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Investigation of the technological spring harvesting variants of the industrial hemp stalk mass

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Abstract. One of the simplest technological solutions of hemp harvesting applied in practice in Latvia and some other countries is harvesting of the hemp stalks in spring. Implementation of this technology does not require expensive specialised machinery. However, there are significant losses of the mass and quality of the product. The loss of hemp stalk mass in two-stage harvesting (Option A: harvesting of the seedy part of the yield by means of grain harvesting combines and subsequent gathering of the stalks in spring) constitutes approximately 50–80%. The basic possible solution for reducing these losses is raising the cutting height of the stalks when the seedy part of the yield is harvested. With spring harvesting, Option B, the mass of the stalks is preserved, while the seedy part of the yield is completely lost. A rational solution for spring harvesting can be established by calculations, considering the crop volume and the prices of the seeds and stalks sold, as well as the value of technological losses. In the tests conducted during a subsequent harvest in spring the tensile strength of the fibres of the uncut hemp stalks was 25–52% lower than the strength of the fibres harvested in autumn.

Keywords: industrial hemp, spring harvesting, loss of stalks.

INTRODUCTION

Over the past 25 years, an active increase in areas under industrial hemp cultivation can be observed throughout the world (Struik, 2000). In addition, the EU has imposed strict control, only allowing the cultivation and subsidising of those varieties whose tetrahydrocannabinol (THC) content – it being a psychoactive ingredient – does not exceed 0.2%. For hemp to have such a content of THC, a narcotic substance, is practically ruled out (Jankauskiene & Gruzdeviene, 2010). In Latvia the cultivation of this crop started in 2009. In EU countries, industrial hemp (*Cannabis sativa* L.) is considered as one of the important renewable resources for the production of a wide range of industrial products (as evidenced by the Resolution of the EU Commission 'COM/2008/03/07') (*Cannabis sativa* L. Hemp., 2009).

At present a search for optimal technological options for growing and harvesting hemp is underway in various farms; new innovative technologies for the use of the raw material are being developed to make it possible to extend the range of application of this product (Burczyk & Kaniewski, 2005). For the time being, the stalks of industrial hemp are traditionally used to produce fibre and wood shives, while the seeds are a raw material for the production of oils, foodstuffs and medical preparations. In recent years investigations have been undertaken in order to create new building materials on the basis of hemp stalk mass. The most complicated factor to determine the production economy of this crop lies in the field harvesting operations (Ivanovs et al., 2014). Among the considerable number of technological harvesting options there is one that attracts the interest of practical growers – namely, the spring harvesting of industrial hemp. However, an apparent drawback of spring harvesting of industrial hemp, in contrast to autumn harvesting, consists in significant losses in the amount of crop yields (the seeds or stalks) and the quality of the product (tensile strength of the fibres). The aim of the investigation was to determine the value of the potential yield of different varieties of industrial hemp, to assess the quantitative losses and strength of the hemp stalk mass when the technological option of spring harvesting is applied.

MATERIALS AND METHODS

The objectives of this study were:

- to determine the potential yield of the stalks of different varieties of industrial hemp;
- to provide an analytical assessment of the degree of quantitative losses of the stalks in two-stage harvesting of industrial hemp due to the use of grain combine harvesters for harvesting the seedy part of the yield;
- to determine the rate of strength degradation of the hemp fibres at the time of its spring harvesting;
- to determine the rate of the operating costs related to the implementation of the spring harvesting technology of hemp.

Field trials were carried out in 2014, in a Research and Study farm 'Pēterlauki' that is supervised by the Latvia University of Agriculture, according to an established methodology (Adamovičs et al., 2012). 11 industrial hemp (*Cannabis sativa* L.) cultivars – 'Bialobrzeskie', 'Futura 75', 'Fedora 17', 'Santhica 27', 'Beniko', 'Ferimon', 'Epsilon 68', 'Tygra', 'Wojko', 'Felina 32' and 'Uso 31' – were sown in the sod calcareous soil (pH_{KCl} 6.7, containing available P 52 mg kg $^{-1}$, K 128 mg kg $^{-1}$, organic matter content in the soil from 21 to 25g kg^{-1}). The overall seeding rate was 50 kg ha^{-1}. The plots were fertilised as follows: N: 120 kg ha^{-1}, P_2O_5: 90 kg ha^{-1}, K_2O: 150 kg ha^{-1}. The biometrical indices of the hemp seedlings, the height and stem diameter at harvesting time, the amount of green and dry above-ground mass, and the fibre content were evaluated. The trial data were processed using descriptive statistics with Microsoft Excel for Windows (Arhipova and Balina, 2006). The mean values were obtained with an LSD test.

