Available online at www.sciencedirect.com
ScienceDirect
Field Crops Research 107 (2008) 161–169
Field Crops Research
www.elsevier.com/locate/fcr

Influence of agronomic factors on yield and quality of hemp (*Cannabis sativa* L.) fibre and implication for an innovative production system

Stefano Amaducci [a,*], Alessandro Zatta [b], Federica Pelatti [b], Gianpietro Venturi [b]

[a] *Istituto di Agronomia e Coltivazioni Erbacee, Facoltà di Agraria, Università Cattolica del Sacro Cuore, Via Emilia Parmense 84, 29100 Piacenza, Italy*
[b] *DiSTA, Università Degli Studi di Bologna, Viale Fanin, 44 40127 Bologna, Italy*

Received 29 May 2007; received in revised form 29 January 2008; accepted 4 February 2008

Abstract

Research and development of an innovative production system for hemp (*Cannabis sativa* L.) fibre for textile use requires the integration of multidisciplinary knowledge from cultivation technique to realization of end products. Research was carried out to study the effect of the agronomic factors cultivation year (2003–2004), genotype (Futura 75 and Tiborszallasi), plant population (120, 240 and 360 plants m^{-2}) and harvesting time (beginning and full flowering) on fibre yield and quality in the whole hemp stem, and in the basal and apical stem portions separately. The study of separate stem portions was done to determine the effect on fibre quality of an innovative harvesting and processing system in which hemp stems are cut in two portions of approximately 1 m at harvest to enable processing on modern flax scutching lines.

Stem and fibre yield were affected by most of the agronomic factors. The extreme drought experienced in the first year reduced stem and fibre yield, but stems had higher percentage of fibre (16.5%), that were finer (22.9 μm) and with a higher degree of maturity (73.6%) in 2003 than in 2004 (respectively 16.0%; 24.5 μm; 55.8%). Between the two genotypes under trial the monoecious Futura 75 largely out yielded the dioecious Tiborszallasi in both years. The latter however had finer primary fibres and less secondary ones. In both genotypes primary fibres maturity and quantity of secondary fibres increased at later harvest.

Plant population affected stem biometrics and fibre characteristics, with finer fibres and less secondary growth at higher stands.

It can be concluded that cultivation technique can be exploited in order to maximize the quality and yield of stems destined for the innovative harvesting and processing system herein described.

Keywords: *Cannabis sativa* L.; Hemp fibre; Plant population; Genotype; Harvest time; Textile

1. Introduction

Hemp (*Cannabis sativa* L.) is a multipurpose crop that, worldwide in the last decade, has been the object of a multitude of research projects and industrial enterprises (Cromack, 1998; Ranalli, 2002; Amaducci, 2003; Müssig and Martens, 2003; Karus and Vogt, 2004). In particular, in the frame of the EU Project HEMP SYS (Amaducci, 2003; http://www.hempsys.-net) research and development of a sustainable production chain for hemp textile production is targeted. Hemp fibre for textile destinations is currently present on the market in very limited amounts, availability is uncertain, and it is produced via chemical retting of the fibre (Linificio, personal communication 2005; Fischer et al., in press). These are all limiting factors for the spinning industry that needs a consistent quantity of a product of defined quality, and produced with sustainable techniques. The production strategy at the basis of the HempSys project aims at the realization of an integrated quality system to control the quantity and quality of fibre along the whole processing line, from field production until the manufacturing of end products. In the field the quantity and quality of raw material produced is controlled by genotype × environment × management interaction (Struik et al., 2000). In particular plant density and harvesting time seem to have a major impact on the determination of fibre production, in terms of quantity, quality (Van der Werf et al., 1995; Struik

* Corresponding author. Tel.: +39 0523599223; fax: +39 0523599222.
E-mail address: stefano.amaducci@unicatt.it (S. Amaducci).

0378-4290/$ – see front matter © 2008 Elsevier B.V. All rights reserved.
doi:10.1016/j.fcr.2008.02.002

et al., 2000; Mediavilla et al., 2001; Amaducci et al., 2002a) and industrial processability (Keller et al., 2001).

The research presented in this manuscript was carried out to determine the effect of genotype, plant density and harvesting time on fibre yield and quality. Considering that the innovative harvesting and processing system proposed by the HempSys project is based on the division of the stem in two portions of 1 m, fibre yield and quality in the base and top part of the stem was also studied. In experiments to determine the effect of cultivation practices on fibre yield and quality there is a major problem: the methodology employed to extract the fibre influences both the yield and the quality of the fibre. From an industrial point of view, reliable results would be obtained if large scale scutching machines would be used in the experiments. However, the quantity of stems needed to feed an industrial system is not compatible with the dimensions of field plot experiments. On the other hand, lab scale equipment that simulates the industrial extraction of fibre is expensive (Akin et al., 2004). In this study fibre was extracted from the stem according to the Bredemann method (1942) and quality was evaluated as single fibre diameter, degree of maturity and presence of secondary fibre (Amaducci et al., 2005b).

