Nonwood Fibre Sources For The Paper Industry.

A Report For Greenpeace International.

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Abstract

The enormous worldwide demand for paper-making raw materials has created serious and growing environmental problems. This document reviews in detail, all the medium to large scale potential sources of nonwood fibre for the paper industry. The plant characteristics and environmental impact of each is examined, as are the potential areas of use, both geographical and technical.
The advantages and disadvantages of utilizing nonwood fibres are discussed, as are the more recent technical developments that could pave the way for large scale nonwood fibre exploitation. Conclusions and recommendations, including those for future research, are given for each plant, and broad conclusions are placed in the detailed summary at the end. All the sources used are cited at the end of each section. It is beyond the scope of this study to discuss the various aspects of the current wood-based paper industry in detail, similarly the subject of recycling is mentioned only where directly relevant.

Clearly the views included within this document, are those of the author and not necessarily those of Greenpeace International.

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Contents.

Section 1. **<u>Introduction.</u>** *See figs. 1-3.*

Paper consists of sheet materials, comprised of small, discrete bonded fibres, usually cellulosic in nature and held together by secondary bonds, most probably hydrogen bonds. The fibres themselves are formed into a sheet on a fine screen from a dilute water suspension. The word paper is derived from papyrus, a sheet made in ancient times by pressing together thin strips of the Egyptian reed *Cyperus papyrus*. Papyrus sheets are not considered to be paper as the individual vegetable fibres were not separated and then reformed.
Paper is traditionally thought to have been invented in China about AD 100, by Cai Lun, a eunuch at the imperial court who used plant fibres of hemp, grass and bamboo. However fragments of hemp-based paper have been carbon dated to as early as 49 BC, and it seems likely that Cai Lun simply improved an existing product.
With the present vast denudation of forests, leading to serious ecological imbalances, even in re-planted forests, it has become imperative to once again turn to nonwood fibres. They have, in fact, inherent advantages over wood based pulping, such as fast growth, quick renewal, less energy and chemical requirements, and a shorter cooking time.
Global production of plant fibres is approximately 5.58 million tonnes, with Asia contributing 75% to the total. The total pulp produced from plant fibres is however less than 7% of the wood pulp total, (6.86% FAO 1986 estimate). The production of fibre crops and nonwood pulp for the paper industry is nearly seven times higher in the developing world than in the developed world, even though it is the latter that uses the majority of paper products, (78% UNEP 1981 figures).
Paper can be produced from any cellulosic raw material, and out of some 250 000 known species of flowering plants, some 400 species belonging to the, *Gramineae*, *Leguminosae*, and *Malvaceae* appear to be the most promising. However barely two dozen species are exploited on a commercial scale for pulp production.
Even though nonwood fibres only comprise approximately 6.8% of the total paper production worldwide, for the pulp and paper industries of most developing countries nonwood fibre supplies are, and will continue to be an indispensable fibrous raw material source. Most developing, and many developed, countries do not have an adequate supply of domestic wood, nor land available for increasing it, (though this should by no means be the primary reason for using nonwood fibres). What they do have is large quantities of fibrous agricultural residues and other nonwood plant fibres.
Nearly 50% of the pulp production in developing countries was based on nonwood fibrous raw materials in 1989. From 1978-1989 nonwood pulp production actually decreased in developed countries by a total of 30.8% (nearly 2.5% per year), whilst over the same period, in developing countries it increased by 130% (nearly 7.9% per year).
In recent years nonwood fibre pulping and papermaking has seen quite significant advances in technology, notably concerning desilication, increased bulk density, high consistency refining, organosolv pulping, and particularly the emergence of bagasse newsprint and kenaf utilization. Significant research is still needed particularly in the fields of chemical recovery, and the reduction of costs concerned with the collection, handling and storage, of in particular, agro-wastes such as straw.

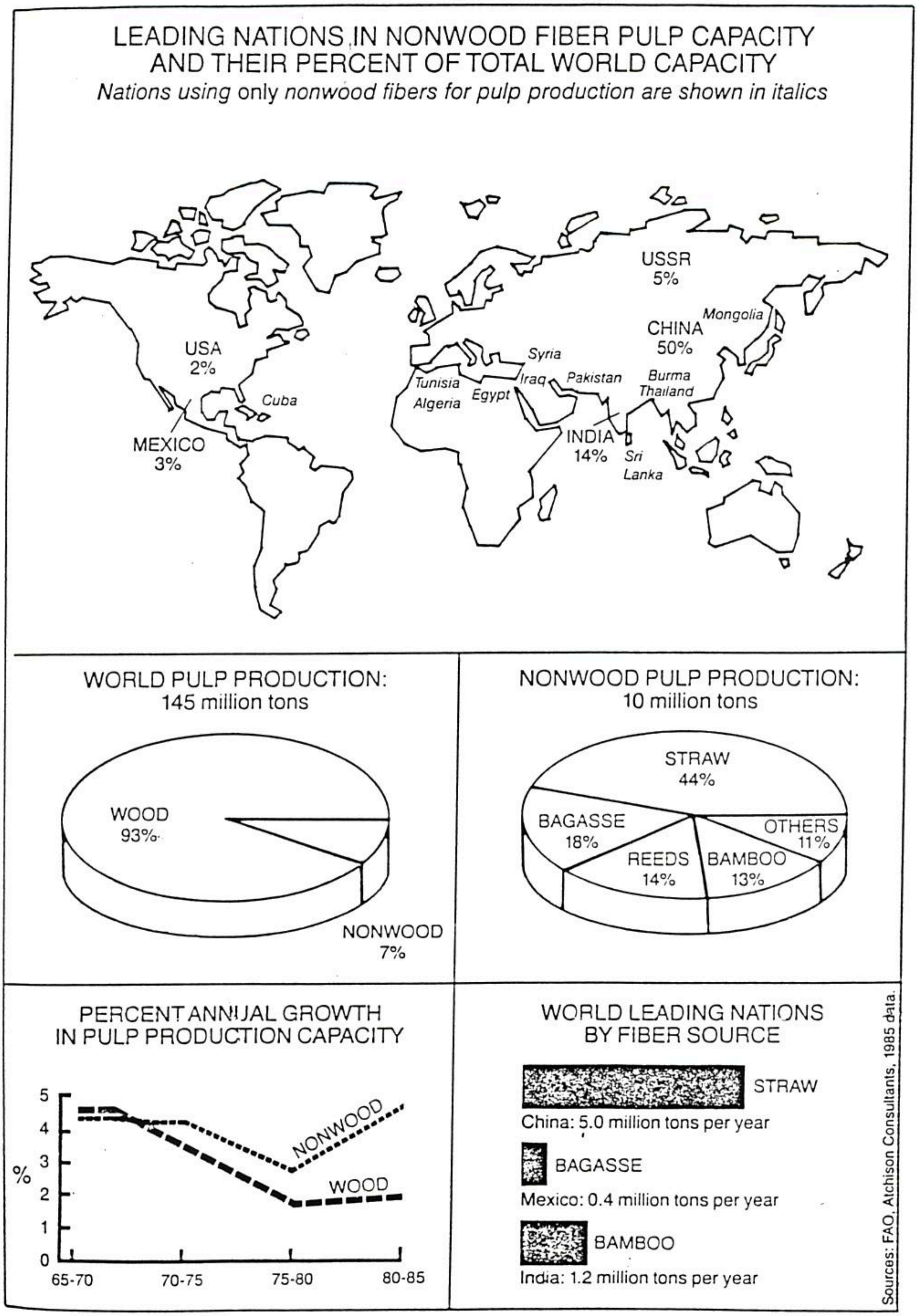

Figure 1. Reproduced from Atchison (1988).

Fig. 2. Top 30 pulp, paper, and paperboard producers and consumers.

THE WORLD'S TOP 30 PRODUCERS AND CONSUMERS 1991

P&B production	1991	% change 91/90	Pulp production	1991	% change 91/90	P&B Consumption	1991	% change 91/91
1. USA	72,151	1.0	1. USA	57,896	1.2	1. USA	76,378	-1.7
2. Japan	29,068	3.5	2. Canada	23,329	2.2	2. Japan	29,106	3.1
3. Canada	16,571	0.2	3. Japan	11,729	3.5	3. Germany	15,931	3.0
4. China, Peo. Rep.	14,787	7.8	4. China, Peo. Rep.	10,750	4.7	4. China, Peo. Rep.	15,888	10.1
5. Germany	12,762	-0.1	5. Sweden	9,769	-1.5	5. United Kingdom	9,177	-2.0
6. Finland	8,777	-2.1	6. Finland	8,483	-4.5	6. France	8,766	0.2
7. Sweden	8,342	-1.0	7. CIS	7,580e	-21.0	7. CIS	7,692e	-20.8
8. CIS	7,682e	-21.6	8. Brazil	4,839	8.7	8. Italy	7,121	0.5
9. France	7,322	3.9	9. France	2,432	10.5	9. Canada	5,688	1.2
10. Italy	5,786	1.0	10. Germany	2,361	-11.2	10. Korea, Rep. of	4,877	13.2
11. United Kingdom	4,951	0.8	11. Norway	2,108	-2.8	11. Spain	4,582	5.6
12. Korea, Rep. of	4,922	8.8	12. South Africa	1,860e	-0.3	12. Brazil	4,182	0.7
13. Brazil	4,888	0.9	13. Portugal	1,619	11.7	13. Taiwan	3,593	8.2
14. Taiwan	3,746	12.3	14. Spain	1,563	1.4	14. Netherlands	3,269	7.2
15. Spain	3,426	-0.6	15. Austria	1,480	1.4	15. Mexico	3,240	8.7
16. Austria	3,090	5.4	16. New Zealand	1,331	0.8	16. Australia	2,645	-5.7
17. Mexico	2,896	0.9	17. India	1,150e	17.9	17. India	2,576	2.0
18. Netherlands	2,860	4.3	18. Chile	1,113	38.3	18. Belgium	2,182	4.4
19. India	2,400	4.6	19. Australia	1,007	-2.1	19. Sweden	1,882	-4.0
20. Australia	2,028	0.8	20. Czecho-Slovakia	978	-12.4	20. South Africa	1,557e	-0.3
21. South Africa	1,905e	0.1	21. Indonesia	800	14.1	21. Switzerland	1,431	-1.2
22. Norway	1,784	-2.0	22. Mexico	705	-8.7	22. Indonesia	1,430	4.2
23. Indonesia	1,700	18.2	23. Argentina	667	-8.1	23. Austria	1,368	6.6
24. Switzerland	1,259	-2.8	24. Italy	597	-11.7	24. Finland	1,262	-9.0
25. Belgium	1,126	-5.9	25. United Kingdom	516	-13.3	25. Turkey	1,148	3.2
26. Czecho-Slovakia	1,045	-21.0	26. Poland	500e	-4.2	26. Thailand	1,373	15.4
27. Thailand	1,015	15.7	27. Belgium	465	-2.5	27. Argentina	1,117	34.3
28. Poland	1,000e	-6.0	28. Taiwan	412	0.2	28. Denmark	1,105	3.5
29. Argentina	963	4.0	29. Turkey	407	0.0	29. Malaysia	1,072	5.6
30. Portugal	866	10.9	30. Korea, Rep. of	327	2.8	30. Hong Kong	1,015e	12.8

Fig. 3. World paper and board production by grade.

WORLD PAPER AND BOARD PRODUCTION BY GRADE 1990-91[1] (1,000 tons)

Region	Newsprint		Pr/wr		Packaging P&B		Other paper		Other board		Total P&B	
	1990	1991	1990	1991	1990	1991	1990	1991	1990	1991	1990	1991
EEC	3,188	3,180	14,271	14,526	12,487	12,606	4,305	4,329	5,093	5,172	39,344	39,813
Scandinavia	4,694	4,230	6,708	6,952	4,234	4,155	892	887	2,684	2,679	19,212	18,903
Other W Europe	598	636	1,700	1,767	1,062	1,069	286	298	581	579	4,227	4,349
Total W. Europe	8,480	8,046	22,679	23,245	17,783	17,830	5,483	5,514	8,358	8,430	62,783	63,065
East Europe	1,980	1,607	2,298	1,869	4,839	4,017	2,918	1,985	2,688	2,566	14,723	12,044
Total Europe	10,460	9,653	24,977	25,114	22,622	21,847	8,401	7,499	11,046	10,996	77,506	75,109
North America	15,065	15,182	23,697	23,447	37,265	38,310	7,060	6,927	4,924	4,856	88,011	88,722
Latin America	981	969	2,506	2,551	4,792	4,922	1,567	1,571	936	959	10,782	10,972
Asia	5,256	5,310	15,385	16,208	22,487	24,146	7,086	7,499	6,857	7,285	57,071	60,448
Australasia	679	721	444	424	1,372	1,366	256	253	70	64	2,821	2,828
Africa	415	399	606	601	1,183	1,195	196	199	336	338	2,736	2,732
Total	32,856	32,234	67,615	68,345	89,721	91,786	24,566	23,948	24,169	24,498	238,927	240,811

1: For countries where breakdown by grade is not possible (i.e., not specified or no estimate possible) total output has been divided between other paper and other board.

ESTIMATED AVAILABILITY OF AGRO-BASED FIBROUS WASTE MATERIALS, 1982

Raw material	Potentially available (1,000 tons)
Sugar cane bagasse	75,000
Wheat straw	570,000
Rice	320,000
Oat straw	60,000
Barley straw	150,000
Rye straw	40,000
Seed flax straw	2,000
Grass seed straw	3,000
Total straw	1,145,000
Total	1,220,000

Source: Josef E. Atchison Consultants.

Fig. 4. Availability of agro-fibres, reproduced from Judt 1991.

Fig. 5. World pulp production by grade.

WORLD PULP PRODUCTION BY GRADE 1990-91[1] (1,000 tons)

Region	Chemical Pulp		Mechanical Pulp		Other Pulp		Total Pulp	
	1990	1991	1990	1991	1990	1991	1990	1991
EEC	5,971	6,086	3,569	3,508	387	235	9,927	9,829
Scandinavia	12,866	12,710	7,580	7,158	523	492	20,969	20,360
Other W. Europe	1,087	1,096	572	571	142	140	1,801	1,807
Total W. Europe	19,924	19,892	11,721	11,237	1,052	867	32,697	31,996
E. Europe	10,071	8,284	2,405	1,825	138	122	12,614	10,231
Total Europe	29,995	28,176	14,126	13,062	1,190	989	45,311	42,227
North America	62,349	63,302	16,277	16,457	1,402	1,466	80,028	81,225
Latin America	5,712	6,386	721	732	826	720	7,259	7,838
Asia	18,963	19,988	2,982	2,976	3,291	3,422	25,236	26,386
Australasia	1,225	1,178	1,022	1,058	102	102	2,349	2,338
Africa	1,356	1,366	439	425	592	592	2,387	2,383
Total	119,600	120,396	35,567	34,710	7,403	7,291	162,570	162,397

1: For countries where no breakdown by grade is possible (i.e., not specified or no estimate possible) total output has been allocated to the Other Pulp category.

