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AGRICULTURAL MECHANIZATION RESEARCH INSTITUTE

SIXTH FRAMEWORK PROGRAMME

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"Energy from Crops"

BIOCARD

Global Process to Improve Cynara Cardunculus Exploitation for Energy Applications

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Task 1.5.4: *Construction of prototype*

- The prototype was built by Cressoni Engineering S. A. according to CRA-ISMA project concept.

Task 1.5.5: *Field tests and changes*

- Field tests were performed in Alcalà de Henarez, Spain, August 13th-17th 2007.

Task 1.7: *Cynara logistic analysis* (involved partners: UPM, CRA-ISMA, TECNATOM)

- Start the activities, developed a first tool.

1. INTRODUCTION (tasks 1.5.4 and 1.5.5)

The CRA ISMA has taken part to the Cynara cardunculus harvesting tests organized 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 Encìn, near Alcalà 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 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 Italian Association of rural genius (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 tab. n.1).

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 tab. n.2).

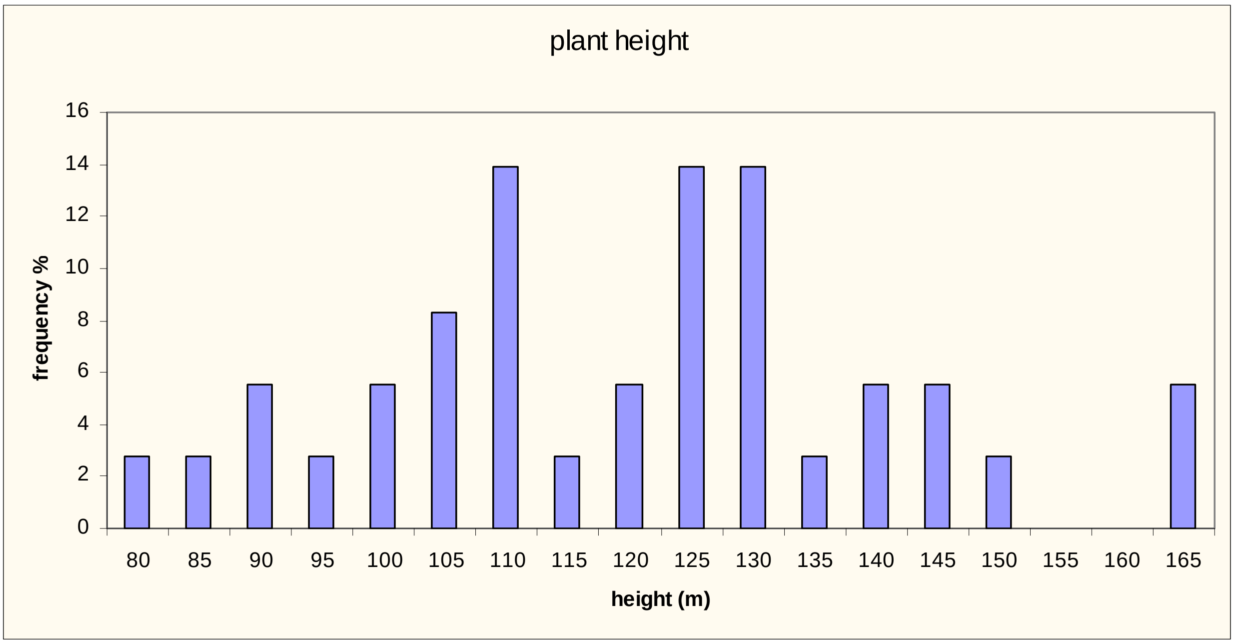
About 2/3 of the field presented the above mentioned short plants, while the remaining produced much taller plants: the test took place in the short plants part, because the other was still not dried. The characteristics in tab. n.2 also refer to this area of the plantation.

