Hemp as A potential bio-ethanol feedstock.

Conference Paper · June 2009

2 authors:

Alessandro Zatta
Società Italiana Sementi S.p.A., San Lazzaro di Savena, Italy

Gianpietro Venturi
University of Bologna

HEMP AS A POTENTIAL BIO-ETHANOL FEEDSTOCK

A. ZATTA[1], G. VENTURI[1]
[1]Department of Agroenvironmental Science and Technologies, phone: +39 0512096692 / fax: +39 0512096241
e-mail: alessandro.zatta2@unibo.it
University of Bologna, Viale Fanin 44, 40127 Bologna, Italy

ABSTRACT: The European Union directives mandating the use of 10% biofuels by 2020 makes it essential to find suitable agricultural crops and cropping techniques for compelling with such directives. Moreover, such crops should fit specific soil and climatic conditions. Keeping this goal in mind, it is worth considering traditional crops in a modern perspective, e.g. with alternative end uses than the traditional ones. In this context, the potential of different hemp genotypes has been studied for the supply of feedstock for bioethanol production.
Postponing hemp harvest until the beginning of seed formation, in contrast with the traditional harvest at full female flowering, produced around 15 Mg ha^{-1} of stems with a high content of cellulose (60% ca.) and hemicellulose (15% ca.). No significant differences between monoecious and dioecious genotypes were found. The calculated bioethanol production with such biomass yield can reach up to 4500 litres ha^{-1}. At this ethanol yield, hemp could be competitive with the most acclaimed lignocellulosic crops, that, although achieving higher biomass yields, have lower cellulose content. The high ethanol yield potential along with the environmental benefits associated to the hemp cultivation, make this crop an interesting candidate for bioethanol production.
Keywords: Biomass, energy, harvest, lignocellulosic.

1 INTRODUCTION

The recent directives from the European Union [1; 2] mandate the use of 10% biofuels by 2020. The aims of this provision are to guarantee lower greenhouse gases (GHG) emissions and less dependency from fossil fuels imports, an improvement on supply security, technological development and innovation, as well as providing jobs and regional development, especially in rural and isolated areas. Biofuels use in road haulage is considered one of the most effective tools for reducing the greenhouse effect and the dependency on oil imports, which currently account for around 99% of the energy used in this sector.

Among the alternatives to fossil fuels for road haulage, are the biofuels from energy crops that could be suitable for specific areas and particular environmental conditions. An increase of 14.7 million hectares of energy crops is foreseen by 2010 and up to 25.1 million hectares by 2030 [3].

Producing ethanol from ligno-cellulosic crops - the so called 2nd generation biofuels - seems to ensure a higher yield per surface area than 1st generation biofuels, thus requiring less lands than starch or sugar crops to produce the same amount of bioethanol. In the last years many studies have been conducted on annual [4; 5; 6; 7] and on perennial ligno-cellulosic crops [8; 9], yet the most suitable combination of crop/management/environment is still uncertain. There is therefore the need of further studies to support decision makers in their choices of energy crops. In this context, the aim of this study was to evaluate the potential of different hemp genotypes to produce feedstock for bioethanol in Northern Italy.

2 MATERIAL AND METHODS

2.1 Field trial

The potential of three hemp genotypes, one monoecious (Futura 75) and two dioecious (C.S. and Fibranova), for bioethanol production was studied during three years 2006-2008. In the first year hemp was harvested only at the beginning of the female flowering (31 July), which corresponds to growth code 2102 [10], while in the last two years hemp was harvested at two different growth stages; one harvest was at full male flowering stage (H1), code 2102 [10]; and the other one was at beginning of seed maturity (H2), code 2203 [10].

The field trials were carried out at the experimental station of the University of Bologna (32 m a.s.l.; 44°33' lat.; 11°21' lon.). In 2006, only one factor, the genotype, was compared, and plots were arranged according to a complete randomized design. In 2007 and 2008 a split-plot design with three replicates was adopted to compare two factors: genotype (main) and harvest time (sub).

