GRASS SPECIES AS RAW MATERIAL FOR PULP AND PAPER

K.A. Pahkala[1], L. Paavilainen[2] and T. Mela[1]
[1]Institute of Crop and Soil Science, Agricultural Research Centre of Finland, FIN-31600 Jokioinen
[2]Jaakko Pöyry Oy, P.O.Box 4, FIN-01621 Vantaa

ABSTRACT

Paper has been made from grasses and other non-wood materials for over 1900 years. Wood is a relatively new papermaking fibre, only 100 years old. Today the commercial non-wood pulp production accounts for 6% of the global pulp production. The main source for the raw material is plants of the *Gramineae* family. Research on non-wood material has concentrated on grasses like *Miscanthus, Phalaris, Sorghum* and cereals. The fibre properties of grass species studied are similar to those of hardwood. A case study on reed canary grass (*Phalaris arundinacea* L.) showed that the short-fibre fraction obtained from birch can be replaced with grass in fine paper.

KEYWORDS

Grass species, paper making, pulp, pulp properties, reed canary grass, *Phalaris arundinacea*, non-wood, fibre

INTRODUCTION

The earliest information about usage of grasses as a writing material dates back to 3000 BC in Egypt where the pressed pith tissue of papyrus sedge (*Cyperus papyrus* L.) was the most widely used writing material. Actual papermaking was discovered by a Chinese Ts'ai Lun, in 105 AD, when he found a way of making sheets using fibres from hemp rags and mulberry plant. Straw was used for the first time as a raw material for paper in 1800, and in 1827 started the first commercial mill to pulp straw in the USA (Atchison and McGovern, 1987). In the 1830's, Anselme Payen found a resistant fibrous material which exists in most plant tissues (Payen, 1842) the substance, which the French Academy named cellulose in 1839 (Brongiart et al., 1839, Hon, 1994). This was the turning point in the use of all fibres, and it led to the invention of the new pulping methods which used soda, sulphite or sulphate as a cooking chemical. Paper could be made from cereal straw, reeds, esparto grass and even from wood by using these new chemical methods. In the 20th century, wood became the main raw material for paper.

In many countries the wood supplies are not large enough for the rising demand of pulp and paper but, on the other hand, the availability of agroresiduals is high. In recent years, active research has been undertaken in Europe and North America to find a new non-wood raw material for paper production. The driving force was the shortage of short-fibre raw material (hardwood) in Nordic countries which export pulp and paper and, at the same time face the problem of agricultural overproduction. The consumption of paper, especially fine paper, continues to grow, which will increase the demand of short-fibre pulp (Paavilainen, 1996).

Promising species for fibre production include the plant families *Gramineae*, *Leguminosae* and *Malvaceae* (Nieschlag et al., 1960). In recent years the attention has focused in the Nordic countries to grasses and other monocotyledons (Olsson, 1993; Mela et al., 1994). Of a number of field crops studied, reed canary grass (*Phalaris arundinacea* L.) was shown the most promising fine-paper fibre in Finland and in Sweden (Berggren, 1989; Paavilainen and Torgilsson, 1994). Also other grasses like tall fescue (*Festuca arundinacea* Schreber) and cereal straw can be used (Pahkala et al., 1996a). In central Europe, *Miscanthus sinensis* L. and *Sorghum* have aroused interest as paper raw material.

PRODUCTION OF NON-WOOD PULP AND PAPER IN THE WORLD

Commercial non-wood pulp production accounts for 6% of the global pulp production and is forecasted to remain at the same level (Paavilainen et al., 1996a). The biggest producer is China with 80% of the non-wood pulp production in the world (Figure 1). More than 70 % of the raw material used in the Chinese pulp industry is from non-wood plants (Atchison, 1988). The main sources of non-wood raw material are agricultural residues from monocotyledons (Figure 2) such as cereal straw and bagasse which is waste from sugar cane. Bamboo, reeds and some grass plants are grown or collected for pulp industry. The biomass and fibre production capacity of non-wood species is in many cases higher than that of wood species (Table 1).

