
Development of a windrower for dual-purpose hemp (*cannabis sativa*)

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Chen, Y. and Liu, J. 2003. **Development of a windrower for dual-purpose hemp (*cannabis sativa*)**. Canadian Biosystems Engineering/Le génie des biosystèmes au Canada **45**: 2.1-2.7. Hemp (*cannabis sativa*) is a dual-purpose crop; the seed and the fibre have to be harvested separately. A hemp windrower was developed to create two separate windrows, one for seed-heads and one for fibre-stalks. The hemp windrower was a modified version of a commercial self-propelled windrower. The original header-lifting mechanism was modified, which increased the maximum header lifting height from 1.08 to 1.58 m for cutting seed-heads. To deliver the seed-head windrow from the cutting height to the ground, a foldable sliding conveying system was designed and attached to the windrower header. When conveying seed-heads, the slide should be inclined at an angle which is greater than the sliding-friction angle of the hemp (25° in the studied case). The hemp windrower was tested in the field and results showed that it fulfilled the design objectives. Specific research was conducted to investigate the mechanical impact on the seed-head during windrow delivery processes. A lower draper speed resulted in a reduced mechanical impact on the seed-head, which may reduce the potential seed loss associated with shattering. The relationship between seed-head length and the plant height was established for selecting the cutting height for seed-head windrowing. From the relationship, the cutting heights for the hemp fields having an average total height of 1.71 and 1.56 m were estimated as 1.40 and 1.29 m, respectively. These cutting heights minimised the percentage of seed in the fibre-stalk windrow and the presence of fibre-stalk in the seed-head windrow. **Keywords:** hemp, windrowing, header-lifting, conveying, cutting height, mechanical impact.

Le chanvre (*cannabis sativa*) dont on peut utiliser les graines et la fibre qui doivent être récoltées séparément. Une andaineuse à chanvre à deux rangs séparés, un pour les graines et un pour les tiges, a été développée. L'andaineuse à chanvre est une version modifiée d'une andaineuse motorisée commerciale. Le tablier de récolte ajustable d'origine a été modifié pour augmenter la hauteur maximale de coupe de 1,08 à 1,58 m afin de pouvoir ainsi couper sous les fleurs pour la récolte des graines. Pour ramener l'andain de graines au sol, un système de convoyeur repliable a été conçu et monté sur le tablier de coupe de l'andaineuse. Lorsque les fleurs sont acheminés vers le sol, la chute doit être à un angle supérieur à l'angle de friction de chute du chanvre (soit 25° pour la présente étude). L'andaineuse à chanvre a été testée au champ et les résultats ont démontré que les objectifs de design ont été rencontrés. Des tests particuliers ont été réalisés pour vérifier l'impact mécanique de la récolte avec l'andaineuse modifiée sur les fleurs. Une vitesse de chute plus basse a résulté en un impact mécanique réduit sur les fleurs ce qui peut réduire la perte potentielle de graines associée avec le brassage des fleurs. La relation entre la hauteur de la fleur et la taille du plant a été établie pour sélectionner la hauteur de la tête de coupe de l'andaineuse. De cette relation, les hauteurs de coupe pour les champs de chanvre ayant en moyenne une hauteur de plants de 1,71 et 1,56 m ont été estimées à 1,40 et 1,29 m respectivement. Ces hauteurs de coupe minimisaient le pourcentage de graines dans l'andain de tiges de fibre et la présence de fibre dans les andains de fleurs. **Mots clés:** chanvre, andainage, tablier de récolte, convoyeur, hauteur de coupe, impact mécanique.

INTRODUCTION

Hemp fibre has great potential for many products such as paper, textile, geo-textiles, and building materials. Hemp seeds can be used to produce oil, paint, and food products. However, research on hemp (*cannabis sativa*) was stopped four decades ago due to the prohibition of its alternate use as a drug. Recently, several countries have considered reintroducing hemp production with the development of new varieties with a low tetrahydrocannabinol (THC) content. Research has been carried out on hemp cultivation and the economic feasibility of hemp production (de Maijer 1995; Bócsa and Karus 1997; MAF 1997). Meanwhile, little research and development have been conducted in the area of hemp harvesting.