Soil was udifluventic Haplustepts fine silty, mixed, superactive, mesic in all three trial years (USDA classification). Sowing was done in 05/04/06, 10/04/07, and 19/03/08, at a row distance of 20 cm; seeds were sown 3-4 cm deep. Nitrogen fertilization (60 kg ha^{-1}) was applied before sowing [11].

Table I: Main soil chemical and physical characteristics during the three-year trial

Soil characteristics	2006	2007	2008
Sand (%)	36	26	42
Silt (%)	41	49	37
Clay (%)	23	25	21
Organic Matter (%)	1.6	1.4	1.5
pH (in H_2O)	7.3	7.9	7.1

In the first year, plots were 490 m^2 (70 m x 7.3 m). From the second year onwards the main plots had the same dimensions as in the first year with the two harvests set as the sub plots. Two square meters per plot were harvested in order to estimate the total biomass and plant density. Thirty representative plants per plot were selected, twenty of which were separated into stems and leaves (when present, inflorescences were added to the leaf part). The samples were oven dried at 105 °C and then weighed in order to determine the dry matter content. The remaining ten plants were oven dried at 60°C and conserved for later chemical analysis.

2.2 Chemical composition

The stem chemical composition in cellulose, hemicellulose and lignin was determined. Samples were first grounded (1 mm grids) with a hammer mill, and then cellulose, hemicelluloses and lignin content were determined though acid detergent fibre (ADF), acid detergent lignin (ADL) and neutral detergent fibre (NDF) as given by Goering and Van Soest [12].

3 RESULTS

Fresh harvested hemp biomass averaged around 45 Mg ha^{-1} with no significant differences among years, harvesting times, genotypes, and their interactions (Table II).

Table II: Main production parameters: Total Fresh Weight (TFW), Total Dry weight (TDW), Stem Dry Weight (SDW) and Leaf Dry Weight (LDW) measured in two harvest times (H1 and H2) and three years.

	2006	2007		2008	
parameters	H1	H1	H2	H1	H2
TFW (Mg ha^{-1})	44,1	42,7	45,8	46,1	42,1
TDW (Mg ha^{-1})	15,3	13,6	15,8	13,5	18,5
SDW (Mg ha^{-1})	12,4	11,2	14,0	11,8	16,5
LDW (Mg ha^{-1})	3,0	2,3	1,7	1,8	2,0
Stems (%)	80,4	82,7	89,1	87,0	88,7
Leaves (%)	19,6	17,3	10,9	13,0	11,3
Height (cm)	193,8	247,3	288,1	294,3	336,0
Diameter (mm)	6,0	9,2	10,1	11,8	13,2

In the first two years, dry biomass accounted for almost 35% of total fresh biomass and it was significantly lower in H1 than H2 (30% and 45%, respectively). The time between full male flowering and beginning of seed maturity in 2008 was 19 longer than in 2007 and therefore allowed hemp to accumulate more biomass.

Weight increase between the two harvests (H1 and H2) was 16% in 2007 and 37% in 2008. Leaf weight was between 2 and 3 Mg ha^{-1} representing 13-20% of total biomass yield for H1 and slightly more than 10% for H2. Stems (the profitable part in agronomic terms) yielded around 12 Mg ha^{-1} when hemp was harvested at full male flowering (H1). Delayed harvest (H2) allowed a yield increase from 2.8 in 2007 to 4.7 Mg ha^{-1} in 2008, that is 25-40% of total biomass. For each day of delay in harvesting, stem weight increase was 78 grams d^{-1} in 2007 and 70 grams d^{-1} in 2008, due to both an increase in stem height (around one centimetre per day) and stem diameter. These results confirm those previously obtained by Venturi [13]. However, yield increases did not generally offset the lower fibre quality [13], so from the textile industry point of view the best harvest time should be when female plants reach the fully blooming stage [14; 15; 16]. But there are still many challenges ahead to considered before hemp is fully utilized as an energy crop. For bioethanol production, for example, the high level of cellulose and hemicellulose present in hemp are of interest, whereas the lignin content represents a negative element since it decelerates the fermentation process [17; 18]

Importantly, this study showed that cellulose content can strongly increase by delaying the time of harvest. Specifically, cellulose yield was about 40% higher (3 Mg ha^{-1}) in H2 compared to H1. According to this, and taking ethanol conversion coefficients given by Badger [19], bioethanol yield were 2000-2500 l ha^{-1} in H1 and 3000-3500 l ha^{-1} in H2. Considering also hemicellulose the total amount of bioethanol would be 2500-3200 l ha^{-1} in H1 and 3800-4500 l ha^{-1} in H2. With delayed harvest the increase was around 35-45%.