Fig. 6. Apparent per capita consumption.

1991 APPARENT PER CAPITA CONSUMPTION (kg)

1. USA	302.3
2. Finland	252.4
3. Japan	234.7
4. Belgium	222.7
5. Sweden	218.8
6. Netherlands	216.0
7. Denmark	212.5
8. Canada	210.7
9. Switzerland	209.5
10. Singapore	207.0e
11. German Fed. Rep.	199.9
12. Austria	174.9
13. Taiwan	174.4
14. Hong Kong	170.5e
15. Luxembourg	168.8
16. New Zealand	162.3
17. United Kingdom	159.6
18. Australia.	154.7
19. France	154.6
20. Norway	153.3
21. Italy	123.3
22. Slovenia	119.0
23. Spain	115.4
24. Korea, Rep. of	112.9
25. Iceland	103.8
26. Israel	102.8
27. Ireland	96.4e
28. Cyprus	93.1e
29. Portugal	79.2
30. Malta	70.0e

Note: Apparent P&B consumptions only.

Figs. 2,3,5,& 6, reproduced from Tappi Jnl. July 1992.

1990-91 THE WORLD'S PULP, PAPER & BOARD

Country	Population (1,000)	Number of mills P&B	Number of mills Pulp	Capacity (1,000 tons) P&B	Capacity (1,000 tons) Pulp	Per capita (kg)	Apparent consumption (1,000 tons) P&B 1990	P&B 1991	Pulp 1990	Pulp 1991	Production (1,000 tons) P&B 1990	P&B 1991	Pulp 1990	Pulp 1991
EUROPE														
Belgium	9,800	15	3	1,250	463	222.7	2,091	2,182	736	685	1,197	1,126	477	465
Denmark	5,200	6	2	340	105	212.5	1,068	1,105	151	81	335	356	102	66
France	56,700	150	21	8,060	2,920	154.6	8,752	8,766	3,652	3,914	7,046	7,322	2,200	2,432
Germany[1]	79,700	241	42	14,619	2,135	199.9	15,461	15,931	6,002	5,951	12,773	12,762	2,659	2,361
Greece	10,256	25	2	500	75	62.8	635	644	185	207	347	323	35	35
Ireland	3,733	1	0	40e	0	96.4	356	360	0	0	35	35	0	0
Italy	57,750	315	22	6,410	950	123.3	7,084	7,121	2,731	2,932	5,731	5,786	676	597
Luxembourg	385	0	0	0	0	168.8	62	65	0	0	0	0	0	0
Netherlands	15,131	32	2	2,963	198	216.0	3,050	3,269	826	800	2,742	2,860	192	175
Portugal	9,853	90	8	1,080e	1,670	79.2	723	780	454	539	781	866	1,449	1,619
Spain	39,700	157	21	3,770	1,730	115.4	4,341	4,582	1,400	1,349	3,445	3,426	1,542	1,563
United Kingdom	57,500	93	6	5,740	612	159.6	9,361	9,177	2,523	2,395	4,912	4,951	595	516
EEC	345,708	1,125	129	44,772	10,858	156.1	52,984	53,982	18,660	18,853	39,344	39,813	9,927	9,829
Finland	5,000	45	46	10,115	9,830	252.4	1,387	1,262	7,504	7,240	8,966	8,777	8,886	8,483
Norway	4,200	19	22	1,990	2,590	153.3	639	644	1,652	1,587	1,820	1,784	2,169	2,108
Sweden	8,600	54	53	9,190	10,885	218.8	1,961	1,882	7,375	7,114	8,426	8,342	9,914	9,769
Nordic	17,800	118	121	21,295	23,305	212.8	3,987	3,788	16,531	15,941	19,212	18,903	20,969	20,360
Austria	7,823	31	11	3,504	1,725	174.9	1,283	1,368	1,661	1,718	2,932	3,090	1,460	1,480
Iceland	260	0	0	0	0	103.8	26	27	0	0	0	0	0	0
Malta	357	0	0	0	0	70.0	25	25	0	0	0	0	0	0
Switzerland	6,832	29	6	1,335	283	209.5	1,448	1,431	630	636	1,295	1,259	341	327
Other W. Europe	15,272	60	17	4,839	2,008	186.7	2,782	2,851	2,291	2,354	4,227	4,349	1,801	1,807
Total W. Europe	378,780	1,303	267	70,906	36,171	160.0	59,753	60,621	37,482	37,148	62,783	63,065	32,697	31,996
Albania	3,251	4	4	15e	15e	2.8	15	9	10	6	10	6	10	6
Bosnia-Hercegovina	4,441	5	3	340	245	55.2	305	245	209	190	290	230	199	180
Bulgaria	8,600	11	3	460	160	31.4	333	270	185	147	276	244	113	97
CIS[2]	280,780	161	50	11,065e	10,780e	27.4	9,713	7,692	9,150	7,420	9,800	7,682	9,600	7,580
Croatia	4,680	4	4	200e	175e	36.3	197	170	156	110	176	150	140	100
Czechoslovakia	15,599	37	19	1,550	1,120	62.2	1,219	970	971	832	1,323	1,045	1,117	978
Estonia	1,581	4	2	87	101	25.3	0	40	0	45	0	40	0	45
Hungary	10,000	9	4	588	72	41.3	557	413	200	142	443	358	67	46
Latvia	2,687	4	1	143	66	29.0	0	78	0	50	0	78	0	50
Lithuania	3,752	5	1	205	53	29.3	0	110	0	25	0	110	0	25
Macedonia[3]	2,088	2	2	38	50e	22.0	44	46	34	30	38	40	34	30
Poland	38,592	35e	17e	1,500e	1,000e	21.6	846	835	579	545	1,064	1,000	522	500
Romania	23,200	15	17	905	953	14.4	514	333	484	327	546	358	445	305
Slovenia	2,000	9	5	550	240	119.0	244	238	273	233	474	423	205	129
Yugoslavia (New)[4]	10,408	8	7	325e	200e	29.3	306	305	182	175	283	280	162	160
E. Europe	411,659	313	139	17,971	15,230	28.6	14,293	11,754	12,433	10,277	14,723	12,044	12,614	10,231
Total Europe	790,439	1,616	406	88,877	51,401	91.6	74,046	72,375	49,915	47,425	77,506	75,109	45,311	42,227
NORTH AMERICA														
Canada	27,000	115	35	19,075	27,498	210.7	5,622	5,688	15,393	14,907	16,540	16,571	22,830	23,329
USA	252,626	544	210	78,890	61,147	302.3	77,684	76,378	56,280	56,680	71,471	72,151	57,198	57,896
North America	279,626	659	245	97,965	88,645	293.5	83,306	82,066	71,673	71,587	88,011	88,722	80,028	81,225
ASIA														
Afghanistan	17,712	0	0	0	0	0.2	3	3	0	0	0	0	0	0
Bahrain	475	0	0	0	0	14.7	7	7	0	0	0	0	0	0
Bangladesh	118,105	9	7	135	126	1.4	169	169	120	120	133	133	100	100
Bhutan	1,637	0	0	0	0	0.6	1	1	0	0	0	0	0	0
Brunei	300	0	0	0	0	10.0	3	3	0	0	0	0	0	0
Burma	42,576	3	2	31	30e	1.1	48	48	29	29	28	28	29	29
Cambodia	8,380	0	0	0	0	0.2	2	2	0	0	0	0	0	0
China Peo. Rep.[5]	1,158,230	250	176	15,500	11,000	13.7	14,429	15,888	10,608	11,421	13,719	14,787	10,270	10,750
Cyprus	720	1	0	10e	0	93.1	67	67	0	0	0	0	0	0
Hong Kong	5,953	1	0	120	0	170.5	900	1,015	0	0	80	115	0	0
India	843,100	327	218	3,300	1,450e	3.1	2,525	2,576	1,125	1,300	2,295	2,400	975	1,150
Indonesia	187,617	46	16	2,374	1,212	7.6	1,372	1,430	737	935	1,438	1,700	701	800
Iran	58,000	6	2	315	188	11.1	575	646	140	165	211	235	90	100
Iraq	18,000	2	2	144	90	0.7	125	13	20	1	55	13	3	1
Israel	5,090	6	0	200	0	102.8	503	523	62	58	193	198	0	0
Japan	124,000	444	57	32,414	15,082	234.7	28,220	29,106	14,203	14,648	28,086	29,068	11,328	11,729
Jordan	4,132	3	0	18	0	16.2	73	67	8	9	15	15	0	0
Korea, Peo. Rep.	22,214	6	2	100e	80e	3.6	80	80	68	65	80	80	60	60
Korea, Rep. of	43,210	139	5	5,294	400	112.9	4,310	4,877	1,453	1,597	4,524	4,922	318	327
Kuwait	2,056	1	0	25e	0	7.8	52	16	7	3	12	6	0	0
Laos	4,182	0	0	0	0	0.2	1	1	0	0	0	0	0	0
Lebanon	2,759	3	0	50e	0	9.1	25	25	2	2	15	15	0	0
Macao	326	0	0	0	0	15.3	4	5	0	0	0	0	0	0
Malaysia	18,000	15	1	278	140e	59.6	1,015	1,072	147	150	275	322	120	120
Mongolia	2,259	1	1	10e	6e	8.9	20	20	5	5	5	5	5	5
Nepal	19,539	2	2	10e	8e	1.1	21	21	3	3	7	7	3	3
Oman	1,556	0	0	0	0	4.5	7	7	0	0	0	0	0	0
Pakistan	126,155	34	1	278	100	2.5	293	310	116	110	131	136	81	70
Philippines	63,935	32	4	577	208	9.0	563	574	184	185	466	472	127	125
Qatar	389	0	0	0	0	28.3	11	11	0	0	0	0	0	0
Saudi Arabia	14,636	0	0	0	0	8.2	115	120	0	0	0	0	0	0
Singapore	2,730	2	0	80	0	207.0	510	565	6	10	80	85	0	0
Sri Lanka	17,000	3	2	38	11	1.4	19	23	8	16	19	23	8	12
Syria	15,500	16	16	12e	14	1.0	14	16	12	14	10	12	11	13
Taiwan	20,600	162	3	4,500	455	174.4	3,320	3,593	854	1,022	3,337	3,746	411	412
Thailand	57,500	35	3	1,225	153	23.9	1,190	1,373	325	365	877	1,015	159	143
Turkey	58,500	29	14	1,162	728	19.6	1,112	1,148	502	529	920	850	407	407
United Arab Emirates	1,635	0	0	0	0	49.5	76	81	0	0	0	0	0	0
Vietnam	68,167	30	1	120e	60e	1.0	66	66	40	40	60	60	30	30
Yemen	9,540	0	0	0	0	1.9	5	18	0	0	0	0	0	0
Asia	3,166,315	1,608	535	68,320	31,541	20.7	61,851	65,586	30,784	32,802	57,071	60,448	25,236	26,386

Fig. 7. The worlds pulp,paper and board industry, production and trade. Continued over page.

