TECHNICAL EVALUATION OF MECHANICAL HARVESTING OF HEMP FIBRE

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ABSTRACT: Hemp (*Cannabis sativa* L.) is considered a high-yielding crop providing raw materials for a large number of final products. Nowadays, the growing demand for more sustainable production systems brought a renewed interest in this crop. Despite the increase, the total hemp cultivated area is still relatively small when compared to most of the commodity crops in Europe. Moreover, the European hemp fibre market is stagnating while the seeds and secondary metabolites markets have had a relevant increase since 2010. To support the sustainable growth of the European hemp fibre market, the hemp stalks should be valorized with optimized agronomic technique and harvesting systems and with an adequate transformation of the raw materials. The study aim at evaluating the technical sustainability of a traditional mechanization system for fibre hemp harvesting that involves cutting, windrowing, baling and logistic chain for industrial process. Two hemp varieties were cultivated in two farms in Northern Italy and harvested at the full flowering stage. The hemp plants processed at the harvesting time resulted adequate in height for the mechanized harvesting and the subsequent baling without compromising crop productivity. The drying period in the field (around 40 days) was adequate to obtain stable and homogeneous balers. The crops were cutted into three sections using a tractor front mounted prototype machine patented by the University of Bologna (UNIBO. To complete the harvesting operations conventional windrowers and round balers, properly adjusted, were used. The working times were in line with other traditional agricultural crops and the qualitative aspects of the harvested hemp were adequate, without damage or clogging. The use of partially modified farm machines resulted in a decrease of the harvesting time with respect to specific machines and in line with other crops management (eg. haymaking).
Keywords: fibre, hemp, harvesting, straw, bales, mechanization

1 INTRODUCTION

Hemp (*Cannabis sativa* L.) is considered one of the most ancient cultivated plants, used for centuries for the high cellulose content of the fibres [1]. The decline in hemp cultivation, since the 1960's, was determined mostly by the adhesion of 97 nations to the Protocol on the Single Convention on Narcotic Drugs proposed by the United Nations, signed in New York on 30th March 1961 [2]. Besides the restriction related to the psychoactive compound, the decline of hemp cultivation was determined also by the advent of more economic feedstocks like raw cotton and synthetic fibre which determined its disappearance in favour of new crops of greater economic interest for industries. Nowadays, the growing demand of more sustainable production systems brought a renewed interest in this crop [3, 4]. Hemp is now considered as a high yielding crop with particular agronomic characteristics, providing raw materials suitable for a large variety of industrial applications [5]. The area dedicated to hemp cultivation had an increase of 75% in the EU between 2015 and 2019. France is the largest producer, accounting for more than 70% of EU production, followed by the Netherlands (10%) and Austria (4%) [6]. Despite the increasing, the total hemp cultivation area is still relatively small compared to most of the commodity crops in Europe, such as wheat, maize, rapeseed, potato, or sugar beet [7].

Nowadays hemp, traditionally harvested at full flowering to optimize long fibre bundle extraction, is mainly harvested at seed maturity for dual-purpose applications [8] and it has a great potential as multipurpose crop [9] or for specific seed production [10].

Furthermore, as with other herbaceous crops for which new machines have been developed or adjusted to simplify and improve the whole crop management in view to increase the achievable biomass [11, 12, 13, 14, 15], hemp can have potential forms of valorisation, both as seeds or residual fractions in addition to the traditional fibre purpose, in a modern concept of circular economy [16].

European hemp fibre market is stagnating if compared to the growing market of hemp seeds and phyto-cannabinoids. The production of seeds increased by 92% between 2010 and 2013, while fibres and shivs production did not show any significant difference. Different experiences are available on seed collection and machine efficiency, oil enhancement and industrial fibre systems [17, 18]. Moreover, hemp stalks are actually considered a by-product in the production of flowers and leaves for the CBD market, source of considerable extra profit for famers [19]. To support a sustainable growth of the hemp fibre market, agronomic and harvest techniques as well as post-harvest processing should be optimized to preserve fibre quality, enabling industrial processing and maintaining, or even increasing, actual fibre applications and improving high-added value applications. The process of separating and cleaning the fibres could also require a research activity to define the forces to optimize the process without damaging the quality of the fibre, according to an approach already adopted on fruit harvesting [20].

The harvesting strategies can differ in relation to the type of conditioning planned for the feedstock (loose, conditioned, chopped) and the type of storage (bale stack, loafing, wet chop ensiled) [21, 22]. To reduce harvesting costs and simplify mechanical operations, the aim of the research was to evaluate the technical sustainability of a traditional mechanization system for fibre hemp harvesting involving cutting, winding, baling and transporting the crop to the industry.

