Agronomy and crop physiology of fibre hemp. A literature review

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AGRONOMY and CROP PHYSIOLOGY of FIBRE HEMP, A LITERATURE REVIEW

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Contents.

1 Objectives of this literature review.

Within the framework of the National Hemp Research Programme, research is conducted to investigate the potential of hemp as a source of fibre for the paper industry in the Netherlands. This programme started on January 1, 1990 and should reach a conclusion on the economic feasability of hemp for fibre by the end of 1992. Major subjects of research in the program are:

- Breeding
- Soil-borne diseases
- Crop physiology and agronomy
- Harvesting and conservation
- Pulp and paper technology
- Economy and logistics

Research on crop physiology is being carried out within a research project at CABO, research on agronomy within a joint LUW-PAGV project.

The objective of the research projects concerning crop physiology and agronomy of fibre hemp is to answer the question:

How much and what kind of fibre can hemp yield in the Netherlands?

This literature review will focus on the literature results most relevant with respect to that question. The objectives of the literature review are:

1. The identification of research objectives in crop physiology and agronomy of fibre hemp, resulting in a coherent program of experiments serving the objectives.
2. Relevant sections of this literature review will be used in an article presenting the results of the experiments conducted by Meijer and Matthijssen in 1988 and 1989.
3. The literature review may be useful to researchers involved in other parts of the hemp research programme.

While conducting the literature research and writing the review, literature on crop physiology of hemp turned out to be rare. Consequently this review mainly covers the agronomy of hemp production.

2 THE HEMP PLANT

2.1 Origin and importance of hemp

The origin of hemp lies in central Asia or China; it was grown in China as early as 2800 BC (Dempsey, 1975).In the past hemp was an important fibre crop, its importance gradually declined in the course of the 20th century (Table 1). The decline was most pronounced in countries having a market economy.

Table 1. Hemp area in 1,000 ha, 1910 - 1988. Data FAO Yearbooks.

Country	Year or period					
	1910[a]	1925[b]	1948-52	1969-71	1979-81	1988
Africa	.	.	1	0	0	0
America N	.	.	1	0	0	0
America S	.	.	4	4	4	4
Asia	.	.	.	.	287	171
Bangladesh	.	.	.	7	3	1
China	.	.	.	.	123	53F
India	.	.	190F	156	132	90F
Japan	.	.	4	1	0	0
Korea N	.	.	10F	7	8	15F
Korea S	.	.	10	5	1	1F
Pakistan	.	.	16	10	10	8F
Syria	.	.	4	1	0	0
Turkey	.	.	12	8	9	4F
Europe	.	.	275	86	59	63
Austria	23	.	0	0	0	0
Bulgaria	3	4	21	10	5	1
Czechoslovakia	.	12	5	2	1	0
France	14	5	5	0	3	1F
Germany E	.	.	4	2	0	0
Germany W	.	.	2	0	0	0
Germany	0	3	6	2	0	0
Hungary	63	14	23	12	7	7F
Italy	79	112	58	1	0	0
Poland	.	43	14	16	3	3
Romania	6	36	64	26	35	50F
Spain	9	7	6	0	0	0
Yugoslavia	15	.	70	17	4	1
USSR	653	858	558	202	140	100F

a: Marquart, 1919. b: Heuser, 1927. F: FAO estimate.