Harvesting hemp is different from harvesting conventional crops in several ways. The hemp plant is tall (1.5 - 2.5 m), has a massive biomass, and contains a high percentage of cellulose and lignin (Bócsa and Karus 1997). The whole plant can not be fed into a conventional combine because of the large biomass. Two products, seed and fibre, are desired from hemp and they may be harvested separately at an appropriate cutting height (Fig. 1). Hemp is a photosensitive crop, and thus the seed maturity varies within a plant. Hemp fibre tends to wrap around rotational machine parts.

The current hemp harvesting technique is straight-combining the hemp seeds in the first field operation (MAF 2001). Straight-combining is performed by a conventional combine with the header being raised to a maximum height (approximately 1 m from the ground) to minimize the combine intake. Subsequent operations are swathing the remaining standing fibre-stalks and baling the swaths when the moisture content is below 15% (wet basis) (Huisman et al. 1994). Straight combining is usually done when seeds are at a stage of approximately 60-70% maturity, which results in a high percentage of immature seeds not being collected. Further delay in combining, however, will cause significant seed loss due to shattering.

The cutting height for collecting seeds is difficult to establish, as the length of the fibre-stalk is highly variable within a field. For seed-head windrowing, the cutting height (CH) shown in Fig. 1 is the theoretical cutting height for Plant 2. However, cutting at this height will result in the combine taking some amount of fibre-stalk of Plant 1 (represented by the length, l_1) (Fig. 1). This will result in significantly increased power requirement for seed threshing and a great risk of damaging the combine as a result of overloading with bulk fibre material. On the other hand, at this

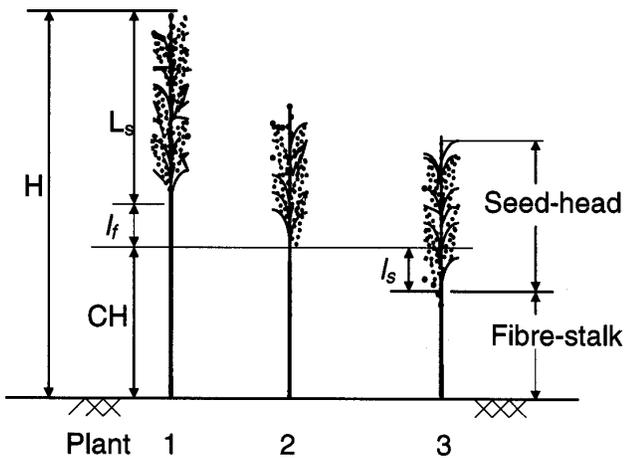


Fig. 1. Diagram showing characteristics of hemp plant, seed-head loss, and combine intake of fibre-stalk at a given cutting height (CH).

cutting height (CH), some portion of the seed-head of Plant 3 (represented by the length, l_s) will not be collected, reflecting some seed losses. Therefore, selection of cutting height is important to minimize both the seed losses and combine intake.

Conventional combine headers can only be raised to approximately 1 m from the ground. For most hemp varieties, cutting at this height often results in excessive combine intake of fibre-stalk. Wrapping and plugging have burned out bearings and started combine fires (Dietz 1999). New harvesting techniques and equipment are required to overcome these problems. The objectives of this project were: (1) to develop and evaluate a hemp windrower for dual-purpose hemp and (2) to propose a method to select cutting height for harvesting seed-heads separately from the fibre-stalks.

