European Union Research Project Biocard: Mechanization Activities Results

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ABSTRACT

The Agricultural European Policy aims to introduce oil energy crops in arable fields. While in northern and central Europe Countries several crops was introduced, in southern European Countries is necessary to develop agro-energetic chains for arid arable fields. For that reason EU funded in 2006 the Project "Global Process To Improve *Cynara cardunculus* Exploitation For Energy Applications" (Biocard) in which CRA-ING was responsible for developing mechanization solutions. From *Cynara Cardunculus* is possible to obtain biomass for energy, seeds for oil and pappus for fine cellulose, so harvesting equipment was designed to collect separately the different biomass fractions. The aim of the paper is to present the performance of the machine developed during the harvesting of 40 ha of *Cynara Cardunculus* in 2008. After concluding the prototypic phase, the harvester reached a satisfactory working capacity of 2.10 ha/h and overcame the difficulties already examined the past season, with an increase in the operating working capacity of 33.78%.

Keywords: Cynara cardunculus, energy crop, harvester, capitula, Italy.

1. INTRODUCTION

Within the Project "Global Process To Improve Cynara Cardunculus Exploitation for Energy Applications" (Biocard) funded by EU in 2006, CRA-ING developed mechanization solutions for *Cynara* harvesting.
The prototype is an head of a combine harvester able to harvest seeds and leave biomass in windrow that will be subsequently harvested by baling machine in a single operation. In this way the derived particles can be used for different conversions, such as achenes oil for biodiesel production and energy production from the combustion of biomass. From *Cynara Carduncul*us, in fact, is possible to obtain biomass for energy, seeds for oil and pappus for fine cellulose.
This paper shows the results of *Cynara Cardunculus* harvesting tests conducted in Spain, in the the UPM Universidad Politecnica de Madrid experimental fields with the prototype developed by CRA ING and built by Cressoni Company of Volta Mantovana (MN).
The tests aimed at determining the efficiency of changes made since the previous year's tests. Although the first year's tests were characterized by good machine performance, it was still

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necessary to modify the header in order to increase productivity during the harvest phase and to improve work quality. At the beginning, the prototype was made up of a mowing system that worked on single rows resulting inappropriate cause of *Cynara Cardunculus* offshoot that don't permit the plantation to be aligned. The blade, in fact, did not work in such a condition and thus caused remarkable biomass losses. According to this, the modifications concerned the previous baseline cutting system that was replaced by a full-length mowing bar.
The field harvested by the prototype has a surface of 40 ha, the tests were conducted on a plot of 1.2 ha in September 2008.

2. MATERIALS

2.1 Harvesting Machine

The unit used for the *Cynara* cultivation was made up of a New Holland CX 8060 combine harvester equipped with a CRA ING head, a New Holland 544 baling machine (roto-baler) towed by a John Deere 6400 SE tractor and a trailer tractor for seed unloading. A third hydraulic jack was installed due to the high head weight.

2.1.1 Head for Cynara Harvest

The developed prototype is the result of a fusion between two different head models. It combines the six-row maize head, placed in the upper, with the standard wheat head, in the lower part (Fig. 1). The first one serves to detach heads to be sent to the threshing system of the combine harvester, whereas the second one performs the mowing, the conditioning and the above-ground biomass windrowing among the combine harvester wheels. Residues derived from head-threshing are left on the windrow and the seeds are then harvested by the combine harvester.

Figure 1. CRA-ING prototype built by Cressoni Firm: full-length mowing bar, in the low, and device operating on six-rows for stalks conditioning and detachment of the heads to be sent to the threshing system of the combine harvester, in the upper.

