SIXTH FRAMEWORK PROGRAMME

SUSTDEV-2004-1.2.5

"Energy from Crops"

BIOCARD

Global Process to Improve Cynara cardunculus Exploitation for Energy Applications

Contract nº - 019829

Interim Technical report

Document ID:	BIOCARD-CRA ISMA-(WP1)-12/06- Crop harvesting
Authors:	L. Pari, M. Fedrizzi, L. Pansini, F. Gallucci
Status:	Draft
Reviewer:	UPM -WP1 Leader
Distribution:	PC
File ID:	BIOCARD-CRA ISMA-(WP1)-Technical report.doc
Issue date:	20/12/2006

CHAPTER 1
CYNARA CARDUNCULUS HARVESTIG TEST WITH DIFFERENT NEW HOLLAND MACHINES.

1. INTRODUCTION

The CRA ISMA has taken part to the Cynara cardunculus harvesting tests organized by the High Institute of Agronomy of Portugal University in the framework of the EU project "Energy crops in the Atlantic space: Possibilities for large scale implementation (ECAS)".

Such project, in phase of conclusion cycle, considers the following components and actions:

1)Agriculture: Comparative analysis of technical and economical aspects related to the installation of species Cynara cardunculus L., Arundo donax L. E Sorghum bicolor (L) Moench, in different regions of the Atlantic Space and under different crop installation and conduction alternatives;

2) Industrial and Laboratorial: Study and implementation of alternative methods for converting products obtained from the agriculture component, e.g., biomass burning of the three considered species for the production of energy at industrial level, alcohol production through sterification of oil obtained from the seed of Cynara cardunculus and alcohol production from Arundo donax and Sorghum bicolour;

3) Integrated Analysis: Integrated analysis of the technical and economical viability of diverse alternatives and combinations of Species / Management Alternative /Industrial Transformation, considering the potential of environmental protection and preservation, rural development and legal conditioning, national and international, actual and future.

The Portugal University cultivates 300 ha of Cynara cardunculus, of which 100 ha only in Beja, where these tests were conducted.

The harvesting tests were carried out in the second half of the month of September 2006 when the cultivation was found in advanced state of maturity and drying. The heads (capitula) were already opened and therefore with a tendency to lose the achenes and pappi.

The tests aimed to evaluate different machines provided by Iberian New Holland for separated harvest of the different fractions obtainable by the cultivation assigned to different transformation: oil extraction from seeds, alcohol production from pith, energy production from epigeous biomass combustion.

1-1: view of the test field

1-2: view of the test field

2. APPLIED METHODOLOGY

2.1. Observations on the cultivations

The observations executed on the cultivation concerned the diameter of the stalk at the cutting height and at the first fertile ramification, the number of heads (inflorescence) per plant, the necessary traction force to detach the head from the stalk (evaluated by means of a dynamometer) and the diameter of the detachment area.

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 chosen machines 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 potentials of the two systems were 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 0,8m between the rows and with a mean distance of 0,33m on the row, therefore the result was an investment of approximately 37.900 plants/ha (see tab. n.1).

Tab. n.1: description of the Cynara cardunculus plantation		
average distance on the rows	m	0,33
distance between the rows	m	0,8
effective density	plants/ha	37879
planting age	year(s)	2
plant age	year(s)	1