The following hemp harvesting options were investigated in this study:

Option A: harvesting of hemp on the field where the seedy part is cut in autumn using grain combine harvesters. A flowchart of this harvesting option (Ivanovs et al., 2014) can be applied in case the most important product is the hemp seed. With this option, the stalks are cut in autumn by means of a grain combine harvester at the maximum possible height, and the seeds are threshed. The stalk mass passing through the combine harvester goes to waste. Any stalks in the passage zone of the wheels of the combine harvester are pressed into the soil and can no longer be used. The uncut part of the stalks, 0.9–1.6 m tall (depending on type of the harvester used), remains in the field and is removed in the spring.

Option B: harvesting of hemp on the field where nothing is done in autumn. The flowchart of the spring operations is similar to that in Option A (except that the various operations are performed during a different time of the year). With this option, the seedy part of the harvested crop is lost completely (it drops off, is eaten by the birds, etc.). However, the amount of harvested stalk mass per hectare of the area is substantially greater – in practice it is approximately 2…3 higher than in Option A.

The loss of hemp stalk mass in two-stage harvesting (where the seedy part of the crop is harvested in autumn and the commercial part of the stalks in spring) was determined in an analytical way, based on the technical and operating indicators of combine harvesters.

An experimental investigation into the springtime hemp stalk harvesting technology was conducted on the farmstead 'Zalers' (Kraslavas reg., Latvia). On an experimental field of one hemp variety ('Futura 75'), the tensile strength (breaking strength) of the fibres was determined after the autumn field-retting (control option S) and then after the winter field-retting of the same variety of hemp. The breaking strength was determined by means of equipment from the laboratory of the Kraslava Flax Factory, using methods corresponding to the standard 'Scutched hemp. Specification' (GOST 10379-76), according to which 30 samples of a specified size were taken with each option. Their breaking strength was tested on the equipment DKB-60. This standard is currently used in Latvia by hemp processing factories in order to determine the quality of the purchased product.

The daily average air temperatures in the period from November 2012 till September 2014 are given in Fig. 1; other weather parameters can also be seen from the statistical data of the Latvian Meteocentre (www.meteo.lv).

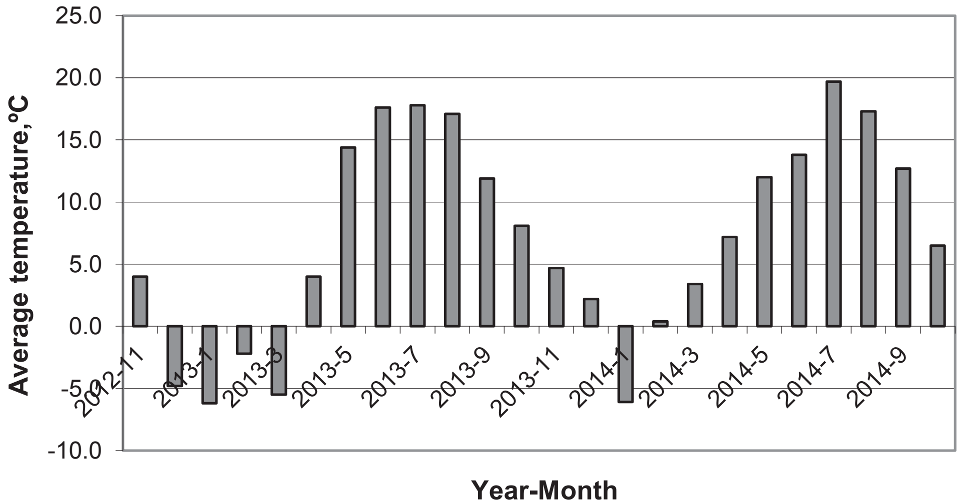
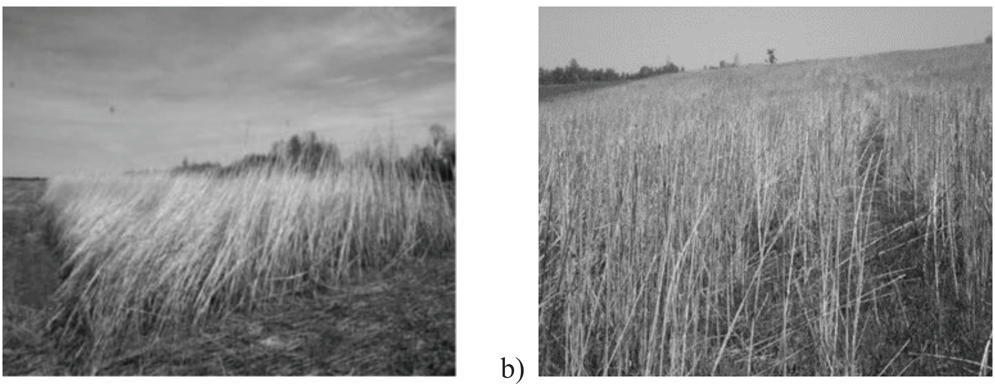