The harvest system must meet the following objectives and solve the criticisms: *a*, definition of the optimal plant size to ameliorate harvesting and yield; *b*, performance in stem cutting with respect to its great hardness; *c*, avoid fibres winding on the machine parts; *d*, adequate field drying duration for biomass quality preservation after crop baling; *e*, reduction of the working times to ensure the cost-effectiveness of the machines; *f*, adequate raw material for industrial transformation.

The proposed mechanization system involves the use of conventional or partially modified machines suitable for hemp harvesting, in view to reduce the cost.

2 MATERIAL AND METHODS

The experimental fields were carried out in 2021 in two commercial farms located in Northern Italy: Bergonzini (44°91’53.12”N, 11°86’67.28”E) and Succi (44°84’99.33”N, 12°13’77.45”E). Two industrial hemp varieties, Felina 32 and Futura 75 were evaluated in the two farms. The selected varieties are monoecious and are constituted in France for dual purpose production (fibre destined for the paper industry and seeds). Both the varieties, when cultivated in Southern Europe, are middle-late flowering with the full flowering stage in August and the seed maturity stage in September with Felina 32 slightly earlier than Futura 75. In the Bergonzini farm the field area was 4686 m^2 for Felina 32 and 5122 m^2 for Futura 75; in the Succi farm the field area was 5130 m^2 for Felina 32 and 4860 m^2 for Futura 75. In both farms the previous crop was wheat. The sowing was on the 13th and on the 18th of April, respectively in the Bergonzini and Succi farms. The crop was sowed with an inter-row space of 15 cm at a depth of 3 cm for a target density of 150 plants m^{-2}. The field was fertilized during the preparation of the seedbed with 40 kg N ha^{-1} only in the Bergonzini farm. The hemp harvest was at the beginning of August, when the crop was at the full flowering stage, the development stage with the highest fibre quality. Experimental sampling was carried out considering 3 one square meter areas randomly identified in the fields. The plants were cut at the soil level for maximum potential biomass yield. For each sample, the number of plants and the fresh weight of total biomass were measured.

Figure 1: Cutted hemp before and after drying in the oven.

The harvested biomass was dried in an oven at a temperature of 105°C for 48 hours until the constant weight was achieved to estimate the total dry biomass in the field [23] (Fig. 1).

The mechanized harvest was carried out in three steps: mowing, swathing and baling after field drying. The crops were mowed using a patented prototype composed by two frontal double-blades cutter bars, operated by a hydraulic engine and with an independent levelling system that controls the dimension of the cutting sections. (Fig. 2).

Figure 2: Prototype for the hemp harvesting, front bars with in evidence the blades for the two cutting heights

The prototype was developed by the University of Bologna (UNIBO) and the DCM Italia s.r.l. (Borgo Val di Taro, PR, Italy). The double-bladed cutting bar was paired on the same tractor to a rear mounted single cutting bar (GS Superior 402 - Gribaldi & Salvia Spa) to obtain the three hemp heights (Fig. 3). The working width of the mower was 1.80 m.

The harvesting time was on August 4th on the Bergonzini farm and on August 11th on the Succi farm; the windrowing was carried out immediately after the harvesting operation. Indeed the swathing was carried out the same day with a rotating windrower, model FCR 86 (F.C.R. Costruzioni Macchine Agricole) with a working width of 3 m. The baling was carried out on the 8th of September in the Bergonzini farm and on the 21st of September in the Succi farm with a variable chamber baler, model Kuhn VB 2190 and Feraboli Xtreme 265, respectively.

Figure 3: Detail of the hemp field during the windrowing operation before the round baling in conclusion of harvesting cycle.

The whole harvesting cycle, except for the harvesting operation performed with the UNIBO prototype, was performed using the conventional mechanization chain for the haymaking process without specific modifications of the machinery. No biomass turning was made and the windrowing was carried out with a single-rotor rake while for the baling operation variable chamber balers were used without denoting any significant problems. All the bales obtained were measured and then weighed directly in the field suspended by belts to a dynamometer. The moisture content was determined on a wet basis, collecting samples of about 2 kg of biomass from one bale for both varieties and farms.