INDUSTRY: PRODUCTION AND TRADE

Country	Population (1,000)	Number of mills		Capacity (1,000 tons)		Per capita (kg)	Apparent consumption (1,000 tons)				Production (1,000 tons)			
		P&B	Pulp	P&B	Pulp		P&B		Pulp		P&B		Pulp	
							1989	1990	1989	1990	1989	1990	1989	1990
LATIN AMERICA														
Argentina	33,092	100	25	1,350	871	33.8	832	1,117	625	633	926	963	726	667
Bahamas	236	0	0	0	0	25.4	5	6	0	0	0	0	0	0
Barbados	261	0	0	0	0	26.8	7	7	0	0	0	0	0	0
Belize	182	0	0	0	0	16.5	3	3	0	0	0	0	0	0
Bolivia	7,504	1	0	2e	0	2.9	21	22	2	2	1	2	0	0
Brazil	146,000	141	38	5,874	5,298	28.6	4,151	4,182	3,492	3,560	4,844	4,888	4,453	4,839
Chile	13,398	10	11	494	1,151	35.8	417	479	227	448	462	485	805	1,113
Colombia	33,627	22	7	667	333	19.3	610	650	289	326	534	559	245	266
Costa Rica	3,069	1	1	18	7	52.8	147	162	9	9	18	18	7	7
Cuba	10,897	12	4	255	110	17.7	249	193	71	60	123	118	34	35
Dominican Rep.	7,344	2	0	15e	0	8.9	65	65	1	1	9	9	0	0
Ecuador	11,059	5	1	70	35e	29.6	301	327	24	22	68	68	12	12
El Salvador	5,433	3	0	50e	0	12.3	67	67	7	3	29	29	0	0
Guatemala	9,250	4	1	64	100	12.0	110	111	12	12	49	50	0	0
Guyana	806	0	0	0	0	8.7	7	7	0	0	0	0	0	0
Haiti	6,630	0	0	0	0	0.8	6	5	0	0	0	0	0	0
Honduras	5,253	0	0	0	0	13.3	65	70	0	0	0	0	0	0
Jamaica	2,530	1	0	20	0	34.8	88	88	1	1	13	13	0	0
Mexico	83,000	68	15	3,815	1,081	39.0	2,982	3,240	1,079	1,025	2,871	2,896	772	705
Neth. Antilles	189	0	0	0	0	21.2	4	4	0	0	0	0	0	0
Nicaragua	4,025	0	0	0	0	4.2	13	17	0	0	0	0	0	0
Panama	2,424	3	0	30e	0	48.7	118	118	2	1	28	28	0	0
Paraguay	4,290	4	1	11	2e	11.4	29	49	0	0	10	11	0	0
Peru	22,032	17	3	220	270	6.4	145	141	102	95	122	118	84	80
Surinam	415	0	0	0	0	12.0	5	5	0	0	0	0	0	0
Trinidad/Tobago	1,318	0	0	0	0	26.6	34	35	0	0	0	0	0	0
Uruguay	3,125	5	2	83	27e	22.1	69	69	33	33	66	66	26	26
Venezuela	20,000	12	4	839	215	39.4	688	788	273	256	609	651	95	88
Latin America	**437,389**	**411**	**113**	**13,877**	**9,500**	**27.5**	**11,238**	**12,027**	**6,249**	**6,487**	**10,782**	**10,972**	**7,259**	**7,838**
AUSTRALASIA														
Australia	17,103	21	10	2,500e	1,100	154.7	2,805	2,645	1,268	1,142	2,011	2,028	1,029	1,007
Fiji	700	0	0	0	0	21.4	14	15	0	0	0	0	0	0
New Caledonia	160	0	0	0	0	12.5	2	2	0	0	0	0	0	0
New Zealand	3,450	6	7	953	1,464	162.3	579	560	707	692	810	800	1,320	1,331
Papua New Guinea	3,990	0	0	0	0	1.5	6	6	0	0	0	0	0	0
Samoa	215	0	0	0	0	14.0	3	3	0	0	0	0	0	0
Australasia	**25,618**	**27**	**17**	**3,453**	**2,564**	**126.1**	**3,409**	**3,231**	**1,975**	**1,834**	**2,821**	**2,828**	**2,349**	**2,338**
AFRICA														
Algeria	25,324	5	3	128	106	6.8	208	172	70	67	91	91	2	1
Angola	10,280	2	1	30e	45e	1.8	19	19	15	15	15	15	15	15
Benin	4,747	0	0	0	0	0.8	4	4	0	0	0	0	0	0
Botswana	1,346	0	0	0	0	1.5	2	2	0	0	0	0	0	0
Burkina Faso	9,252	0	0	0	0	0.2	2	2	0	0	0	0	0	0
Burundi	5,665	0	0	0	0	0.5	3	3	0	0	0	0	0	0
Cameroon	12,201	0	0	0	0	0.8	10	10	0	0	0	0	0	0
Central African Rep.	3,087	0	0	0	0	0.3	1	1	0	0	0	0	0	0
Chad	5,843	0	0	0	0	0.2	1	1	0	0	0	0	0	0
Congo	2,376	0	0	0	0	0.4	1	1	0	0	0	0	0	0
Egypt	63,773	18	2	220	62	9.2	581	589	124	130	223	225	56	60
Ethiopia	50,676	1	1	15	7e	0.3	15	14	6	5	8	8	2	3
Gabon	1,200	0	0	0	0	1.7	2	2	0	0	0	0	0	0
Gambia	880	0	0	0	0	2.3	2	2	0	0	0	0	0	0
Ghana	15,480	0	0	0	0	0.3	4	4	0	0	0	0	0	0
Guinea	5,974	0	0	0	0	0.8	5	5	0	0	0	0	0	0
Guinea-Bissau	1,021	0	0	0	0	1.0	1	1	0	0	0	0	0	0
Ivory Coast	12,456	0	0	0	0	6.4	80	80	0	0	0	0	0	0
Kenya	27,200	6	1	142	131	3.7	99	100	66	69	91	92	65	68
Lesotho	1,852	0	0	0	0	1.1	2	2	0	0	0	0	0	0
Liberia	2,686	0	0	0	0	0.4	1	1	0	0	0	0	0	0
Libya	4,766	10	0	10e	0	3.4	16	16	3	3	6	6	0	0
Madagascar	11,000	2	2	28	6	0.5	10	6	7	4	9	5	4	2
Malawi	6,838	0	0	0	0	2.3	16	16	0	0	0	0	0	0
Mali	9,494	0	0	0	0	0.1	1	1	0	0	0	0	0	0
Mauritania	2,058	0	0	0	0	1.9	4	4	0	0	0	0	0	0
Mauritius	1,314	0	0	0	0	5.3	7	7	0	0	0	0	0	0
Morocco	28,000	7	1	130	100	8.7	216	243	22	45	119	117	100	87
Mozambique	16,124	2	0	10e	0	0.8	13	13	0	0	1	1	0	0
Namibia	1,856	0	0	0	0	1.1	2	2	0	0	0	0	0	0
Niger	7,954	0	0	0	0	0.4	3	3	0	0	0	0	0	0
Nigeria	111,894	3	3	230	200	2.9	314	330	45	26	74	60	34	17
Rwanda	7,452	0	0	0	0	0.5	4	4	0	0	0	0	0	0
Seychelles Is.	61	0	0	0	0	65.6	4	4	0	0	0	0	0	0
Senegal	7,504	0	0	0	0	0.5	4	4	0	0	0	0	0	0
Sierra Leone	4,313	0	0	0	0	0.2	1	1	0	0	0	0	0	0
Somalia	7,680	0	0	0	0	0.1	1	1	0	0	0	0	0	0
South Africa	36,077	19	9	2,225	2,256	43.2	1,561	1,557	1,380	1,375	1,904	1,905	1,865	1,860
Sudan	25,931	2	0	4	0	0.5	26	13	0	0	4	3	0	0
Swaziland	700	1	1	30	180	5.7	3	4	-3	3	25	25	130	158
Tanzania	28,283	2	4	69	76e	1.0	18	29	52	50	29	40	52	50
Togo	3,612	0	0	0	0	0.0	0	0	0	0	0	0	0	0
Tunisia	8,372	5	1	50e	25e	11.6	95	97	27	29	40	42	20	20
Uganda	19,496	1	0	5e	0	0.4	8	8	0	0	3	3	0	0
Zaire	36,636	1	0	4e	0	0.3	11	11	2	1	3	3	0	0
Zambia	8,823	1	0	13	0	1.6	14	14	1	1	4	4	0	0
Zimbabwe	10,001	3	2	90	42	9.7	97	97	64	64	87	87	42	42
Africa	**669,558**	**91**	**31**	**3,433**	**3,236**	**5.2**	**3,492**	**3,500**	**1,881**	**1,887**	**2,736**	**2,732**	**2,387**	**2,383**
TOTAL WORLD	**5,368,945**	**4,412**	**1,347**	**275,925**	**186,887**	**44.5**	**237,342**	**238,785**	**162,477**	**162,022**	**238,927**	**240,811**	**162,570**	**162,397**

Fig. 7. Continued from over page.

Paper made from agro-wastes could be the first step to increased production as this will give lower and more stable factory gate prices. The increased demand for fibres with high tear strength, caused by weakening during recycling, could be met by nonwood pulps. Efforts to encourage the use of nonwood fibres, such as the tax incentives offered by the Indian Government should be encouraged, and those incentives given to wood pulp industries, particularly those in countries with declining forest reserves, should be reconsidered, as they are not only positively encouraging deforestation, but by maintaining an artificially low price, they do not allow competitive access to the pulp and paper market. In short, the options for use of nonwood fibres and agro-wastes in particular, are enormous, but as yet it is only those countries forced by economic necessity to look elsewhere for their fibre resources that appear willing to commit incentives and support toward the utilization of these resources.

Section 2.

Disadvantages and advantages associated with pulping nonwood fibres.

Several problems are inherent to most nonwood resources, agricultural fibres in particular, these are set out below;

1. A low bulk density, ranging from 80-85kg m-3. Not a problem with bamboo, bagasse, roselle, and kenaf which are higher.
2. Alternative competing uses. Particularly animal feed, fertilizer, and with bagasse a power source.
3. Seasonal nature. A steady year round supply requires bulk storage. This problem has been effectively overcome with developments in bagasse technology which are being transferred to other resources.
4. The material is often scattered over a wide area. This is not a problem with bagasse which is of course located at the sugarcane plant. It was overcome in China by the setting up of local paper mills associated with farming co-operatives.
5. High costs of collection, handling and storage. Labour costs in developing countries are substantially lower than in the developed countries, where this would be more of a problem. Research is needed in this area as a high priority.
6. Some require de-pithing. This adds to overall costs.
7. Cleaning costs. Preparing the fibres for pulping remains labour intensive. Investment in technology is required to reduce costs.
8. High moisture content. This accelerates biodegradation. Research into bagasse storage is helping to reduce this problem, bulk loss is now substantially less.
9. Small cell size and silica-rich epidermis. Most existing technology is designed to cater for longer fibres, and a less silica rich liquor. With investment in new technology, aimed specifically at nonwood pulping, this would be less of a problem.

Many of these problems are already being overcome, and nonwood fibres pulps do have some inherent advantages over traditional wood pulps:

1. Open cell structure. This allows almost instantaneous liquor penetration.
2. Reduced cooking time. Reduces costs, eg. fuel consumption.
3. Reduced cooking temperature. Reduces costs, eg. fuel consumption.
4. Reduced fuel consumption, see above.
5. Reduced chemical input. Nonwood pulps require less chemicals for pulping.
6. Low in lignin. Less time required for cooking and bleaching.
7. Higher amounts of hemi-cellulose required for pulp production. Higher yield.
8. Some nonwood fibre crops produce a higher yield per hectare, therefore a more efficient use of the land.
9. Agricultural fibres are readily available, they do not require large scale environmental damage or exploitation.
10. They may provide valuable cash crops in areas of difficult terrain or harsh climate.
11. After each cycle of wastepaper recycling, tear strength is lowered, nonwood fibres with high tear strengths appear ideal as a furnish.
12. The current disposal of unused agro-waste damages the environment.

A more detailed account of the various environmental impacts follows this section.

A more detailed account of the various environmental impacts follows this section.

Relative costs compared with wood-based fibres.

Due to the higher raw fibre characteristics and their "speciality" characteristics, nonwood fibre pulps command higher prices than softwood and hardwood pulps. Judt (1992), set out the following scheme based on the pulp price situation in October 1991.

* Category 1. Well-cleaned, bleached fibre pulps (abaca, flax, hemp, and sisal). *$2,400- 1,800* per tonne.
* Category 2. Not so well-cleaned, unbleached fibres (hemp, flax, kenaf, cotton linters). *$1,800-1,200* per tonne.
* Category 3. Special softwood pulps. *$850* per tonne.
* Category 4. Normal softwood pulps. *$750-550* per tonne.
* Category 5. Normal hardwood pulps. *$550-450* per tonne.

It is easy to see why the market for nonwood plant fibres is in the speciality paper field, with production at such low levels, and prices high.

Section 3. 3.1 Environmental impact of nonwood fibre pulping.

There is little doubt among those who write and discuss nonwood pulping, that it is more "environmentally friendly", than conventional wood pulping. This view is based on the knowledge that nonwood pulps require fewer chemicals, less energy, and less water to produce. Also nonwood products are bought with the knowledge that they are renewable, and sustainable, and they have helped to prevent deforestation.
The label "environmentally friendly" is likely to be very important if nonwood paper grades are to increase in importance, particularly in the developed countries. Consumer demand has played an important role in the development of recycled paper grades and chlorine free grades, indeed at present consumer demand for these products cuurently outweighs supply, creating a genuine price premium. It is possible that this under supply will result in a move toward greater use of nonwood, recycled and total chlorine-free paper grades.
Recent articles in the paper industry journals are already describing the 1990s as the "green decade". Much of this is clearly hype, aimed at persuading governments and populations that steps are already being taken to "clean up " paper production. Nonetheless, there is a growing environmental concern amongst most local, national and supra-national authorities, this combined with the work of green pressure groups, is resulting in mandatory re-cycling programmes, and legislative measures to restrict pollution. Consumer pressure has created new markets for "green" products, though a broad agreement on terms such as "chlorine free", "total chlorine free", "non chlorine compound", "elemental chlorine free", etc. is still required. By the end of the 1990s it is expected that a major percentage of the paper supplied to western Europe will be totally chlorine-free.
However it is questionable how far countries can go to achieve "environmentally friendly" goals without restricting imports, a broad base of supra-national agreement is needed. The General Agreement on Tariffs and Trade (GATT), recently ruled that the USA could not restrict imports from a country simply because they have "different" environmental policies, though this is currently under review.

The major environmental problem created by the current production of nonwood pulp, is the inability to recover liquors, caused indirectly by the relatively small scale of most nonwood mills. The technology developed for the large scale paper mills is difficult to scale down. Liqour and silica concentrations also tend to be higher than for conventional paper mills. However it seems only a matter of time before fully closed systems (effluent free), can be created for both nonwood and wood pulps. This is clearly an area, particularly in nonwood research (where less work has been carried out), that requires greater investment. It is already possible to produce acceptable grades of nonwood pulp from a chlorine-free process.

To conclude, there is little doubt that increased use of nonwood pulps at the expense of conventional wood pulps would be environmentally advantageous. Agro-residues in particular reduce the pressure on already depleted forest resources, (this may not be the case for fibre farms), they do not increase the strain on the existing ecological balance, and they provide wealth and labour to often impoverished rural areas. Their primary environmental advantage remains, that they are renewable <u>and</u> sustainable to a far greater extent than wood-based pulps.

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Section 4. 4.1 Detailed analysis of potential nonwood fibre sources.

See tables 1 & 2.
The following section deals with each potential fibre source individually. Only those regarded by the paper industry or independent researchers as acceptable or potentially viable are reviewed. Values given for such things as fibre length and yield may be at variance with some of the figures in the accompanying diagrams, those within the text are regarded by the author as the most accurate.
Specific sources for each plant, follow each review, whilst the more general references are found at the end of this section.

4.2 *Bast (Stem) Fibre Sources.*

4.2.*1* Bagasse.

Saccharum

Origin. Asia.

Theoretical Geographical Distribution. Sub-tropical and warm temperate.

Plant morphology and physical characteristics. Bagasse is the fibrous residue from sugarcane, *Saccharum*, after the cane has been harvested and processed. With regard to physical structure bagasse has two main components, the inner pith and the outer fibre. The true fibre comprises 50% of the dry weight of the cane. The two portions must be separated prior to pulping. Sugarcane stalks reach a height of 3-5m, and have a diameter of 5-6cm. They take from 8-18 months to grow.