Figure 1. The monthly average air temperatures in the period from November 2012 till October 2014 (Riga, Latvia).

In the winter season of 2012–2013 sub-zero temperatures were dominant within the range of -2…-6 C. Only in November and April was the daily average temperature +4 C. At sub-zero temperatures any biological processes in the stalks (including rotting) are practically suspended or proceed very slowly. In the winter season of 2013–2014 the prevailing temperatures were +1…+5 C, and only in January was the daily average temperature below zero, i.e. -6 C.

The operating and economic indicators of machine performance were determined on the basis of experimental data (efficiency, fuel consumption), taking into account the operating costs (wages paid to the staff, the cost of fuel, repairs and depreciation), according to established methodologies (Kopiks & Viesturs, 2010, Barwicki et al., 2014).

Under Latvia's weather conditions hemp is ready for fibre harvesting at the end of August or the beginning of September. The seeds take longer to mature and are ready for harvest in the second half of September and the beginning of October. The weather conditions in such late autumn season are usually not favourable to a further processing of the hemp stalks. It is a venture to spread the stalks on the field for retting: in rainy or cold weather the process is slow and prolonged; besides, it is very difficult to obtain stalks that are suitable for baling with a moisture content less than 16–18%. Specialised machinery for harvesting the hemp stalks in autumn (specialised combine harvesters or mowers) is very expensive, and its use is justified only at a full load, i.e. for a large amount of work (Ivanovs et al., 2014). Therefore, rational solutions are being sought for the preservation of the hemp yield and a reduction in costs. One of the simplest and cheapest technological solutions already applied in practice is harvesting the hemp stalks in spring. The hemp stalks left uncut till spring (or with the upper part cut off) maintain a position close to vertical (Fig. 2) and at favourable temperatures undergo biological processes that ensure a further separation of the fibre from the wooden part (i.e. the so-called retted stems are produced).



a) b)

Figure 2. A hemp field in spring: a) without previous harvesting of the seedy part, b) with harvesting of the seedy part in autumn.

A natural field-retting process takes place under the impact of moisture and the sun before the frost and in spring. Decomposition of pectin substances occurs during this process, ensuring an easy separation of the fibre from the wooden part. Furthermore, under a prolonged influence of the sun (about 5 months), a natural bleaching of the fibre takes place, producing a specific beautiful colour that is required for the production of several kinds of products. A drawback of this retting method is a partial loss of fibre strength due to the fact that the winter period the retting process cannot be regulated.