The main features of the new header prototype compare to the 2007 ones, are:

- rolls were modified in order to have the conditioning of the stalks and not the chopping for easily harvesting them during the subsequent baling action;

- a full-length mowing bar, placed on the vertical side in the front of the rolls, was added to cut stalks at the base of the plant;
- once cut and conditioned, the stalks were moved by the means of a screw extending from the head towards an opening in the combine harvester lengthwise axis, in order to make a compacted windrow on which threshed residues were then left. Such a windrow can be harvested by a baling machine, without the use of any swather; thus, earth quantity in the product and ash production during the combustion phase in power plant were reduced;
- a rectilinear reel was installed with the aim of moving the detached heads towards the threshing system, aided by a screw.

Head dimensions: Width = 4940 mm; Height = 1731 mm; Length = 2770 mm; Weight = 3342 kg.
In the conveyor heads system towards the power supply channel (of 1280 mm) of the combine harvester, a screw and a reel are used. The screw is 4516 mm long and 370 mm in diameter, with a rotation speed of 144 rpm, whereas the reel is 4590 mm long and 600 mm in diameter, with a speed of 50 rpm. The rolls (two placed for each row) are slightly tilted towards the front, and each of them has five knives, in order to improve the method of receiving and conditioning. The diameter and the length are 110 mm and 460 mm, respectively. The rotation speed is 954 rpm, with a marginal speed of 5.5 m/s. At a distance of 115 m under the rolls, knives of 354 mm total length were placed. The rotation speed is 2084 rpm. The lower separators were spaced at 800 mm. The mowing bar is placed 450 mm below the stem chopper; it operates at 644 cuts/ minute. The biomass is moved to the opening of the lower outlet (1280 mm) from a second screw of 4560 mm length and 445 m diameter, with a speed of 130 rpm.
The head tilt is determined by a mechanical system of double screws. The mechanical power derives from the coupling of two combine harvesters, one for each side, whereas the hydraulic system power derives from a hydraulic coupling system.

3. METHODS

3.1 Cynara Crop Surveys

Both before and after the harvesting stage, surveys of *Cynara* cultivation aimed at the evaluation of the quality of the work, were conducted on 30 plots of 25 m^2 distributed throughout the test area. From survey results, it is possible to determine the real density (plants/ha and stalks/ha), the allotment percentage, the height and the average diameter of the plants, the height of the first branching, the head diameter and the number of heads per ha, and the biomass that can be gathered.

3.2 Machine Performances

Harvesting times were calculated following the standard methodology of the Commission Internationale de l'Organisation Scientifique du Travail en Agriculture (C.I.O.S.T.A.) and with reference to the Italian Association of Genio Rurale (A.I.G.R.) 3^A R1, which bases its records on the software Visual Basic. We also documented all the necessary times with regard to the operations and subsequent processing during the harvesting phases.

3.3 Quality of the work

Cut height, product losses, impure residues and the percentage of broken seeds were examined in order to evaluate the quality of the work performed by the machine deployed.

3.4 The Harvested Product

Harvested product was classified according to the standard methodology of the Specified Techniques of the Comitè Europeen de Normalisation (TS/CEN) from sampling to laboratory analysis. On the basis of the samples collected, the following aspects were evaluated: 1. seeds, bales and volumetric mass; 2. seed and biomass moisture; 3. the weight of 1000 seeds.

4. RESULTS

4.1 Crop Morphology

The crop, planted on 40 ha level grounds of marginal lands with an average annual rain of 470 mm especially concentrated in winter, resulted to have a non homogeneous degree of growing. Field surveys calculated average distance among the rows and on the row of 0.8 m and 0.42 m, respectively, with an investment of about 29.500 plants/ha. The harvested plot, rectangular-shaped and level, occupied a total area of 1.2 ha and, the last seed-dispersal was two years earlier. Cause of the uneven level of growth of *Cynara Cardunculus* in the plot, we identified certain areas with the same development conditions (Fig. 2). *Cynara* cultivation was characterized by plant growth over a net area of 0.83 ha (A1), whereas small plant growth characterized four different zones (F1, F2, F3, F4) of an overall surface of 0.37 ha.