2.2 Varieties of hemp

Most hemp growing countries grew one or more varieties which in general were selections from indigenous varieties. In Europe the two main types of hemp used to be Russian hemp and Italian hemp (Heuser, 1927).
Russian hemp reached Europe by a Northern route, through Russia. Italian hemp reached Europe through Turkey and the Mediterranean region. Russian hemp has a good early vigour (rapid growth in spring), is early maturing and short (1.5 to 1.8 m). The plant is strongly branched and has a high seed yield. Italian hemp has a poor growth in spring, it is late and tall (3.5 m). Italian hemp does not branch much, fibre yield and quality are high, seed yield is poor (Marquart, 1919; Heuser, 1927).
Havelländischer hemp, an early German variety, is based on Russian Material. Kuhnowse hemp, a late German variety, is based on Italian hemp (Heuser, 1927). The so-called Fleischmann or Kompolt hemp from Hungary is based on Italian material (Hoffmann, 1957).
Currently good quality seed of several monoecious French and dioecious Hungarian (de Meijer et al., 1990) varieties can be obtained commercially. When grown in the Netherlands the French varieties flower in the first half of August, the Hungarian varieties flower in the second half of August. Both French and Hungarian varieties are susceptible to *Botrytis cinerea* and *Sclerotinia sclerotiorum*. Whether varieties are available from breeding and/or seed production programmes in other countries is not known.

2.3 Sex expression of hemp

Hemp is a dioecious plant, monoecious individuals however do occur. Monoecious varieties have been obtained through breeding.
The morphology of the inflorescence of hemp may be either feminin: leafy, stocky, no branches, or masculin: few leaves, strongly branched. Each of these two types may present only female flowers, only male flowers or flowers of both sexes in different proportions. Hoffmann (1957) presents denominations for each of the six combinations. Plants bearing both male and female flowers are graded into one of five classes depending on the proportion of male flowers.
Male plants die shortly after anthesis. Female plants live 2 to 4 weeks longer than male plants, until the seed is ripe. In a dioecious crop the number of female plants is 10 to 50 % higher than the number of male plants (Hoffmann, 1957).

2.4 Anatomy of the stem

The stem of mature hemp may be divided in a vegetative and a reproductive section. In the lower vegetative part leaves are opposite, in the upper reproductive part leaves are alternate. In fibre hemp vegetative internodes are 3 to 4 times longer than reproductive internodes (Verzar-Petri et al., 1981).
The stem tissues outside the vascular cambium (henceforward called "bark" in this review) consist of the epidermis, the cortex and the phloem. In the phloem are sieve tubes and phloem fibres or bast fibres. The tissues inside the vascular cambium ("wood" in this review) are the pith and the xylem. The xylem consists of vessel members, ray and paratracheal parenchyma cells and libriform fibres.

Hemp presents both primary and secondary bast fibres. Secondary bast fibres are shorter than primary bast fibres (2 versus 20 mm) and are more lignified (Hoffmann, 1957).
According to Heuser (1927) the length of wood fibres is almost constant at 0.5 mm, the length of primary bast fibres varies from 10 to 100 mm, on average 35 to 45 mm. Bast fibres are 18 to 25 μ wide, but in the lower part of the stem much wider. The diameter of the lumen is about 1/3 of that of the fibre. Kundu (1942) measured the length of primary and secondary fibres from near the base of a plant with nearly mature fruits. For primary fibres average length and width were 12.7 mm and 34.2 μ; for secondary fibres average length and width were 2.18 mm and 16.56 μ. The length of the primary fibres increased with the length of the internode (Kundu, 1942).
According to Bredemann (1940) the length of primary bast fibres is largest in the middle of the stem, decreasing to top and basis. Likewise, Bredemann (1940) states that bast fibre contents is highest in the middle of the stem. Both Heuser (1927) and Arnoux et al. (1969) found the bast fibre contents to increase from the basis to the top of the plant. Arnoux et al. (1969) conclude that that a stem section situated between 30 and 40 % of the total height of the stem (going from base to top) will form a good sample of the stem as it has the average content of bark, wood and bast fibre.
After 17 years of breeding, Bredemann (1952) increased the content of bast fibre in the stem of a hemp population from 12 to 29 %. Concomitantly the fraction of bark in the dry matter of the stem increased from 29 to 48 % (wood decreasing from 71 to 52 %) and fibre content in the dry matter of the bark had increased from 45 to 72 %. Hoffmann (1957) states that breeding for high bast fibre tends to favour secondary bast fibre over primary bast fibre, unless secondary bast fibre is monitored during breeding to prevent this.
Bredemann et al. (1961) found bast fibre contents in the dry matter of the stem to decrease with an increase in the dry weight of the stem. Within the bast fibre fraction, the proportion of secondary bast fibre increased with an increase in the dry weight of the stem.
Horkay (1982) assessed the high bast fibre varieties of the Hungarian Kompolt breeding programme. She found larger ratios of secondary fibre cells to primary fibre cells with increased bast fibre contents.
Bast fibre content in the stem increases with plant density (Von Lucke, 1925; Heuser, 1927; Jakobey, 1965), probably as a result of less secondary thickening in the plants at a high density. Other factors influencing the proportions of bark and wood in the stem have not been found in the literature on hemp.
In other species the fraction of libriform fibers has been found to decrease with the availability of soil water to the plant (Tobler, 1957). Mechanical stimulation (e.g. shaking) may affect the development and growth of mechanical tissues of plants as was shown for collenchyma by Walker (1960). Growth regulators may affect the proportions in which xylem and phloem are formed by the cambium. According to Bruinsma (1983) auxin promotes the formation of xylem and gibberellic acid accelerates phloem formation. Waisel et al (1966) however found giberellic acid to increase the production of xylem.