Harvesting takes place after the soil has dried and the machines can pass through (in Latvia this usually occurs at the end of April or the beginning of May). There is no need to cut such stalks in spring – instead, the stalks are rolled down using rollers, because the part of the stalks in contact with the soil becomes brittle (it starts rotting) and the stalks can break easily. In addition to rolling down the stalks, the technology of the spring operations also includes swathing (gathering the stalks into swathes) and harvesting by means of pickup balers. The essence of the two-stage hemp harvesting technology is the following: in stage one, the upper part of the plants is removed using grain combine harvesters in order to obtains seeds; in stage two, the remaining stalks are harvested (this may be done in autumn or in spring). The use of a grain combine harvester for harvesting the seedy part of the plants entails a specific quantitative loss of the stalks (some of the plants perish under the impact of the wheels, and some of the tops of the stalks gathered with the seeds go to waste).

Let us define the analytical expressions of the quantitative losses.

With spring harvesting, Option A, the total technological loss of stalks W (%) is:

$$W = W_m + W_r \tag{1}$$

where: W_m – the loss of the upper parts cut off by a grain combine harvester that go to waste after the threshing of the seeds, %; W_r – the loss of the upper parts of the stalks pressed into the soil under the wheels of a combine harvester, %,

$$W_m = [(H - m) / H]100 \tag{2}$$

where: H – the technical height of the hemp stalks, cm; m – the cutting height of the stalks harvested by a combine harvester, cm.

$$W_r = (B / L)100 \tag{3}$$

where: B – the width of the imprint zone formed by the combine wheels (as a rule, equal to double width of a big driving wheel), cm; L – the width of the harvester header, cm.

After the corresponding expressions are inserted, we obtain a formula for the determination of the total technological loss of stalks:

$$W = W_m + W_r = 100[(H - m) / H] + B / L \tag{4}$$

In order to estimate the efficiency of the spring harvesting options, it is necessary to compare the possible earnings from the sales of the product under particular conditions (prices, productivity, etc.), including the technological losses mentioned above.

RESULTS AND DISCUSSION

The yield of industrial hemp stalks depends on the variety, the used fertilisers and the nutrients available in the soil, as well as a number of other factors. In order to find out the possible volume of harvesting operations, experiments have been conducted to determine the stalk yield of the most widespread hemp varieties in Latvia. The industrial hemp cultivars ‘Bialobrzeskie’, ‘Futura 75’, ‘Fedora 17’, ‘Santhica 27’, ‘Beniko’, ‘Ferimon’, ‘Epsilon 68’, ‘Tygra’, ‘Wojko’, ‘Felina 32’ and ‘Uso 31’ could be successfully grown in Latvia for biomass and fibre production. The highest biomass yield during the trial years was obtained from cv. ‘Bialobrzeskie’. The experimental results obtained under equal circumstances with the aim of establishing the average green mass and dry matter yields of different varieties of industrial hemp as well as their averaged values are presented in Table 1. The highest crop yields in Latvia are produced by the varieties ‘Bialobrzeskie’, ‘Epsilon 68’ and ‘Futura 75’. On the whole, these crop yield values are, to a certain degree, evidence for the potential productivity of hemp stalks. We can conclude from the data that the growing season and the industrial hemp cultivars chosen had a significant ($p < 0.05$) effect on the hemp yield. However, in practice the crop yield values on large agricultural farms are usually 20–25% lower.

With Option A, a grain combine harvester is used in autumn to harvest the seedy part, whereas with Option B the combine harvester is not used at all. Therefore, in order to obtain results that are comparable with the expected income in Option A, the operating costs of the combine harvester should be deduced. Due to a lower actual crop yield of the harvested mass in Option B (due to the losses) the machines perform harvesting at a lower efficiency by mass in t h^{-1} (with a similar efficiency by area in ha h^{-1}). The operating costs consist in the depreciation of the machinery and repair deductions, as well as fuel and electric energy expenses, wages and the cost of crop transportation to the processing sites.