PROPERTIES OF GRASS FIBRE AS RAW MATERIAL FOR PAPER

Grass fibres originate mainly from the vascular bundles in monocotyledonous stems and leaves or in separate fibre strands which are situated on the outer sides of the vascular bundles. Vascular tissues can be distributed in two circles as in cereal straw and in most temperate grasses, with a continuous cylinder of sclerenchyma close to the periphery. They can also be scattered throughout the stem section as in corn, bamboo and sugar cane (Esau, 1960).

Fibres are dead cells which consist mainly of cell walls made of cellulose, hemicellulose, pectines and lignin. The amount and the composition of these substances affect the pulping properties of the plant. Because the lignin content is lower in grass than in woody species, grasses are easier and faster to pulp. In sulphate process, for instance, only 10 minutes of cooking is needed as compared to 90 minutes for hardwood. Reed canary grass lignin is of the p-hydroxy phenyl-guaiacyl-syringyl type (Galkin et al., 1995) as reported also for other grass species (Lewis and Yamamoto, 1990). The chemical composition of two grass species and wheat is compared to wood species in Table 2. Reed canary grass was collected in early spring as delayed harvest, when the plants were dead. Tall fescue was harvested at late seed stage.

The pulping properties of grass and straw as compared to those of hardwood in the sulphate cooking process are shown in Table 3. The grass species reed canary grass, tall fescue and timothy (*Phleum pratense* L.) were harvested at the seed ripening stage. Reed canary grass was cooked also in early spring as delayed harvest. The cereals rye (*Secale cereale* L.), oat (*Avena sativa* L.), barley (*Hordeum vulgare* L.) and wheat (*Triticum aestivum* L.) were harvested at their usual harvest time in September. Common reed (*Phragmites communis* Trin.) was harvested at the dead stage in winter. Birch (*Betula spp)* chips were obtained from a commercial pulp mill. The pulping characteristics of delayed-harvest reed canary grass, barley and rye are comparable to those of hardwood. The screened pulp yields of cereal straw and delayed-harvest reed canary grass were nearly the same as that of birch, but the amount of uncookable rejects was higher. The kappa numbers, which represent the lignin content and its degradability in pulp, were lower after 10 minutes of cooking than in birch pulp after 90 minutes of cooking (Table 3).

In papermaking the first step is the fibre separation in a mechanical, chemical or semi-chemical pulping process which ruptures the chemical bonds within the vegetable raw material structure, loosening the fibres. Paper is made by mixing different fibre components and additives. When water is removed from the fibre suspension on the paper machine, fibres form fibre-to-fibre bonds, keeping the fibre network together as a thin sheet.

The pulps used depend on the quality requirements of the paper in question. Fine papers are made of chemical pulps from which lignin is removed. The amount of short-fibre pulp in fine paper furnish is more than 60%. The short hardwood fibres (deciduous 0.6-1.9 mm, grass fibres 0.7 mm) improve the paper printability, especially the opacity, surface smoothness, porosity and stiffness. The required strength for runnability is adjusted by adding long softwood fibres from coniferous plants (fibre length 2-5 mm). Non-wood plants like flax, hemp or kenaf (fibre lengths 28 mm, 20 mm 2.7 mm respectively) can be used qualitywise to replace softwood pulp in paper furnish. Long fibres from softwoods are necessary to form a matrix of sufficient strength in the paper sheet.

The proportion of fibre cells in a commercial grass pulp is 65-70% by weight (Gascoigne, 1988; Ilvessalo-Pfäffli, 1995). Except fibre cells the grass pulp contains also small particles from different vessel elements, tracheids, parenchyma cells, sclereids and epidermis which make the grass pulp more heterogeneous than the wood pulp where all fibres originate in the xylem of the stem. The great amount of fines lower the dewatering properties of the pulp and may thus cause runnability problems on the paper machine (Wisur et al., 1993, Paavilainen et al., 1996b). However, the amount of fines decreases, if the leaf fraction, the main source of fines can be decreased or only the straw fraction of the grass is used for pulping.