2.5 Length and diameter of the stem

Hemp varieties differ in height: late varieties are taller than early varieties (Heuser, 1927; Verzar-Petri et al. 1981). The height of hemp plants is very sensitive to growing conditions. Poor conditions such as drought, a bad soil structure or nutrient deficiencies limit plant height (Heuser, 1927; Dempsey, 1975). Plant density also affected plant height. In early maturing, short varieties plant height increased with plant density; in tall, late-maturing varieties plant height decreased as plant density increased (Marquart, 1919). All other authors (Heuser, 1927; van der Schaaf, 1963 and Jakobey, 1965) found that plant height decreased with increasing plant density. Presumably these authors did not investigate short varieties.
Stem diameter decreased with increasing plant density. The length to diameter ratio of the stem increased with increasing plant density (Heuser, 1927; van der Schaaf, 1963).
The diameter of a hemp stem is largest at about 1/3 of its height; within an internode the diameter is largest in the middle of the internode and smallest at the nodes. The form of a section through a hemp stem is circular at the base of the plant, hexagonal half-way and square in the upper part (Heuser, 1927).
According to Heuser (1927) the bast fibre content of a hemp plant has a strong positive correlation to its height/diameter ratio. Bredemann (1927) however did not find this strong positive correlation. Von Lucke (1925) finds that bast fibre content is positively correlated with plant height and negatively with stem diameter.

3 CULTURAL PRACTICES OF THE HEMP CROP

3.1 Soil requirements and fertilization

Hemp grows best on loose soils (Marquart, 1919; Heuser, 1927). In Germany hemp did particularly well on the nitrogen-rich lowland bog ("Niederungsmoor") soil, especially in a rotation with potatoes, as hemp prevented deterioration of the soil structure (Heuser, 1927). Hemp is particularly sensitive to water logging (de Meijer et al., 1990) and it requires a well-drained soil (Friederich, 1964; Dempsey, 1975). According to Heuser (1927) hemp is very sensitive to drought. Dempsey (1975) stated that hemp needs ample water especially during the first 6 weeks of its growth. Drought and high temperatures towards the end of the growing season hasten the maturity and lead to short plants.

Marquart (1919) stressed the importance of N and K for Hemp. Heuser (1927) and Dempsey (1975) both stressed that hemp requires much Ca. Bredemann (1945) and Mathieu (1980) present data on the uptake of nutrients. The nutrient content at flowering is much higher than at seed maturity (Table 2).

Table 2. Nutrients in hemp crops (kg/ha). A crop yielding 6.6 tonnes of stem+leaves dry matter and 0.7 tonnes of seed dry matter (Bredemann, 1945). A crop yielding 10 tonnes of stem+leaves dry matter (Mathieu, 1980).