Table 1. The yields of green biomass and dry matter with different hemp cultivars

Hemp cultivars	Yield of green mass, t ha^{-1}	Yield of dry matter, t ha^{-1}
\`Bialobrzeskie\`	60.99	15.86
\`Futura 75\`	49.65	14.81
\`Fedora 17\`	42.87	12.78
\`Santhica 27 \`	45.07	13.47
\`Beniko\`	39.96	11.96
\`Ferimon\`	43.24	12.93
\`Epsilon 68\`	48.67	14.47
\`Tygra\`	45.07	13.40
\`Wojko\`	39.59	11.79
\`Felina 32\`	42.98	12.80
\`Uso 31\`	40.43	11.98
Average	45.32	13.30
$LSD_{0.05}$ cultivars	6.35	2.69

The operating costs (rolling down of stalks, swathing by loosening rakes, picking and baling) in different spring harvesting options of hemp are shown in Fig. 3. The expenses are calculated using actual performance data and fuel consumption. With

Option A the specific operating costs are approximately 62–78% higher than with Option B. This is due to the fact that the amount of stalks harvested from one hectare, the harvested areas being equal, is at least two times smaller, which affects the efficiency in t h^{-1}.

In experimental tests the upper part of the hemp stalks was harvested for seeds in autumn by the combine harvester Class Mercator 75 (Option A1) or New Holland (Option A2).

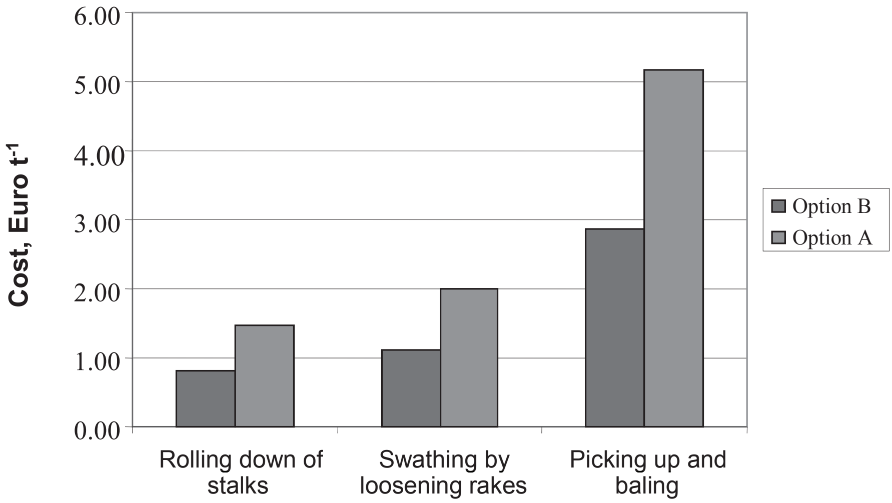


Figure 3. Operating costs in different spring harvesting options.

The average height of the stalks remaining on the field was 89 cm (combine harvester Claas Mercator 75) or 155 cm (combine harvester New Holland). Such a height was determined by the design parameters (technical possibilities) of a particular combine harvester. With the brands of grain combine harvesters that are widespread in Latvia, the value of the maximum height setting of the header varies within the range of 90...160 cm, representing the lowest and highest values available (Sheichenko & Lukjanenko, 2013).

After the technical data are inserted into Formula 4, we find that the total value of stalk loss is 79% with Option A1 and 47% with Option A2. The correlation between the width of the wheels of the combine harvester and the width of the header with different brands of combine harvesters varies to an insignificant degree (Ivanovs et al., 2014). Therefore, the use of grain harvesting combines with a higher setting of the cutting apparatus (header) might prove a real solution for reducing the loss of stalks in two-stage hemp harvesting. With spring harvesting, Option B, the stalk mass is preserved, while the seedy part of the yield is completely lost. In order to give an economic estimation of the advantages of this or that harvesting option, we need to know the potential crop yield and harvesting loss; in addition, a calculation is needed on the basis of the actual indicators of the purchasing prices of the hemp stalk mass and seeds, the distance of the farm from the marketing sites of the products, the operating costs of a particular set of harvesting machinery, and so on.

Among all the parameters of hemp fibre quality (length, colour, linear density, etc.) the most characteristic property of the fibre is its breaking strength.

Studies on the influence of winter retting on fibre strength were carried out for two seasons. Three options were tested:

S) standard – autumn retting and harvesting;

A) only the lower part of the stalks was left in winter, the upper part was cut by a combine harvester to obtain seeds;

B) the stalks were left in autumn on the field in the natural environment without any processing.