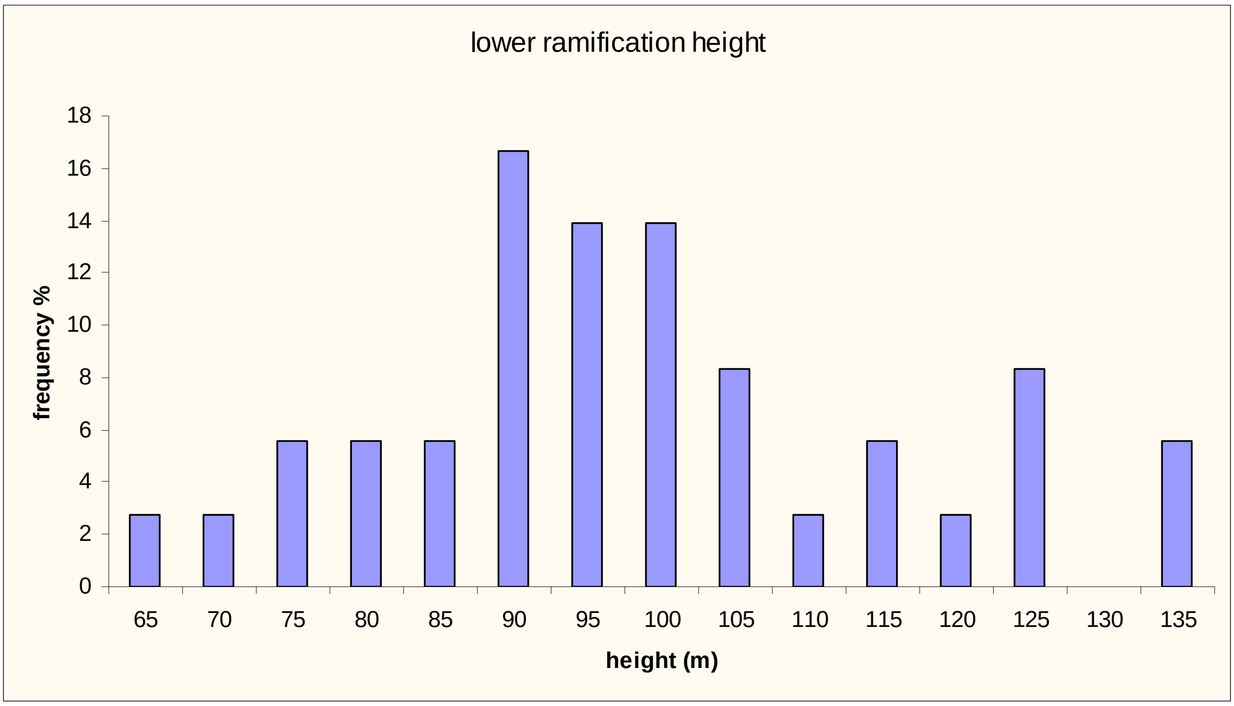
Data regarding the well developed plants characteristics will be available soon.

Tab. n.1: description of the Cynara carduncolus 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

Tab. n.2: 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

An analysis of the distribution in frequency classes of the cultivations relieves was conducted to define the morphologic characteristics variance.
The main results are reported in the following diagrams.





Cynara cardunculus main morphologic characteristics

Comparing these data with last year's, 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 last year in Spain and Portugal, CRA-ISMA supplied the project concept of a combine head to be developed and built by Cressoni Engineering A.M., a firm that already builds heads for maize, wheat, sunflowers, soybean and so on.

During last year 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.

The changes are the following:

- 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. Finally the windrow would be picked up by a baling machine.

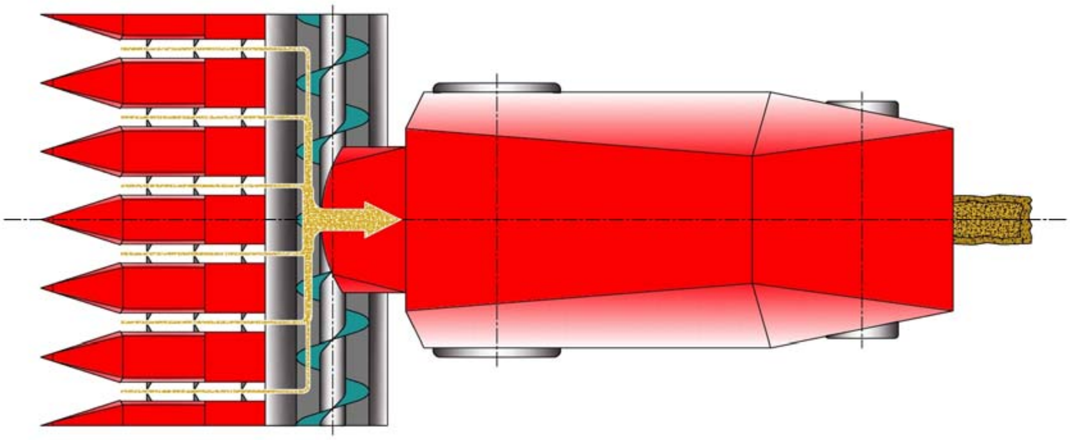


Fig. 1. Project concept.