Yield (49% moisture) mill run bagasse, 22-28%
bone dry bagasse, 11-14%

Chemical analysis, whole dry basis	cellulose	41-59% (alpha cell. 30-38%)
	ash	1-3.9%
	lignin	13-22%
	pentosans	20-32%
Chemical analysis, fibre	cellulose	59-63% (alpha 38-42%)
	ash	0.6-1.2%
	lignin	19-22%
	pentosans	27-32%
Cell fibre dimensions,	length mm,	0.5 (1.5) 4
	diameter mm,	0.0071 (0.021) 0.052

TABLE 1 FIBRE PLANT SPECIES, THEIR COMMON NAMES, AND THE COUNTRIES GROWING THE FIBRE CROPS

No. in order of importance	Species	Common name	Countries where grown or its pulp used
1	*Saccharum officinarium*	Sugarcane	Argentina, Brazil, Cuba, Mexico, USA, Peru, Taiwan, Venezuela, Puerto Rico, Egypt, India, Philippines, Thailand, Indonesia, Pakistan, Bangladesh, South Africa
2	*Dendrocalamus strictus* *Bambusa arundinacea*	Bamboo Bamboo	India, Pakistan, Bangladesh, China, Burma, Thailand, Indonesia
3	Straw of *Oryza sativa* *Secale cereale* *Triticum aestivum* *Sorghum vulgare* *Zea mays* *Hordeum vulgare*	Rice Rye Wheat Sorghum Maize, Corn Barley	China, Taiwan, Brazil, Egypt, India, Sri Lanka, Thailand, Bangladesh, Mexico, Italy, Spain, Netherlands, Poland, Portugal, Greece, Hungary, Romania, Turkey
4	*Hibiscus cannabinus* *Hibiscus subdariffa*	Kenaf, Deccan hemp Mesta, Roselle	Sri Lanka, USA, India, Thailand, Yugoslavia, UK, Philippines, Bangladesh
5	*Cannabis sativa* *Musa textilis*	Hemp Abaca, Manila hemp	Italy, France, Yugoslavia, Turkey, Philippines, UK
6	*Agave sisalana* *Agave fourcroydes*	Sisal Henequen (Mexican sisal)	Brazil, UK, Taiwan, Tanzania, Kenya, Haiti, Angola, Mozambique, Madagascar, Venezuela, Mexico
7	*Corchorus capsularis* *Corchorus olitorius*	Jute	India, Pakistan, Bangladesh
8	*Boehmeria nivea*	Ramie	India, Brazil
9	*Linum usitatissimum*	Fibre flax, Linseed	USA, Mexico, India
10	*Crotalaria juncea*	Sunhemp or Indian hemp	India, Brazil
11	*Sesbania cannabina*	*Dhiancha*	India, Pakistan
12	*Stipa tenacissima* *Lyganum spartum* *Eucaliopsis trianta*	Alfa grass Esparto proper Sabai grass	Esparto grass: W. Africa, Spain Algeria, Tunisia India, Pakistan
12	*Panicum* sp. *Setaria* sp. *Echinochloa* sp. *Pennisetum* sp. *Paspalum* sp. *Eleusine* sp.	Major millets	India, China, Pakistan, Bangladesh, Central and Eastern Africa
12	*Phragmites communis*	Reed	China, Romania, USSR, North Korea, Egypt
13	*Ricinus communis*	Castor	—
13	Grasses and weeds *Imperata cylindrica* *Eichornia crassipes*	 Elephant grass Water hyacinth	 Africa, India
14	*Cyperos papyrus*	Paper reed	Egypt, many areas of Africa, Middle East, South America, Sudan

Table 1. Reproduced from Hunsigi (1989).

TABLE 2 APPROXIMATE FIBRE DIMENSIONS OF SOME AGRICULTURAL CROPS AND SHRUBS

Sl. No.	Crop/Shrub	Fibre length mm (l)		Average l (mm)	Diameter (d) mm		Average d (mm)	l/d	Bulk density kg m^{-3}	Source
		Max.	Min.		Max.	Min.				
1	Mesta	2.40	0.300	1.00	0.048	0.010	0.024	41.6	98	[26]
2	Esparto grass	3.55	0.093	1.25	0.016	0.004	0.010	125	–	
3	Flax	3.20	0.131	–	0.023	0.008	–	120	–	
4	Manila hemp	8.32	5.180	6.20	0.023	0.016	0.018	344	–	[27]
5	Sisal	4.29	1.600	2.70	0.031	0.008	0.019	142	–	
6	Jute	3.78	1.140	2.50	0.028	0.008	–	156	–	
7	Wheat straw	2.63	0.680	1.50	0.039	0.012	0.018	83	–	
8	Kenaf bast fibre	–	–	2.60	–	–	0.020	130	–	
9	Corn stalks and sorghum depithed	1.50	1.000	1.25	–	–	0.020	62.5	–	
10	Cotton fibre	–	–	25.00	–	–	0.020	1250	–	[11]
11	Cotton stalks	0.80	0.600	0.70	0.020	0.030	0.025	28	–	
12	Sunnhemp	–	–	3.70	–	–	0.025	148	–	
13	True hemp	–	–	20.00	–	–	0.022	909	–	
14	Reeds	1.80	1.000	1.40	0.020	0.010	0.015	93	–	
15	Water Hyacinth	2.53	0.660	1.60	0.020	0.001	0.005	320	–	
16	Rice straw	1.00	0.500	0.75	0.010	0.008	0.009	83	–	
17	Parthenium weed	1.62	0.280	0.69	0.031	0.006	0.016	43.1	46	
18	Depithed bagasse	2.87	0.560	1.20	0.050	0.012	0.023	52.2	67.4	
For comparison purposes										
19	*Eucalyptus* hybrid	1.00	0.120	0.50	0.018	0.006	0.018	50	235	
20	Subabul (*Leucaena leucocephala*)	2.10	0.400	0.85	0.031	0.013	0.022	38.6	208	
21	*Acacia auriculiformis*	1.30	0.470	0.81	0.031	0.012	0.018	45	–	[26]
22	*Sesbania grandiflora*	1.80	0.400	0.90	0.020	0.006	0.010	90	–	
23	Pine (*Pinus radiata*)	5.40	1.500	3.40	0.059	0.001	0.037	91.9	–	
24	Bamboo	3.40	0.500	1.90	0.022	0.006	0.015	126.6	202	

Table 2. Reproduced from Hunsigi (1989).

Yield per hectare, 100 tonnes of bagasse and 15 tonnes of sugar.

Harvesting. The sugarcane crop is ready to harvest just before flowering during a period of some 3-11 months. In some countries the cane can be harvested all year round. Harvesting itself maybe by hand or mechanical. The former produces the highest quality cane. The leaves are removed prior to harvesting by burning or manually during the harvest. A large storage area is required as bagasse has a low bulk density, approx. 100 kg/m3.

A variety of storage methods are available, these vary in the presence, absence and quantity of liquors and presence/absence of baling:

1 Dry bale method
2 Dry bulk method
3 Wet bulk method eg. the "Ritter type"
4 Moist bulk method
5 Begatex process

all have there relative merits; however dry storage is associated with the lung disease bagassosis. Storage for a year can lead to a loss of 10-20% dry bulk weight.
Several depithing methods are available; all are either wet, moist or dry.

Current and potential uses, (excluding paper). Historically bagasse has been burned as a fuel for steam production in sugar factories and this remains the most widespread use. The alpha cellulose content has been experimented with as a potential source for dissolving pulp in the rayon industry. The pith and associated lignin are used in the manufacture of a range of chemicals and soil conditioners. After lignin reduction bagasse can be used with some success as cattle and animal feed. Another potential role could be as a cellulose source for microbial protein production. Bagasse has even been used in the production of rum.

Pulp and paper research. Pulp and paper have been produced from bagasse since 1938, however it is only relatively recently that the technology to produce several grades of paper has been developed. Over 85 bagasse pulp and paper mills are located in the following countries; Argentina, Bangladesh, Brazil, China, Colombia, Cuba, Egypt, India, Indonesia, Iran, Iraq, Kenya, Mexico, Pakistan, Peru, Phillipines, South Africa, Thailand and Venezuela.

The production of paper now no longer requires blending with large amounts of long fiber pulp (hard and softwoods). This is very important in developing countries as it removes the need for pulpwood. Bagasse is already fully competitive with wood in the manufacture of particle board.

Only a fraction of the total available supply (75,000,000 tonnes worldwide), is pulped, and replacement of bagasse as the primary fuel in sugar production would add greatly to costs. Bagasse print has good formation, bulk, opacity and printability, requires little energy and has a low effluent load, but its physical strength is low and runnability poor. It is for these reasons that long fibres are usually added.

More recent technological advances have improved the yield and quality of bagasse pulps, but they continue to be blended. It now appears possible to use cotton stalk kraft pulps instead of hardwoods as the long fibre blend (Shaikh, A.J. 1990). This could relieve demand on the chronic shortage of bamboo and hardwoods in many developing countries. Experimentation with bleaching conditions and cold alkali extraction is producing pulps of equivalent standards to woods, (Valdes, J.L. etal. 1991).

The effluent load has been reduced in a newsprint mill, (Granfeldt, T. etal. 1988), to a level that theoretically allows complete closure of the effluent system.

Environmental impact. The energy required to pulp bagasse is lower than that needed in the pulping of hard and softwoods, and the effluent load is generally regarded to be less. Wet storage of the bagasse produces substantial quantities of suspended solids in the effluent, particularly post-depithing, these can be removed by mechanical treatment, dewatering and sludge removal.

Conclusions. It is clear that bagasse paper, particularly newsprint, has already arrived. Successful bagasse-based pulping operations are being carried out in Cuba (the Cuba-9 project), Çolombia, Mexico, South Africa (particularly the Stanger Mill), and Argentina, where one company (Ledesma), averages 93% bleached bagasse pulp in high quality business papers.
Bagasse has become the driving force in the development of a nonwood paper sector, and the fibre source for which most of the technological advances have been developed. Two major problems lie in the way of a largely increased bagasse paper industry; the short fibre length that leads them to compete only with hardwoods, and the sugarcane industry's reliance upon bagasse as a fuel.

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4.2.2 Flax.

Linum ussitatissimum

Origin. Europe.

Theoretical geographical distribution. All temperate moderately moist climates.

Plant morphology and physical characteristics. *Linum ussitatissimum* is an annual plant with a slender, greyish green stem that grows to a height of 90-120cm. It is the stem that is used as a fibre source.

Yield (% plant basis),	line fibre	12-16%
	g/m2	48-72
Chemical analysis, wt % retted	cellulose	71.20%
	hemi/cell.	18.60%
	pectins	2.00%
	lignin	2.22%
	water sol. comps.	4.30%
	Fats/waxes	1.70%
Cell fibre dimensions,	length mm,	8 (32) 69
	diameter mm,	0.008 (o.o19) 0.031
Strand dimensions,	length cm,	20-140
	width mm,	0.04-0.62

Harvesting. Several harvesting methods are used and the correct time to obtain optimum fibre and seed quality is important. The plants are pulled by machine or hand and after deseeding the straw is retted. Finally the straw is broken and cleaned, most of the fibres are then used in the manufacture of linen.

Current and potential uses, (excluding paper). The most important application is in linen for clothing, sheets, fabrics and lace. Flax fibre is also used in canvas, threads, twines and various industrial applications.
The other major application is for the production of linseed oil, from its seeds, it is in this process that the agro-fibre residue is produced, that may in future be more fully utilised by the paper industry.

Pulp and paper research. Flax has had limited applications in the paper industry for many years, in 1978 the USA used 60,000 tonnes of seed flax straw as cigarette and other lightweight speciality papers. There are at least 8 major pulping mills located in the following countries; China, France, Japan, Spain,the UK and USA.
Increased interest has been shown in recent years, particularly in the developing world where flax occurs as an agricultural waste, and is being grown in increasing amounts. Studies in India have proven the suitability of flax kraft pulp in the production of various grades, including writing and printing papers, (Shaikh, A.J., 1988).
Research in China has produced acceptable grades of paperboard, (Chen, L., 1987), and cardboard, (Nie, X., 1987), using alkali-sulphate/anthraquinone and kraft pulping respectively.

Environmental impact. Little has been published concerning the impact of widespread pulping of flax fibres, however it is worth noting that 2,000,000 tonnes of fibre is available annually as a waste product (and not utilised in the linen industry), which negates the necessity of further plantation cultivation of flax for paper, and its use would not increase the pressure on a restricted amount of farmland.

Conclusions. Worldwide there are 14 flax pulp mills producing about 75,000 tonnes/year any potential increase is hampered by the lack of research, that probably derives from current utilisation of flax fibres in the textile industry. As forest demand increases flax may well play an important part in paper production along with several other agro-residues.

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Hemp.
Cannabis sativa

Origin. Central China.

Theoretical geographical distribution. All temperate zones.

Plant morphology and physical characteristics. The hemp plant grows to a height of 5-7m when cultivated, with a polygonal stem 6-16mm thick. The stem is hollow and it is this that is used for fibre.

Yield (% plant basis),	line fibre	3.5%
	g/m2	50-75
Chemical analysis, wt %	cellulose	77.07%
	moisture	8.76
	ash	0.82
	lignin/pectin	9.31
	extractives	4.04
Cell fibre dimensions,	length mm,	5 (25) 55
	diameter mm,	0.013 (0.025) 0.041
Yield per hectare,	(no figures) approx. 4x that of conventional wood fibres.	

Harvesting. The smooth hollow stems are usually hand cut and placed on the ground prior to dry or water retting. The leaves and seeds are removed and the stems manually or machine broken. They are then graded on density, strength, colour, lustre, cleanliness and spinning quality.

Current and potential uses, (excl. paper). Hemp fibres have been used for centuries in cordage and cloth manufacture, and can be an adequate substitute for flax in some yarns. Hemp seed can be used to manufacture oil for a variety of uses including paints and varnishes. Even after the fibre has been removed the woody "hurds", that remain can be used in a variety of products from cellophane to dynamite. Hemp has also been used to produce a tofu-like food, as a petroleum substitute, and is purported to have medicinal qualities. The blossom of the female hemp plant is used to make marijuana, a narcotic, and it is impossible to cultivate hemp without producing the blossom. This remains the primary obstacle to large scale culture, but not large scale processing, in the West.

Pulp and paper research. There are over 20 relatively large hemp pulping mills in the UK, China, Taiwan, USA, France, Japan, India, Phillipines, Turkey and Yugoslavia, producing approximately 80,000 tonnes/year, with one mill in India producing upto 20,000 tonnes/year. The high alpha cellulose content makes hemp a potential paper source for almost all paper grades, with a yield per hectare of approximately 4 times that of conventional pulp land, (hard and softwoods included). However, it is suggested by the pulp and paper manufacturers that because of the high costs of storage and transport that paper production could cost as much as three times that for wood-based paper. However, hemp remains one of the nonwood fibres with the greatest potential for use in the pulp and paper industry.

Environmental impact. High production appears possible with a low chemical input. It should be noted that with the wide variety of potential other uses it should be possible to reduce wastes to a minimum. It is possible to produce high quality paper grades without chlorine, and without a large chemical input. Large scale cultivation could increase the pressure on farm land.

Conclusions. The alpha cellulose content and relatively long fibre length make hemp a suitable raw material for the production of paper. Large scale use would necessitate plantation cultivation, hemp is not an agro-waste. The annual harvesting would create transport and storage difficulties (though these are being overcome elsewhere, notably with bagasse storage) and may substantially increase costs. Its most valuable role may be replacing long fibre wood blends in agro-waste papers, this would not necessitate the massive cultivation required for a hemp "based" paper and place less of a burden on restricted agricultural land.
Clearly the continued association with the narcotic, marijuana forms a major obstacle to cultivation in some countries, notably the USA where it was outlawed in 1937,(nb Columbus sailed to America with hemp sails and hemp rigging, and President George Bush bailed out over the pacific with parachute webbing made from 100% hemp fibres). Hemp if fully utilized could very easily become a valuable crop for many temperate zone farmers.