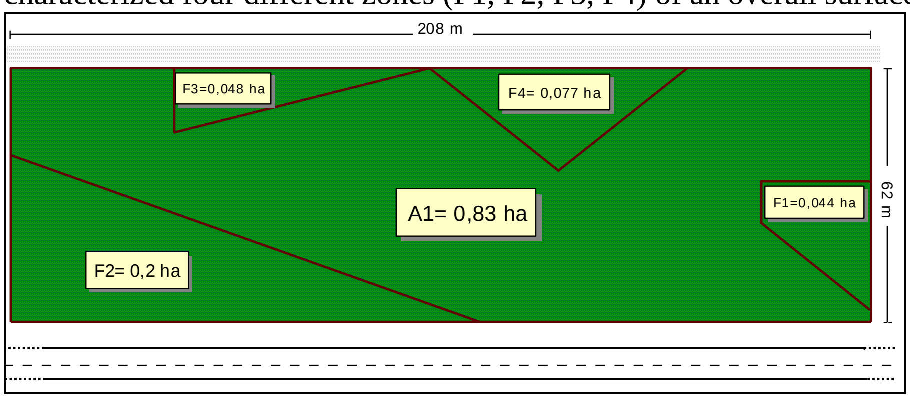

Figure 2. Graph of the experimental plot: the F1, F2, F3 and F4 zones represent the low productivity areas, characterized by plants height lower than 1 m. The A1 zone is, however, representative of a well-developed area.

In the A1 area (Fig. 3), plant height and average diameter were 2.10 m and 20.58 mm, respectively. Effective density was 23.600 plants/ha (theoretical density was 29.414 plants/ha), with 44.800 stalks/ha. The allotment percentage was 19.64%, and the primary branching height was 1.41m. We calculated an average of 11.57 heads with an average diameter of 59.7 mm, for a total of 273.280 heads/ha.

Regarding the F1, F2, F3 and F4 zones (Fig. 4), the monitored *Cynara* crop area presented different growth levels. In this area, plant density (21.600 plants/ha) and stalk density (36.800 stalks/ha) seem to be slightly lower than in the previous area.


Figure 3. Well-developed area


Figure 4. Under-developed area with a low density of the crop

The diameter and average height of the plants were 13.79 mm and 0.97 m, respectively. We calculated an average of 3.27 heads per plant, with an average head diameter of 53.48 mm and a total of 70.800 heads/ha (Table 1).

Table 1. *Cynara Cardunculus*: planting and average morphological features of the crop

Cynara cardunculus plantation		Under-developed crop	Well developed crop
Area	ha	0,37	0,83
Distance on the row	m	0.425	0.425
Distance among the rows	m	0.80	0.80
Theoric density	plants/ha	29.414	29.414
Effective density	plants/ha	21.600	23.600
Planting	years	2	2
Plants	year	1	1
Height	m	0,97	2,10
Diameter at 10 cm	mm	13,79	20,58
Height main branching	m	0,75	1,41
N. branchings	n°	2,10	3,2
Stalks per plant	n°	1,70	1,89
Stalks per ha	n°	36800	44.800
Bent plants	%	0	19,64
Heads per branching	n°	1,09	1,90
Heads per stalk	n°	1,92	6,1
Heads per plant	n°	3,27	11,57
Heads per ha	n°	70.800	273.280
Diameter of heads	mm	53,48	59,7

4.2 Productivity

The quantity of seeds harvested in the 1.2 ha plot was 1.03 ton, whereas the estimated biomass at harvest was 7.46 tons, for a total of 6.20 t/ha (Table 2).