Table III: Stems chemical composition and potential ethanol yield at two harvesting periods (H1 and H2). Since genotype X harvest time interaction was not significant, average values of monoecious and dioecious genotype are presented

	2006	2007		2008	
Parameters	H1	H1	H2	H1	H2
Cellulose (%)	63	58	65	61	62
Hemicellulose (%)	17	13	12	16	16
Lignin (%)	9	10	9	9	10
Cellulose (Mg ha^{-1})	8	7	9	7	10
Hemicellulose (Mg ha^{-1})	2	1	2	2	3
Lignin (Mg ha^{-1})	1	1	1	1	2
Ethanol from cellulose (l ha^{-1})	2710	2299	3164	2494	3544
Ethanol from hemicellulose (l ha^{-1})	732	501	602	650	959
Total ethanol (l ha^{-1})	3442	2799	3766	3144	4503

4 DISCUSSIONS

Though delaying harvest can significantly affect the fibre quality for textile use [20; 21; 16], this could be of secondary importance for bioethanol end use. Therefore, late harvest time could be worthwhile when hemp is processed for ethanol as late harvest is generally associated to a higher biomass production. In this study, irrespective of genotype used, about 40% higher biomass yield was reached through a late harvest, a result which is also corroborated by previous findings [13]. This biomass production seems still not to be competitive with other biomass crops for thermo-electrical conversions [22], but it would be very competitive for 2nd generation ethanol, due to the higher cellulose content of hemp compared to ligno-cellulose crops [6; 23; 24]. But delayed harvesting also brings to an increase in lignin content. The presence of lignin and hemicellulose it may create difficulties during the processing phase because makes the access of cellulose enzymes to cellulose difficult, thus reducing the efficiency of the hydrolysis [23]. Nevertheless, the non carbohydrate components of lignin have potential for use in value-added applications such as organosol lignin used to produce PF resin [25].

Late harvest time could be also desirable for the lower biomass moisture content and the less presence of leaves, which is considered useful either for stalk chipping and drying. This is considered as an advantage both in the case of direct chipping the standing plants and in the case of mowing and leaving the stalks to dry in the field for further windrowing and chipping, or even in the case that the stems are mowed, dried in the field and subsequently baled. The last two options allow to reduce the time necessary for stems to dry up. Moreover such harvesting methodologies favours the ratio of dry matter over the total biomass volume, increasing the energy value and reducing the volumes and transportation costs.

During the three-year trial, no significant differences in biomass production have been found between monoecious and dioecious genotypes that have medium and late growing cycles respectively. However, under the environmental conditions where the present study has been carried out, it may be advisable to use late growing cycle genotypes that would allow delayed harvest until the first half of September when autumn rains still have not started and thus leaving enough time for soils preparation for the subsequent cereals crops. The local genotypes used in this study do not show pre-flowering phenomena which induces to earlier harvest and lower yields [26; 27; 28; 16].

The other important agronomic and environmental aspects related to hemp cultivation must also be highlighted. Hemp has been traditionally used as a crop capable of enhancing soil condition and therefore it is advisable to include it in crop rotations with cereals cultivated either for food or fuel production. Hemp can improve soil structure, thanks to its deep root system [29], and above all, it can help to the control of weeds in subsequent crops [30; 31]. Moreover, the characteristic fast growing of hemp at early growth stages gives hemp the advantage over weeds to fully utilize the light and soil resources [32; 33]. Hemp cultivation needs little chemical inputs since it does not have high fertilisation requirements [34; 6]. Moreover, pesticides are not normally used in hemp cultivation because the low incidence of insects and disease [13; 35]. This latter aspect, added to those previously described in this paper makes hemp a very sustainable crop. The main constrain of this crop still remains the uneconomical extraction process and conversion (e.g. pre-treatment process and hydrolitc enzymes) of cellulose and hemicellulose into ethanol [23], however recent results would suggest that this issue could be overcome soon [36].