4.2. Choice of the firm

Several firms were invited to carry out a feasibility study on our project concept. They were asked to abide by our suggestions in reference to the operations the machine would perform:

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

Moreover, the firm should transport the machine to the testing fields and to supply technical personnel for possible modifications during the tests.

The assignee firm was eventually chosen, in addition to the required above-mentioned conditions, because of the know-how in building heads for different crops, the experience of a long presence on the market and for their commercial network.

The agreement between CRA-ISMA and Cressoni Engineering A.M. includes, for year 2007, the scheduling to build the machine and move it where the tests would be carried out, the presence of technical personnel for possible modifications during the tests, the transportation back to the factory and the final changes.

4.3. Description of the machine

The head 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.

Fig. 2. View of the Cynara head.

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).

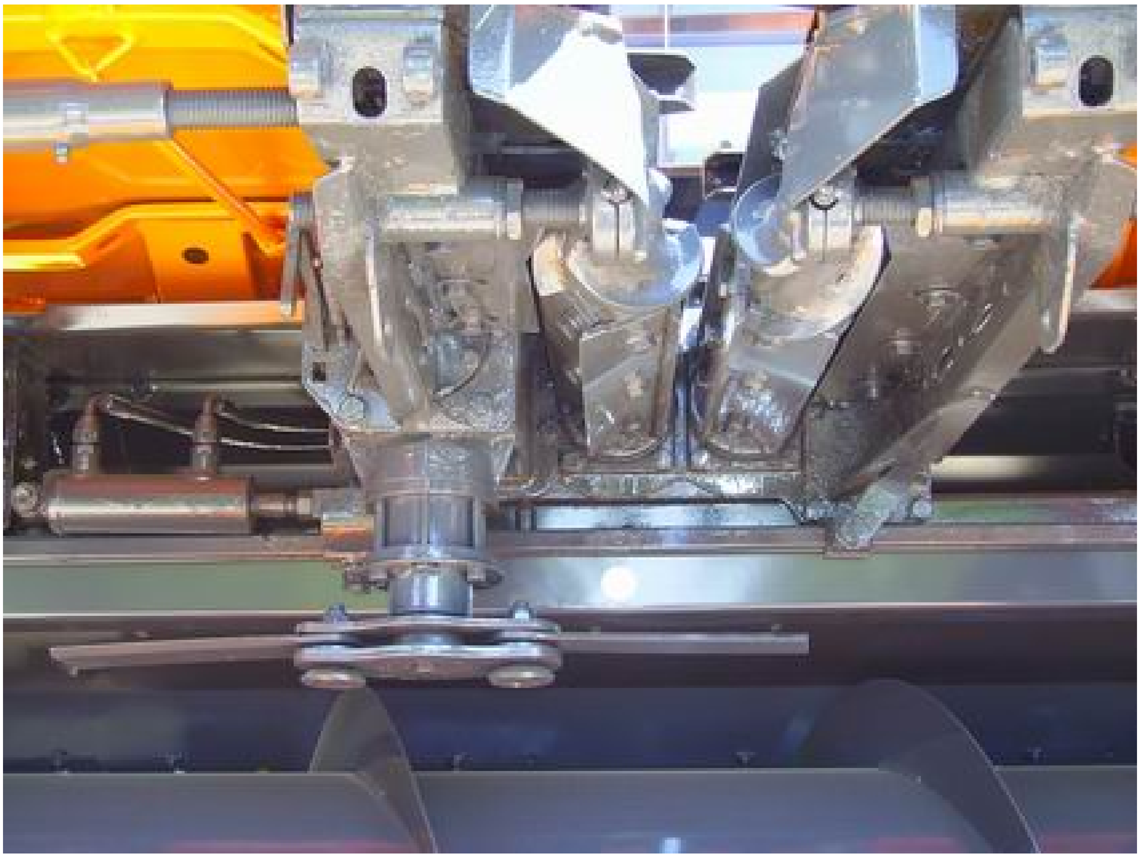


Fig. 3. Squeezing rolls, adjustable detaching plates and rotating blades.

Fig. 4. Mower and shaped metal sheet.

The head has two different devices on a single frame: the upper part is basically a maize head, with squeezing rolls and adjustable plates to detach the capitula, disconnectible rotating blades (fig. 3), about 40 mm lower than the “basic” maize head, with a revolving paddle wheel and an Archimedean screw (fig. 5) to move the detached capitula towards the threshing device, through the provided upper slot on the back of the frame (fig. 6); 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 (fig. 7) to move the biomass towards the lower slot (fig. 6), through which it is dropped between the front wheels in a windrow. On the same windrow the threshing remains are dropped.