Nutrient	Highest nutrient content in shoot + root kg/ha (Bredemann)	Nutrients harvested		
		Bredemann		Mathieu
		kg/ha	kg/tonne dm	kg/tonne dm
N	211	111	15.2	9.0
K_2O	241	124	17.0	15.0
CaO	259	108	14.8	15.0
MgO	43	22	3.0	1.5
P_2O_5	62	36	4.9	2.5

Rivoira and Marras (1975) found the highest stem yield at 150 kg of N/ha after a dry spring and at 225 kg of N/ha after a wet spring.
Bast fibre yields however were highest at 75 kg of N/ha in both years. Plant density at harvest decreased with increased levels of N fertilization.
For France, a soil pH of at least 5 was recommended (Anonymous, 1982). A yield of 10 tonnes/ha of stem dry matter would require 1000 to 1500 kg/ha of lime, 80 to 120 kg/ha of N, 80 to 120 kg/ha of P_2O_5 and 160 to 200 kg/ha of K_2O.
In Denmark, Nordestgaard (1976) obtained maximum bast fibre yields at the highest N rate applied (140 kg/ha).
For the Netherlands, Friederich (1964) recommended 120 kg of N/ha, 80 kg of P_2O_5/ha and 160 to 180 kg of K_2O/ha.

In six trials in the Netherlands Aukema and Friederich (1957) compared 100, 150 and 200 kg of N/ha. Both stem and bast fibre yield were highest at 200 kg/ha. Bast fibre content in the stem however decreased with increasing N-fertilization

3.2 Sowing date and depth

Thousand kernel weight of hemp seed ranged between 9 and 25 g (Marquart, 1919). According to Hoffmann (1957) the thousand kernel weight was between 18 and 22 g; for monoecious varieties it was about 16 g.
For Germany, Heuser (1927) advised to sow in the second half of April or in the first half of May. In his trials, earlier sowing reduced yields, probably due to a lower plant density caused by frost damage. Provided that the soil moisture content was sufficient, the crop emerged in 3 to 5 days.
For Italy, Rivoira and Marras (1975) found sowing in early April to be better than sowing in early May. The former sowing date extended the duration of the biological cycle with 10 to 15 days.
Tschaneff (1959) advised sowing in early March for Bulgaria.
In the Netherlands, hemp should be sown around the 15th of April according to Friederich (1964). Earlier sowing may cause more weed problems.

On non crust-forming soils hemp should be sown at a depth of 4 to 5 cm (Heuser, 1927). Spaldon and Laskos (1964) advised a sowing depth of at least 4 cm, up to 6 cm in dry years and for late sowing.

3.3 Sowing rate, plant density and row width

Heuser (1927) investigated the effect of five sowing rates ranging from 42 to 174 kg/ha on hemp yield. The yield of above-ground plant dry matter was maximal at 82 kg/ha. Stem yield however was maximal at the highest seed rate, as both the fraction of leaves and seed in the above-ground plant dry matter were negatively correlated with seed rate. Bast fibre fraction in the stem increased with seed rate. Unfortunately no data on plant density were given for this experiment. Heuser does state however, that 80 kg of seed/ha resulted in a plant density at harvest of about $260/m^2$ on a mineral soil and about $160/m^2$ on a moor soil. This difference is attributed to the more rapid growth on the nitrogen-rich moor soil which enhances inter-plant competition.
A reduction in the number of plants failing to reach maturity can be obtained by promoting homogeneous conditions for germination and early growth. Marquart (1919), sowing the same amount of seed at row widths ranging from 8 to 30 cm, found plant densities at harvest to increase with decreasing row width. In these experiments a reduction of row width probably led to a more homogeneous distribution of plants, thus reducing inter-plant competition. Broadcast sowing of the same amount of seed led to a very low plant density, probably as a result of clustering of plants or of large differences in germinating conditions and moment of emergence.
In Italy, Rivoira and Marras (1975) used 60 kg of seed/ha in several experiments. Plant densities at harvest varied from 40 to over 200 plants/m^2. One of the factors affecting plant density was nitrogen fertilization. Particularly in trials in which nitrogen caused a large