2. Materials and methods

2.1. Field trial

Field trials were carried out at A.U.B. (Azienda Università Bologna) in Cadriano (32 m a.s.l.; 44°33′ latitude; 11°21′ longitude) in 2003 and 2004, comparing two genotypes, three plant densities and two harvesting times in factorial combination.

The two varieties were the French monoecious Futura 75 and the Hungarian dioecious Tiborszallasi. Target plant densities were: 120, 240 and 360 plants m^{-2}, and will be from now on referred to as D1, D2 and D3, respectively. According to the field protocol two harvests were carried out at specific phenological stages according to Mediavilla et al. (1998): beginning of flowering (cod. 2301 for Futura 75 and cod. 2101 for Tiborszallasi) and full flowering (cod. 2302 for Futura 75 and cod. 2200 for Tiborszallasi). Harvesting was carried out when 50% of plants had reached a predetermined stage of growth (Mediavilla et al., 2001).

The experiment layout was a completely randomized block design for the two varieties and the three densities while two harvest times were split into the main plots. Main plots were 62.4 m^2 (6.24 m × 10 m).

According to the USDA classification the soil was loamy in both years, pH 8.01 organic matter content of 1.91% in 2003, pH (in H_20) 7.07 and organic matter content 1.5% in 2004. In both years nitrogen fertilization was applied before sowing at a rate of 60 kg ha^{-1}, which proved to be the optimal dose in the area where the experiments were carried out (Amaducci et al., 2002b).

Sowing took place on 16 April 2003 and 8 April 2004 with an experimental sowing machine (Vignoli), row distance was set at 13 cm and seeds were sown 3–4 cm deep.

Immediately after sowing, a 50 cm row of plants was randomly selected and every other day for a 2-week period the number of emerged plantlets was counted. Flowering observations were carried out on 25 marked plants in all the plots of one block. Inspection of these plants was performed weekly and number of flowering plants was noted.

At each harvesting time 5 m^2 of crop per plot were cut at the base of the stem. Total biomass and number of plants were determined directly on field. Twenty plants per plot were brought in the laboratory to be divided in stem and leaves (when present inflorescences were added to the leaves), these were weighed and subsequently dried at 105 °C in order to calculate dry matter content. Plant height, diameter, internodes length, phenological stage and sex (in the dioecious cultivar Tiborszallasi) were determined on 100 plants.

Fifteen representative plants per plot were selected and dried at 105 °C for further processing and quality determination.

2.2. Laboratory analysis

2.2.1. Fibre extraction

Stems from each density and harvesting time were cut in two portions of 1 m. Fibre extraction was carried out with NaOH in the laboratories of A.U.B. according to the Bredemann method (1942).

The stem samples were boiled for 1.5 h in a solution of NaOH (0.35%) in order to facilitate the separation of the woody core from the bark. A second treatment was carried out on the bark, that was boiled for 2 h in a 2% solution of NaOH. The fibres were then laid on a sieve and rinsed with abundant tap water. The fibre obtained was dried at 105 °C and weighted. Bast fibre yield was calculated by multiplying the stem yield by the bast fibre content (Sankari, 2000). From here on, fibre content and fibre yield calculated with this method will be referred to as pure fibre (Müssig and Martens, 2003).

2.3. Microscopic analysis

Thin cross sections were hand cut from the middle part of the 1st, 3rd, 5th and 7th internodes immediately after harvest in both years for Futura 75 and only in 2004 in the case of Tiborszallasi. For the latter variety 50% female and 50% male plants were selected for the analysis. Stem cross section was carried out at the beginning of flowering and at full flowering in both years. In 2004 a third sampling was carried out at the end of flowering (code 2203 for Tiborszallasi and 2305 for Futura 75).

Stem cross sections were coloured with green methyl and red Congo and observed and photographed under Leitz Orthoplan light photomicroscope at 40, 100 and 250 times magnification (Amaducci et al., 2005b). These images were then processed with the software UTHSCSA Image Tool IT Version 2.03 in order to measure mean primary cell diameter ((larger diameter + smaller diameter)/2), degree of maturity ((mean cell diameter − mean lumen)/mean cell diameter × 100) which will be referred to as maturity index (MI) and to evaluate the presence of secondary fibre cells. Since