Fig. 5. Paddle wheel and upper Archimedean screw.

Fig. 6. Upper and lower slots.

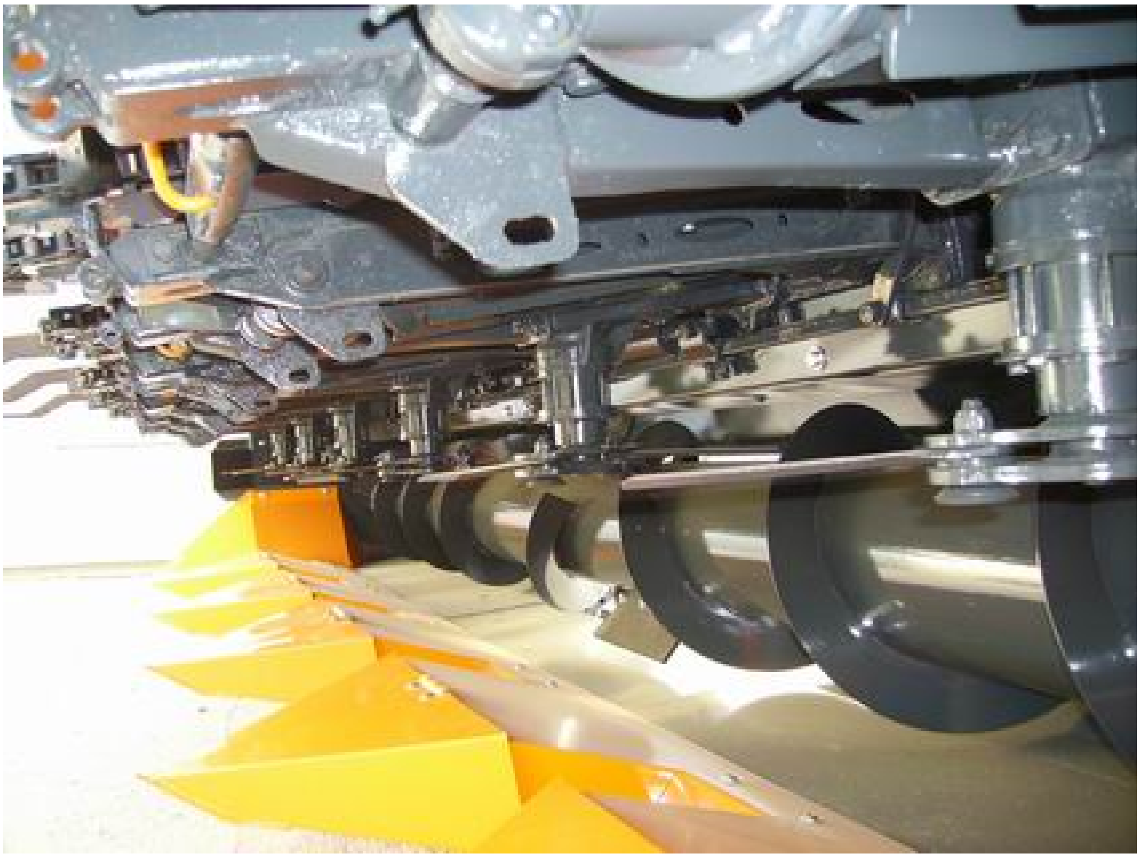


Fig. 7. Lower Archimedean screw.

4.4. Technical characteristics

The overall dimensions of the head are (see fig. 8, fig. 9 and fig. 11):

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

The head is built for six rows; the distance between dividers (fig. 10) is 800 mm. The gap between dividers is 131 mm.

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 (fig. 10) 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. 11).

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. 11).