MINERAL COMPOSITION OF GRASS SPECIES

When grass species are pulped, most frequently the entire plant is used and the raw material contains all cellular elements including inorganic substances from the inner part of plant cells. Undesirable elements in the recovery system of cooking chemicals include potassium (K), chlorine (Cl), aluminium (Al), iron (Fe), silicon (Si), manganese (Mn), magnesium (Mg), calcium (Ca) and nitrogen (N) (Keitaanniemi and Virkola, 1982). One of the most harmful minerals is silicon, and it has to be removed from the process. The mineral contents of several delayed-harvest grass species, reed canary grass, tall fescue, timothy, cocksfoot (*Dactylis glomerata* L.), brome grass (*Bromus inermis* Leyss.) and common reed, were compared with those of cereals and hardwood. Grass biomass has a significantly higher mineral content than wood (Table 4).

The mineral and fibre concentrations of grass biomass are highly dependent on the development stage of the plant at harvest time. The growing conditions, e.g. soil type, fertilization and climate, have a stronger effect on these properties in grass than in woody species (Judt, 1993, Wisur et al., 1993). The mineral contents at various stages of plant development (flowering, seed ripening and delayed harvest) on clay and humus soil are shown in Figure 3. The contents of different minerals were lower on humus soil than on clay soil. Ash, potassium, calcium and nitrogen contents decreased with age (Pahkala et al., 1996b) being lowest at delayed harvest in spring. However, the silica, iron, manganese and aluminium contents were lowest at flowering and highest at delayed harvest. The crude fibre content increased with the age of the plants and it was highest at delayed harvest.

DEVELOPMENT OF REED CANARY GRASS PRODUCTION AND PROCESSING SYSTEM IN FINLAND

In the Agrofibre Research Programme, profitable methods for producing specific, short-fibre raw material from field crops available in Finland were developed and the material was processed to high-quality paper. It encompassed the entire production chain from field to paper mill. Of 17 plant species studied, reed canary grass proved to be one of the most potential source of short fibre (Pahkala et al., 1994). The properties considered important were biomass and pulp yields per hectare as well as mineral content and composition. In Sweden, reed canary grass proved to be also a potential source of bioenergy (Olsson, 1993).

Reed canary grass is a native winterhardy grass species all over the northern hemisphere. It is grown as a forage crop in several countries e.g. in Norway, Russia, Canada and the USA. However, the cultivation practices of reed canary grass grown for paper pulp are different from those for feed purposes. In pulp production the aim is to get a high biomass yield with a high proportion of straw fraction, high fibre and cellulose contents and low mineral content. Reed canary grass is harvested in spring, when the overground parts of the grass are dead, by so called delayed harvesting system. This method gives the highest pulp yield, the highest length-weightened fibre length and the lowest content of fines in the pulp. This is mainly due to a higher relative amount of stem fraction and the lower leaf fraction.

The crop production and harvest systems were developed at the Agricultural Research Centre of Finland and the University of Helsinki. The pulp production and process concepts were tested in pilot-scale trials in late 1995. Reed canary grass grown by Finnish farmers was cooked in a rotating digester at Tervakoski Ltd and bleached at Enso Research Centre. The pulp was made into paper on the pilot machine of the Finnish Pulp and Paper Institute.

The cultivation of reed canary grass for fibre purposes can be carried out as follows: sowing is done in spring without a cover crop, using a narrow row space. Nitrogen fertilization requirement is half of that for feed purposes and weeds are controlled with spring cereal herbicides, if necessary, at the 2-5-leaf stage of the crop. The first harvest for pulping is cut two years after sowing. The harvest period in spring is about 10-15 days when the moisture content of the dead grass is between 10 and 15% and high drying costs can be avoided. The maximum height of the new shoots is then 15-20 cm. Harvesting can be performed by mowing followed by baling. The economical transport distance for the bales to a pulp mill is about 50 km. The variety tests performed on nine sites showed differences in yield levels and straw fractions. Although the varieties bred for forage purposes, Palaton, Vantage and Lara proved to be the most promising ones for fibre production, too, the breeding of reed canary grass for non-food purposes is under way in Finland and in Sweden.

