KENAF (Hibiscus cannabinus L.)
Agronomy and Crop Management

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Origin of the genus

- **Kenaf** (*Hibiscus cannabinus* L.) has been cultivated long, as early as 4000 BC (Roseburg, 1996)
- Its existence of *semi-wild kenaf in Africa* (Kenya and Tanzania) might be an indication of its origin from this continent.
- At the beginning of the 18th century kenaf introduced in *southern Asia* and was first cultivated and commercially utilized in *India*.
- In the beginning of 1900, kenaf was disseminated into mainland *China* from *Taiwan*.
- In 1902 *Russia* started to produce kenaf.
- In 1930 kenaf cultivated in *Asia* and *USSR*.
- During the *Second World War* the crop introduced to *USA*.

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Kenaf it originated from eastern Africa and through Egypt disseminated to India and China. From Asia was moved to USSR and then during the second word disseminated to USA and then to central and south America. Kenaf can be cultivated from 30°S to 45°N.
Common names of *Hibiscus cannabinus* L.

Kenaf is connected with a long list of 120 common names that reflect the diversification and common uses of the crop.

- in **English** is *kenaf*;
- in **India** is *mesta, palungi, deccan hemp* and **Bimli jute**;
- in **Taiwan** is *ambari,*
- in **Egypt** and **Northern Africa** is *til, teel;*
- in **Indonesia** is *Java jute;*
- in **Brazil** is *papoula de Sao Francisco;*
- in **south Africa** is *stokroose* and
- in **West Africa** is *dah, gambo* and *rama.*
Taxonomy of kenaf

- **Kenaf** is a *short day annual herbaceous* plant belongs to the *Malvaceae*, a family notable for both its economic and horticulture importance.
- **Kenaf** is closely related to *cotton*, *okra* and *hollyhocks*.
- **Kenaf** along with *roselle* is classified taxonomically in the *Furcaria* section of Hibiscus (that has 40-50 species).
- The **chromosome number** in the section Furcaria is a *multiple of 18* (36, 72, 108, 144, 180). The diversity in number of chromosomes found in the Furcaria section is not common in the plant kingdom.
- The **diversity** represents a rich source of material potentially useful for *planting breeding*.
- A genome analysis found that *kenaf* and *roselle* share a *common set of chromosomes*.
The Crop

- Bark
- Core
- Tops and flowers
- Tap Root
- Leaf shapes
- Seeds and capsules
Area of its cultivation

- Over the last 20 years, the total planting area of combined kenaf/jute in China ranks the third in the world next to India and Pakistan (together representing > 90% of the total kenaf area).
- In China the mean cultivated area was **150,000 to 400,000 ha** with a **over 900,000 ha in 1985**. However, kenaf production has been declining in the last years due to the strong competition by synthetic materials.
Area of its cultivation

Almost 60% of the kenaf production in Far East countries (2010/11) is in India (140 thousand tones), with China to contribute with 32% to the total production, Pakistan with 5% and Indonesia with 1%.
Traditional uses of the crop

- The *traditional uses* of the crop connected with its *fiber stems* (paper pulp, etc.)
- In Africa the *leaves* and the *scions* was used as food either raw or cooked.
- Its *seeds* were used for its *oil* and *various plant parts* were used in *medicines* and in certain *superstitious rites*. 
Research on kenaf at world level

- The research on kenaf is being carried out worldwide (USA, Australia, South America, Thailand, India and Japan).

- In **USA** the research started in 1940s as substitute of jute due to supply distribution from the Far East during the World War II.

- In **Australia** the research started in 1972 for paper pulp but even now the crops is not yet commercialized due to fact that the Australian pulp mills are mainly based on wood.

- In **Europe** the research started in 1990s as non-food crop for biobased products and bioenergy.

- In **China** a emphasis is being given on the development of new varieties.
Crop management

In order kenaf to compete successfully with the traditional crops and maximize monetary returns the effects of **agronomic practices** on **yield** and **crop quality** must be better understood.

The most important agronomic practices are: **varieties**, **sowing dates**, **plant densities** (and/or **row spacing**), **fertilization requirements**, **irrigation needs**, **weed management**, **crop rotation**, **management of insect and diseases**, **harvesting time**.
Varieties

Kenaf according to their reaction to flowering are divided in two groups the early and the late-maturity varieties.

