

CYNARA CARDUNCULUS EXPLOITATION FOR ENERGY APPLICATIONS: DEVELOPMENT OF A COMBINE HEAD FOR THRESHING AND CONCURRENT RESIDUES COLLECTING AND UTILIZATION

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ABSTRACT: The CRA-ING took part to the *Cynara cardunculus* harvesting tests organized in Spain in 2007, where UPM has experimental cultivations in the Instituto Madrileño de Investigación y Desarrollo Rural, Agrario y Alimentario (IMIDRA) de la Consejería de Economía y Innovación Tecnológica de la Comunidad de Madrid in El Encin, near Alcalá De Henarez. The harvesting tests were carried out in week 33 (August 13th-17th); the cultivation was found part in good condition of maturity, part still not ready for harvesting. The project concept, supplied to a firm that already builds heads for maize, wheat, sunflower, soybean and so on, included the upper devices of a maize head and a classic wheat head (without the paddle wheel) in the lower part, to obtain capitula detachment and effective threshing and, at the same time, the stalk cut. The basic concept of the machine, to separate and thresh the capitula and to drop in windrow the biomass and then pick it up with a baler with a minimum soil presence, was proved to be feasible. The effective working capacity was good, so the costs should be sustainable.

Keywords: *Cynara Cardunculus*, energy crop, separate harvest.

1 INTRODUCTION

The CRA-ING has taken part to the *Cynara cardunculus* harvesting tests organized within the BIOCARD project (EC contract No. 019829) in Spain, where UPM has experimental *Cynara cardunculus* cultivations in the Instituto Madrileño de Investigación y Desarrollo Rural, Agrario y Alimentario (IMIDRA) de la Consejería de Economía y Innovación Tecnológica de la Comunidad de Madrid in El Encin, near Alcalá De Henarez.

The 2007 harvesting tests were carried out in week 33 (August 13th-17th); the cultivation was found part in good condition of maturity, part still not ready for harvesting. The test was carried out on the dried part of the crops.

The tests aimed at evaluating a new mechanical equipment working (head) connected to a self-propelled combine for separated harvesting of the different fractions obtainable by the cultivation assigned to different transformation: oil extraction from seeds and energy production from epigeous biomass combustion.

2 APPLIED METHODOLOGY

2.1 Observations on the cultivations

The observations executed on the cultivation concerned the height of the plants, the height at the first fertile ramification and the number of heads (inflorescence) per plant.

As a result arithmetical mean and the distribution in frequency classes were elaborated.

2.2 Observation on the harvest machines performances

The tests aimed at finding the performances of the machine during the *Cynara cardunculus* harvest.

The times of the various operations during the harvest for each machine were taken according to the official methodology of the Commission Internationale de l'Organisation Scientifique du Travail en Agriculture (CIOSTA) and the recommendation of the Associazione Italiana del Genio Rurale (A.I.G.R.) 3a R1.

Through the measurement of the necessary time to cover during the work a base of a known length, the effective

average speeds of the two systems were calculated.

Through the measurement of the effective and operative working width the average effective and operative potential was calculated.

3 CROP CHARACTERISATION

The plantation dated back to two years and was at its first harvest. It had been executed with a mechanical seeders with a distance of 0,8 m between the rows and with a mean distance of 0,29 m on the row, therefore the result was an investment of approximately 42.500 plants/ha (see table I).

Notwithstanding it was a two year cultivation, there were many gaps along the rows. Probably because of a dry winter, the crops were partly underdeveloped, with low heights, low ramifications and few capitula per plant (see table II).

About 2/3 of the field presented the above mentioned short plants, while the remaining produced much taller plants: the test took place in the short plants part, because the other was still not dried. The characteristics in table II also refer to this area of the plantation.

Table I: Description of the *Cynara cardunculus* plantation

average distance on the rows (m)	0,29
distance between the rows (m)	0,8
effective density (plants/ha)	42500
planting age (year(s))	2
plant age (year(s))	1

An analysis of the distribution in frequency classes of the cultivations relieves was conducted to define the morphologic characteristics variance (the dimensioning of the machine is derived from these data).

Table II: Mean morphologic and productive characteristics of the cultivation

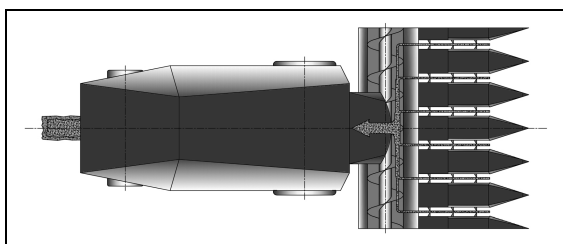
height (m)	1,20
ramification height (m)	0,99
heads per stalk (n)	2,6
stalks per plant (n)	1,23
heads per plant (n)	3,18
stalks density (n/ha)	52250
heads density (n/ha)	135312

Comparing these data with those collected during 2006 tests, we can observe that plant and ramification heights are about 50%, while the number of head per plant is 72% lower. According with UPM, the cultivation underdevelopment is due to a warm winter with low rainfall.