5 ACKNOWLEDGEMENTS

This study was founded by the "Interregional Programs" (L. 499/1999), under the approval of the interregional committee lead by the Friuli Venezia Giulia Region.

6 REFERENCES

[1] PE-CONS 3736/08, 2008. Directive of the European Parliament and of the Council on the promotion of the use of energy from renewable sources amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC

[2] 8040/09 ADD1, (2009). Council adopts climate-energy legislative package.

[3] European Energy Agency, (2006).

[4] J.W. Worley, D.H. Vaughan, J.S. Cundiff, Energy analysis of ethanol production from sweet sorghum. Bioresource technology, (1992), Vol. 40(3) pag. 263-273.

[5] G.A. Smith and D.R. Buxton, Temperate zone sweet sorghum ethanol production potential. Bioresource Technol. (1993), vol. 43(1) pag. 71-75.

[6] S. Amaducci, M.T. Amaducci, R. Benati, G. Venturi, Crop yield and quality parameters of 4 annual fibre crops (Hemp, Kenaf, Maize and Sorghum) in the North of Italy. Ind. crops and prod., (2000), Vol. 11 pag. 179-186.

[7] L. Barbanti, S. Grandi, A. Vecchi, G. Venturi, Sweet and fibre sorghum (Sorghum bicolor (L.) Moench), energy crops in the frame of environmental protection from excessive nitrogen loads. Europ. J. Agronomy, (2006), Vol. 25 pag. 30–39.

[8] Lewandowski, J. M.O. Scurlock, E. Lindvall, M. Christoud, The development and current status of perennial rhizomatous grasses as energy crops in the US and Europe. Biomass and Bioenerg, (2003), Vol. 25 pag. 335–361.

[9] Monti and A. Zatta, Root Distribution and Soil Moisture Retrieval in Perennial and Annual Energy Crops in Northern Italy. Agric. Ecosyst. Environ., (2009), vol. 132 pag. 252-259

[10] V. Mediavilla, M. Jonquera, I. Schmid-Slembrouck, A. Soldati, A decimal code for growth stages of hemp (Cannabis sativa L.) J. Int. Hemp Assoc., (1998), Vol. 5(2) pag. 68-74.

[11] S. Amaducci, M. Errani, G. Venturi, Plant population effects on fibre hemp morphology and production. J. of ind. hemp, (2002), Vol. 7(2) pag. 33-60.

[12] H.K. Goering, P.J. Van Soest, Apparatus, reagents, procedures and some applications. Agricoltural handbook No. 379, United States Department of Agriculture, Washington DC., (1970), pag. 1-20.

[13] G. Venturi, Risultati di un sessennio di sperimentazione sulla canapa. Riv. di Agronomia, (1967), Vol. I(3) pag. 137-150.

[14] Bòcsa and M. Karus, The coltivation of hemp: botany, varietes, cultivation and harvesting. (eds.) Hemptech, (1998), pag. 176.

[15] G. Venturi, M.T. Amaducci, Canapa (Cannabis sativa L.). In "Le colture da fibra", Collana PRisCA, (eds.) Edagricole, (1999), pag. 33-55.

[16] S. Amaducci, A. Zatta, F. Pelatti, G. Venturi, Influence of agronomic factors on yield and quality of hemp (Cannabis sativa L.) fibre and implication for innovative production system. Field Crops Res., (2008), Vol. 107 pag. 161-169.

[17] J.D. McMillan, Pretratmentof lignocellulosic biomass. N: Himmel, M.E., Baker J.O., Overend R.P. (eds), Enzymatic conversion of biomass for fuels production. American Chemical Society, Washington, DC, (1994), pag. 292-324.