Table 2. Crop productivity

Cynara cardunculus plantation			
Area	ha	1,20	
Harvested seeds	t	1,03	
Harvested seeds	t/ha	0,856	
Windrowed biomass	t	7,46	
Windrowed biomass	t/ha	6,21	
		Parts F1, F2, F3, F4	**Part A1**
Area	ha	0,37	0,83
Harvested seeds	t	0[1]	1.03
Harvested seeds	t/ha	0	1,24
Harvestable biomass	t	1,02[2]	6,44[3]
Harvestable biomass	t/ha	2,78	7,71

[1] The crop height is lower than 1 m, thus seeds production from heads it was not possible.
[2] This value includes both the epigeal biomass and the weight of not threshed heads due to the plants too low.
[3] This value includes both the epigeal biomass and the threshing residues

The plot was characterized by a productive area A1 and by four sectors F1, F2, F3 and F4 where the height of the most plants did not reach 1.1 m, and the level of seed production was insignificant. Plant height of 1.1 m is the minimum height at which the head is able to function. Even if the weight of heads (still not threshed) was quite remarkable, the biomass produced in the F1, F2, F3, and F4 areas was rather modest. In these areas, the quantity of product was calculated to be 1.02 t in an area of 0.37 ha, corresponding to 2.78 t/ha. From these data, it is clear that biomass production decreased in these areas as compared to the A1 zone, where total production was 7.71 t/ha (on a surface of 0.83 ha with a production of 6.40 t).

4.3 Working Times

In the table 3 we can find the harvesting times of the whole unit at work. The proof aimed at the evaluation of the prototype performance surveying only standard times.

Table 3. Standard times and performance of the combine-harvester equipped with *Cynara Cardunculus* head as well as of those of the baling machine

Standard times			
		Head	Baling (machine)
Effective time	%	84,25	72,66
Accessory time	%	15.75	27,34
- Time for turns	%	12,10	5,88
- Uploading times	%	3,65	19
- Maintenance times	%	0	2,46
Rest time	%	0	0
Inevitable dead time	%	0	0
Standard time	%	100	100
Machine performance			
Operating performance	%	84,25	72,66
Effective speed	m/s	1,46	0,85
Operative speed	m/s	1,23	0,62
Effective working capacity	ha/h	2,50	1,46
Operative working capacity	ha/h	2,10	1,06
Hourly operative production (seeds)	t/h	1,50	0
Hourly operative production (biomass)	t/h	13,05	6,58

The combine harvester equipped with a head for *Cynara Cardunculus* (Fig. 5) displayed accessory times comprising a 12.10% time for turns and a 3.65% time to unload harvested seeds (Fig. 6).

Figure 5. New Holland CX 8060 combine harvester equipped with Cressoni/CRA-ING *Cynara Cardunculus* head in harvesting phase

Figure 6. Seeds unload at the end of the proof

Flooding, rest times and inevitably dead times were not recorded. The performance was 84.25% of the operative time. This machine, operating at a speed of 1.23 m/s (4.41 km/h), performed well, at about 2.10 ha/h. The potential harvest is estimated to be 6.20 t/ha for biomass and 0.856 t/ha for seeds; hourly production is estimated to be 13.05 t/h for biomass and 1.50 t/h for seeds. Control values established on the combine harvester are the following:

- beater rotating speed: 280-300 rpm;
- grid opening: at best 5.4 cm;
- ventilator rotating speed: 760 rpm;
- upper sieve/screen/riddle opening: 11 mm;
- lower sieve opening: 6 mm.

In the subsequent baling phase (Fig. 7, 8a and 8b), conducted with a baling machine equipped with a pick-up, the accessory times comprised times for turns (5.88%), maintenance times (2.46%, mainly due to flooding of the feeding device compression chamber), and times for unloading bales (19%).

Figure 7. Harvesting and baling of the windrowed biomass by New Holland 544 roto-baler with fixed camera equipped with pick-up

Figure 8a - 8b**.** Bales produced by New Holland 544 baler with stalks and threshing residues

The performance is equal to 72.66% of the operative time. The machine with a speed of 0.62 m/s (2.22 km/h) reached a working capacity of 1.06 ha/h. Potential biomass harvest is estimated to be 6.20 t/ha, and hourly production was equal to 6.58 t/h.