At the pulp mill, leaves, dust and dirt are removed by air fractionation which removes 40% of the silica particles before cooking. The mechanical pretreatment improves the quality of the raw material decreasing the amount of fines and increasing the bleachability of the pulp. Pretreated reed canary grass can be pulped by the same technology as used in wood pulping. Pilot trials made in Finland used the sulphate cooking method. There were no differences in the bleachability of birch pulp and reed canary grass pulp either in the chlorine dioxide or total chlorine-free (TCF) bleaching sequence. In the recovery system, desilication is performed either by precipitation of silicon from a weak black liquour with flue gas or by two-stage causticizing of silica by commercially availably systems (Paavilainen and Tulppala, 1996).

In papermaking, no runnability problems were encountered when the amount of reed canary grass pulp was increased up to 70% of the total fibre on a slow pilot machine. The remaining 30% of the fibre was bleached, long-fibre pine pulp. The dewatering and drying characteristics remained constant when the amount of reed canary grass pulp was increased in the pulp blend. When the proportion of reed canary grass pulp in the paper furnish was increased from 0 to 70%, no critical changes in base paper properties were detected (Table 5). Increasing the proportion of reed canary grass has a favourable effect on the surface strength, smoothness and optical properties of the paper. The tensile and especially the tear strength decreased, but grass addition did not change the TEA value. Reed canary grass is thus a promising short-fibre component for fine paper.

FUTURE PROSPECTS

Future paper consumption trends are characterised by rapidly increasing total papermaking fibre consumption, especially in Asia where the availability of raw material is the key issue in the expansion of the paper industry. Short fibre is there produced mainly from agricultural residues in small mills. Therefore a concept for a simple, cost efficient and environmentally sound small-scale mill is of great importance.

Besides restricted availability of wood raw material, political, environmental and economic issues support a more effective utilisation of existing non-wood fibre sources, especially straw. The research on grass species grown for the pulp and paper industry has also shown promising results and short fibre obtained from forage crops can replace hardwood in fine paper. Plant breeding work on varieties more suitable for fibre purposes is under way in Finland and in Sweden.

The use of non-wood fibres have the public approval. Non-wood fibres offer an alternative in sustainable agriculture and in preserving forest resources when building paper industry. The more efficient utilisation of the agricultural residues and the use field crops grown for fibre purposes require not only the adoption of new technologies and the optimisation of fibre production and processing but, primarily, a new way of thinking.

REFERENCES

Atchison, J. E. and N. J. McGovern.1987. History of paper and the importance of non-wood plant fibres. Pages 1-3, *in* F. Hamilton, B. Leopold and M.J. Kocurek, eds. Pulp and paper manufacture. Secondary fibers and non-wood pulping. Vol. 3. TAPPI and CPPA, Atlanta and Montreal.

Atchison, J. E. 1988. World wide capacities for non-wood plant fiber pulping increasing faster than wood pulping capacities. Pages 25-45, *in* Proceeding of TAPPI Pulping Conference 1988. Book 1, New Orleans, LA.

Berggren, H. 1989. Lusern och rörflen i framtidens massor. Svensk papperstidning **17**: 28- 33.

Brongiart, A., T.J. Pelouze, A.B. Dumas and C.R. Hedb. 1839. Seances Acad. Sci. **8**: 51.

Esau, K. 1960. Anatomy of seed plants. John Wiley & Sons, New York. 376 p.

FAO Production Yearbook 1995. Vol. 49. FAO Statistics Series No. 130. 235 p.

Galkin, S., E. Ämmälahti, I. Kilpeläinen, G. Brunow and A. Hatakka. 1995. Structure of lignin in non-wood plants of potential use for pulp and paper industry. Proc. of The 8th International Symposium on Wood and Pulping Chemistry, June 6-9, 1995, Helsinki, Finland. Vol. 2, pp. 479-482.

Gascoigne, J. A. 1988. Bamboo growth and and utilization. Pages 183-193, *in* A. Wong, ed. Tropical wood pulp symposium '88. Singapore. Proceeding Arbokem. Beaconsfield, Canada.

Hatakka, A., A. Mettälä, T. Härkönen and L. Paavilainen. 1996. Biopulping of gramineous plants by white-rot fungi. Pages 229-232 *in* E. Srebotnik and K. Messner, eds. Biotechnology in the Pulp and Paper Industry: Recent Advances in Applied and Fundamental Research. Faculta-Univ.-Verl., Vienna.

Hon, D. N.-S. 1994. Cellulose: a random walk along its historical path. Cellulose **1**: 1-25.