[18] M. Balat, H. Balat, C. Öz, Progress in Bioethanol processing. Progress Energy Combust Sci, (2008), Vol. 34 pag. 551-573.

[19] P.C. Badger, Ethanol from cellulose: A general review. In: J. Janick and A. Whipkey (eds.), Trends in new crops and new uses. ASHS Press, Alexandria, VA, (2002), pag. 17–21.

[20] Smeder, and S. Liljedahl, Market oriented identification of important properties in developing flax fibres for technical uses. Ind. Crops Prod., (1996), Vol. 5 pag. 149-162.

[21] H.M.G. Van der Werf, M. Wijlhuizen, J.A.A. de Schutter, Plant density and self-thinning yield and quality of fibre hemp (Cannabis sativa L.). Field crop Res., (1995), Vol. 40 pag. 153-164.

[22] P. Venturi, G. Venturi, Analysis of energy comparison for crops in European agricultural systems., (2003), Vol. 25 pag, 235 – 255.

[23] Sun Y., Cheng J., Hydrolysis of lignocellulosic

materials for ethanol production: a review. Bioresource Technology, (2002), Vol. 83 pag. 1-11.
[24] Ververis, K. Georghiou, N. Christodoulakis, P. Santas, R. Santas, Fiber dimensions, lignin and cellulose content of various plant materials and their suitability for paper production. Ind. Crops and Prod., (2004), Vol. 19 pag. 245-254.
[25] Arato C., Pye E. K. and Gjennestad G, The Lignol approach to biorefinig of wood biomass to produce ethanol and chemicals. Appl. Biochem. Biotech. (2005), vol. 121-124 pag. 871-882.
[26] Amaducci M.T., Ricerche sulla tecnica colturale delle canape moniche utilizzate per la fabbricazione di carte pregiate. Sementi Elette, (1969), Vol. 3 pag. 166-179.
[27] G. Venturi, Prove quinquennali di confronto fra cultivar di canapa (Cannabis sativa L.). Riv. di Agronomia, (1970), Vol. IV(3) pag. 140-154.
[28] M. Di Candilo, D. Liberalato, A. Del Gatto, D. Laureti, V. Di Bari, R. Colucci, P. Tedeschi, L. Postiglione, M. Poli, M. Dirozzi, G. Grassi, P. Ranalli, Comportamento morfo-produttivo e qualitativo di cultivar di canapa (Cannabis sativa L.) in varie località italiane. Agroindustria, (2002), Vol. 1(1) pag. 19-27.
[29] S. Amaducci, A. Zatta, M. Raffanini, G. Venturi, Characterization of hemp (Cannabis sativa L.) roots under different growing conditions. Plant Soil, (2008), Vol. 313 pag. 227-235.
[30] Légère, Residual effects of crop rotation and weed management on a wheat test crop and weeds. Weed Science, (2002), Vol. 50 pag. 101–111.
[31] G. Avola, R. Tuttobene, F. Gresta, V. Abbate, Weed control strategies for grain legumes, Agron. Sustain. Dev., (2008), Vol. 27 pag. 13-18.
[32] J. Berger, The world's major fibre crops, their cultivation and manuring. (eds.) Centre d'etude de l'azote. Zurich, (1969), pag.216-222.
[33] P. Ranalli and B. Casarini, Canapa: il ritorno di una coltura prestigiosa. (eds.) Avenue media, Bologna, (1998), pp. 92 and 224-225.
[34] Venturi G., Amaducci M.T.,. Effetti di dosi di azoto e densità di semina su produzione e caratteristiche tecnologiche di Cannabis sativa L. Rivista di Agronomia (1997) vol. 3 pag. 616-623.
[35] E. Rosenthal, Hemp realities. In: Rosenthal E., (ed.). Hemp today. Oakland: Quick American Archives, (1993), pp. 9.
[36] D. R. Keshwania and J. Cheng, Switchgrass for bioethanol and other value-added applications: A review, (2009) Bioresource Technology vol. 100 pag. 1515–1523.