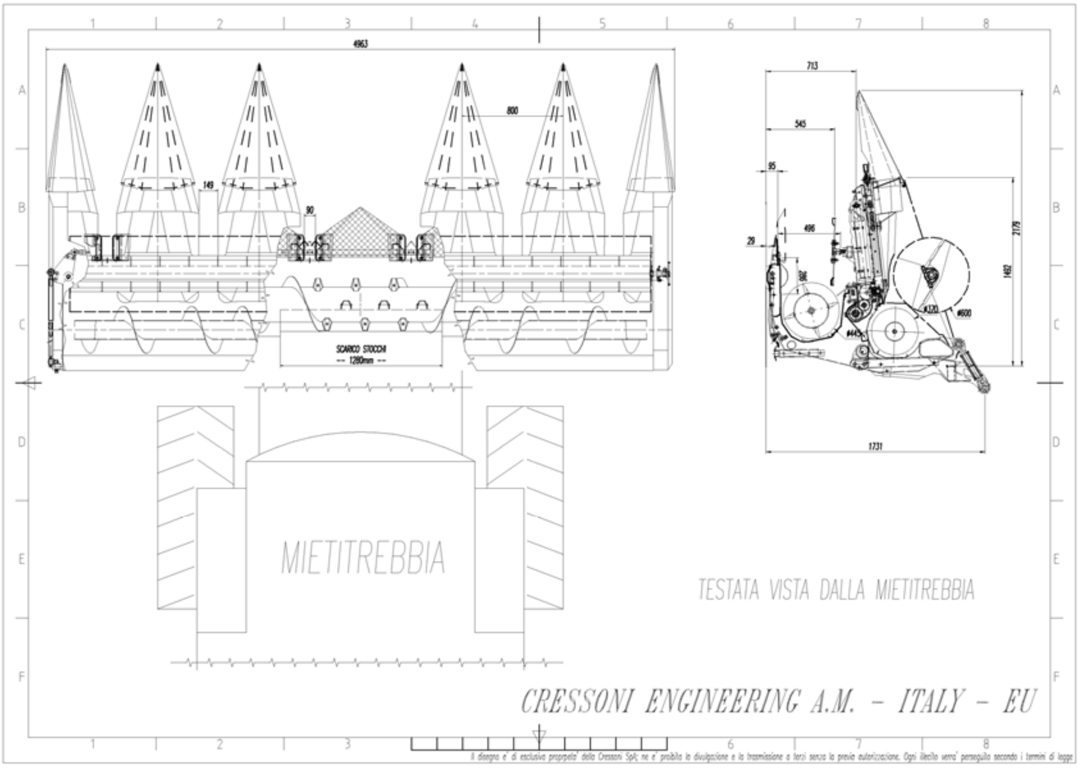


Fig. 8. Top view of the Cynara head.

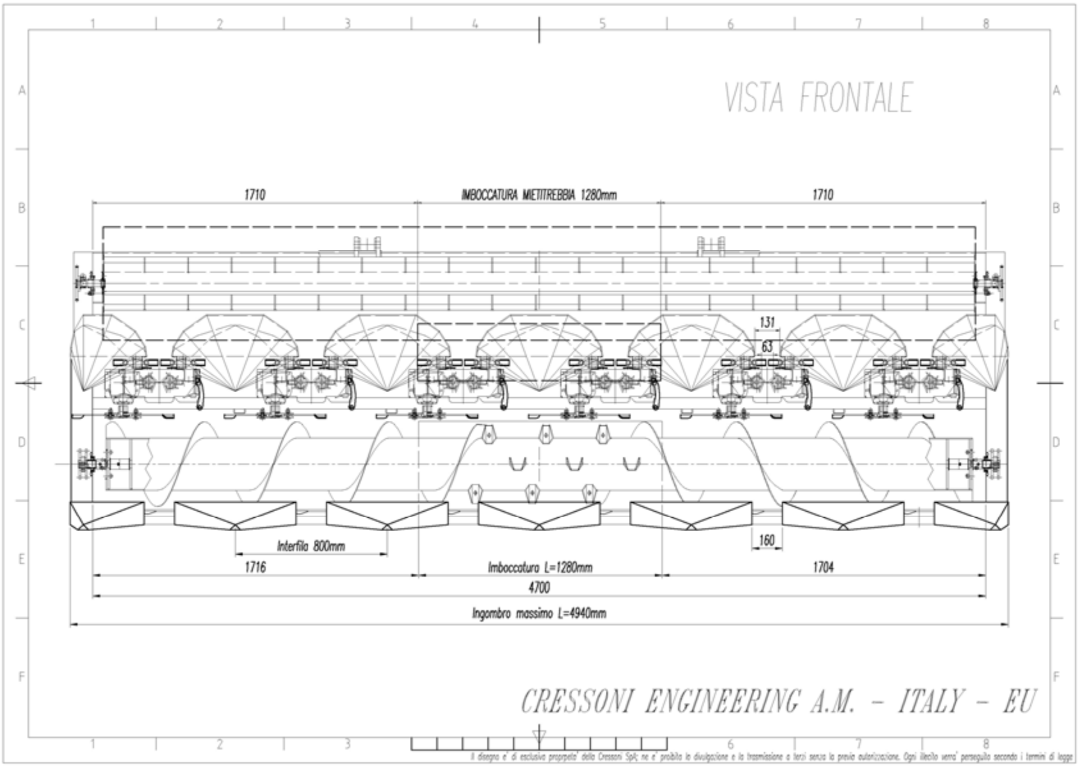


Fig. 9. Front view of the Cynara head.