Ilvessalo-Pfäffli, M.-S. 1995. Fiber Atlas. Identification of papermaking fibers. Springer- Verlag. Berlin. 400 p.

Janson, J., T. Jousimaa, M. Hupa and R. Backman. 1996. Phosphate-based pulping of agrofibre including papermaking and spent liquor recovery. Nordic Pulp and Paper Research Journal **11**:4-9, 14.

Judt, M. 1993. Non-wood plant fibres, will there be a come-back in paper-making? Industrial Crops and Products **2**: 51-57.

Keitaanniemi, O. and N.-E. Virkola. 1982. Undesirable elements in causticizing systems. TAPPI. Vol. 65, **7**: 89-92.

Lewis, N. G. and E. Yamamoto. 1990. Lignin: Occurrence, biogenesis and biodegradation. Annual Review of Plant Physiology and Plant Molecular Biology **41**: 455-496.

Mela, T., A. Hatakka, M. Hemming, J. Janson, M. Järvenpää, B. Lönnberg, L. Paavilainen, K. Pahkala, A. Pehkonen and A. Suokannas. 1994. Production of agrofibre and its suitability for paper manufacture. Pages 85-90, *in* Alternative oilseed and fibre crops for cool and wet regions of Europe. COST 814. European Comission Workshop, April 7-8, 1994. Wageningen.

Nieschlag, H.J., G.H. Nelson, I.A. Wolff and R.E. Perdue. 1960. A search for new fiber crops. TAPPI 43, **3**: 193-201.

Olsson, R. 1993. Production methods and costs for reed canary grass as an energy crop. Conference bioenergy 93, Espoo, Finland. Publications **2**: 201-211.

Paavilainen, L. 1996. Reed canary grass. A new nordic material for high-quality fine papers. Know-How Wire. Jaakko Pöyry Magazine **2** (1996): 8-11.

Paavilainen, L. and R. Torgilsson. 1994. Reed Canary grass - a new nordic papermaking fibre. TAPPI Pulping Conference, San Diego, CA, Nov. 6-10, 1994. pp. 611-618.

Paavilainen, L. and J. Tulppala. 1996. Top-quality agro-based fine paper produced on pilot scale. Tappi Pulping Conference, Nashville, TN, Oct 27-31, 1996. Vol 2, pp. 577-582.

Paavilainen, L., J. Tulppala, A. Varhimo, M. Ranua and J. Pere. 1996a. Production and use of agrofibre in Finland. Final report of the study, IV part. Reed canary grass sulphate pulp as raw material for fine paper. Agricultural Research Center of Finland. Maatalouden tutkimuskeskuksen julkaisuja. Sarja A. 6. 57 p.

Paavilainen, L., J. Paltakari, Z. Cheng and T. Tuhkanen. 1996b. Behaviour of special reed pulp on the paper machine. 3rd International Non-Wood Fibre Pulping and Papermaking Conference, Bejing, Oct 15-18, 1996. Vol 2, pp. 562-572

Pahkala, K., T. Mela and L. Laamanen. 1994. Prospects for the production and use of agrofibre in Finland. Final report of the preliminary study in 1990-1992. Agricultural Research Center of Finland. Maatalouden tutkimuskeskus. Tiedote 12/94. 55 p.

Pahkala, K.A., T.J.N. Mela and L. Laamanen. 1996a. Pulping characteristics and mineral composition of 16 field crops cultivated in Finland. Pages 119-125, *in* J.F. Kennedy, G.O. Phillips and P.A. Williams, eds. The chemistry and processing of wood and plant fibrous materials. Woodhead Publishing Ltd. Great Yarmouth, Cambridge.

Pahkala, K., T. Mela, H. Hakkola, A. Järvi and P. Virkajärvi. 1996b. Production and use of agrofibre in Finland. Final report of the study, I part. Production of agrofibre crops. Agronomy and varieties. Agricultural Research Centre of Finland. Maatalouden tutkimuskeskuksen julkaisuja. Sarja A. 3 (1996), 68 p.

Payen, A. 1842**.** Quatrieme Memoire sur les Developments des Vegetaux, Estrait des Memoires de l'Academic royale des Sciences. Tome VIII des savants etrangers. Paris: Imprimerie Royale.