3 RESULTS AND DISCUSSION

The hemp crop is characterized by a high intraspecific variability and competition [24] resulting in wide differences within the same plot in term of plant density and height. Nonetheless, the crop was well established in both the farms. The plant density in the Succi farm was on average lower than the one in the Bergonzini farm, 23.1% for Futura and 57.6% in Felina (Table 1). Consequently, the estimated dry biomass yields were on average lower in the Succi Farm than in the Bergonzini farm (6.0% in Futura and 24.5% in Felina).

Table I: Hemp traits at harvest (mean ± Std.dev.)

A	Bergonzini farm	
Variety	Futura 75	Felina 32
Density	68.0 ± 8.2	101.3 ± 26.5
Height	222.9 ± 59.9	188.5 ± 40.4
EDY	13.3 ± 1.1	10.6 ± 2.8
B	Succi farm	
Variety	Futura 75	Felina 32
Density	52.3 ± 11.5	43.0 ± 4.6
Height	209.2 ± 57.8	179.8 ± 39.6
EDY	12.5 ± 3.9	8.0 ± 2.2

Density: plant density n. m^{-2}; Height: plant height (cm); EDY: Estimated dry yield (Mg ha^{-1})

Despite the same sowing density in the Succi farm the hemp showed a lower plant density with respect to the Bergonzini farm, this could be related to the intraspecific competition for nutrients that could cause the death of the weak plants [1, 23, 25]. Biometric traits affect harvesting and post-harvest processing, as increase of compression load and energy requirements at increasing stem diameter [26].

The harvest was carried out on the 4th of August in the Bergonzini farm with a working speed of 4.5 km h^{-1} and on the 11th of August in the Succi farm with a working speed of 7.5 km h^{-1}. The difference in the working speed registered in the two farms was consequent to an inadequate set-up of the rear cutter bar in the first farm than solved at the harvesting time in the Succi farm. The swathing was carried out at a speed of 5 km h^{-1} with swaths spaced 5.5 m. The baling was carried out with a round baler Kuhn VB 2190 that worked at a speed of 5 km h^{-1} and a round baler Feraboli Xtreme 265 that worked at a speed of 5.5 km h^{-1}. 15 round-bales for the variety Futura and 9 round-bales for the variety Felina were collected in the Bergonzini farm, for a total of 6.7 Mg of biomass; while 16 round-bales for the variety Futura and 13 round-bales for the variety Felina were collected in the Succi farm for a total of 7.7 Mg of biomass. A production of 55.3% with respect to the estimated dry yield was recorded for Futura and 45.5% for Felina in the Bergonzini farm, while smaller differences were obtained in the Succi farm, 62.9% for Futura and 75.7% for Felina. The differences between the estimated dry yields and the achieved yields are the results of the mechanized harvesting losses; moreover, the higher losses observed in the Bergonzini farm could be explained as a consequence of more thin stems of the hemp then loosed during the swathing and baling process.

The working times were in line with other traditional agricultural crops and the qualitative aspects of the harvested hemp were adequate, without damage or clogging.

The harvesting period (early August) resulted in plants with an adequate height for mechanized harvesting and subsequent baling without compromising crop productivity while the drying period in the field was adequate to reduce the moisture content for a long term storage of the bales.

Conventional hay-making equipment integrated with a simplified double front cutting system proved to be adequate for hemp harvesting. The possibility of adjusting the same harvesting system for more crops will increase the use during the harvesting period allowing for a reduction of the fixed costs of harvest machinery per unit of feedstock. The proposed simplified mechanization line could be of potential interest for small farms to approach hemp cultivation. Furthermore, since the final product can be packed in round bales the transport to the processing plant is largely consolidated and economically sustainable.

4 CONCLUSION

The results of the field evaluation underlines as key points for hemp cultivation the adequate crop management and mechanical harvesting to improve biomass quality for different purposes at the farm level. To reach the expected potential valorisation chain of the hemp requires the appropriate management of the crop from the agronomic point of view and the right approach in the harvesting mechanisation to obtain high quality raw material at low cost.

Taking into account the high adaptability of the crop and the Italian situation characterized by a very heterogeneous network of farms and contractors, the possibility to adapt conventional machines developed for other crops (e.g. haymaking) to the needs of hemp cultivation can represent a real possibility to enhance the development of the hemp supply chain in Italy.

The availability of the right amount of hemp raw materials will correspond to the needs of the different processing systems (e.g. primary fibre for fabrics, secondary fibre for insulation and other biomaterials for the construction sector). Contemporarily new technologies specifically developed (e.g. inflorescence harvesting) are required to process properly the hemp fractions of greater added value addressed to the biorefinery.

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