Fig. 10. Upper and lower dividers.

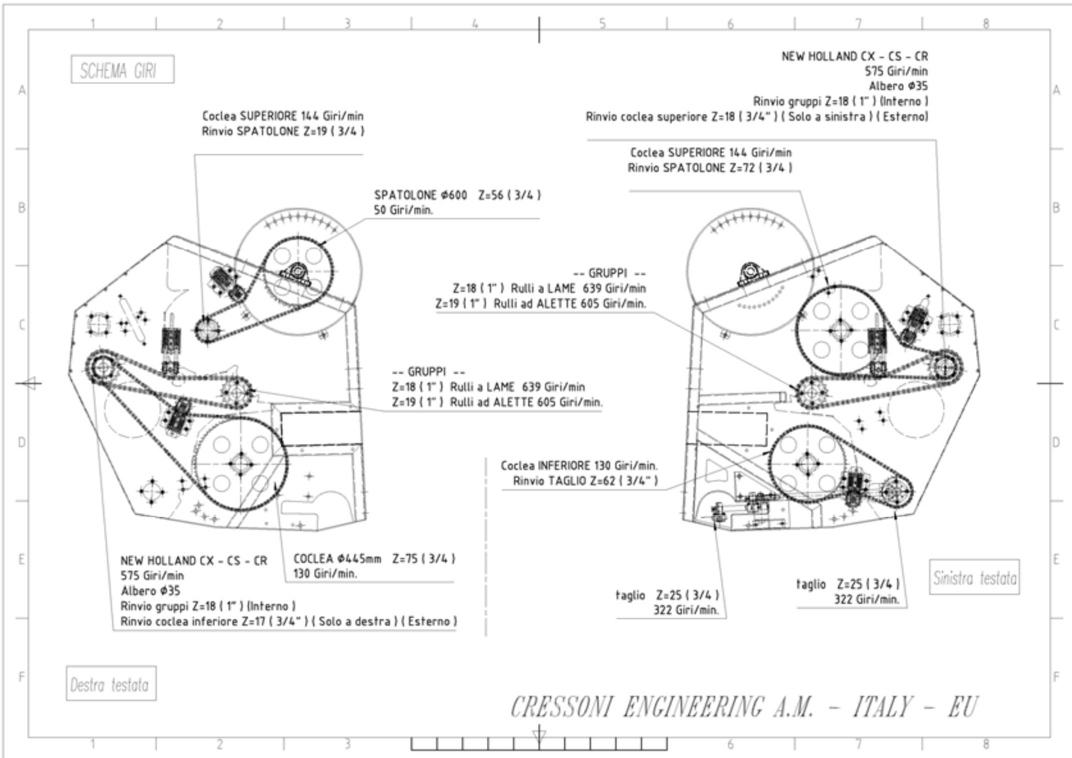


Fig. 11. Transmission layout.

Fig. 12. Tilting device and hydraulic quick coupler.

In 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, in 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 (fig. 13).

The head is provided of two support devices (fig. 14).

The combine harvester provided was a New Holland CS 6080 (fig. 15). 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 (fig. 16) in order to raise and operate the head with the provided combine.

Fig. 13. Left power take-off.

Fig. 14. Left support device.

Fig. 15. New Holland CS6080 with Cynara head.

Fig. 16. Third hydraulic cylinder installation.

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

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-ISMA and Cressoni technical personnel.

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 tab. n.3):

Tab.n.3: 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

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 (fig. 17) but with a low biomass density due to the plantation characteristics. To make worse the situation, the ground was not levelled off but worked with ridges (fig. 18), 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).

Furthermore the ridges made even more difficult to head the machine (the driver cannot see the ground).

Fig. 17. Windrow.

Fig. 18. Ridges.

6. CHANGES AND FUTURE PROSPECTS

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

6.1. Tuning during the tests

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 (fig. 19) 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. 20), with consequent biomass loss. We tried to widen the space between the tips up to about 150 mm, cutting and welding the sheet metal (fig. 21), but without appreciable results.

One of the lower tips, probably because of a stone, raised up and was hit by the rotating blades (fig. 22).

Fig. 19. Rubber shields.

Fig. 20. Mower cut high on the ground.

Fig. 21. Modified lower dividers.

Fig. 22. Lower divider hit by rotating blades.