HARVESTING CONCEPT

A two-windrow harvesting concept using a single windrower was proposed. The first operation pass (Fig. 2a) is to cut the seed-heads off and leave them in a distinct windrow outside the cutting area. In the return pass (Fig. 2b) along the same path of the first operation, the windrower cuts the remaining standing fibre-stalks and leaves them in a second windrow in the middle of the cutting area. One disadvantage of this concept is that during the first operation, the windrower travels on standing fibre-stalks the heights of which are generally greater than the clearance of most windrowers. The bottom of the tractor must be shielded to prevent damage to hydraulic hoses, valves, and wires under the tractor, as done in this study. Another disadvantage is that the first seed-head windrow in the field has to be put along the field border where there may be no stubble.

DEVELOPMENT OF A HEMP WINDROWER

A hemp windrower was developed in 1999 by modifying a conventional self-propelled windrower with an 80 kW tractor (Model 972 Windrower, MacDon Industries Ltd., Winnipeg, MB). The header featured a 7.6 m sickle cutting bar which could leave sufficient distance (D) between the centre of seed-head windrow and the edge of fibre-stalk windrow (Fig. 2) to accommodate the subsequent combine operation. The decks on

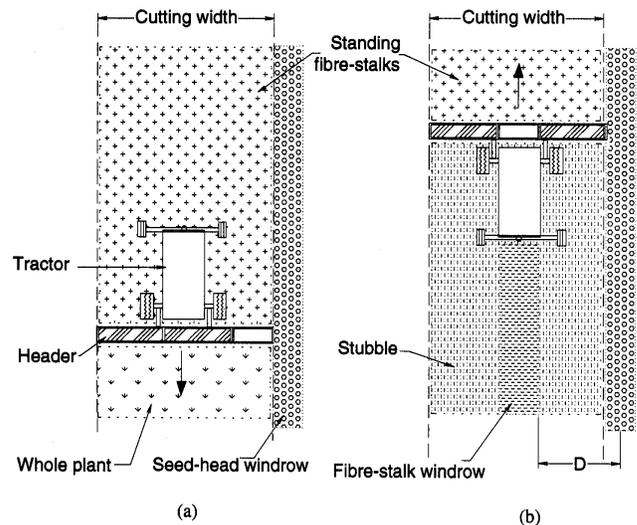


Fig. 2. Diagram showing the two-windrow harvesting concept.

the header could be hydraulically shifted to deliver crop to the centre or either end of the header.

Criteria for modifications of the windrower

Modifications of the windrower were based on the following criteria:

1. The modified unit (referred to as a hemp windrower hereafter) should perform both seed-head and fibre-stalk windrowing operations;
2. The header should be raised to a sufficient height for windrowing seed-heads;
3. Seed-heads should be gently delivered onto the stubble;
4. New mechanisms should have add-on features for easy adaptation to existing windrower;
5. The hemp windrower should still be usable for harvesting traditional crops after modification.

Based on these criteria, two main tasks were performed as discussed below.

Design of a header-lifting mechanism

The original header-lifting linkage The original header-lifting mechanism included a header support, a floating spring, a hydraulic cylinder, and the tractor frame. The floating feature of the linkage had a unique advantage that permitted the header to float over rough terrain in a lateral direction. The linkage could lift the header to a height of 1.08 m. This was not, however, high enough to windrow seed-heads of typical hemp crops and had to be increased.

Constraints The maximum lifting height and forward distance of the header were restricted by driving visibility and machine stability. Using the geometric relationships between the header and the tractor and assuming that the driver's eyes were at 0.6 m above the seat, the maximum header lifting height was calculated at 1.6 m to maintain a view of the sickle cutting bar. The header lifting height should be limited to this value, although a higher value might be desired. Considering the tractor and header weights, and their centres of gravity, the maximum change in forward location of the header was calculated as 0.4 m to maintain the stability of the machine.