Wisur, H., L. Sjöberg and P. Ahlgren. 1993. Selecting a potential Swedish fibre crop: fibres and fines in different crops as an indication of their usefulness in pulp and paper production. Industrial Crops and Products **2**: 39-45.

Table 1
Annual dry matter and pulp yields per hectare for different fibre plants. The dry matter yields for cereal straws are estimated by using a harvest index of 0.5, when the straw yield is as high as the grain yield.

Plant species	DM yield t/ha/a	Pulp yield t/ha/a
Wheat straw	[1]2.5	1.1
Oat straw	[1]1.6	0.7
Rye straw	[1]2.2	1.1
Barley straw	[1]2.1	1.9
Rice straw	[2] 3.0	[2]1.2
Bagasse (waste from sugar cane)	[2] 9.0	[2] 4.2
Bamboo	[2] 4.0	[2]1.6
Miscanthus sinensis	[2]12.0	[2]5.7
Reed canary grass	6.0	3.0
Tall fescue	8.0	3.0
Common reed	9.0	4.3
Kenaf	[2]15	[2]6.5
Hemp	[2]12	[2]6.7
Temperate hardwood (birch)	[2]3.4	[2]1.7
Fast growing hardwood (euca)	[2]15.0	[2]7.4
Scandinavian softwood (conif.)	[2]1.5	[2]0.7
Fast growing softwood	[2]8.6	[2]4.0

[1] FAO 1995, [2] Paavilainen and Torgilsson, 1994

Table 2
Lignin, cellulose and hemicellulose content in reed canary grass, tall fescue, wheat straw and hardwood.

	Lignin %	Cellulose %	Hemicellulose %
Reed canary grass[1]	9	35	35
Tall fescue[2]	19	34	29
Wheat straw[3]	20	37	23-30
Birch[3]	21	41	33
Eucalyptus[3]	25	46	26

[1] Hatakka et al., 1996, [2] Janson et al., 1996, [3]Paavilainen and Torgilsson, 1994

Table 3
Screened pulp yield, rejects, kappa number, viscosity and length-weightened fibre length (LW) for crop plant samples and for commercial birch sulphate pulp.

Species	Screened pulp %	Rejects %	Kappa number	Viscosity	LW mm
Reed canary grass, seed stage	41.7	0.7	9.9	1200	0.70
" , delayed harvest	48.3	1.5	15.4	1170	0.70
Tall fescue	32.6	0.1	10.2	910	0.60
Meadow fescue	40.1	0.3	12.0	1080	0.72
Timothy	33.7	1.2	13.5	1020	0.60
Common reed	38.1	11.8	31.7		
Barley	48.3	2.0	19.9		
Wheat	43.4	2.1	10.0		
Rye	48.2	2.6	12.5	1100	0.90
Oat	42.3	0.6	14.4	1180	0.80
Birch	50.0	0	17-20	>1000	0.90

Table 4
Mineral and crude fibre contents in DM of delayed harvest of grass species and cereal straw. Common reed was harvested at the dead stage in winter. Birch chips were obtained from a commercial pulp mill.

Species	Ash %	SiO_2 %	N %	K g/kg	Ca g/kg	Na mg/kg	Fe mg/kg	Cu mg/kg	Mn mg/kg	Al mg/kg	Crude fibre %
Reed canary grass	5.8	4.9	0.63	1.8	1.11	52.4	155.9	5.7	70.3	161	46.0
Tall fescue	5.2	3.9	0.86	1.6	2.50	115.9	444.0	3.8	116.0	471	44.8
Timothy	3.0	2.1	0.54	1.0	1.78	41.6	197.3	2.7	60.2	172	46.9
Cocksfoot	5.7	4.3	0.92	1.7	3.11	87.2	417.0	4.3	227.0	423	41.5
Brome grass	4.2	3.2	0.57	1.3	1.98	86.7	375.8	3.4	89.5	453	45.9
Barley	7.9	4.9	0.64	11.5	1.71		68.0	3.5	20.7	10	41.8
Wheat	5.4	3.5	0.54				97.3	1.8	13.0		45.3
Rye	5.3	3.6	0.52				131.3	3.3	18.8		49.0
Oat	9.1	3.7	0.96				159.0	5.0	46.2		38.4
Common reed	4.2	3.8	0.31				72.7	2.8	13.4		45.9
Birch chips	0.41	0.03	0.11	0.59	0.93	11.3	22.3	0.90	114.0	20	60.7

Table 5
Paper runnability on a paper machine and its printability in a blend of grass/pine pulp as compared with the birch-pine furnish (Paavilainen and Tulppala, 1996).

