.2–2.4
Brix (%)	1.4–10.0
Sucrose (%)	2.3–7.5
Purity (%)	6.3–64.9
Extraction (%)	39.1–63.1
Fibre (%) (OD basis)	21.3–31.9

cted. These clones were then subjected to proximate analysis and six clones, namely SES 3, SES 159, IJ76-342, IMP1536, Mythan-A and EA-Cuttack, were finally selected based on lignin content and other characters such as rind–cortex ratio, tillers, internodes, cane weight, internode length and flowering nature.

Of the above six clones, all except IJ76-342 are non-flowering. Non-flowering clones have the advantage of indeterminate and uninterrupted vegetative growth. Non-flowering nature will also prevent its natural spread through seed dispersal. Three clones – SES 3, IJ76-342 and EA-Cuttack – had higher stalk weight and hence are likely to give higher yield of stalk and fibre per unit area, thus being more renumerative to the farmer. SES 3 showed higher sucrose content with good purity and has the potential to yield alcohol as a co-product on fermentation. Fibre–pith ratio, extraction % and fibre content were highest in EA-Cuttack. Cane yield for all the six clones and sugarcane (for comparison) is presented in Table 4. The results confirm the observations from initial germplasm screening, where SES 159 was found to be superior among all the clones, viz. SES 159, SES 3, Mythan-A, EA-Cuttack, IMP1536 and IJ76-342. After SES 159, SES 3 (86 t/ha) gave the highest cane yield followed by Mythan-A (79 t/ha), EA-Cuttack (63 t/ha), IMP1536 (57 t/ha) and IJ76-342 (56 t/ha). In comparison, sugarcane (Co 86032) gave 100 t/ha.

Table 3. Unbleached pulp properties of bagasse of sugarcane and *Erianthus*

Pulp property	Sugarcane	*Erianthus*
Total yield of pulp (%)	51–52	53
Kappa number	17–18	15
Brightness (%) ISO	32–34	35.5
Viscosity ops	16–18	22
Pulp strength properties (at 300 ml csf)		
Breaking length (m)	8000	8650
Tear factor	51–52	55
Burst factor	47–48	51

Table 4. Results of cultivation trial of *Erianthus* clones and sugarcane variety

Clone	Cane yield (t/ha)	
	Conventional	Organic
SES 159	98.8	111.2
SES 3	–	86.4
Mythan-A	79.0	–
EA-Cuttack	63.2	–
IMP 1536	57.5	–
IJ76-342	56.1	–
Co 86032 (sugarcane)	100	90

Table 5. Juice analysis results

Clone	pH	COD (ppm)	Brix (%)	Pol (%)	Purity (%)	TRS (%)
SES 3	5.1	60240	6.4	2.2	35.2	4.5
SES 159	5.0	93974	7.9	2.1	26.5	2.5
EA-Cuttack	4.9	89155	7.0	1.5	17.1	2.5
Mythan-A	4.8	81123	6.0	1.0	17.1	3.5
IMP 1536	5.1	69075	8.2	1.4	17.2	2.9
Sugarcane	5.3	60500	20.0	16.0	85.0	0.5

The juice collected during the crushing trial was analysed and the results are presented in Table 5. As expected, the quality of juice, i.e. brix%, pol% and total reducing sugars was found to be poor in all the clones studied, when compared to conventional sugarcane. This is mainly due to higher fibre content in wild cane, which is an added advantage for paper making. Since the juice is not suitable for extracting sugar due to its poor quality, we have explored the possibility of utilizing it for bio-energy gene-

Table 6. Mean value of three plants in each clone

Parameter*	EA-Cuttack	SES 3	SES 159	IJ76-342	Mythan-A	IMP1536	SE	CD
1	436.7	528.3	546.7	461.7	530.0	575.0	18.16	59.20
2	37.17	55.5	74.17	25.83	58.17	62.00	15.17	NS
3	25.83	29.17	51.83	15.00	34.33	40.5	10.83	NS
4	35	39	71	27	47	52	13.20	NS
5	250	353	333	303	346	329	5.73	18.68
6	20.6	23.5	20.8	18.3	20.2	20.0	0.81	2.63
7	28	35	27	28	30	29	3.06	NS
8	10.9	14.3	16.8	13.0	13.7	16.2	1.80	NS
9	600	650	500	450	600	400	0.41	1.33
10	350	450	400	300	350	250	–	–
11	41.67	30.77	20.2	33.33	41.67	37.50	–	–
12	7.1	8.8	9.8	7.3	6.7	4.8	–	–