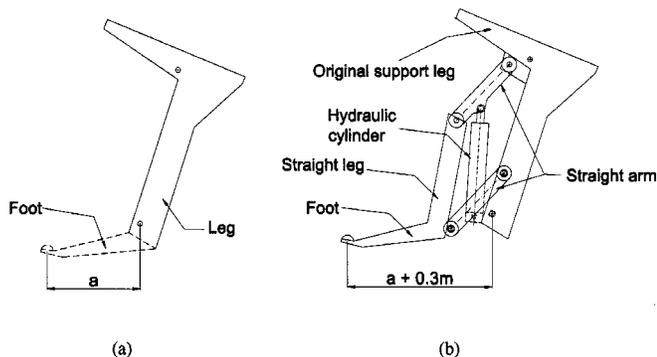


Fig. 3. Header-lifting mechanism: (a) the original header support; (b) the four-lever linkage.

Design of a new header-lifting mechanism To maintain the unique spring flotation of the header, the original linkage on each side was retained and only its support foot was cut off (Fig. 3a). This support foot was welded to a new straight leg, forming a new support leg and foot (Fig. 3b). The new support leg was connected to the original support leg through two straight arms, and a hydraulic cylinder was added between the original support leg and the straight arm (Fig. 3b). The new four-lever linkage (Fig. 4) provided an extra raising height, increasing maximum lifting height to 1.58 m. The addition of the four-level linkage resulted in the header being moved forward 0.3 m. These changes were within the constraints of driving visibility and machine stability. The new mechanism and the control system (Chen et al. 2002) added to the machine were easy to adapt to existing windrowers.

Design of a seed-head conveyor

A foldable sliding conveyor was designed to convey seed-heads to the ground outside the cutting area from the elevated cutting height, as described previously. The conveyor consisted of a driving mechanism and a slide that featured a main board and an extension board as an option (Fig. 5a). The right end of the slide



Fig. 4. The new combined header-lifting mechanism.



(a)



(b)

Fig. 5. The foldable sliding conveyor on the hemp windrower: (a) the slide in an unfolded position for windrowing seed-heads; (b) the slide in a folded position for windrowing fibre-stalks and transport.

was positioned under the left end of the deck. The header deck could be freely shifted left or right above the slide. When windrowing seed-heads, the header was raised to a desired CH. While the deck was being shifted to the right to create a left end-delivery opening, the slide was unfolded simultaneously. Seed-heads are expected to slide down to the ground along the surface of the slide. The inclination angle of slide, θ , at the unfold position can be adjusted to achieve the desired sliding function.

For cutting fibre-stalks, the slide has to be folded (i.e. the slide should be in a position parallel to the ground) (Fig. 5b) so that the header can be lowered to a level near the ground. This was achieved when the deck was shifted to the side to create a centre-delivery opening; the extension board was folded underneath the main board that was folded under the deck. The slide should also be in a folded position for transport.

The conveyor did not require any extra powering unit, and the movement of the slide was synchronised with the deck shifting action in both the folding and unfolding processes. For details of the design, readers are referred to Chen et al. (2002). The slide should be the same width as the deck (1.89 m in the studied case). The main board should have the same length as the delivery opening size (1 m in the studied case), and the length of the extension board can be variable, depending on the selected θ and CH. The prototype slide was made of sheet metal, but a different material can be used.

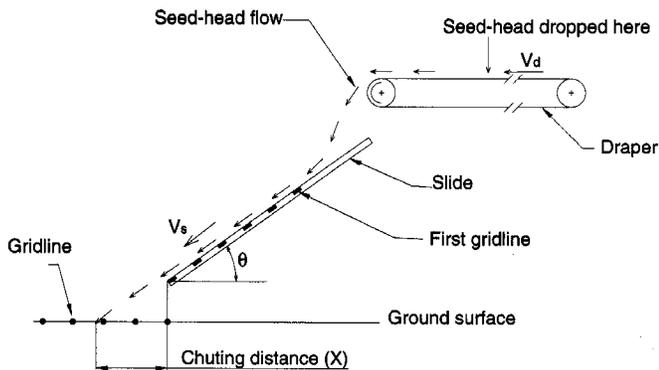


Fig. 6. Diagram showing hemp sliding speed (V_s), chuting distance (X), and draper speed (V_d).