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Sunn Hemp.
Crotalaria juncea

Origin. India.

Theoretical geographical distribution. Tropical and sub-tropical countries.

Plant morphology and characteristics. *Crotalaria* is a legume, and a member of the family *Fobaceae*. It is a herbaceous shrub with a thin cylindrical branch free stem (the fibre source), it can grow to a height of some 5ms, and has a long tap root. Fertility and water requirements are less exacting than plants such as kenaf. A useful attribute is its ability to fix relatively large quantities of nitrogen.

Yield, (% plant basis)	dry retted,	3.4%
	dry stems,	5.0%
Chemical analysis, wt%	cellulose	80.4%
	moisture	9.6%
	ash	0.6%
	lignin/ pectins	6.4%
	extractives	3.0%
Cell fibre dimensions,	length mm,	2(7)11
	diameter mm,	0.013(0.031)0.061
Fibre length mm,	3.70 (average)	
diameter mm,	0.025 (average)	

Harvesting. The plant is harvested in the seed pod stage by hand cutting or pulling, and left in the field for defoliation. The stems are water-retted, washed, stripped, and dried.

Current and potential uses, (excl. paper). Sunn hemp has a wide variety of uses, notably in canvas, twine, nets, ropes, and speciality fine fibres. Its ability to fix nitrogen has led to its use as an organic fertilizer.

Pulp and paper research. Sunn hemp is not exploited on a large scale for paper, (or any other) production, but is used in countries such as India and Brazil in the manufacture of speciality grades, notably cigarette papers. However this may change as agronomic manipulation of this crop is considerably easier than for kenaf, with less pests and diseases. Fertility and water requirements are excellent. Recent research has suggested a potential link with bagasse plantations, several of which grow sunn hemp between harvests, because of its properties as a manure.

Environmental impact. With its ability to fix nitrogen, sunn hemp has several environmental advantages as a cash crop, particularly if used in parallel with other nonwood pulp sources such as bagasse and kenaf. Clearly it is not an agro-waste, and large scale utilization may increase pressure on the use of open land.

Conclusions. As has already been stated, sunn hemp has several advantages for use as a cash crop, and its properties as a source of paper are acceptable. Research needs to be carried out to discover the best way to utilize this plant, as a speciality paper source, a furnish with more conventional fibre blends or as a major blend in itself.

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Jute.

Corchorus capsularis
Corchorus olitorius
Corchorus spp.

Origin. Two species yield true jute *C. capsularis*, (white jute), with origins in Asia and *C. olitorius*, (tossa or daisie jute), originally from Africa.

Theoretical geographical distribution. Jute is widely cultivated, particularly in the tropics and sub-tropics, notably Bangladesh, Brazil, Burma, India and Nepal.

Plant morphology and characteristics. The two true species of jute are broadly similar, the primary difference being in the shape of the seed pods. Those of *C. capsularis*, are rounded, whilst those of *c. olitorius*, are elongate.
Jute stems (the fibre source), are cylindrical in cross section, 2-4m tall and 10-20mm wide when harvested, which is usually annually.

Yield,	decorticulated	(% plant basis)	3.5%
		g/m2	150
Chemical analysis, wt %		cellulose	63.24%
		moisture	9.93%
		ash	0.68%
		lignin and pectins	24.41%
		extractives	1.42%
Cell fibre dimensions,		length mm,	0.65 (2.5) 6
		diameter mm,	0.005 (0.018) 0.025
Strand dimensions,	length cm,	150 - 360	
	width cm,	0.03 - 0.14	

Harvesting. This is carried out by hand, the stalks are cut and left in the fields to encourage defoliation. The stems are gathered for wet-retting which lasts for 10-20 days, and then stripped and dried. Grading is carried out in a similar way to hemp.

Current and potential uses, (excl. paper). The bulk of the jute crop is made into hessian, sacking, rugs, webbing and twine.

Pulp and paper research. Recent studies have succeeded in producing quite high grades, suitable for printing and writing papers. As it is the fibre that is sought by the textile industry, jute stems are not available as wastes and the paper industry must compete with the established industrial applications. This may explain the low levels of paper research and production. Their are over a dozen relatively large pulping mills in; Bangladesh, Brazil, China, India, Japan, Thailand and the UK.
Much of the paper industry research has been carried out in Bangladesh, Pakistan and India. It has been established that at least three pulping processes can obtain acceptable newsprint grade paper, and with bleaching and chemical treatment all can produce writing and printing grades, (Islam, M.A., etal., 1988, 1989) and (Karim, S. 1989). Of these the soda-anthraquinone and soda-sulphur processes pulp whole jute sticks whilst the soda process pulps a mixture of jute stick and jute cuttings.

Environmental impact. As with paper production from several other nonwood sources, the mills themselves tend to be small and ill equipped for effluent recovery, and jute pulping is steam and liquor intensive. As jute is not an agro-waste, but would require special cultivation, future large scale pulping could place increased demand on limited agricultural land.

Conclusions. Overrall jute production has been decreasing for many years, with subsidy the industry could be maintained and the shortfall in textile demand made up by the paper industry.
Any future jute paper industry would have to overcome several problems; its fast decay, low density, seasonal harvest, and chemical and energy intensive nature. However similar problems have been overcome with other nonwood fibres notably bagasse and cotton straw.

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Kenaf.

Hibiscus cannabinus

Origin. East and Central Africa.

Theoretical geographical spread distribution. Temperate, preferrably warm temperate or suitable tropical and sub-tropical conditions..

Plant morphology and characteristics. Kenaf is a herbaceous annual that grows to heights of 1-4m, with a stem diameter of 10-20mm.

Yield,	dry retted,	(% plant basis)	4.8%
		g/m2	50-300
Chemical analysis, wt %		cellulose	65.7%
		moisture	9.8%
		ash	1.0%
		lignin and pectins	21.6%
		extractives	1.9
Cell fibre dimensions,		length mm,	2 (3.3) 11 (bark)
		diameter mm,	0.013 (0.023) 0.034
Yield per hectare, approx.		2 tonnes per hectare	
		6-8 tonnes per acre	

Harvesting. Growth to harvest takes approximately 5 (frost free), months, though it is unusual to grow more than one crop per year, it is preferable to rotate as root nematodes can become a problem if the soil is used too often. The kenaf plants are harvested as flowering begins, they are usually hand cut but can be mowed or pulled. Defoliation is generally done by field drying. Further preparation is done frequently by machine, less commonly by hand, and the bark separated from the core. Tank-retting may follow, or more commonly the kenaf is stem-retted, stripped and washed. The washed fibre is then dried and graded, based upon colour, strength, uniformity and cleanliness. Integrated harvesting, baling and transporting techniques have been developed in Australia, capable of harvesting over 2 acres per hour.

Current and potential uses, (excl. paper). Kenaf fibre is thought of as a jute substitute, but as its fibres are coarser and shorter than those of jute it is generally blended. Other than paper it is found in sacks, bags, canvas, carpets, and twine. Its fibres are easier to cultivate than jute, and kenaf often does not require fertilizer.

Pulp and paper research. Recently a great deal of interest has been shown in kenaf as a potential mass fibre crop for the paper industry. Much work has concentrated on converting whole-stalk kenaf (rather than separating the bark from the core), into chemimechanical pulp, in concentrations of up to 90% kenaf/10% blend,(nb. 100% kenaf paper is of a very high standard and the long fibre blend is used solely to aid the runnability of the machines). Large scale operations are planned in Australia and the USA.
Bleached kenaf pulps are less common, though a mill in Thailand uses chlorine dioxide bleaching and produces a paper that is competitive with hardwood and bagasse-based pulps.
Optimum pulping conditions are obtained when the bark and core are separated prior to pulping and an automated fibre separation process has been developed in Australia. Chemical pulping is normally carried out using conventional processes including sulphate, soda and soda-anthraquinone. The bulk of the laboratory testing is carried out using the soda-anthraquinone method which gives a bleached yield of 57% for bark and 41% for the core. This results in a yield differential of approximately 45%/55%, bark/core.

It has been established that kenaf can compete favourably with high quality wood pulps, see below after Kaldor, A.F. et al. 1990.

	Southern pine	Kenaf
Growing cycle	15-20 years	5-6 months
Average yield of dry fibres	3 tns wood/ acre/year	2.5 (6) 12 tns/ acre/year
Bleached yield	43%	46% ave.(bark+core)
Tons of pulp/acre	1.45 a.d. tns/ acre/year	3.05 a.d. tns/ acre/year
Delivered cost of raw material	US$ 120-180/tn of pulp	US$ 100-120/tn of pulp

It is necessary to examine the paper-making potential of the bark and core pulps separately:

Bark pulp. The exceptional qualities of kenaf bark pulp (35-40% plant basis), have been known for many years, in particular its long fibres, 3-4mm, that make it suitable for a wide range of specialities, eg. filter paper, cigarette paper and banknotes. Chemical bark pulps compare very favourably with softwood pulps often with improved tear strength and bulk factor. An advantage over softwoods is that only a fraction of the refining energy is required to develop the strength properties. Clearly bark pulp can replace many softwood grades including newsprint, and printing and writing papers. In addition its favourable diameter-to-fibre-length ratio means kenaf can serve as a speciality pulp, enhancing the financial attractiveness.

Core pulp. Kenaf core fibres are short, 0.5-0.7mm, but have very strong internal bonding. The papermaking properties of core pulp are extremely similar to those of hardwood pulp and have a great many potential end uses in printing and writing papers, base papers, paperboard and tissue grades. It has been suggested (Kaldor, A.F., 1990), that core pulp is best used in an unrefined condition as it is extremely sensitive and prone to overrefining.

When compared with bleached hardwood kraft pulps, its opacity and bulk are slightly lower, surface smoothness similar and porosity higher.

Bark and core pulp mixtures. Mixtures of bark and core pulps combine characteristics with minimum refining requirements. The addition of the shorter core fibres does not have a significant effect on physical properties and could be used as a means of reducing costs and wastes as well as optimizing the saleable quantity.

Historically, kenaf has been used in whole stem pulping, which can produce excellent newsprint grade pulp, but with such major differences in fibre characteristics, yield, and applications, fibre separation prior to pulping appears essential for future development. It would permit the production of a large variety of pulp grades ranging from speciality pulps to long and short fibre substitute pulps.

The need for covered storage facilities between harvests can be offset by reduced fibre, pulping and bleaching costs, mill capacity need not be on the same scale as wood-based pulp mills. In Thailand kenaf is grown in the poorest soils and with the application of irrigation and limited fertilizers high yields can still be produced.

Environmental impact. As is true for most nonwood fibres discussed here, kenaf pulps readily with a lower chemical consumption and shorter cooking cycle than conventional wood grades. Energy consumption is 30% less than wood for mechanical pulping and accounts for 30% of pulp production costs.
The silica content of the liquor is low, and chemical recovery can be carried out through conventional processes.
Kenaf can be cultivated with minimal use of pesticides, and irrigation and fertilizers need only be used in inferior soils for the optimization of yields.

Conclusions. Kenaf makes an ideal pulp for newsprint, printing and writing papers linerboard and speciality grade papers. Attention has now turned to harvesting, storage and transportation. Because kenaf is a low yield crop, it takes vast plantations to produce the tonnage required, sample calculations from the southern U.S. indicate a pulp mill with a capacity of 100,000 tonnes/year to 150,000 tonnes/year, would have to be supported by a kenaf growing area of 50,000 - 75,000 acres, including provisions for crop rotation.
Current predictions of paper and board consumption anticipate an increase from the current 220 million tonnes/year to 300 million tonnes/year in 2000. Kenaf represents one of the strongest contenders to meet this increased demand, particularly where wood is increasingly scarce and paper consumption set to rise.
The lower labour costs in some developing countries may allow smaller capacity paper mills to be financially viable.
Several large-scale kenaf pulping plants are due to open in the U.S. and Australia, and in the case of the latter, it is intended that the environmental impact will be kept to a minimum with a non-sulphur pulping process and dioxin-free effluent.
In summary, kenaf is an outstanding fibre source for the future, it can be used in most paper grades, alone or in combination with other fibres. The low refining power and price premium of the speciality grades are important. The lower fibre, pulping and bleaching costs allow pulp mills to be built on a smaller scale than for wood based mills. The environmental impact is substantially less than for wood based mills.

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Miscanthus/Amur Silvergrass.
Miscanthus sinensis "Elephant grass"
Miscanthus sacchariflorus

Origin. Northern China and Japan.

Theoretical geographical distribution. Temperate to sub-tropical, (sub-tropical preferred).

Plant morphology and physical characteristics. Miscanthus is an annual reed or "ornamental grass", with a feathery panicle and variegated leaves (not used for fibre). Possible growth is up to 3m per season (less in temperate environments). It prefers high temperature and high light conditions, and is capable of absorbing relatively large quantities of nitrogen, leading to the efficient utilization of fertilisers.
The cellulose content compares favourably with hardwoods.

Yield per hectare,	20 - 35 tonnes

Harvesting. Harvesting occurs annually and a high level of production is possible with minimal chemical imput, pesticide sprays are not required. It may be harvested manually or by machine.

Current and potential uses, (excl. paper). Miscanthus may be a future large scale source of bio-mass fuel. The yield, if proven to be over 20 tonnes/hectare, is greater than most forest plantations. In Germany it is being grown as a source of hydrogen for oil refining. Small scale, local power stations appear to be the most logical use, providing sufficient storage facilities are available.

Pulp and paper research. Miscanthus is being investigated by various government agencies and private companies for use in the paper industry. The ministry of Agriculture, Fisheries and Food (U.K.), have various plantations in Devon, Herefordshire and Cambridgeshire. A Dresden based paper manufacturer has been testing miscanthus as a future alternative to timber, findings so far are promising. The cellulose content compares favourably with timber and better than any other annual farm crop.

Environmental impact. As with kenaf, Miscanthus is not an agro-waste and cultivation may well place increased burden on farm land, however its nitrogen absorbing properties may make it useful in a crop-rotation cycle, and prevent nitrogen seepage into ground waters. As was stated earlier, high production is possible with minimal use of chemicals and zero use of pesticides.

Conclusions. Insufficient work has as yet been carried out to definitely state that Miscanthus, will be a future source for the paper industry. However the apparently very high yields /hectare, if proven, and high cellulose content are promising. Research must now be carried out to examine pulp quality, energy efficiency, effluent characteristics etc...

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Roselle/Mesta.

Hibiscus sabdarifa

Origin. Africa.

Theoretical geographical distribution. Sub-tropical, possibly warm temperate and tropical.

Plant morphology and characteristics. Roselle is a herbaceous annual that grows in a single stem (the fibre source), to heights of 1-5m, with a stem diameter of 10-20mm. It is closely related to the slightly smaller species *Hibiscus cannabinus*, (kenaf).