yield increase, plant densities at harvest decreased with an increase in nitrogen applied. Castellini (1962) gave a common seed rate for Italy of 40 to 50 kg/ha, this yielded about 200 plants/m^2 at emergence, but at harvest only 120 to 150 plants/m^2 were present.
In France, the use of 50 to 70 kg of seed/ha, is recommended (Anonymous, 1982), resulting in about 250 plant/m^2 (probably shortly after emergence).
In Hungary, Jakobey (1965) compared 11 initial plant densities ranging from 1.6 to 400 plants/m^2 in three years. Straw weight was maximum between 200 and 400 plants/m^2, bast fibre yield and bast fibre content were maximum at 400 plants/m^2 in 2 out of 3 years. In Hungary 80 to 90 kg of seed/ha is recommended, yielding an initial plant density of over 300 plants/m^2. At harvest plant density will be about 150 plants/m^2 (de Meijer et al., 1990).
In Denmark, Nordestgaard (1976) used 100 kg of seed/ha. The number of plants/m^2 decreased from 420 at emergence to 360 at harvest.
Danell (1965), comparing seed rates of 40, 60, 80 and 100 kg/ha in Sweden found the highest yields of stem and bast fibre when respectively 100 and 80 kg of seed/ha were applied.
In the Netherlands, Aukema and Friederich (1957) tested seed rates from 60 to 130 kg/ha in four trials. They found no consistent effects on the yield of bast fibre or above-ground dry matter. Van der Schaaf (1963) compared 50, 70 and 90 kg of seed/ha in one trial. Yield of bast fibre was highest at 50 kg seed/ha. Du Bois (1984) conducted 3 trials on different soil types during one year, comparing seed rates of 20, 40, 60 and 80 kg/ha. A seed rate of 20 kg/ha resulted in 74 plants/m^2 at harvest, of which 21 % were diseased; 80 kg of seed/ha resulted in 214 plants/m^2 at harvest, of which 39 % were diseased. The lowest seed rate resulted in the highest stem yield.

Marquart (1919) indicated that a row width of 25 cm or more may cause weed problems, unless the crop is cultivated.
Heuser (1927) recommended a most suitable row width of 20 cm. A row width of up to 30 cm could be used without significantly reducing the quantity and quality of bast fibre yield. Rivoira and Marras (1975) advised a row width of 15 to 18 cm, while a row width of 15 to 17 cm was recommended in France (Anonymous 1982).
In the Netherlands, Aukema and Friederich (1957) found both a higher stem dry matter yield and a higher bast fibre content at 10 cm row width compared to 20 cm row width.

3.4 Weeds

Under favourable circumstances hemp will grow rapidly and suffocate weed plants (Heuser, 1927).
Sown at 4 to 5 cm depth, lightly harrowing a dry soil shortly after emergence killed weeds without harming the crop (Heuser, 1927).
Lotz et al. (1991) found that hemp reduced growth and reproduction of the weed *Cyperus esculentus* to a much larger extent than other crops such as maize or winter barley