MATERIAL and METHODS

Site description

Experiments were conducted on the dual-purpose hemp grown at the Glenlea Research Station, University of Manitoba, in 2000, and at Shott farm in Arborg, Manitoba, in 2001. The hemp cultivar was Felina 37 at the Glenlea site and USO 14 at the Arborg site. In both years, plant sampling was performed on a ten-hectare area and harvesting on a five-hectare area.

Measurements of selected hemp properties

Plant height and seed-head length Nine groups of plant samples were taken in 2000 and three groups in 2001, each group taken from an area of 1 m² randomly selected in the fields. The plants were cut at the soil surface. A total of 420 plants were obtained in 2000 and 133 in 2001. Plant height (H) and seed-head length (L_s) (Fig. 1) were measured for each plant sample.

Sliding-friction angle Measurements were performed with the hemp windrower in a stationary position. The θ was initially set at 20°. A seed-head sample of approximately 1-kg was randomly picked by hand from field windrows and gently put on the top of the slide's surface. If the sample could not slide freely along the slide, θ was increased by 1° increments, until the sliding action occurred. The value of θ was then recorded as the hemp sliding-friction angle.

Moisture content Ten hemp samples of approximately 1-kg each were randomly collected from each site for moisture content measurements. According to the ASAE (1999b) for forage, samples were oven-dried at 60 °C for 72 hours to determine the moisture content.

Field test on the functions of the hemp windrower

In field operations, θ should be adjusted to be greater than the sliding-friction angle. A sliding-friction angle of 25° was obtained for the specific hemp and the given slide surface used in this study. Note that the type of slide material would influence the sliding-friction angle to a certain extent (ASAE 1999a). The selected angle used for windrowing seed-heads was between 30 and 35°, a much greater angle than the sliding-friction angle to ensure a good sliding function. The header was raised to the cutting height of approximately 1.35 m for the Glenlea site and 1.25 m for the Arborg site. The header was lowered to 0.20 m from the ground when windrowing fibre-stalk.

The hemp windrower was tested for its functionality in delivering separate seed-head and fibre-stalk windrows through visual observations. It was first tested in 2000 at Glenlea at an early growing stage (in August) and a late growing stage (in October of the same year). The hemp windrower was modified after these two tests and the improved windrower was tested again in September 2001 at Arborg.

Measurements of mechanical impact to seed-head

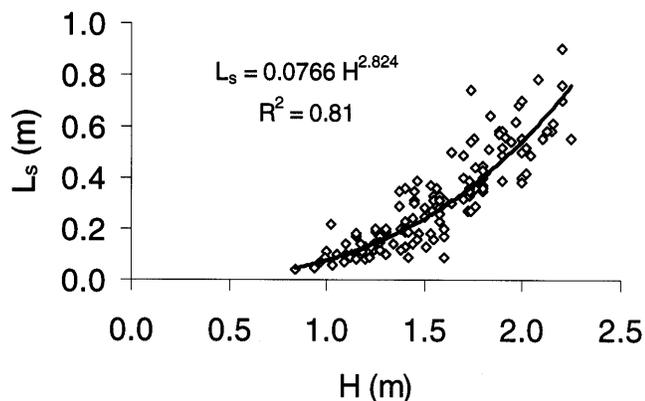
Mechanical impact to the seed-head during conveying was assumed to be mainly caused by the action of dropping the seed-heads to the stubble ground, which occurs after the seed-heads leave the slide. Excessive mechanical impact may cause shattering and, consequently, seed loss. According to Newton's second law, the impact force response of a seed-head on the ground is related to the velocity of the seed-head before contact with the ground. As this speed was difficult to measure, the speed of the seed-head on the slide (referred to as sliding speed) was measured as described below to characterize the mechanical impact.

Experimental design A randomized factorial (3x3) experiment with three replications was designed with three draper speeds, V_d , (1.27, 2.03, and 2.79 m/s) and three inclination angles of slide, θ , (25, 35, and 45°), forming a total of nine treatments. The selected V_d represented the low, intermediate, and high draper speed, according to the manufacturer.