- **Early maturity kenaf varieties**: The flowering is irrelevant to the day length. In the pedoclimatic conditions of South Europe the duration of the vegetative phase may be 75 to 105 days (early varieties) or 105 to 120 days (semi-early varieties). The early varieties were developed for the Asiatic regions of former USSR.

- **Late maturity kenaf varieties**: The flowering is depending on the daylight and the first flowers appears when day length is less than 12 hours and 30 min. The vegetative phase lasts from 120 to 140 days.
Sowing dates

- Kenaf seeds are relatively small and require good seed-soil contact for germination. The seedbed should be fine, firm and well prepared.

- The soil temperature should be at least $15^\circ C$ and the sowing depth should be from 1.5 to 2.5 cm.

- Under favorable soil conditions kenaf seeds emerge after two to four days after sowing.

- The sowing date strongly depends on the specific pedoclimatic conditions of the area of cultivation. Early planting dates often result in poor emergence and slow non-competitive growth. On the other hand, the late planting dates will often result in reduced yields potential due to the reduced solar radiation availability.
Plant densities

- Kenaf is a *self thinning crop* and reduces its population during the growing season.
- It is cultivated at high plant populations, ranging from **300,000** to **500,000 plants/ha**.
- It is required a total quantity from **8 to 15 kg seeds/ha**.
- A large number of plant densities have been tested worldwide from **99,000 to 932,000 plants/ha**.
- In most of the research works it is reported that when the plant densities increased from **150,000 to 350,000 plants/ha** the yields were also increased.
Fertilization requirements

- When the crop is harvested after the first killing frost the stems are defoliated and the leaves returns **significant quantities of nitrogen** (4% by weight), calcium, magnesium, phosphate and potassium back to the soil.

- Kenaf requirements for nitrogen are high, up to **30 kg N per ton of stems**.

- It has been estimated that in Australia that kenaf gave 10 t/ha yield the fertilization was: **Phosphorus: 30 kg N/ha, sulfur: 30 kg N/ha, Potassium: 50 kg N/ha, Nitrogen 230 kg/ha and Copper: 3 kg/ha.**
Irrigation needs

- **500 – 625 mm rainfall** over a period of 5 to 6 months is needed for a successful production of kenaf fiber.
- When the **plants are irrigated well higher yields** were achieved.
- **Kenaf roll its leaves during drought** and **water stress** is not always injurious although it **reduces vegetative growth** it sometimes **improve the quality of the plant products**.
- In general the **water stress results** in shorter plants with lower LAI, thinner stems and **lower stem yields**.
- **Kenaf** can be grown successfully on a **saline soil** when **the irrigation water** has **good quality**.
Crop rotation

- Because the crop host the root-knot nematodes *Meloidogyne incognita*, *M. javanica* and *M. arenaria* crops that are sensitive to these should be avoid to follow kenaf cultivation such as *cotton* and *peanut.*

- When kenaf is rotating with a legume (like soybean) the stunt nematode (*Tylenchorhynchus* spp) that is responsible for the most soybean yields losses can be reduced. Kenaf may not be suitable for rotations with cotton and peanut but with soybean. To reduce the incidence of nematodes in affected areas, *kenaf could be planted following maize and sorghum.*

- Another non-food crop that could be used as nematicide is *hemp*, especially when rotated with susceptible crops such as *potatoes, maize, peas, grains and pastures.*
Crop rotation

- **In China** in order to reduce the nematodes populations it is proposed to rotate kenaf **with non-host nematodes crops such as groundnut, rice, maize and sesame**. Maize is as a good rotation crop to follow kenaf in high-infested nematodes.

- In the southern areas of Europe, for example the combination of **conventional** (wheat, legumes, maize, sunflower) and **new energy crop species** (sweet/fiber sor-ghum, kenaf) in rotation would optimize the utilization of soil resources and fit the prevailing climatic conditions.

- In 4FCROPS European project (www.4fcrops.eu) the following rotation systems were proposed for kenaf:
  a) sweet sorghum – cereal (wheat) – soybean – hemp (kenaf),
  b) sweet sorghum – cereal (wheat) – hemp (kenaf) – cereal (barley).
Nematodes problems in central Greece (light sandy soil)

Kenaf roots clear from nematodes

Kenaf roots with nematodes problems
Kenaf applications

- Organic absorbent
- Polymer compounds
- Insulation material
- Insulation mats
- Bioplastic for
- Bioplastic for
Pyramid value of the added economic value of the biomass uses

- Biofuels for renewable energy
- Agrochemicals, Green Chemicals Biomaterials (biopolymers, construction materials, composites, etc.)
- Pharmaceuticals, nutraceuticals, cosmetics, fine chemicals
The overall objective of the project was to introduce and evaluate kenaf as a biomass energy crop for alternative land use and provide “new opportunities” for farmers in agricultural regions of southern EU.