4 DEVELOPMENT AND DESCRIPTION OF THE PROTOTYPE

4.1 Project concept

Following the tests carried out in 2006 in Spain and Portugal, CRA-ING supplied the project concept of a combine head (see figure 1) to be developed and built by Cressoni Engineering A.M., a firm that already builds heads for maize, wheat, sunflowers, soybean and so on.

**Figure 1:** project concept

During 2006 tests, it was observed how a combine harvester with a maize head was able to separate the seed with good accuracy. Likewise the difficulty of collecting the lignocellulosic fraction after its passage was highlighted. A combine with a wheat head could cut the stalk in an appropriate height range, but could not separate the head from the stalk. A sunflower head did cut head, but didn't provide the cut of the stalk.

The project concept included the upper devices of a maize head and a classic wheat head (without the paddle wheel) in the lower part, to obtain capitula detachment and effective threshing and, at the same time, the stalk cut.

Some modifications were specified to allow the cut of the stalk next to the ground and its successive tier in the space between the front wheels, where the discharge system of the threshing device would then provide to drop the remains of the capitula threshing, to be picked up by a baling machine:

- the removal of the cutting blade under the squeezing rolls;
- the lowering of the rotating blades under the squeezing rolls;
- the positioning, next to the ground and under the first section of the squeezing rolls, of a mower to cut the stalk;

- the development of a directing system to move the biomass from the side towards the central area of the harvesting head, between the front wheels of the combine, to form the afore-mentioned windrow.

The Firm was asked to abide by our suggestions in reference to the operations the machine would perform:

- entrance of the stalk in the working part of the machine;
- cut of the stalk next to the ground;
- downward traction of the plant to detach the capitula against a fixed frame;
- capitula transportation towards the attached combine thresher device;
- biomass transportation towards a central outlet slot and
- its dropping to form a windrow between the front wheels;
- capitula threshing remains dropping onto the same windrow.

The head (see figure 2) was designed to work on two heights: the upper part cuts and moves the capitula to the threshing device, the lower cuts the stalk next to the ground and drops the conditioned biomass between the front wheels: the residues of the capitula threshing are then discharged onto the biomass, while the seeds are collected by the combine.

The new head differs from a maize head in several points:

- the squeezing rolls allow to drop to the ground conditioned stalks, not broken into fragments, for an easier packing (Fig. 3);
- a mower below the first section of the squeezing rolls cuts the stalk next to the ground (Fig. 4);
- cut and conditioned stalks are moved from side areas towards the central area of the harvesting head, between the front wheels of the harvest machine, to form a compact windrow on which the threshing residues are dropped. Then the windrow is picked up by a baling machine (no need to use a hay-rack, less problem with soil in the crop, hence less ashes in the power plant).

**Figure 2:** view of the Cynara head

The head has two different devices on a single frame: the upper part is basically a maize head, with squeezing



Figure 3: squeezing rolls and rotating blades

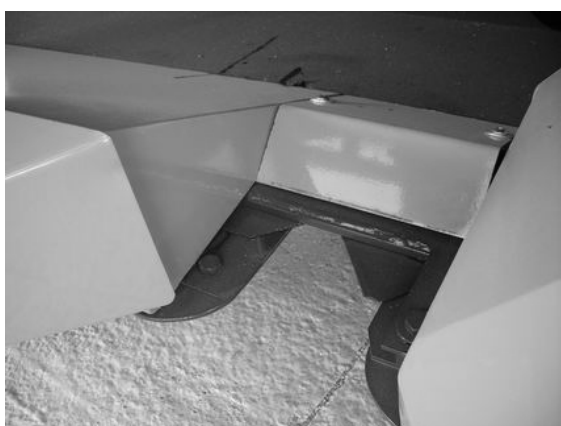


Figure 4: mower and shaped metal sheet

rolls and adjustable plates to detach the capitula, disconnectable rotating blades (Fig. 3), about 40 mm lower than the “basic” maize head, with a revolving paddle wheel and an Archimedean screw to move the detached capitula towards the threshing device, through the provided upper slot on the back of the frame (Fig. 5); likewise a maize head, the Cynara head is for row cultivations (six rows, in this case). The lower part as well is for row cultivations: there is a mower working between the final end of the lower tips (Fig. 4), with shaped metal sheets to ease the entry of the lower part of the stalks and a second Archimedean screw to move the biomass towards the lower slot (Fig. 5), through which it is dropped between the front wheels in a windrow. On the same windrow the threshing remains are dropped.