*1, Plant height (cm); 2, Biomass yield/plant (kg); 3, Stalk yield/plant (kg); 4, No. of millable canes/plant; 5, Stalk length (cm); 6, Stalk diameter (mm): 7, No. of internodes; 8, Internode length (cm); 9, Single cane weight (g); 10, Bagasse weight (single cane) (g); 11, Extraction % and 12, Hand refractometer brix %.

ration, like producing biogas by anaerobic digestion process. The COD value of juice, especially for SES 159 (93,974 mg/l), indicates that theoretically 1 l of juice can produce 40 m^3 of biogas and 1 t of cane, by simple crushing without any milling, can produce roughly about 250 l of juice and 10 m^3 biogas with a calorific value of 5400 kcal/Nm^3. Therefore, juice from 1 t of wild cane would save 6.0 l of furnace oil.

The high-yielding SES 159 gave bagasse yield of 53%, with fibre–pith ratio of 1.83. All the clones studied gave more than 50% bagasse yield, which is much more than the commercial sugarcane where the bagasse yield would be around 28–30%. In the case of fibre–pith ratio, the wild cane clones are in the range of 2.1 : 1–2.8 : 1 against the 1.5 : 1–1.7 : 1 for conventional sugarcane. This indicates that wild cane can produce high yield of good-quality fibre per unit area. Higher fibre–pith ratio allows the use of whole bagasse as such to produce pulp directly without depithing or with mild depithing consisting of 5–10% pith removal, against the conventional depithing consisting of around 25–30% pith removal.

For estimation of biomass and cane yield, small plot trials were taken up both at the Sugarcane Breeding Institute farm as well as on farmers' fields near the paper factory during 2002–03. Trial plots of 10 m^2 in farmers' fields gave about 125 t/ha of millable cane and 173 t/ha of green biomass after one year of growth. Yield trials on the six promising clones (Table 6) were carried out at the Institute farm. On an average, biomass yield was in the range 25–74 kg per plant; stalk yield ranged from 15 to 51 kg per plant; sucrose content range was 1.9–6.8% and fibre content (oven-dry basis) ranged from 21 to 31%. *E. arundinaceus* produces high leaf biomass which can be used to produce either fibre or energy. We have also carried out some studies to utilize the entire aboveground biomass to manufacture bagasse. The leaf also has good calorific value like other bio-fuels and can be used to power boilers or even be utilized for paper production along with bagasse.

The most critical issue facing the Indian industry is the availability of cost-effective fibrous raw materials. There has been a chronic shortage of forest-based raw materials, viz. bamboo and pulpwood. This is likely to escalate with dwindling forest cover. Sugarcane bagasse was considered to be a promising alternative to the other raw materials. There was a surplus of bagasse available for paper mills, especially from efficient sugar industries. However, recently a massive effort by the Government of India to make these factories also produce electricity via cogeneration will create shortage of bagasse for paper manufacturing. The foregoing investigation indicates that wild cane has a good potential as a renewable and sustainable source of fibre and alcohol, and can be a substitute for sugarcane. Initial cultivation trials in farmers' fields and pulping tests carried out at the Tamil Nadu Newsprint and Papers Limited, Pugalur, have been encouraging. The cultivation is similar to that of commercial sugarcane and the seed material (known as 'setts') is stalk-cuttings with nodal buds. The wild cane need not compete or replace existing crops; it can be better grown in the problematic or marginal soil, where no other crop can be cultivated. It may also be grown in the vast uncultivated wastelands. To conclude, it is clear that studies on development of a new source of fibrous raw material such as wild cane can be useful to make the uncultivated wastelands productive and solve the raw material shortage of many bagasse-based pulp and paper industries.

1. Almazan, O., Gonzalez, L. and Galvez, L., The sugarcane, its by-products and co-products. *Sugarcane Int.*, 2001, **19**, 3–8.
2. Bor, N. L., *The Grasses of Burma, Ceylon, India and Pakistan*, Pergamon, London, 1960.
3. Anon., *The Wealth of India – Raw Materials, Volume IX*, Council of Scientific and Industrial Research, New Delhi, 1972, pp. 97–98.
4. Sreenivasan, T. V., Amalraj, V. A. and Jebhadas, A. W., *A Catalogue on Sugarcane Genetic Resources IV: Erianthus spp.* Sugarcane Breeding Institute, Coimbatore, 2001.

Received 30 November 2007; revised accepted 8 October 2008