The specifics objectives were:

- To determine the sustainable yielding potential of kenaf, as an energy crop at different locations in Southern Europe, and to assess the limitations that certain cultivating techniques (irrigation, nitrogen, sowing date and plant density) place on crop growth.

- To develop a dynamic crop growth simulation model for kenaf as a useful tool for yields and energy production predictions.

- To evaluate the effect of harvest timing and storage methods to the quantity and quality of the harvested material for energy exploitation.

- To evaluate the quality characteristics of kenaf as a fuel for the thermochemical conversion processes (combustion, gasification and pyrolysis).

- To conduct an economic evaluation of the crop for alternative land use in selected agricultural systems of southern EU regions.
The presented work aimed to determine the sustainable yielding potential of kenaf in Europe and in the view of a large number of field trials were conducted in several sites in Europe (Greece, Italy, Spain, Portugal and France 2003-2007) as well as to provide data to a growth simulation model for kenaf.

This work is a part of BIOKENAF project: Biomass Production Chain and Growth Simulation Model for Kenaf (http://www.cres.gr/biokenaf)
**Tested factors**

- **Varieties**
  Tainung 2, Everglades 41, Gregg, Dowling, SF459, G4

- **Sowing dates**
  Early-late, from early March to the beginning of August

- **Plant densities**
  200,000 and 400,000 plants/ha

- **Irrigation rates**
  0, 25, 50 and 100% of PET

- **Fertilizations rates**
  0, 50, 75, 100 and 150 kg N/ha

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# Details of the field trials

<table>
<thead>
<tr>
<th>Experimental field trials</th>
<th>Countries</th>
<th>Factors under study</th>
<th>Experimental design</th>
<th>Plot size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Screening trial</td>
<td>Greece</td>
<td>Six kenaf varieties</td>
<td>Randomized complete block design in three blocks</td>
<td>6x6 m²</td>
</tr>
</tbody>
</table>
| Sowing times and plant populations | Greece, Italy, Spain, Portugal and France | 2 varieties  
2 sowing times  
2 plant populations | A factorial in three blocks | 6x8 m²    |
| Irrigation and nitrogen fertilization effects | Greece, Italy, Spain, Portugal and France | 4 irrigation rates  
3 nitrogen fertilisation rates | A split-split split plot design in three blocks | 6x8 m²    |
| 2 ha kenaf field trial    | Greece, Italy                                 | The best-performed variety will be sown under the best plant population and will be irrigated and fertilized according to the results from the previous trials |                                                         |           |
Kenaf varieties

- **Everglades 41** (late variety that produce reasonable fiber production and a cotton-like leaf shape)
- **Tainung 2** (late variety, with superior raw fiber production and palmate leaf shape)
- **Gregg** (is a new variety with slightly longer growing period that may contributes to greater fiber production and palmate leaf shape)
- **Dowling** (new variety, that may prove to be a very high fiber producer with non-palmate leaf shape)
- **SF 459** (new variety that is favored for soils with nematode problem and palmate leaf shape)
- **G4** (it is considered as a photoperiod-insensitive variety that combines a short maturity cycle (100-130 days between emergence and flowering) and high productivity when grown in the Mediterranean region)
Leaves and flowers of the three realized kenaf varieties (Gregg, SF 459 and Dowling) (Source: Onalee’s Home Grown Seeds and Plants, [http://www.onalee.com](http://www.onalee.com))
Sites of the established kenaf field trials
*two of them were not in the cultivation zone of kenaf*
Measurements

- Growth data (plant height, stem diameter, number of plants, LAI, SLA).
- Harvests (large number of subsequent harvests) were made for dry matter determinations as well for investigation of the appropriate harvesting time.