		Grass	Birch
Runnability	Tensile strength	0	0
	Tensile energy absorption (TEA)	+	0
	Tear strength	-	0
	Drainage	(-)	0
Printability	Opacity/light scattering	0(+)	0
	Bulk/conformability	0	0
	Smoothness	(+)	0
	Porosity	0	0
	Surface strength	+	0
	Stiffness	0	0
	Dimension stability	0(-)	0

Figure 1
Production of non-wood pulps in the world (Jaakko Pöyry).

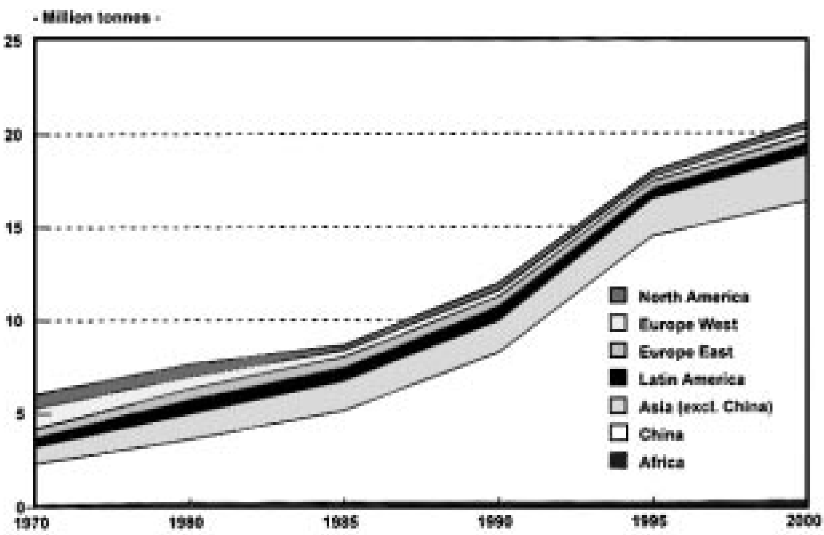

Figure 2
Consumption of non-wood pulps in paper production from different non-wood raw materials (Jaakko Pöyry).

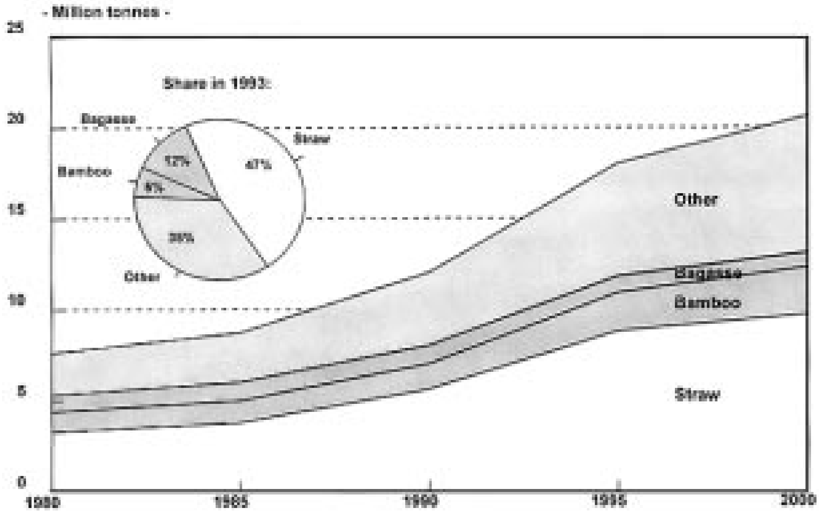

Figure 3
Ash, silica, potassium and crude fibre contents in reed canary grass at different stages of development.