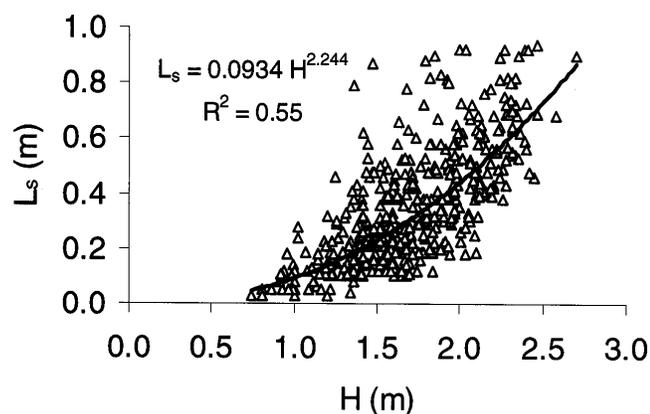
Measurements Measurements of sliding speeds were first tried in field operations in August 2000. A line of seed-heads along the field plot was pre-painted with orange colour before the test run. Gridlines (Fig. 5a) equally spaced at 150 mm apart were marked along the slide to track the seed-head movement. After θ and V_d were set at the desired treatment values, the seed-head windrowing was performed and the movement of the seed-heads on the slide was recorded simultaneously by a digital video camera. The videotape was played to track the position of the coloured seed-head to determine the sliding speed. However, the coloured seed-heads could not be clearly identified among a massive flowing plant material, and the sliding speeds could not be obtained from this test.

Measurements of sliding speed were made again in 2001 with the hemp windrower being in a stationary situation. The hemp windrower was parked in the field and the slide was set at a desired treatment angle. Gridlines were made on both the slide and the ground with the first gridline right under the left end of the slide (Fig. 6). A seed-head sample of approximately 1 kg was randomly picked by hand from field windrows. A line (perpendicular to the direction of the plant length) of orange colour was sprayed on the sample for tracking purpose. For each treatment, the sample was manually dropped (all at once) on the middle of the running draper (Fig. 6) after the draper was running steadily at the desired treatment speed. A digital video camera was used to record the motion of the seed-heads on the slide until they hit the ground.

The videotape was played and the coloured line of a seed-head was tracked. The number of picture-frames (30 frames per second) was manually counted to determine the time spent by the seed-head sliding from the first to the last gridline on the slide. The V_s was calculated by taking the distance between the first and the last gridline, divided by the time spent. The point where the seed-head first touched the ground also was located



(a)



(b)

Fig. 7. Relationships between the seed-head length (L_s) and the plant height (H): (a) data obtained from the hemp plants sampled in a 9-m² area at Glenlea, 2000; (b) data obtained from the hemp sampled in a 3-m² area at Arborg, 2001.

by visually observing the picture frames. Thus, the chuting distance (X) was estimated by the number of gridlines on the ground passed by the seed-head.

Data analysis

Analysis of variance (Steel and Torrie 1980) was performed on the effects of V_d and θ on the V_s and X . Means were compared using Duncan's multiple range tests at a significance level of $P < 0.05$. Regression analysis was made on the data of H and L_s .

RESULTS and DISCUSSION

Selections of cutting height for seed-head windrowing

Theoretical cutting height Theoretical cutting height of a plant is equal to $H - L_s$ (Fig. 1). The parameter L_s is highly variable as shown by the standard deviation of over 0.20 m obtained in this study. Values of L_s were found to be correlated with those of H in a power relationship (Fig. 7a,b):

$$L_s = aH^b \quad (1)$$

where a , b = regression coefficients.

The values of R^2 (coefficient of correlation) are 0.55 and 0.81 for the data from the Glenlea and Arborg sites, respectively. The lower R^2 value in the former site was partly due to the uneven plant growth associated with spring flooding at the site. The cutting height can be estimated as:

$$CH = H - aH^b \quad (2)$$

The average value of H can be used to estimate the CH using Eq. 2. Given that the average H was 1.71 m for the Glenlea site and 1.56 m for the Arborg site, the corresponding values of CH were estimated as 1.40 and 1.29 m. The windrower should be operated at these cutting heights when windrowing the seed-heads at these two sites.