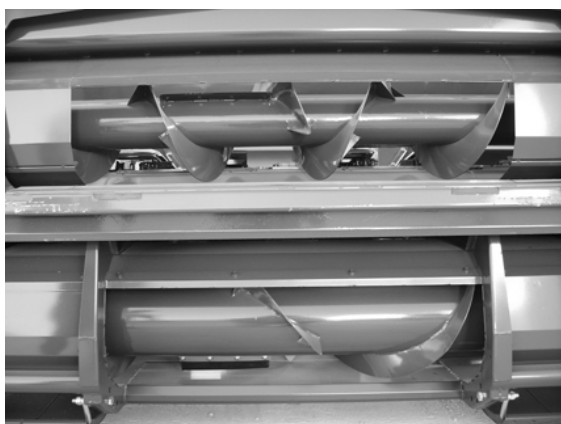


Figure 5: the slots and the Archimedean screws

4.2 Technical characteristics

The overall dimensions of the head are:

- width: 4940 mm
- height: 1731 mm
- length: 2770 mm

The head is built for six rows (see figure 6); the distance between dividers is 800 mm. The gap between dividers is 131 mm.



Figure 6: upper and lower dividers

To move the capitula towards the threshing device inlet (1280 mm width), there are an Archimedean screw, 4516 mm long, with a diameter of 370 mm, rotating at 144 rpm, and a rotating paddle wheel, 4590 mm long, with a diameter of 600 mm, rotating at 50 rpm.

The squeezing rolls, two for each row, are slightly tilted forward: the roll has five knives, for a better pre-cut and conditioning. The diameter is 110 mm, the length is 460 mm. The rotation speed is 954 rpm, with a linear tip speed of 5.5 m/s.

About 115 mm under the front end of the squeezing rolls there are rotating cutting blades, whose overall length is 534 mm. The rotation speed is 2084 rpm.

The lower part, as well as the upper, is for a six row cultivation; again the distance between dividers is 800 mm.

Aligned with the gap between dividers, 450 mm below the rotating blades, there is the mowing device, with 644 cut per minute; the gap between lower dividers is 100 mm.

The biomass is moved towards the dropping slot (1280 mm width) by a second Archimedean screw, 4560 mm long, with a diameter of 445 mm, rotating at 130 rpm.

Tilting of the head is achieved by means of a double screw mechanical system (Fig. 7).

The mechanical power is supplied by the combine through two Hooke’s joints (one per side), the hydraulic power through a hydraulic quick coupler (single location) (Fig. 7).

On the right side of the machine take place the transmission gears to the paddle wheel, the right half squeezing rolls and rotating blades and the lower Archimedean screw, on the left side to the upper Archimedean screw, the left half squeezing rolls and rotating blades and the mower.

The above-mentioned speeds are relative to the New Holland CX/CS/CR combine models, whose power take-off spins at 575 rpm.

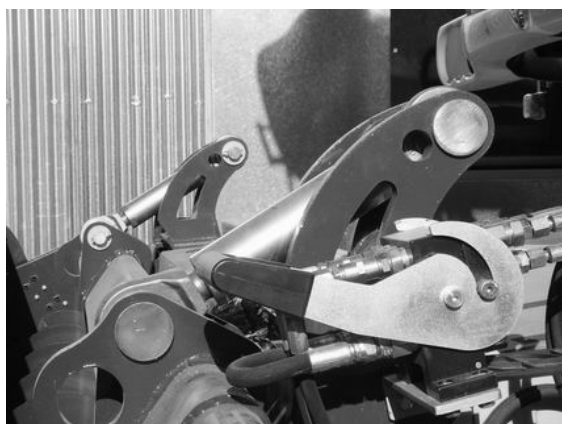


Figure 7: tilting device and hydraulic quick coupler

The combine harvester provided was a New Holland CS 6080 (Fig. 8). The head was supposed to work connected to a CX Series machine, because of its weight (over 3 tonnes): it was necessary to install a third hydraulic cylinder in order to raise and operate the head with the provided combine.

As the new head derives from the union of two different heads on a single frame, the head weight requires it to be mounted on top class combine (CX Series for New Holland).

The overall weight of the head is 3342 kg.

5 FIELD TESTS

5.1 First test

First tests of the new head took place in Spain, in week 33 (August 13th-17th): the machine was modified and fine tuned during the tests by CRA-ING and Cressoni technical personnel.