3.5 Diseases and pests

Marquart (1919) stated that diseases and pests have been rare in Germany so far.
Heuser (1927) mentioned that diseases and pests are very rare in hemp.
Hoffmann (1957) mentioned: *Alternaria* sp., *Rhizoctonia solani* Khn., *Pythium debaryanum* (=*P. ultimum* Trow.), *Botrytis cinerea* and *Sphaerella cannabis* (= *Mycosphaerella cannabis* (Wint.) Roeder). Of these, the latter two also damage fully grown plants. *Sclerotinia sclerotiorum* causes similar damage. As both *B. cinerea* and *S. sclerotiorum* damage the bast fibre, and *B. cinerea* in particular occurs more and more frequently, Hoffmann recommended to take these two diseases into account in breeding programmes.
Hoffmann further mentioned the strongly increased incidence of a hemp anthracnosis which reduced quality and yield of hemp. This anthracnosis was caused by *Colletotrichum atramentarium* (Berk & Broome) Taubenhaus (= *C. coccodes* (Wallr. Hughes).
Hoffmann mentioned two insects: *Psyloides attenuata*, the hemp flea beetle and *Pirausta nubilalis*, the European corn borer, which may cause damage in hemp.
Copper defficiency may cause a disease called "gummi"-hemp: the xylem in the plants has lost its rigidity, causing the plants to lodge severely.
Friederich (1964) mentioned that a large row width or the use of too much seed will cause a large number of small backward plants which will lodge and be infested by *B. cinerea*, forming a source of infestation.
According to Friederich, *B. cinerea* was the worst disease in hemp in the Netherlands.
Meijer and de Meijer (1990) reported severe yield losses in hemp grown in the Netherlands caused by *B. cinerea* and *S. sclerotiorum*. In field trials a frequent (at 10- or 14-day intervals) application of fungicides kept the crop disease free.
NB An extensive review of the literature concerning diseases of hemp is being prepared by A. Termorshuizen (IPO).

3.6 Harvest timing

According to both Marquart (1919) and Heuser (1927) lodging is very rare in hemp, so it should not complicate harvesting. Marquart (1919) advised to mow hemp for fibre when the stem and the lower leaves of the female plants begin to yellow, while the lower leaves of the male plants are already falling. Heuser (1927) does not give a clear definition of the optimum harvest stage. He mentioned that after flowering female plants continued to increase in diameter (+ 7 to 34 %) and in bast fibre content (secondary fibre). Lignification of bast fibres occured during and after ripening of the seed. Hoffmann (1957) mentioned that harvest for fibre generally occurs at the end of female flowering.
According to Spaldon and Laskos (1964) in Czechoslovakia the highest yield of long bast fibre is be obtained when the crop is harvested when 75 to 100 % of the male plants are shedding pollen in half or more of their inflorescences.
In southern Hongaria male flowering begins in early July, technical maturity (= harvest for fibre) is reached in the beginning of August (Jakobey, 1965).

In Italy flowering starts at the beginning of July and the highest bast fibre yield is attained during the last decade of July or in the beginning of August. Hemp for fibre is harvested during full flowering. The seed is ripe one month later and the crop can be harvested for both seed and fibre (Rivoira and Marras, 1975).
In France, harvest for fibre takes place by mowing the crop at the end of flowering. The end of flowering occurs around August 20 or later, depending on the variety. The crop then lies on a 5 cm-long stubble and reaches a humidity of 14 to 18 % in 4 to 8 days. A crop mown with a mower crusher will dry more rapidly. When the crop is sufficiently dry it is baled. Harvest for both fibre and seed occurs when the seed is ripe, this will be between September 5 and 30, depending on the variety (Anonymous, 1982). In one trial in the Netherlands, van der Schaaf (1963) harvested Fibrimon 21 on August 10 and 24 and on September 7. Highest stem and bast fibre yields were obtained on September 7.

3.7 Yield components and yield level

Marquart (1919) analysed whole plant dry matter of several indigenous varieties of hemp. A crop of Italian hemp consisting of plants with a mean height of 298 cm yielded 12 tonnes of whole plant dry matter/ha. The crop consisted for 10 % of root, 72 % of stems, 14 % of leaves and 4 % of seed. Similar data are given for other varieties.
In a seed rate trial, 42 kg of seed yielded plants with a mean height of 185 cm and an above-ground dry matter yield of 7.8 tonnes/ha. The crop consisted for 63 % of stems, 22 % of leaves and 15 % of seed. In the same trial 174 kg of seed/ha yielded plants which were 176 cm high, yielding 7.7 tonnes/ha above-ground dry matter and consisting for 72 % of stems, 15 % of leaves and 13 % of seed (Heuser, 1927).
On July 25 a hemp crop in which female plants started flowering consisted for 40 % of leaves+inflorescenses and for 60 % of stems. On September 9 when female plants started to mature, the crop consisted for 37 % of leaves+inflorescenses and for 63 % of stems; when the crop was ready to be mowed, on the 25th of September, it consisted for 23 % of leaves+inflorescences and for 77 % of stems (Bredemann, 1945).