Results and discussion

- Variety effect
- Sowing dates effect
- Plant populations effect
- Irrigation effects
- Nitrogen fertilization effect
Effect of variety (Tainung 2, Everglades 41, Gregg, Dowling, SF 459 and G4) on final stem yields

When the six varieties were compared in the same field of a period four subsequent years it was found that the most productive was the new released variety SF 459 (14.55 t/ha), followed by Everglades 41 (14.38 t/ha), Gregg (13.98 t/ha), Tainung 2 (13.32 t/ha), Dowling (13.30 t/ha) and G4 (9.68 t/ha).
In three trials (Aliartos, Catania and Madrid) **Tainung 2** was more productive than Everglades 41, while in two sites (Palamas and Bologna) **Everglades 41** was the most productive and in two sites (Palamas and Paris) the yields were the same for both varieties.
In all sites the **early sowings resulted in higher dry stem yields** (2003-5). The most profound superiority of the early over the late sowing in terms of yields was recorded in Palamas-GR (23%), in Bologna-IT (32%) and in Lisbon-PT (34%). In the first case a quite early sowing time was tested (March), in the second case the late sowing took place in June, while in the third the late sowing took place in the beginning of July.
View of kenaf plots (in the middle of June 2004, Greece) were sown at the end of April 2004 and at the end of May 2004 (Source: CRES)
In 2005 when the two sowings had two months difference (5/4/05, 2/6/05) the early sowing gave significantly higher dry yields compared to the late one (21.4 t/ha versus 16.7 t/ha).
Effect of plant density (200,000 and 400,000 pl/ha) on dry stem yields

There is **no clear picture regarding the effect of plant population**.

In cases like Aliartos-GR, Catania-IT and Madrid-ES a clear superiority of the low density (200,000 plants/ha) over the high one (400,000 plants/ha) was recorded, while in Bologna-IT and Lisbon-PT the opposite was happened. In Palamas-GR and Paris-FR both densities gave almost the same yields.
Kenaf stems at an early stages of growth and at plant density 400,000 plants/ha (5 cm within the row and 50 cm between the rows) (Aliartos-Greece, Source: CRES; Biokenaf network)
It was proved that *when the irrigation rate was increased the growth and yields were also increased and in most of the cases statistical significant differences were recorded.*

It should be pointed out that the clearest effect of the irrigation on growth and yields was recorded in Madrid trial.
Effect of irrigation on kenaf development
(Source: CRES, Biokenaf project, [www.cres.gr/biokenaf](http://www.cres.gr/biokenaf))

Irrigated plants (100% of PET)

Plants that received only 25% of PET

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Effect of nitrogen rates (0, 75, 150 kg N/ha) on dry yields

In most sites it was found that when the nitrogen application was increasing the dry stems yields were also slightly increased.

The clearest picture of this trend was recorded in Lisbon.

Only in few cases the differences among the nitrogen rates were statistically significant.

Averaged all trials, it was found that the dry stem yields were 7.6 t/ha (0 kg N/ha), 8.1 t/ha (75 kg N/ha) and 8.8 t/ha (150 kg N/ha).
Effect of nitrogen rates (0, 50, 100 and 150 kg N/ha) on dry stem yields

The results recorded in the six sites for a period of three years **cannot** give a clear picture regarding the effect of the nitrogen fertilisation of kenaf growth and yields and thus additional research is needed.

It should be also pointed out that in the international literature **quite contradictory results have been reported with clear and no effects of nitrogen fertilisation of yields.**
Main conclusions on agronomy

- **The late maturity varieties** more productive compared to the early.
- The **new variety SF 459 is very productive** with yields higher than the yields of the two traditional varieties Tainung 2 and Everglades 41.
- **The yields were increased when the sowing time was between the early to the middle of May.** When the sowing time was delayed until the middle of the end of June a serious decline of the yields were recorded.
- A mixture picture was recorded regarding the effect of plant density on the yields. **Both densities (200,000 and 400,000 pl/ha), averaged overall trials, gave almost the same mean yields.**
- Similar findings with plant densities were also recorded for the two varieties. **It was found that their yielding capacity was almost the same with a slight superiority of Tainung 2 over Everglades 41, when grown in South Europe.**
- **It was found that by increasing the applied water in the kenaf fields their productivity was increased** and in most cases the yields that were recorded for the applied irrigation rates were differ statistically (P<0.05). This trend was quite strong and clear in all years in the case of Madrid
- **On the contrary the dry yields did not or slight increased by the increase of the applied nitrogen.**
A new dynamic crop growth simulation model named “BIOKENAF” was developed and it is able to predict kenaf phenology, growth characteristics (leaf area index, soil water balance, etc.) and biomass yields (stems, leaves, petioles) under a wide range of soil climatic environments in Europe.