Figure 8: New Holland CS6080 with Cynara head

Unfortunately, the crops were not as developed as to match expectations.

The design of the machine was done according to the morphologic characteristics measured during the 2006 test in Portugal (see table III).

The upper part of the machine needs to work on a crop of at least one meter high, to have the upper and lower devices working properly.

The windrow made by the combine head on which the combine dropped the threshing residues was well done but with a low biomass density due to the plantation

Table III: Mean morphologic and productive characteristics of the cultivation - Portugal 2006

base stalk diameter (mm)	33,9
stalk diameter at ramification height (mm)	25,34
height (m)	2,56
ramification height (m)	1,9
heads per plant (n)	11,3
head diameter (mm)	54,92
force to detach 1 head (N)	216,21
strain to detach 1 head (N/mm ²)	0,39

characteristics.

To make more difficult the situation, the ground was not levelled off but worked with ridges, in which the collected biomass gathered, so it was not possible to harvest it with the baler as it was scheduled. The ridges compelled the driver to keep the mower higher than it was necessary, to avoid soil entrance in the head (polluted biomass and possible mower damages).

5.2 Fine tuning and final test

The machine was partly modified during the tests by Cressoni and CRA-ING personnel; deeper modifications were highlight and will be carried out during the winter in the factory.

The threshing was very good and no clogging was observed (the feeding was rather poor though, due to the above-mentioned plantation underdevelopment).

The machine worked with and without rotating blades. It was highlight that it worked better with active rotating blades, because they help moving the biomass towards the Archimedean screw, so the device to disconnect them will not be present on the final machine, with some weight saving.

The plates to detach the capitula were put as close as possible due to the small capitula diameter: the opening was adjustable both hydraulically and mechanically; the distance between the plates was put at about 20 mm, not to let capitula pass through the squeezing rolls: with such a distance only the smallest capitula, allegedly poor in seeds, will be lost. The vertical rubber shields put over the squeezing rolls were supposed to avoid the capitula falling back from the head: in fact, we observed their presence, with the current crops, interfered with the entrance of capitula. So, they were removed.

The shaped metal sheets (Fig. 4) mounted on the cutting bar to avoid collecting material and soil also stopped the product movement, so they were removed.

The lower tiltable tips (set for row cultivations) often barred the cut of the stalk, because these tips, when the driver did not exactly follow the row, bent the stalks which were cut higher than due (Fig. 9), with consequent biomass loss. We tried to widen the space between the tips up to about 150 mm, cutting and welding the sheet metal, but without appreciable results.

The head on the machine, initially horizontal, was tilted backwards: to achieve this task, the four connecting screws (Fig. 7) were cut of about 20 mm. It was pointed out the need to have a simpler device to regulate the head in relation to the crop characteristics.

The mower worked efficiently, with a very neat cut (Fig. 9); the rotating blades gave a scraped cut, still effec-



Figure 9: mower cut

tive (Fig. 10); the squeezing rolls scratched the stalk without really cutting it.

The machine, after the field set up and fine tuning, worked at 0,9 m/s speed, harvesting 1,57 ha in 1 hour.

A pair of sleighs or pivoting wheels will be mounted under the head, to support part of the head weight (better handling) and to avoid lowering too much the head, remembering that the driver cannot see the ground.

The main problem, anyway, is the lower part of the machine: the cynara is a long-standing crop, so it starts as a row cultivation, but later develops in a narrower row cultivation, because of the offshoots. The current head has row cutting devices, so, when the plant is not aligned with the row, part of the stalk, uncut by the rotating blades, happens to remain on the ground, with considerable loss of biomass.



Figure 10: rotating blades scraped cut

To solve this problem, the final head will mount a full length mowing device, to cut all the stalks facing the machine. As a matter of facts, the current saw misses the stalks that are not directly aligned with the gaps between the lower tips, leaving uncut up to 1.2 m.

The separate harvesting of seeds didn't show any particular problem.



Figure 11: pappi loss during harvesting

6 CONCLUSIONS

The basic concept of the machine, to separate and thresh the capitula and to drop in windrow the biomass to help the following collecting with a big baler, was proved to be feasible.

The effective working capacity was good, so the costs should be sustainable.

The crops underdevelopment and the ridges on the ground prevented the team from evaluating the real system capacity and collecting the biomass with a baler.

The main problem tests pointed out is the mowing device: it will be deeply modified to work on the whole machine width and not only along the rows.

The cut height will be defined through sleighs or pivoting wheels: this will prevent the operator from lowering the working head too much, given the impossibility to check it directly.

Changes will be carried out before summer 2008, so to supply the commercial machine, tested on fully developed cultivations, next August.