Seed-head losses To estimate the loss of seed-head at a given CH , the distribution of plant samples should be examined at each theoretical cutting height ($H - L_s$). Based on this information, the accumulative length of uncollected seed-heads can be calculated. Then, seed losses can be assessed by the seed-head loss index defined as:

$$I = \frac{10 \sum l_s}{A} \quad (3)$$

where:

- I = seed-head loss index (km of seed-head per ha),
- $\sum l_s$ = accumulative length of uncollected seed-head (m), and
- A = sampling area (m²).

Note that the seed-head loss index may not directly reflect the amount of seeds lost due to the uneven distribution of seeds among plants and along the length profile within each plant.

With the cutting height varying from 0.5 to 2.0 m with 0.1 m increments, the observed frequency of plant sample is shown in Fig. 8 for the hemp plants sampled at the two sites. Curves from both sites had a skewed distribution feature with the mean nearer the higher theoretical cutting height than the median. The values of I estimated from Eq. 3 for different CH are shown in Fig. 9. The results showed that the value of I increased at an increased CH . At the selected cutting heights, 1.40 and 1.29 m,

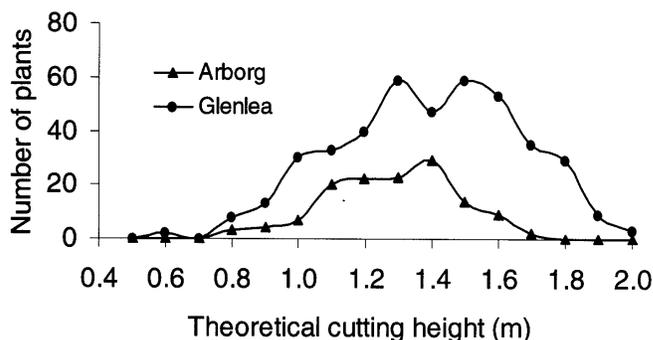


Fig. 8. Numbers of plant samples at different theoretical cutting heights for two sites: data from Glenlea were obtained from the hemp plants sampled in a 9-m² area, 2000; data obtained from Arborg were obtained from the hemp plants sampled in a 3-m² area, 2001.

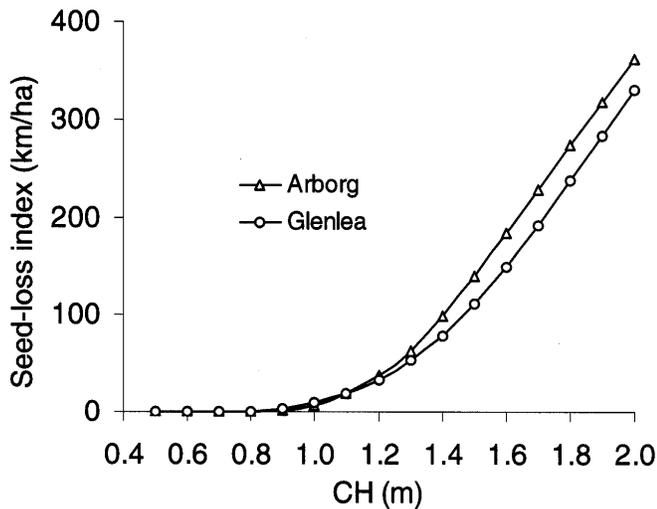


Fig. 9. Seed-head loss indices (I) at different cutting heights (CH) at the two sites.

estimated above, the I is 80 km/ha at Glenlea and 60 km/ha at the Arborg site (Fig. 9). If the combine intake is not a concern, one may want to use a decreased cutting height to collect more seeds.