According to Marquart (1919) yields of dry hemp stem varied from 3 to 10 tonnes of dry matter/ha in Germany. In Italy a hemp crop yielded 11.5 tonnes of stem dry matter when harvested at the end of July (Rivoira and Marras, 1975). Averaged over 11 trials conducted from 1959 to 1963 in Sweden, Fibrimon 21 yielded 8.7 tonnes of stem dry matter/ha (Danell, 1965). Averaged over 8 trials conducted from 1965 to 1969 in Denmark, Fibrimon 21 yielded 8.9 tonnes/ha of stem dry matter (Nordestgaard, 1976).
In the Netherlands Aukema and Friederich (1957) obtained 11 tonnes/ha of above-ground dry matter on sandy peat soils. On clay soils above-ground dry matter yields ranged from 9 to 14 tonnes dry matter/ha. Friederich (1964) obtained 10 tonnes of straw/ha with Fibrimon 56.
For trials conducted from 1987 to 1989 Meijer and de Meijer (1990) reported yields ranging from 8 to 13 tonnes of stem dry matter/ha.

4 Discussion and conclusions

The economical importance of fibre hemp has been diminishing steadily in the course of this century. Within Europe, hemp barely survives as a crop in France and Hungary where a few thousand hectares are grown. In Romania and the USSR hemp is more important (50,000 and 100,000 hectares respectively).

The currently available French and Hungarian varieties do not perform satisfactorily in the Netherlands, as they are too early and too susceptible to diseases. Hemp grown in The Netherlands for paper pulp does not necessarily have to be harvested early or to produce seed. Later varieties may yield more stem, as leaf area duration will be longer and no assimilates are diverted to the inflorescenses. The potential of late varieties may be investigated in field trials in which the varieties currently used are prevented from flowering by means of a long day treatment. Late disease resistant varieties may be obtained through breeding.

The anatomy of the stem of is the key to a definition of quality of hemp stem material as a source of fibre. Hemp stems contain three types of fibre: primary bast fibres which are long and low in lignin, libriform fibres which are short and high in lignin and secondary bast fibres which are of intermediate length and lignin content. Variability of fibre characteristics within each of the three types of fibre does not seem to be large relative to the differences in fibre characteristics existing between types of fibre. Quality of hemp stem therefore will depend mainly on:

a) the size of the fibre fraction in the dry matter of the stem

b) the proportion of each type of fibre in the total fibre fraction

At the crop level genotype and plant density seem to be the main factors determining the size of the fibre fraction and the proportion of each of the three types of fibre in the stem. Literature results on other factors determining the proportions of the three types of fibre (primary bast fibre, secondary bast fibre and libriform fibre) in the stem are scarce. A better understanding of factors governing the initiation of fibre cells in the apex and in the vascular cambium as well as of factors determining the distribution of assimilates to bast and libriform fibres seems indispensable. This type of knowledge may be obtained through both field experiments (plant density trials) and experiments in a controlled environment investigating the effects of factors such as : temperature, light (quantity and quality), mechanical stimulation and plant growth regulators.

Literature data on fertilization of hemp are not sufficient to formulate a fertilization advice which would take the soil fertility status and other crops in the rotation into account. For the time being it seems best to fertilize hemp according to the uptake of minerals. Considering the data collected by Bredemann and Mathieu, nutrients harvested per tonne of above-ground dry matter can be estimated at: 15 kg of N, 5 kg of P_2O_5, 17 kg of K_2O, 3 kg of MgO and 15 kg of CaO. Fertilization trials might allow a more accurate fertilization strategy, this type of research however does not seem to be a priority.