Yield,	(% plant basis),	dry retted	4.4%
	g/m2		50-300

Chemical analysis, (very similar to kenaf)

Fibre dimensions, (very similar to kenaf)

Harvesting. Roselle, unlike kenaf, is harvested prior to flowering, and is almost always hand pulled. De-foliation often occurs in the field. To improve the quality by removing dirt, and increasing the softness and lustre the roselle may be hackled. The stems are retted, stripped and dried.

Current and potential uses, (excl. paper). Roselle is produced mainly in China and Thailand, where like kenaf, it is used as a jute substitute in sacking, bags and twine. The red fleshy calix is also used for jellies, sauces, and beverages, whilst the leaves are processed like spinach.

Pulp and paper research. Unlike kenaf very little research has been carried out into the possibilities of producing large quantities of paper pulp from Roselle stem fibres. Both India and Thailand, (and possibly China), utilise roselle for paper production. Newsprint grade pulp can be successfully produced from the "whole-plant", but unlike kenaf, no attempts appear to have been made to separate bast and core fibres.
Trials carried out into kraft pulping of the roselle fibres have produced a good quality bleached pulp, that could very easily be used in papermaking, (Islam, M.A., 1989).

Environmental impact. As with kenaf the environmental impact of large-scale pulping of Roselle is less than that for wood pulp grades. Energy consumption is less, and a reduced cooking time and chemical input could be anticipated. Roselle is grown with a minimal use of pesticides and fertilizers. One problem is that roselle cultivation, as with the cultivation of all non agro-waste fibres, would increase the pressure on open land.

Conclusions. It is certainly possible to make very high quality pulp grades from roselle fibres but, it is difficult to come to firm conclusions concerning environmental impact and marketability as little research has been carried out. However the close morphological similarity to kenaf suggests further research would be worthwhile.

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Bamboo.

Esp.*Dendrocalamus strictus*
Bambusa arundinacea

Origin. Tropics.

Theoretical geographical distribution. All tropical and sub-tropical areas with reasonable rainfall, and to a lesser extent warm temperate.

Plant morphology and characteristics. Bamboo belongs to the grass family (*Gramineae*), and consists of approximately 45 genera and literally hundreds of species. It is annually grown but the roots are perennial. The vast majority occur in tropical and sub-tropical countries, where they are of immense economic importance. They range in size from dwarf varieties to some greater than 50m in height, and 15-30cm in diameter.
The more economically important genera are *Arundinaria* and *Dendrocalamus*. The stems are hollow with cross partitions at the nodes. The "wood", itself is elastic and very strong, due to the deposition of silica.

Fibre length, mm,	0.500(1.90)3.40	
diameter, mm,	0.006(0.015)0.022	
Chemical analysis, avg.dry wt%	cellulose	67.3%
	pentosans	17.7%
	lignin	26.6%

Harvesting. Bamboo is usually not harvested all year round and therefore requires storage. When it is cut, the tops and branches are discarded. Compared with the felling of wood and the harvesting of other nonwood fibre plants, bamboo is usually more difficult, due primarily to its preferred growth in clusters. Transport to the paper mill is primitive and expensive due to bamboo's voluminous nature. Chipping and washing succeed harvesting, followed by silica removal, which can be complicated.

Current and potential uses, (excl. paper). Bamboo has an enormously important role to play in most tropical countries, where it is used in everything from, house building, to food, and the cradle to the coffin.

Pulp and paper research. Bamboo is the traditional raw material for the pulp and paper industry of many countries, notably; India, China, Pakistan, Burma, Bangladesh, Indonesia, Taiwan, Thailand, Nigeria, and Brazil. It is a highly efficient grass, and physiologically is well suited to the role of biomass fuel.

Detailed agronomic research is yet to be carried out, but efficient farming, including cleaning and thinning should be possible.

Relative to other nonwood fibre pulps, a great deal of research has been carried out into the pulping of bamboo, particularly with regard to increasing yield. Alkali-sulphate and anthraquinone pulping are effective, as are various types of kraft pulping. Further work has centred on the different properties of bamboo varieties, at different growth stages, and the differing pulping characteristics of nodes and internodes.

As has been seen bamboo provides a long fibre pulp, ideal for papermaking and capable of being blended with the currently under utilized agro-residues, produced in most countries.

Environmental impact. The handling of bamboo during transport, storage and initial preparation causes few environmental problems. However the second washing of the bamboo chips results in a dissolution of greater amounts of extractives. No information is available on BOD-discharges at this time, but they are not thought to pose a significant threat. A problem accompanying bamboo preparation is the dust produced from the accompanying soil, or produced in the chipping and crushing. This dust contains a high amount of silica, and can cause illnesses similar to bagassosis, if the bamboo is not kept wet.

The overriding environmental problem with bamboo use, is the scale of current pulping. The reserves in countries such as India are decreasing faster than thier own Governments recomendations, and even though its use has declined recently (due to bamboo's erratic flowering habit), it remains the major pulp industry raw material in such countries.

Conclusions. Bamboo has proven to be a useful and geographically important pulping raw material in many tropical and sub-tropical countries. However over-use, and a lack of agronomic studies hinder the efficient utilization of this crop, which has still not achieved its potential biomass yield.

Extensive farming may well place a substantial burden on the availability of open land, a way of minimising this would be to use bamboo primarily as a long fibre blend in various agro-residue pulps such as rice straw. Over-use clearly restricts the quantity of bamboo available for use in other areas.

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Straw and cereal sources.

<u>**Cotton straw and linters.**</u>
Gossypium hirsutum
Gossypium barbadense
Gossypium arborium
Gossypium herbaceum
Gossypium spp.

Origin. Central America, Africa and India.

Theoretical geographical distribution. Warm temperate, tropical and sub-tropical climates, with moist (loamy), soils.

Plant morphology and characteristics. Cotton is a member of the *Malvaceae* or mallow family, and is widely grown and cultivated in warm climates. The cotton plant is a herbaceous shrub having a normal height of 1.2-1.8m, although some tree varieties reach a maximum height of 6.0m. The most important four are listed above, the first two typical of the new world and the last two, old world species. The most favourable growing conditions require a warm climate (17-27 degrees centigrade, mean temperature), with moist and loamy, rather than rich, soils; seeds planted in dry soils produce strong but short fibres of irregular lengths and shapes.

Yield,	bleached pulp	44% (not whole plant basis)

Chemical analysis, wt%	cellulose	90.00% (cotton plant stalk 69%)
	moisture	8.00%
	ash	1.00%
	lignin/ pectins	0.50%
	extractives	0.50%

Cell fibre dimensions,	length mm	10 (25) 50
	diameter mm	0.014 (0.019) 0.021

Fibres/strands,	length cm	1.5-5.6
	width mm	0.012-0.025

Harvesting. This takes place between 45 and 90 days after planting dependant upon environment and cotton type. Defoliants and desiccants are often used to prevent further plant development. Until the middle of this century cotton was picked entirely by hand and this is still the case in many countries, however mechanical harvesting has largely replaced hand-picking in the more developed countries. If the straw is allowed to remain in the fields it can harbour insects and other potential pests for next years crop, therefore in countries such as India, it is mostly burned. Bulk harvesting of cotton straw is carried out either by hand or by machine.
The chief cotton growing countries are, the CIS (USSR), with (22%), China (19%), the USA (11%), India (9%), Pakistan, Brazil, and Turkey (all 4%) and Egypt (3%).

Current and potential uses, (excl. paper). Cotton fibres are the most important source of vegatable fibre for spinning and is used in all grades of textiles and cordage, (the fibres remaining from this process are called linters). The cotton straw, if not burnt in the field may be used as cattle feed, fertilizer or burnt to produce energy.

Pulp and paper research. Cotton straw and cotton linters are an abundant agro-waste and considerable research has already been carried out into their potential utilization in paper production. The majority of research being carried out in the East. Pulp mills already exist in Australia, Austria, Bangladesh, Brazil, China, Germany, India, Mexico, Spain, Turkey, Great Britain, and the USA, though few of these supply the paper industry.
It is undoubtedly possible to produce good quality pulps from blends of cotton straw and long fibre raw materials.
Sheets produced from semi-mechanical pulps, can be economical when compared with those from conventional raw materials, and are suitable for wrapping and other low grade papers, whilst chemical pulps of very high quality are suitable for use in printing and writing grades, and speciality papers. The blends used need not be hardwood, as is often the case, blends of cotton stalk kraft pulp with chemi-mechanical bagasse pulp, yields good quality paper grades.
In Australia the supply of cotton linters is already fully utilized in the production of paper pulps.

Environmental impact. As with most nonwood fibre sources, the pulping of cotton straw and linters requires less chemical and energy input, when compared with conventional wood fibre sources, even though the scale of mill pulping is often considerably smaller. Its status as an agro-waste also means that the pressure on agricultural land does not increase, a factor in any future large scale cultivation of fibre sources such as kenaf and miscanthus.

Conclusions. In the East, traditional raw materials such as wood and bamboo are in short supply and attention is being focused on alternative sources. Cotton straw is a important as it is so plentiful, eg. 15 million tonnes per year are generated in India. It has already been demonstrated that various grades of paper can be obtained from cotton stalk. This process can be economical, as cotton stalk is available in large quantities at a very low price. The use of cotton plant stalk for the production of pulp and paper appears to be increasing worldwide, this will not only solve the disposal problem of this agrowaste but also reduce the burden on depleted forestry reserves, particularly in the East.

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Rice straw.

Oryza sativa

Origin. The Far East.

Theoretical geographical distribution. All tropical and sub-tropical areas.

Plant morphology and physical characteristics. *Oryza sativa* is a cultivated species of *Oryza* Linn. of the natural order Gramineae. It is very widely cultivated in tropical and sub-tropical regions, either as a dry land crop or more usually in water. Both wild and cultivated forms of *Oryza* are annuals and take between two to three months up to nine months to mature. The stem is typically 2.5-3.5m high and 6-8mm in diameter.

Yield, processed (organosolv), approx 51%

Chemical analysis, dry		cellulose	70.1%
		pentosans	20.0%
		lignin	10.0%

Fibre	length mm,	0.7(1.2)3.5
	diameter mm,	0.0051(0.0085)0.0136

Harvesting. In the East much of the harvesting is still carried out by hand or simple machine, in the more developed countries mechanisation is very much the rule, the same applies for the subsequent threshing and winnowing. Preliminary drying, in Eastern countries, is often carried out in the field.

Current and potential uses, (excl. paper). The straw is often burnt in the fields soon after harvesting as it has an adverse affect on the drying out of the land if left. Some is used as an additive in compost or is ploughed in. In Japan straw is laid on the young plants to protect them from the winter weather. Other uses include; braiding, hat making, mat making, mushroom cultivation, and as an additive in cattle food. Burnt straw products are used in Java for washing hair and when taken internally, as an abortifacient.

Pulp and paper research. Over 320 million tonnes of rice straw are potentially available annually, 161 million tonnes in China alone. However it is not clear how much is used in other ways *sic.* The bulk of research and development has been carried out in the East, particularly India and China, where as has already been demonstrated forest reserves are under intense pressure. A large number of pulp mills already exist in Bangladesh, China, India, Pakistan, Sri Lanka and Thailand.
The relatively high percentage of alpha cellulose allows the production of good quality writing and printing papers, particularly when blended with long fibre pulps such as jute and bamboo. Headway is being made in reducing chemical and energy use in the production of the higher grades of paper, sulphur-free organosolv pulping produces a high yield with little cellulose degradation and soda pulping requires low concentrations of chemicals. In general, and particularly in China, sulphate cooking is now giving way to soda-anthraquinone pulping.
The major drawbacks in using rice straw, are the shortness and non-uniformity of fibre length and the contamination of extraneous cells. However, the loose nature of the cells allows easy penetration by chemicals.

Environmental impact. Large scale utilization of rice straw will require large areas to be set aside for storage and produce transport problems in the harvesting season. Compared to conventional fibre sources the pulping of rice straw has less impact on the environment requiring less energy and chemicals, however as most mills are small and old, new innovations in improving the impact on the environment have been slow to appear, when compared with the large northern hemisphere paper mills.

Conclusions. For years, boards, and printing and writing grades have been made using often up to 100% rice straw furnish. The addition of 10-20 long fibre pulp improves quality and machine performance. Some wood pulp mills now add 5-10% rice or wheat straw to enhance formation, bulk and ink receptivity. Bleached straw pulp has even been used in speciality paper grades, such as cigarette papers.
The availability and inexpensive cost of the rice straw makes it a potential source for large quantities of paper, and its status as an agro-waste indicates large scale utilization need not

increase the pressure on farm land. The annual nature of the crop produces problems with storage and transport. In countries such as China, collecting straw from a large number of small farmers will require the formulation of a new strategy such as the allying of co-operative farming societies to a local paper mill.

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Wheat straw.

Triticum aestivum
Triticum durum
Triticum spp.

Origin. The precise origin of the cultivated wheat varieties is still debated.

Theoretical geographical distribution. Worldwide, especially temperate and sub-tropical.

Plant morphology and characteristics. Wheat plants are commonly 0.6-1.5m high when harvested, but may be less than this in especially dry climates, or substantially greater in exceptionally favourable growing conditions. Most wheat stems are hollow with restricted nodes, however some varieties do have solid stems.

Yield,	pressure soda,	46.4%	
	bleached pulp,	35-40%	
	organosolv,	55%	
Chemical analysis,		cellulose,	63%
	dry wt %	pentosans,	19.8%
		lignin,	14.7%
Fibre	length, mm,	0.7(1.2)3.5	
	diameter, mm,	0.007(0.013)0.024	

Yield per acre, variable, 0.25-1.5 tonnes

Harvesting. Still sometimes carried out by hand, mechanised in most large scale wheat producing countries such as the USA, Canada and Ukraine. World wheat production has increased dramatically this century, and there is now potentially, over 570 million tonnes of wheat straw available, worldwide.

Current and potential uses, (excl. paper). Clearly, wheat is not cultivated as a source of vegetable fibres, but as the worlds second commonest cereal plant. The straw remaining after threshing may be utilized in a variety of ways, notably fertilizer and cattle fodder, though much is disposed of by stubble burning.