On the experimental field of the variety 'Futura 75' the breaking strength (tensile strength) of the fibre was first determined after autumn retting and then after winter retting.

Table 2. Tensile strength of the fibre with different retting options

Stalk retting option	Mean value of breaking strength, N	Variation coefficient	Relative value of breaking strength in relation to the standard option
	Spring harvesting May 4, 2013;	standard harvesting – November 2, 2012.	
S (standard)	202	28.3%	100%
B	148	32.1%	73.2%
A	136	34.5%	67.3%
	Spring harvesting April 29, 2014;	standard harvesting – October 21, 2013.	
S (standard)	181	25.2%	100%
B	87	39.3%	48.0%
A	94	35.7%	51.2%

As evident from the data obtained, by the time of spring harvesting the fibre had lost 27…33% of its breaking strength in the year 2013 and 49…52% in 2014. No substantial difference in the strength of the fibre was found between Options A and B; however, the strength varies significantly by season (year). Apparently, a prolonged (more than 4 months) impact of temperatures +1…+5°C on the hemp stalks in the winter season of 2013–2014 had an unfavourable effect on their strength. That period saw not only decomposition processes on the organic bonds between the fibrous and wooden parts of the stalks, but also active destruction processes on their structure (rotting). With all the options, the values of the variation coefficient were quite high (25–39%); however, this is due to the fact that hemp fibre is not a homogeneous material and, in relation to the initial stalk strength, many various random factors exert continual influence on the biological processes.

In order to achieve short fibre and wood shives, Latvian hemp processing enterprises purchase their hemp stalks after spring harvesting (in 2013 their average price, depending on quality, was approximately 110–140 EUR t^{-1}).

It should be noted that a significant loss (12–23%) of wood shives occurs during baling in spring (Ivanovs et al, 2014). This is due to the fact that after picking in spring the wood shives start separating from the fibres, breaking into small pieces when turned into a cylindrical bale, and drop out onto the soil surface through the gaps between the baling rollers. In autumn the retted stems separate from the fibres only under mechanical coercion, and therefore the dropout-related losses constitute no more than 3%.

Another limiting factor for the application of the spring harvesting technology of hemp stalks is the short period of time that is left in the spring for soil preparation and sowing of a new crop on a particular field (in Latvia's weather conditions no more than 15–20 days are usually left for these operations).

In spite of these drawbacks, the spring harvesting of hemp is not cost-intensive and, as practice shows, it can find some limited application in certain cases:

- if the seedy part of the crop yield ripens late and is harvested by grain combine harvesters, one might manage to harvest the seeds in autumn, preserving and gathering up to 50% of the stalks in spring;
- if the hemp stalks ripen and are harvested late, for instance, at the beginning of November (i.e. when there is great risk that the field-retting of the cut stalks and their picking up by pickup balers cannot be finished before winter sets in, and all the crop yield may be lost), one might manage to preserve and gather most of the stalks in spring;
- if hemp is grown for the main purpose of obtaining wood shives (as a building material), one might manage to preserve most of the stalks and obtain the necessary raw material;
- in the first stage of the adoption of the technology on farms that have insufficient technical means for autumn harvesting (a lack of specialised combine harvester or mower) one might manage to preserve and gather most of the stalk yield.

CONCLUSIONS

In the experiments the average dry matter yield of the stalks of 11 cultivars of industrial hemp was 13.30 t ha^{-1}, while the highest yield, with the 'Bialobrzeskie' variety, was 15.86 t ha^{-1}. We can conclude from the data that the growing season and the selected industrial hemp cultivars had a significant ($p < 0.05$) effect on the hemp yield.

The loss of hemp stalk mass in two-stage harvesting (Option A: harvesting of the seedy part of the yield by means of grain harvesting combines and subsequent gathering of the stalks in spring) constitutes approximately 47–79%. The basic possible solution for reducing these losses is raising the cutting height of the stalks when the seedy part of the yield is harvested. With spring harvesting, Option B, the stalk mass is preserved, while the seedy part of the yield is completely lost.

In the tests conducted during a subsequent spring harvest the tensile strength of the fibres of the uncut hemp stalks was 25–52% lower than the strength of the fibres harvested in autumn.

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