Sowing dates recommended in the literature vary. Optimum sowing date will depend much on the specific spring wheather conditions in each country. Yields obtained so far in The Netherlands range from 8 to 13 tonnes of stem dry matter/ha. These results were obtained with crops sown in the second or third decade of april. As hemp shows good growth at low temperatures, earlier sowing might result in earlier crop establishment and higher yields. Sowing date trials should be conducted in the research on agronomy of hemp as they will reveal the potential and hasards of earlier sowing.

The literature has shown a high plant density to be desirable. Although the effect of plant density on whole plant dry matter yield generally was insignificant, a high plant density decreased the fraction of leaves and inflorescences in the plant, thus increasing the stem fraction. Furthermore, a high plant density resulted in a higher fraction of the more valuable bast fibre in the dry matter of the stem, thus improving the quality of stem dry matter. Literature data from Germany, Italy, Hungary and France all indicate that plant density shortly after emergence generally was at least twice as high as plant density at harvest. Data obtained in The Netherlands show even more severe self thinning. The plants which die during the growing season not only represent a loss of dry matter, but may also hasten the occurence of fungal diseases in the crop.

In a hemp crop, the individuals which die during the growing season are the small ones. Any measure reducing variability in plant size will therefore probably contribute to a reduced mortality. A more homogeneous plant size may be obtained either through breeding or by agronomic measures. Both approaches seem worth pursuing. Apart from reducing mortality, less variability in plant size would probably be beneficial as well during harvesting and processing (better separation of leaves and inflorescences from stem material). To which extent a reduced variability in plant size will reduce mortality (self thinning) may be investigated in field trials by creating hemp crops differing in plant size variability through hand thinning, the use of precision sowing versus conventional sowing and by varying inter-plant distances through a varying row width.

Weed control does not seem to be a problem in hemp. Herbicides are not needed, provided the crop has a high plant density. Research in this field therefore does not seem to be a priority.

Diseases or pests were not a large problem in hemp according to the literature. In general this may be due to the more continental climate of the countries in which hemp was and is being grown. *B. cinerea* and *S. sclerotiorum* are less of a problem in a dry summer. Furthermore, in the Netherlands crop rotations are shorter than in most hemp growing countries. In general disease problems are more frequent in shorter crop rotations. Finally, statements in the literature on the lack of diseases in hemp may be the result of a lack of thorough investigations into the status of diseases in hemp. Fungal diseases are an important problem in hemp in the Netherlands. Hopefully more disease-resistent varieties can be bred to solve this problem. At the agronomical level the effect of applying a fungicide once or twice will be investigated.

The plant development stage in which fibre hemp is harvested varies from one country to another, it lies between flowering and seed maturity. Fibre yield continues to increase after flowering. When varieties become available which flower very late or not at all, the development stage at which the crop is harvested will be before or at flowering. Therefore, an extensive investigation into the optimum harvest stage of fibre hemp in the Netherlands does not seem a priority at this moment.

Yields obtained so far in field experiments in the Netherlands range from 8 to 13 tonnes of stem dry matter/ha. Yields obtained in other European countries are somewhat less. Perspective for increasing yield level seems present. Measures that may contribute to increased stem yields are: earlier sowing, late varieties and less variability in plant size resulting in less self thinning.

It may be concluded from the literature reviewed that the following experiments are most likely to contribute to an answer to the question: How much and what kind of fibre can hemp yield in the Netherlands?

Field experiments:
* Sowing date and yield and quality of hemp
* Plant density and yield and quality of hemp
* The potential of a non-flowering hemp crop
* Inter-plant variability and self thinning
* Reduction of damage by *B. cinerea* and *S. sclerotiorum* using fungicides

Greenhouse or growth room experiments:
* Plant growth regulators and quality of hemp
* Temperature and light intensity and quality of hemp
* Level of red/far-red light and quality of hemp

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