4.4 Product Losses

Overall losses were 0.66 t/ha (10.65% of harvested production), which have been classified in three groups (Table 4): a) Plants that were not cut but rather left on the ground because the header separator device bent them (especially during the turn phase); b) the harvested biomass that was not conveyed from the screen to the windrow, namely, small fragments left on the ground due to blade action that crushed the stalks; c) biomass that was not harvested by the baling machine due to pick-up losses and compression chamber losses.

Table 4. Losses sharing during harvest

Losses	t/ha	%
Plants not harvested by head	0,012	1,8
Product not shake in windrow	0,004	0,6
Product not harvested by baling-machine	0,055	8,3
Total	0,66	10,7

4.5 Work quality

The threshing system performed well when working only on heads. The percentage of seed impurities (Fig. 9) was 0.61%; the percentage of seed breakage was 3.25%.

Figure 9. Seeds produced by heads threshing

Seed mass was equal to 700.12 kg/m^3 with 5.45% moisture, whereas that of baled biomass was 165.93 kg/m^3 with 9.30% moisture (Table 5). Stalks were cut with a complete/whole cut at an average height of 222.75 mm (DS ±78.93) because of the drainage system, for which the header position had to be slightly raised in order to avoid damage due to the cutting system and ground contact. The windrows were standard (Fig. 10), and the cut biomass was conveyed in an optimal manner between the combine harvester's front wheels, allowing performance during the harvest phase when used in combination with the towed baling-machine equipped with pick-up (Fig. 11). The average weight of each bale was 215.40 kg (1.30 m^3) for a total of 26 bales per hectare.

Table 5. Features of the product and work quality

Seeds mass-volume	Kg/m^3	700,12
Seeds moisture	%	5,45
Seeds impurities	%	0,61
Damaged seeds	%	3,25
1000 seeds weight	g	5,40
Bales mass-volume	Kg/m^3	165,93
Biomass moisture	%	9,30
Cut height	mm	222,75 (std. dev. ±78,93)

Figure 10. Windrow after passage of the machine

Figure 11. Ground with no biomass residues after the passage of the roto-baler

5. COMPARISON OF EXPERIMENTAL RESULTS

Comparing the results of the tests conducted in 2007 and 2008 highlights the successful performance of the innovative *Cynara Cardunculus* harvest machine. The previously developed header was equipped with cutting system based on rows, resulting inappropriate by flooding due to offshoots irregular alignment along rows.
After replacing the cut system mentioned above with a full-length mowing/cutter bar, machine performance improved significantly. Results from tests performed with the newly fitted device demonstrated neither flooding problems nor biomass accumulation/store in the conveyor and windrow system, increasing productivity from 1.57 ha/a to 2.10 ha/h and increasing operative work capacity by 33.78%.

6. CONCLUSIONS

These experimental tests demonstrated the success of the combine harvester’s working capacity, which overcame previous period obstacles (due to separate harvests of baled biomass and seeds). The mower device in combination with the conveying biomass (drop) in the windrow system performed effectively, as did the threshing process; in addition, no flooding problems have been encountered in the midst of other required operations.
The effective working capacity revealed allows us to expect sustainable harvest costs. According to the machine features described above, it seems possible in the future to develop a commercial header capable of modifying its structure for different cultivations, such as sunflower and maize. Such an innovation would inevitably reduce costs throughout the amortization of the self-propelled combine harvester provided with the bar, as its long-term utilization, the purchase of only a multifunctional bar instead of three specified bars and the management of different harvesting campaigns conducted in the same period.
Taken into account the features of marginal lands where the crop is cultivated as well as limited annual rains, the crop productivity seems to be very interesting compare with other oil crops in the south of Europe. The possibility of using the ligno-cellulosic fraction for energy production let the crop economic balance attractive.