Test results of the hemp harvester

Functions of the hemp windrower In the tests of 2000, the operations of header lifting and conveyor folding and unfolding were successfully achieved. The two-windrow harvesting concept was also proven to be feasible. Smoother windrow delivery was observed in the test at the early growing season where the hemp crop was fairly green with 45% average moisture content (dry basis). Plugging was occasionally observed at both delivery modes in the test in the late growing season, as the dry plants (30% moisture content, dry basis) were rigid and did not settle as much before passing through the delivery openings. Furthermore, the dry seed-heads did not favour the gravitational sliding, which caused accumulations of plant material on the slide. An increased inclination angle of slide should be used for a dryer crop. However the maximum

Table 1. Seed-head sliding speeds (V_s) and chuting distances (X) averaged over draper speed (V_d) and inclination angle of the slide (θ), 2001.

Treatment	V_s (mm/s)*	X (mm)
V_d (m/s)		
1.27	3.54 c	499 a
2.03	5.66 b	559 a
2.79	7.19 a	491 a
θ (degrees)		
25	5.26 a	694 a
35	5.63 a	491 b
45	5.49 a	364 b

*Means in the same column followed by different letters are significantly different ($P < 0.05$) according to Duncan's multiple range test.



(a)



(b)

Fig. 10. Field operations and results: (a) seed-head windrowing; (b) seed-head and fibre-stalk windrows. Pictures were taken at Arborg, 2001.

angle was limited by the delivery distance required, other solutions had to be sought in the studied case to solve the plugging problem.

To solve the plugging problem, the delivery opening size of the hemp windrower was enlarged from 1.0 to 1.63 m. The main board of the slide was lengthened to match the enlarged opening size. The extension board was removed due to the increased length of the main board. The hemp windrower was tested again in September 2001 when the hemp had 35% moisture content (dry basis). Plugging problems were not observed in either delivery mode. Seed-heads were smoothly conveyed to the desired cutting area (Fig. 10a), and two separate windrows for seed-head and fibre-stalk were properly laid (Fig. 10b).

Seed-head sliding speed (V_s) The V_d had a significant effect on the V_s with a higher V_s being observed at an increased V_d (Table 1). This may be explained by the higher initial speed of the seed-head when touching the slide at a higher V_d . The X was decreased when θ was increased from 25 to 35° with no significant decrease of X observed at the 45° angle. This result indicated that when the slide was set at a smaller angle, the seed-head windrow was placed further from the standing fibre-stalk, which was favourable for operating the windrower in fibre-stalk windrowing. The interaction effect of θ and V_d was not significant, and effects of θ on V_s and those of V_d on X also were not significant.

It is important to note that the measurements were performed with the hemp windrower in a stationary condition. In practice, the windrower travel speed may affect V_s . This effect is expected to be non-significant as the relative movement between the seed-head and the slide is not affected by the hemp windrower travel speed once the seed-head comes into contact with the slide. However, the X may be significantly affected by the hemp windrower travel speed. Additional measurements are required to verify this hypothesis.

CONCLUSIONS

A two-windrow concept for harvesting dual-purpose hemp (seed and fibre) is feasible and can be implemented by modifying a commercial windrower. The new components had add-on features for easy adaptation. A new header-lifting mechanism allowed the header to be raised an additional height of 0.5 m. A foldable conveyor was adapted to convey the seed-heads to the stubble ground. The windrower can still be used for conventional crops when the conveyor is in fold position. Greater mechanical impact of the seed-heads against the ground was expected at greater draper speeds, which resulted in higher sliding speeds. The effect of inclination angle of the slide was not significant in this regard. The selection of cutting height can be based on only the average plant height. Seed losses and combine intake for the subsequent combining operation can be minimized using the selected cutting height.

Seed losses were not directly measured in this study. The evaluation of the hemp windrower was limited to visual observation of its desired design functions. From a commercialization standpoint, studies on the strength and surface characteristics of the slide, as well as estimates of cost for modifications and measurements of seed losses may be necessary.

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