The head on the machine, initially horizontal, was tilted backwards: to achieve this task, the four connecting screws (fig. 12) 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. 20); the rotating blades gave a scraped cut, still effective (fig. 23); the squeezing rolls scratched the stalk without cutting it (fig. 24).

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

Fig. 23. Rotating blades scraped cut.

Fig. 24. Squeezing rolls scratches on the stalk.

6.2. Modifications that will be carried out during the winter

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 (fig. 25). 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.

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 (fig. 26).

Fig. 25. Offshoots.

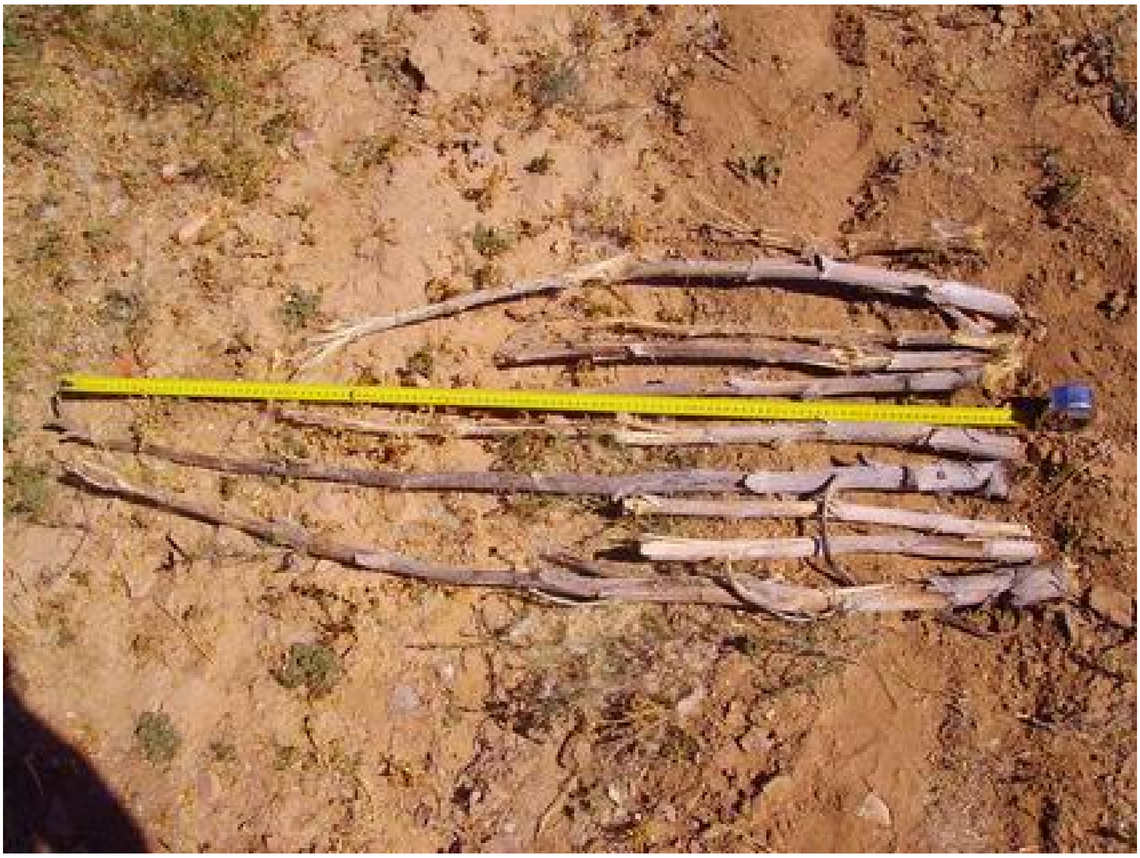


Fig. 26. Uncut stalks.

This redesigned mower would settle another issue: in a line of about 40 m, there were four small fires, all on the same side of the machine; the correspondent tooth of the mower was hot, while the rest of the saw was cold: probably the friction between the mower and its seating itself or some external object (i.e. a stone) produced some sparks that began very slowly to develop in fire (we intervened before it actually went up in flames).

Probably the separate collecting of pappi will be quite hard, because of the loss induced by the head (fig. 27) and the difficulty in dividing them from the biomass in the windrow (fig. 17).

The separate harvesting of seeds didn’t show any particular problem (fig. 28).

Fig. 27. Pappi loss during the work.

Fig. 28. Threshed seeds.