This model was based on the Wageningen photosynthesis modeling approach and it can simulate biomass production under two productions situations: potential and water-limited.
View of the harvesting (mowing-chopping) and storage trial in Trieste (Italy) and transportation to KEFI ITALIA premises (Source: CETA, BIOKENAF project)
THE PRODUCTS

Bark fiber

Insulation panels

Composites for testing (A&F)

Schematic composition of kenaf stem and bast fibre
(Source: A&F)

Moulded test pieces
Market opportunities have been identified for Kenaf as a fuel, in the manufacture of paper, tea bags, and as a fibre-glass substitute. Kenaf is also a viable feedstock for chemical pulp mills for the production of specialty paper.

High yields of 18 t/ha and above may be economically viable for Kenaf as an energy crop on large farms. Moderate yields of 14 t/ha will be economically viable for Kenaf if the product price is €80/odt.
Comparison of kenaf with other biomass sources in terms of ash content (%) and initial deformation temperature (°C)

<table>
<thead>
<tr>
<th>Sample</th>
<th>Ash content [wt%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kenaf core</td>
<td>2.0</td>
</tr>
<tr>
<td>Kenaf whole plant</td>
<td>2.4</td>
</tr>
<tr>
<td>Beech (hardwood)</td>
<td>2.3</td>
</tr>
<tr>
<td>Pyne (softwood)</td>
<td>0.3</td>
</tr>
<tr>
<td>Miscanthus</td>
<td>2.0</td>
</tr>
<tr>
<td>Switch grass</td>
<td>4.8</td>
</tr>
<tr>
<td>Arundo</td>
<td>4.5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sample</th>
<th>Initial Deformation Temperature [°C]</th>
<th>Fluid Temperature [°C]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kenaf core</td>
<td>&gt; 1270</td>
<td>&gt;&gt;1270</td>
</tr>
<tr>
<td>Kenaf whole plant</td>
<td>&gt; 1270</td>
<td>&gt;&gt;1270</td>
</tr>
<tr>
<td>Beech (hardwood)</td>
<td>&gt; 1270</td>
<td>&gt;&gt;1270</td>
</tr>
<tr>
<td>Pyne (softwood)</td>
<td>&gt; 1270</td>
<td>&gt;&gt;1270</td>
</tr>
<tr>
<td>Miscanthus</td>
<td>1060</td>
<td>1210</td>
</tr>
<tr>
<td>Switch grass</td>
<td>1080</td>
<td>1230</td>
</tr>
<tr>
<td>Arundo</td>
<td>1000</td>
<td>1150</td>
</tr>
</tbody>
</table>

- Kenaf core is a good material for combustion, while the whole plant has problems with feeding systems. Combustion of the whole plant gives high NOx emissions.
- The initial deformation temperature is higher (>12700 C) compared to other energy crops miscanthus, switchgrass, giant reed) and this prevent ash melting problems at thermal conversion.
Progress on kenaf research in Greece

- The last two years a large number of varieties are being tested in Greece in both marginal and typical agricultural lands.
- The yields in typical lands were around 20 t/ha for most of the tested varieties.
- The tested varieties have been imported by USA, Mexico, Israel and currently by China.
- The varieties from Israel are for both fibre and seeds production.
- A new project has been just started between Greece and China and will last 30 months and in the view of this projects new varieties will be tested and biomaterials will be produced.
Kenaf trial in Greece (2012) comparing 12 varieties in three blocks
Future challenges

- To develop varieties appropriate for south Europe with high yields. In China there is a lot of research in kenaf breeding, while in south Europe we cultivate varieties that imported mainly from USA and Mexico.

- To cultivate dual purposes varieties (stems and seeds) in the specific climatic conditions of south Europe and to investigate firstly their productivity and secondly the products that can be obtained from both stems and seeds.

- Through breeding and appropriate cultural practices to increase the yields of stems and seeds.
More information about kenaf can be found:
BIOKENAF project, www.cres.gr/biokenaf
FIBRA project, www.fibrafp7.net
FIBRACOM project, http://fibracom.physics.auth.gr

Thank you very much for your attention
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