Pulp and paper research. A great deal of research has been carried out into various methods of wheat straw pulping, primarily because of the huge quantities available particularly in the less developed countries where conventional paper sources are under intense pressure, eg. India and China.
The major problems associated with using wheat straw as a pulping resource have been encountered before in this study; a relatively low pulp yield, the difficulties of collecting a seasonal and scattered crop, and the high costs of transport and storage, less of a problem in countries with low labour rates.
Two relatively new processes appear to possess most of the necessary characteristics to boost what has been a declining industry, these are carbonate delignification, where the carbonate is the sole cooking agent, and organosolv, which produces pulps in a high yield. In both processes no catalysts are required and the recovery of cooking agents is simpler than in conventional pulping processes. Both of these are more suited to small or medium sized mills rather than the large scale operations carried out in some countries.
Some advantages also accrue in soda-oxygen pulping, where the loose and open structure of the wheat straw makes one stage oxygen pulping possible, and without pre-treatment, at lower temperatures and for a shorter time.
The quality of the paper pulp can also be increased if the fine fraction, consisting primarily of parenchyma cells, is reduced.
When blended with hardwood pulps the addition of semi-mechanical wheat straw is to increase the strength and fluting properties. Good quality newsprint grades are already manufactured from 50:50 blends of hardwood and wheat straw, with good stength and optical properties.
In the more developed countries the most probable applications of wheat straw pulp are at mills with restricted refining capacity, where it could be used to improve smoothness and reduce porosity, or in a mixture with rough sheet-forming pulp, such as cotton linters, long fibre mechanical pulps or high coarseness chemical pulps, where it could be used to increase the bulk, tear, and strength properties of the resultant paper grades.
A revival of the wheat straw pulping industry can only be achieved by modernization of straw collection and storage as well as the development of new processes more suited to small scale mill operations. Future research should concentrate on reducing pollution load in order to avoid expensive abatement costs, simplifying the recovery of cooking agents, diversification of paper grades and the production of marketable by-products to improve profitability.

Environmental impact. As has already been stated, most agro-residues, are more energy and chemical efficient, and have less of an impact on their surroundings, though more work still needs to be carried out into the development of small scale recovery systems.

Unlike large scale cultivation of kenaf or other fibre plants, utilization of wheat straw would place little extra burden on land use and would create substantial, though seasonal employment in what are often deprived farming areas.

Conclusions. To conclude, wheat straw as a resource suffers from high collection and transport costs and requires bulk storage. Its pulp properties are similar though generally inferior to most hardwood and eucalyptus pulps, though it would have some advantages where minimal energy use, low beating requirement (to separate fibres), or low porosity were critical.
As an extremely abundant agro-fibre, capable of producing acceptable paper grades, often very good when blended, wheat straw may well have a very important role to play in conserving existing fibre resources. As with cotton and rice straw, the scale of the pulping would be relatively small and would require cooperation between a number of farmers and, what would probably be, local, small scale, pulp mills.

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Other cereals.

Barley	*(Hordeum spp.)*
Sorghum	*(Sorghum spp.)*
Millet	*(Panicum spp., Pennisetum spp. etc..)*
Oats	*(Avena spp.)*
Mustard	*(Brassica spp. Sinapsis spp. etc..)*
Rye	*(Secale spp.)*
Poppy	*(papavar somniferum)*

A limited amount of research has been carried out into all of the above, and they are dicussed briefly in turn, and in each case it is the straw that represents the fibre source). It must be noted that many of the factors concerning the exploitation of wheat straw, and rice straw are also applicable with the above and have been discussed already. Very little additional demand would be placed on open land, if any or all were to be utilized, and less energy and chemicals would be required, when compared with conventional paper sources. Like wheat, large quantities of barley, oat and rye straw were used in the British pulp and paper industry in the 1940s and 1950s, this has now been replaced by wood and more recently waste paper.
One problem, particularly with the northern hemisphere crops such as barley and oats, is that they primarily occur where labour costs are high, western Europe and the USA, and it has already been noted, that the cost of transport and storage of annual fibre sources can be prohibitive, and labour intensive.

Barley straw.

Barley is an cereal crop, adapted to cool weather and short growing seasons, typical of the temperate, northern hemisphere countries of Western Europe. The quantity of land set aside for barley cultivation increased dramatically after the Second World War, but has been decreasing since the late 1970's. It is no longer used in large scale food production, but plays an important role in beer production and cattle feed. The largest producers, in decreasing order of magnitude, are; the CIS (USSR), France, Great Britain, Spain, and the USA.
With the advances in wheat straw pulping it is undoubtedly possible to make paper grades from barley straw, even if it may require blending with long fibre pulps. However, post 1950s effectively no research has been carried out into utilizing an agro-waste to be found in very large quantities, (150 million tonnes in 1982). The probable reason for this lies in its geographical distribution. The developed countries, where barley is most commonly found, carry out very little research into any nonwood fibres, preferring to increase the efficiency of wood pulping, and the quantity of recycling. Until this attitude changes it is unlikely that any large scale utilization of cereal straw is likely to occur again within Western Europe. It is however possible that small amounts may be used in speciality grades and to increase bulk values of conventional pulps.

Sorghum straw.

Sorghum is adapted to warm areas that may become dry during the growing season. Most is cultivated in Africa and Asia, where it is grown for human consumption, with minor quantities used for cattle feed in the USA. Sorghum cannot be milled using conventional

techniques, and its usage worldwide is in decline, (approx. 60 million tonnes p.a. is produced).
As with wheat straw and rice straw, the bulk of the research has been carried out where the need is greatest, and it is certainly possible to produce good quality paper grades from sorghum stalks, though this process remains rare. More modern pulping methods such as soda-anthraquinone, have improved the yield and strength properties of sorghum derived paper, and as the other constraints to mass production are removed, (transport, storage etc.), the exploitation of this currently under used resource becomes more likely.

Millet straw.

Millet shares many of the characteristics of sorghum, being cultivated mainly where the soils are poor and rainfall scanty. In Africa and Asia, where it is most commonly cultivated, it is regarded as a "poor man's food", and 85% of the sorghum produced is for human consumption, the remainder is grown as cattle feed.
Approximately 27 million tonnes of millet is available annually, and as with sorghum, little of the straw is utilized at the present time, in the paper industry.

Oat straw.

Much of what was said about the utilization of barley straw is also true for oats straw, it being a northern hemisphere crop, typical of temperate, western countries, with extensive wood pulp industries. Consumption worldwide has declined rapidly with the decrease in the utilization of horses, particularly in the USA.

Rye straw.

Rye too is a northern hemisphere crop typically cultivated in the developed, wood-centred, western economies. It is particularly useful as a crop in countries with poor sandy, or acid soils and relatively cold temperatures. Production has declined post-war. As far as the author is aware there is no large-scale pulping of oat straw or rye straw, though in the past it has been possible to obtain at the very least, packing and wrapping grades of paper.

Mustard straw.

A limited amount of research has been carried out by Indian research workers into the possibility of obtaining pulp from mustard straw. Chemical pulps were obtained with a reasonable, 35-41% yield (unbleached), using the soda process. The resultant strength properties were good, but a far more drastic and intensive digestion was needed, than would be required for rice or wheat straw.

Poppy straw.

Poppy straw has been used in small quantities in the East, for paper pulp primarily because of its high cellulose content (78.0% holo cellulose, 42.2% alpha cellulose), the lignin and pentosans content is comparable with bagasse.

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Other potential sources.

<u>**Esparto**</u>.
Stipa tenaccisima
Lyganum spartum

Origin. North Africa.

Theoretical geographical distribution. Warm temperate and subtropical.

Plant morphology and characteristics. The paper making variety of esparto will reach a height of between 1 and 1.3m, with leaves 15 to 90cm in length, however cultivated crops are generally, substantially shorter,(35-75cm). The stem fibre source is cylindrical and covered with short hairs. Esparto grows in bunches or tufts about 1.5-2ft. in diameter. Where they are more prolific these may merge to form a "sea" of plants, covering many miles.
Large amounts of esparto grow wild in North Africa and the Mediterranean steppe of southern Spain, it is the only form of vegetation that can be supported on the dry sandy and calcareous soils, bordering the Sahara. It is found at altitudes of from 350m to 1,400m above sea level. It cannot withstand frosts, but is able to resist drought.
A variety of esparto,cultivated in Spain known as "Albardin", yields substantially longer fibres than normal varieties, the ultimate fibres being 0.6-2.5mm long.

Yield,(average, dry bleached pulp), 40-45%

Cellulose content, 45-50%

Fiber length, mm, 0.4(1.5)1.8
diameter, mm, 0.013 (average)

Harvesting. Under cultivation a commercial crop can be taken every 4-5 years, with one, or rarely two, harvests per year. In North Africa, where the plant is uncultivated, they are harvested in the dry summer months, by hand pulling, and is labour intensive. The leaves, after pulling are dried and bundled for transport, often overseas. In Spain the process is similar but more highly mechanised, and went into serious decline in the 1950s.

Current and potential uses, (excl. paper). A cordage variety of esparto exists, with longer and finer leaves. It is used for spinning, twine, rope, brush making and even upholstery.

Pulp and paper research. Esparto has been used in papermaking for many years, particularly in the British Isles. The traditional process has involved boiling with a solution of caustic soda. Mills currently in operation are located in, Algeria, France, Germany, Tunisia, Uruguay, and the U.K.
The paper produced is of exceptional quality and is used in speciality grades of paper.

Environmental impact. Little research appears to have been carried out into modernising the pulping process involved, however it still appears to be less energy and chemical intensive than conventional wood pulping.
A large increase in supply would require cultivation, in North Africa this could be carried out with a minimal increase in land use pressures, due to its unusual environment, but elsewhere this would probably not be the case.

Conclusions. Esparto remains a high quality source for the paper industry, and a valuable crop in countries with restricted rainfall and periods of drought. Little recent research has been carried out into this crop, and it seems certain to remain as primarily a source for speciality grade pulps.

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Other Grasses.

Sabai grass *(Eulaliopsis binata)*

Various grasses have been experimented with, as potential fibre sources. Of these sabai grass is probably the most well known. It was used in India in large quantities until relatively recently, but has declined, in favour of agro-residues and hardwoods.
It has a relatively low cellulose content, and a high lignin content. When compared to most nonwood raw materials its fibres are relatively large with an extremely variable diameter.

Cellulose content,	54.5% (average)
Fibre length, mm,	0.48(2.08)4.9
diameter, mm,	0.004(0.009)0028

Recent research, particularly in China, has concentrated on using various grasses in blends rather than as single pulps, in some cases blended with synthetic fibres for speciality paper grades.

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Elephant grass (*Imperata cylindrica*)

This is distint from miscanthus but many of the properties are similar. It is used in both India and Africa to produce small quantities of paper pulp. Precise figures are not available concerning its physical characteristics. However it seems reasonable to assume that they are similar to other grass and straw varieties, ie. short fibres, good bulk, poor runnability etc. They could not be regarded as agro-wastes as they would require specific large scale cultivation, if the crop is to be renewed, and as such would compare unfavourably with most straws, already in use.

Leaf fibres.

Abaca (Manila hemp)
Musa texilis

The abaca fibre is obtained from the leaves of the banana-like plant *Musa texilis*, it is also known as manila hemp, though it has no relationship with hemp, a bast fibre. The Philipines are the principal world suppliers, though it is also harvested in Borneo, Sumatra, Indonesia, and Central America. There are nine abaca mills worldwide with a total production capacity of 35,000 tonnes/year, one of which, located in the Philipines, can produce 8,000 tonnes per/year. The mature plant has 12-20 stalks, 2-7-6.7m tall and 10-20cm thick at the base. It is the leaves however that are the source of the fibre, these are 1.2.4m long, 10-20 cm wide and 10mm thick at the centre, the fibres are in the outermost layer. The plant produces a crop every 5 years; 2-4 stalks can be harvested about every 6 months.
Abaca is regarded by many as the best papermaking fibre there is. It is the strongest of leaf fibres followed by sisal, phormium and henequen, all also used in papermaking. It has properties that cannot be found in wood pulps, especially for making strong products such as tea bags, currency, cigarettes, and filter papers. It has a particularly fine wet strength and a high porosity.
Its fibre dimensions are comparable to those of kenaf, however the cost of harvesting, transport etc. are relatively high and abaca appears destined to remain a speciality paper grade of paper.

Caroa.
Neoglaziovia variegata

This is a hard leaf fibre obtained from a relation of the pineapple family, that grows wild in eastern and northern Brazil. The sword shaped leaves are 1-3m long and 2.5-5cm wide. The fibre is primarily used for cordage and acoustic material. The cellulose content is lower than for most vegetable fibres (approx.60%) and the fibre dimensions comparable to those of kenaf. Its use in papermaking is very limited, and detailed research appears absent.

Henequen.
Agave fourcroydes

Henequen is typically found in dry tropical climates and first cultivated by the Mayans, in Mexico. Today it is also grown in Cuba, Australia, and El Salvador. The plant produces for

20-30 years. The bottom leaves grow upto 2m long and 10-15cm wide. Henequen fibre is inferior to the related sisal fibres, and is usually restricted to use in ropes and cordage. Henequen fibres are used in small quantities in papermaking, but there is little available information, concerning agronomics, and pulp characteristics.

Mauritius.
Furcreae gigantea

This is obtained from the giant cabuya plant, native to Brazil where it is called pita or piteira. It is cultivated on the Island of Mauritius, hence the name Mauritius hemp. The plant itself resembles the Agaves, except it is much heavier and larger.
The cellulose content is relatively high (75.6% approx.), and comparable to hemp. Unfortunately the fibres are very short (2-6mm), and Mauritius hemp would only be suitable for low grades of paper or blending with long fibre pulps.

Phormium.
Phormium tenax

Phormium is native to New Zealand, and is commonly called New Zealand flax or hemp, though it has no bast fibre characteristics. The plant is a perennial with a fan shaped cluster of leaves 1.6-4.3m long, and 6-10cm wide. The cellulose content is comparable with kenaf (63%), and the fibres slightly longer (2-11mm). As with henequen and Mauritius hemp, it is known that small quantities are utilized in the paper industry, its properties appear similar to those of sisal.

Sisal.
Agave sisalana

Sisal is very widely cultivated in the western hemisphere, Africa, Asia, and Oceania. It possesses long and fleshy leaves 1-2m long, and 10-15cm wide. Sisal produces a coarse and strong fibre utilized in twines cordage and speciality blends of paper. There is already at least one large pulp mill in operation in Brazil.
Like Mauritius hemp the cellulose content is relatively high (approx. 77.2%), and the fibres short, in papermaking its properties appear best suited to speciality grades, such as tea bags and cigarette papers.

Hesperaloe and Yucca.
Hesperaloe funifera
Yucca spp.

Recent research has suggested that both hesperaloe and yucca, members of the family *Agavaceae* are capable of producing superior grades of paper due to their relatively long fibre characteristics. The pulps produced were superior to those of abaca and sisal, which would require blending. Both have been grown commercially for fibre in the past but cultivation today is rare.

Other Fibres.

Mitsumata.