7. CONCLUSIONS (tasks 1.5.4 and 1.5.5)

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 Ce 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 during next months, so to supply the commercial machine, hopefully tested on fully developed cultivations, in August 2008.

1. INTRODUCTION (task 1.7)

CRA-ISMA, together with UPM and TECNATOM, is involved in a logistic analysis of cynara products (whole plant, biomass and achenes) in a 100 km radius area around Cadiz.

A tool will be developed aiming at:

- identifying the best product to harvest according to the relative position of field and power plant or stocking centre (whole plant, biomass and achenes);
- locating intermediate stocking centres, where to convey the product with trailers and whence to start with trucks towards the power plant(s);
- identifying the position of the fields given the position of the power plant or vice versa.

A first version of the tool was developed mainly to identify best stocking centre amongst several.

Starting from four scenarios of convertible land (see tab. n.4), we defined the cynara production in the communes in the considered area around Cadiz.

Tab. n.4: possible scenarios of convertible land	
case I	50% of fallow land
case II	50% of fallow land + 10% of current herbaceous crops
case III	50% of fallow land + 30% of current herbaceous crops
case IV	100% of fallow land + 30% of current herbaceous crops

The power plants taken into account are Biosur and BioOils for biodiesel, North-West of Cadiz, and Endesa Los Barrios for biomass co-combustion, South-East of Cadiz (see fig. 29). Available data were restricted to communes, so the minimal study level was necessary the commune. If more detailed data will be available, deeper analysis will be possible with minor changes to the software.

The tool, still in its first release, was developed to evaluate, chosen a scenario, given the product, the power plant and the means of transport, which is the best stocking centre to collect the product of several production centres (communes) amongst these centres.

In fig. 30, given the production centres 1-4, all of which potentially stocking centres, and given the power plant PP, the costs of the product both at the stocking centres and at the power plant are evaluated: the lower figures will return the best stocking centre.

Fig. 29. Biodiesel (green) and biomass (red) power plants.

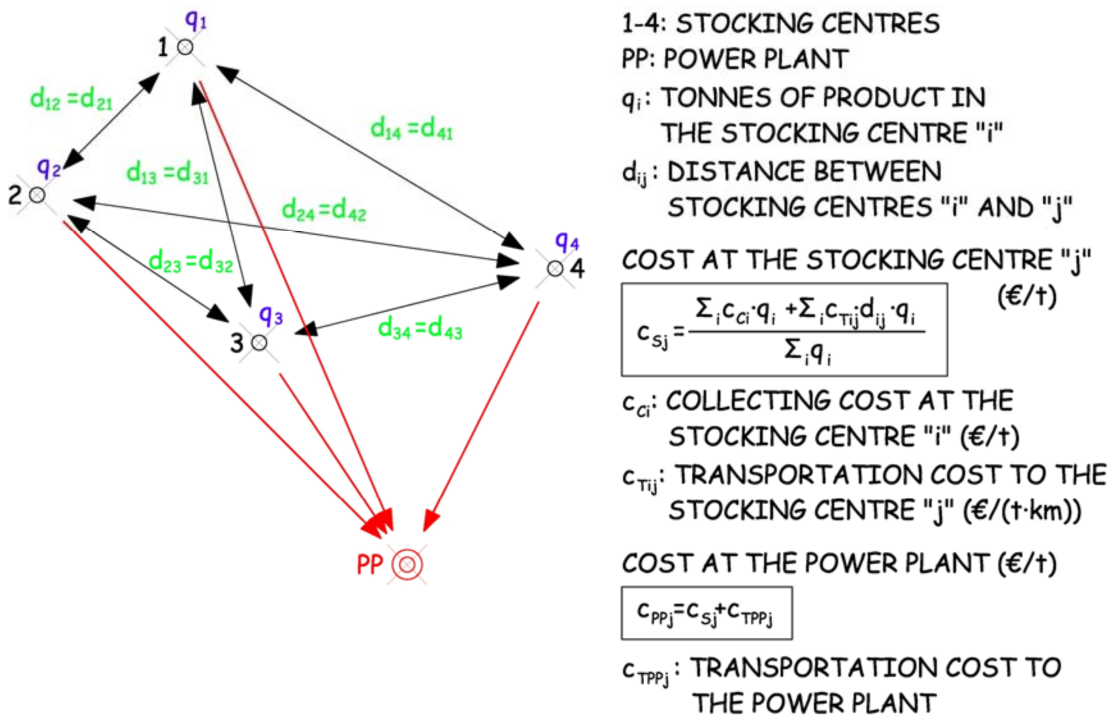


Fig. 30. Logistic diagram.