Edgeworthia papyrifera
Edgeworthia chrysantha

Various pulping techniques have been tried on mitsumata basts, particularly for the production of "washi", a type of fine Japanese paper. High quality pulps have been achieved using alkali pulping (hydrogen peroxide), that do not require sulphur cooking, and have a chlorine free bleaching. The yield was generally high.

Papyrus reed.

Cyperus papyrus
cyperus antiquorum

A reed typical of North Africa, but also grown in the Americas. It has been used since ancient Egyptian times though the paper produced then was not "true paper", as it was not re-constituted. As a source of paper pulp, it is cultivated in Egypt, many areas of Africa, the Middle East, South America and the Sudan.

Reed.

Phragmites communis

This is a relatively important source of paper pulp in China, the "old" USSR, Rumania, North Korea, and Egypt. The pulp produced is soft and bulky, with a medium length fibre. The fibre characteristics are set out below;

Fibre length, mm	1.00(1.40)1.80
diameter, mm	0.01(0.015)0.02

In 1982 China produced 521,000 tonnes of reed pulp, equivalent to 12.4% of total pulp production. The pulping itself frequently lacks waste liquor recovery systems, particularly in the older plants, and three pulping processes predominate; sulphate, magnesium bisulphate and neutral sulphate, which may turn out to be the best,if a suitable chemical recovery system capable of operating on such a small scale could be developed. Outside of China there appears to be very little published information on *Phragmites communis*, and without further agronomic information, little more can be said of this fibre source.

Tobacco stacks.

Nicotiana tabacum
Nicotiana rustica

Tobacco stacks have a similar chemical composition to jute stick, having 57.2% cellulose, but considerably shorter fibre lengths, the fibre properties are set out below;

Fibre length, mm	0.42(0.95)1.89
diameter, mm	0.010(0.018)0.03

When subjected to sulphate pulping they produce a yield of approx. 44%, comparable with all but the very best nonwood fibres. As an agro-waste, large quantities of tobacco stalk are available, this combined with its physical properties, suggests that further research should be carried out in this area.

Parthenium.
Parthenium hysterophorus

This is a hazardous weed common in India. It has short fibres and would appear to be of use solely as a means of conserving long fibre pulp sources. Widespread use as a short fibre blend would have the advantage of removing substantial amounts of this weed from the environment. It is unlikely to play anything more than a very minor role in paper production.

China jute.
Abutilon theophrasti

This is a bast fibre located primarily in China, that is used extensively in the production of cordage and coarse textiles. *A. theophrasti* is a member of the mallow family, it is a herbaceous annual growing to a height of some 3-6ms with a stem diameter of 10-18mm. Apart from China it is also cultivated in small quantities in the CIS (USSR), Japan, Korea, and Argentina. Harvesting and fibre preparation may be mechanical or manual. The ultimate fibres are comparable in length and diameter to kenaf (they are 2-6.5mm long and 7-33 microns in diameter). Little work appears to have been carried out into the possibility of large scale pulp usage of this plant, despite its close morphological similarity to true jute.

Ramie.
Boehmeira nivea

Ramie is a member of the nettle family and is used widely for fabrics and fishing nets. It originated in China, hence its name "China grass", but is now also cultivated in, the Philipines, Japan, Brazil, and Europe. Harvesting is normally by hand, and because of the high gum content, manual or machine retting is not possible. The plant itself grows up to 2.5m high and is 6-16mm thick. The eventual de-gummed bleached fibre contains 96-98% cellulose. Ramie possesses the longest ultimate fibres of any of the vegetable sources discussed here, they are 60-250mm long and 16-120 microns wide. However the actual fiber stands are substantially shorter than those of its nonwood counterparts.
The relatively high cellulose content and long fibres make ramie a potential source of long fibre pulp for the paper industry, however as yet little research appears to have been carried out.

Cadillo.
Urena lobata

As with ramie, very little research appears to have been carried out into the papermaking properties of this plant, despite its close physical similarities to jute and kenaf, and its perennial nature. Cadillo is a grass, typical of Zaire and Brazil, it grows to a height of 4-5m with a stem diameter of 10-18mm. Its primary use is in cordage and coarse textiles.

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Section 5. Summary and Conclusions. *See table 3.*

In view of the depleting forest wealth, particularly in developing countries, and the scandalous waste of agro-residues worldwide, the importance of nonwood fibre plants in pulp and paper production, particularly that of annual crops, required a detailed review. The chemical and physical characteristics of a series of such fibre plants have been analysed, as was the potential environmental impact. Recommendations were made for the possible utilization of each, along with the technical and geographic restrictions. These can be referred to within the text.

Paper has an enormously important position within society, being used in commerce, the home, industry and education. Its use in the developed world continues to increase at a relatively slow rate; however in the developing world paper consumption has increased dramatically and is set to continue. It is for this reason that the bulk of nonwood research has been carried out.
The worlds forest reserves continue to decrease at an alarming rate in both developing, and developed countries and attention has fallen on to the potential use of nonwood fibres. In fact massive amounts of agro-waste fibres are available annually, 1,220,000,000 tonnes in 1982, a large percentage of which are left unused or burnt with subsequent deleterious effects on the environment.
Research into crops such as kenaf, roselle, miscanthus and hemp has shown a ready source of renewable pulp, capable of producing all necessary grades of paper, from paperboard to newsprint and high quality writing papers. Many nonwood fibres have considerable advantages over wood pulp fibres, particularly in the production of speciality paper grades, chemical and energy requirements, rate of growth and even yield per hectare.
The technology for the production of nonwood pulp is advancing, with increased awareness, of pollution, water use, and energy requirements. This has lead to the development of new production techniques such as Organosolv pulping, and the NACO process, the latter utilizing soda oxygen in the cooking stage. Some work is still required in reducing costs (transport and storage), and in liqour recovery which is complicated by the small scale of most operations.
Advanced projects to utilize straw for liner and packaging board are already active in Europe and North America, but these do not compare with the quantity of pulping already carried out in the developing world, particularly the East.
It is in the developing world that the greatest short term benefits are to be obtained. Bagasse pulping is already established, even in countries with substantial forest reserves such as South Africa. Much of the pioneering research is being carried out in countries such as Cuba and Argentina. It is bagasse that has been the driving force in the nonwood sector, particularly in the development of new technologies, which are already being transferred to other nonwood fibres such as kenaf, and the various abundant straw residues, (wheat, rice etc.).
Kenaf research has been carried out for many years with little subsequent action. However recent work on converting whole-stalk kenaf into chemi-mechanical pulp has been very successful and mills may soon be established in Australia and the USA. The future may lie in separating the core and bast fibres, which have very different properties, to produce a long-fibred chemical pulp and a short-fibred mechanical pulp, which would be ideal for newsprint production.

NON-WOOD FIBRE PULPING CAPACITY

Country	Straw 1978	Straw 1982	Bagasse 1978	Bagasse 1982	Bamboo 1978	Bamboo 1982	Other 1978	Other 1982	Total 1978	Total 1982
	— In 1000 tons —									
Algeria	24	27	-	-	-	-	85	85	109	112
Egypt	44	44	20	48	-	-	-	-	64	92
South Africa	-	-	108	108	-	-	-	-	108	108
Tunisia	-	-	-	-	-	-	26	26	26	26
Cuba	-	-	61	69	-	-	-	-	61	69
Mexico	19	19	287	472	-	-	18	18	324	509
Argentina	-	-	-	-	-	-	1	1	1	1
Brazil	-	-	139	149	49	83	36	102	224	334
Colombia	-	-	89	94	-	-	1	1	90	95
Ecuador	-	-	15	15	-	-	-	-	15	15
Peru	-	-	200	235	-	-	-	-	200	235
Uruguay	6	6	-	-	-	-	-	-	6	6
Venezuela	-	-	110	120	-	-	3	3	113	123
Bangladesh	-	-	20	20	30	30	21	27	71	77
Burma	-	-	-	-	12	12	-	-	12	12
China	?	?	415	425	-	-	4675	5305	5090	5730
India	85	85	15	30	685	772	150	150	925	1037
Indonesia	41	45	6	35	14	14	-	-	61	94
Iran	-	-	60	60	-	-	-	-	60	60
Iraq	-	-	5	12	-	-	22	55	27	67
Japan	-	-	-	-	-	-	4	4	4	4
Jordan	4	4	-	-	-	-	8	8	12	12
Kampuchea, Demo.	5	5	-	-	1	1	-	-	6	6
Korea, Rep. of	18	18	-	-	-	-	10	10	28	28
Pakistan	-	-	30	30	-	-	-	-	30	30
Philippines	-	-	27	27	-	-	23	23	50	50
Sri Lanka	17	17	-	-	-	-	1	1	18	18
Syria	-	27	-	-	-	-	-	-	-	76
Thailand	-	-	-	-	6	6	70	70	76	76
Turkey	33	58	-	-	-	-	2	4	35	62
Viet Nam, Soc. Rep	10	10	-	-	-	22	-	-	10	32
Albania	5	5	-	-	-	-	-	-	5	5
Bulgaria	28	28	-	-	-	-	-	-	28	28
Czechoslovakia	-	-	-	-	-	-	25	25	25	25
Denmark	45	45	-	-	-	-	28	28	73	73

1) Source: FAO Pulp and Paper Capacity Survey 1977-1982

Table 3. Reproduced from UNEP (1982). Contd. over page.

Table 3. Contd.

Country	Straw		Bagasse		Bamboo		Other		Total	
	1978	1982	1978	1982	1978	1982	1978	1982	1978	1982
German Dem.Rep	-	-	-	-	-	-	53	69	53	69
Greece	32	32	-	-	-	-	-	-	32	32
Hungary	22	22	-	-	-	-	-	-	22	22
Italy	428	444	-	-	-	-	-	-	428	444
Netherlands	45	45	-	-	-	-	2	2	47	47
Poland	21	5	-	-	-	-	2	2	23	7
Portugal	12	12	-	-	-	-	30	30	42	42
Romania	58	58	-	-	-	-	44	44	102	102
Spain	240	240	-	-	-	-	40	40	280	280
United Kingdom	-	-	-	-	-	-	25	25	25	25
Yugoslavia	8	8	-	-	-	-	-	-	8	8
Australia	-	-	-	-	-	-	5	5	5	5
TOTAL	1250	1309	1662	2004	797	940	5410	6163	9119	10422

In 1000 tons

Clearly most nonwood fibre sources can be divided into two catagories, agro-wastes (straw, bagasse etc.), and annual fibre crops (hemp, kenaf, roselle, miscanthus etc.). The utilization of the former will not place an additional burden on land use, and its removal may have a favourable environmental impact. This however, cannot necessarily be said for the latter. Land will have to be found for large scale fibre farming, which will be in competition with existing crop harvests. This is where sunn hemp may have an advantage, as it is an efficient nitrogen fixer and would make a suitable rotation crop. Hemp *sensu stricto*, has also proven a valuable and versatile fibre crop that could have a future as a source of paper pulp, unfortunately its association with marijuana and subsequent illegality, makes widespread farming in many countries highly unlikely, although progress has been made in Australia in producing a variant with a low narcotic content. The most promising fibre crops, particularly for temperate and sub-tropical environments remain kenaf and roselle, and possibly miscanthus. Detailed agronomic research is still required to discover which crops have the greatest potential for use, and in which area of pulp production they should best be utilized.

Much experience already exists in the pulping of agro-fibres such as bagasse and straw. In the developing world, particularly China and India, the future expansion of nonwood paper production is certain. A potential model for how this may be achieved comes from China, where a large number of farms are linked by a co-operative to a local pulp mill. This could also help in the possible production and harvest of a long-fibre crop, perhaps by rotation, as a means of improving the furnish. A similar model could be proposed for the developed countries as a means of utilizing their agro-wastes, but unfortunately co-operatives are sadly out of vogue at present.

Recent political developments, particularly in Europe may herald increased use of nonwood pulps. EC ministers in June 1992, have already called for a common policy on forestry, as a means of safeguarding future supplies of timber. Measures are being taken to outlaw stubble burning, which could lead to increased use of straw pulps in paper manufacture, although the necessary incentives needed to invest in nonwood fibres remain absent in the affected countries.

In the more developed economies, it is postulated that with the correct use of incentives and the removal of large scale subsidy from the wood-pulp industry, it should be possible to utilize considerable quantities of agro-waste fibres such as straw, in the production of medium grades of paper, newsprint, liner and packaging. This is partly because annual fibres should take or share the low cost role, that recycled fibres have at present, (the recycled fibres slowly taking over the higher quality roles) and it is expected that consumer pressure in the west will be to use raw materials produced on an open landscape, (not plantation cultivation) some of these developments can alredy be seen in Europe.

High quality pulps will increasingly contain a recycled furnish and percentages of annual fibre crops such as miscanthus and kenaf, will be added to counterbalance the reduction in tear strength that accompanies recycling.

The utilization of farmed fibre plants will provide a new cash crop for many hard pressed farmers.

Perhaps the best chance to increase nonwood use, in the developed world, is to once again rely upon consumer pressure, in the same way as the campaign for recycling has, (though this may require more sophisticated labelling), and to build on the clear price incentives that already exist in the production of "environmentally friendly products", such as chlorine free paper.

To conclude, the future of nonwood fibres should be assured (deforestation and the conversion of natural forests to plantations, cannot continue at the current rate without enormous environmental damage being caused), making the utilization of agro-wastes in particular, a necessity rather than an option.

Varieties suitable for pulp have effectively already been identified, and detailed agronomic investigations are required for the more promising fibre crops (kenaf, roselle, miscanthus, hemp, sunn hemp etc.). Their use in speciality papers, carbon paper, cigarette paper, tea bags etc. may well compensate for their high transport, handling and storage costs.

The widespread use of agro-fibres would give lower and more stable factory gate prices. In future only sulphur- and chlorine-free pulping and bleaching processes should be used, with an emphasis on producing high tear and dewatering properties to aid running on high-speed paper machines.

It remains scandalous that supposedly responsible governments, particularly in the developed countries still use valuable crops and materials such as virgin woodland, whilst leaving agro-wastes easily capable of performing the same tasks to pollute the countryside or be burnt as stubble.

It is surely irresponsible to allow the squandering of such resources, whilst simultaneously destroying fragile ecosystems.

The possibilities for the development of a nonwood pulp and paper industry, based on renewable, sustainable resources are enormous if given the same economic incentives and support that the current wood-based paper industry receives.

When combined with re-cycling, nonwood fibres provide a viable means of reducing the current rate of deforestation, whilst maintaining an adequate supply of pulp and paper for the growing market in the developing world. It is surely time for responsible governments to invest in this area for the good of the global environment in general, and for the long-term interest of each country, to preserve forest reserves by utilizing wastes.

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