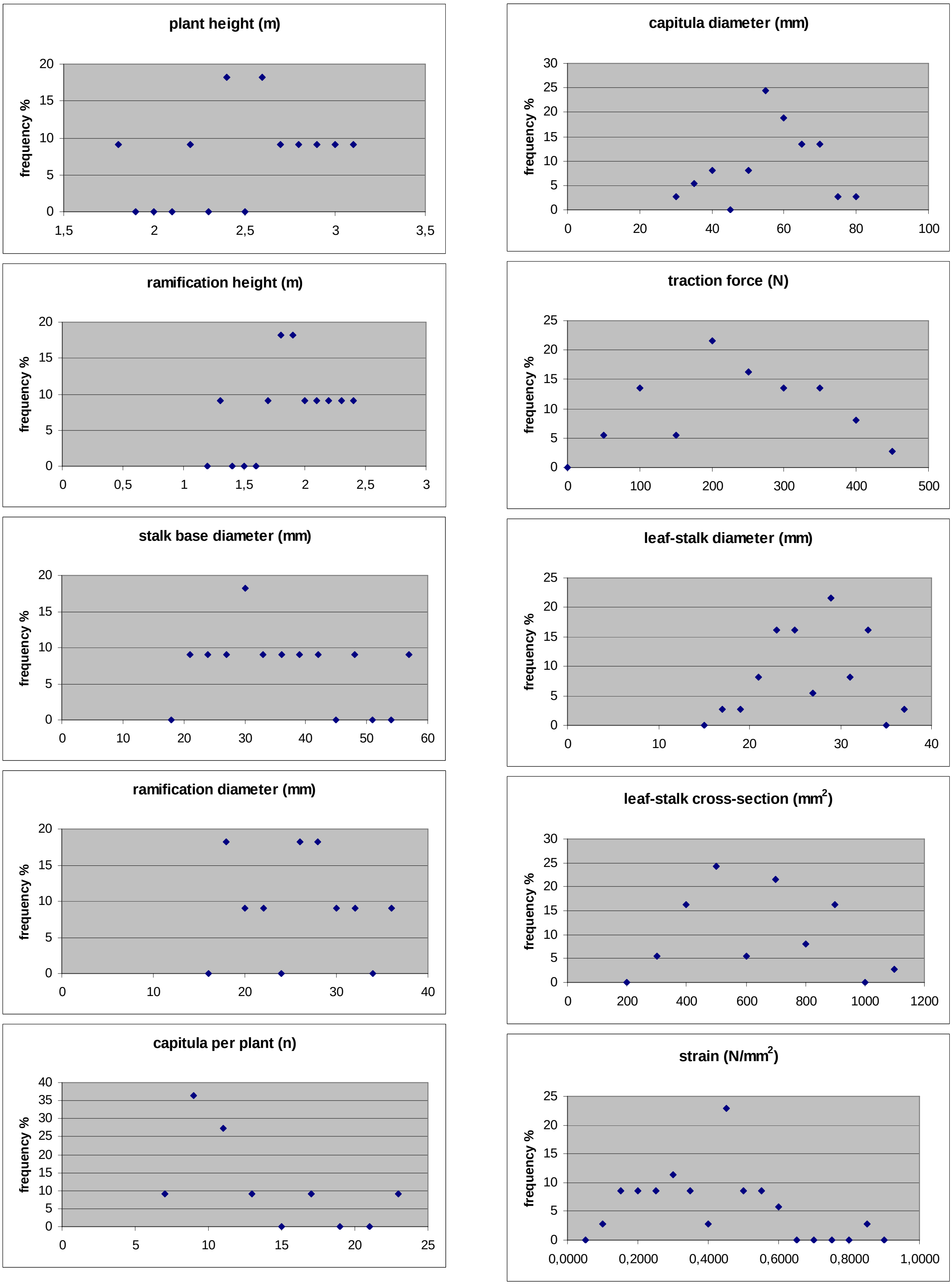
1-3: cultivation of Cynara cardunculus

1-4: traction test

The cultivation observations showed that the mean plant has a height of 2,56 m, the first ramification of the stalk is positioned to a 1,9 m of height , there are 11,3 heads per plant, each detachable acting with a force of traction equal to 220 N (see tab. n.2).

Tab. n.2: mean morphologic and productive characteristics of the cultivation		
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

An analysis of the distribution in frequency classes of the cultivations relieves was conducted to define the morphologic characteristics variance.
These results are very important to design a harvester machine adaptable to the variability of the cultivation.
The main results are reported in the following diagrams.



Cynara cardunculus main morphologic characteristics

4. DESCRIPTION OF THE HARVESTING SYSTEMS

4.1. Harvesting and cutting of the entire plant

The tests were carried out with a New Holland self propelled maize chopper FX 60 model, endowed with a kemper-like mowing head and with a working width of 4,30 m (tab. n.3), able in a single passage to cut the plant to the base, to break into small pieces the product and send it to a wagon that can be hauled by the same machine or by a tractor beside the operating machine.

The machine was supported by three agricultural tractors equipped with trailer of various volume which alternate to permit the continuous drainage of the product from the FX60 and the successive transport and drainage in the farming centre away approximately 1 km from the field. During these harvesting operations, the FX60 was supported also by a truck equipped with a 88 m^3 trailer, as the farm practicability and the lying position of the cultivation allowed it.

Tab. n.3: New Holland FX 60 technical caracteristic		
engine		Caterpillar, Diesel
displacement	l	14.6 l
cylinders	n	6
fuel capacity	l	908.5
Pmax	kW	392
rpm Pmax	rpm	2100
propelling drive		hydrostatic
transmission		4 speed
max ground speed	km/h	40
FEEDING SYSTEM		
number of feedrolls	n	4
width of housing	mm	760
CUTTERHEAD		
speed	rpm	1229
cutterhead diameter	mm	610
available knife configuration		4/6/8/12
BLOWER		
diameter	mm	972
speed	rpm	738/818
number of paddles	n	4

1-5: self- propelled mower-cutter-loader machine New Holland FX60

1-6: discharge stage of the product on an 88 m^3 truck

1-7: discharge stage of the product on the ground

1-8: combine harvester New Holland FX60

4.2. Achene harvesting only

Two different models of self-propelled combine harvester machines were used to harvest the achenes (often improperly called seeds).

The first model was a New Holland CX 720 equipped with a six row maize head New Holland MF675N with a working width equal to 4,30 m.

The second model was a New Holland TC56 equipped with a corn head New Holland 15 with a working width equal to 4,75 m.

1-9: combine harvester New Holland CX 720 equipped with maize harvest head

1-10: combine harvester New Holland CX 720 equipped with maize harvest head

1-11: combine harvester New Holland TC56 equipped with wheat harvest head

1-12: combine harvester New Holland TC56 equipped with wheat harvest head

Both models of combine harvesters cut the plant at a height from the land between 0,25 and 0,4 m.

Regarding the New Holland TC 56 the cutting height was necessarly increased to protect the mower system from the impact towards the surfaced stones and to lower the achene/biomass ratio reducing biomass entering into the machine: in this way the threshing and separation systems were put in a better operating condition.

After the passage in field of the New Holland TC 56, the residues of the cultivation remain in the field, mainly composed by the plants stalks and by the residues of heads threshing; the residues of the plants were represented whether by the basically stalk (cut at a remarkable height) or by fragmented stalk passed by the machine parts put in irregular pathways.

Regarding the New Holland CX 720, it has been operated at a cutting height necessary to permit the entrance of the plants stalks into the opening of the strings head.

Since the maize harvest head of the CX 720, under the squeezing parts, there are six rotating disks with shredding cutters, , after the passing of the combine harvesters the residues of the cultivation remained in field were found in two distinct forms.

The residues of the stalks that had not entered in CX 720 were roughly shredded and were irregularly scattered on the entire area, while the residues of the threshed heads were released in pathways situated over the previous.
The lighter portions of the plant, the pappi, for both machines, were airborne and were found also out of the cultivation.

4.3. Description of the system for harvesting the cultivation residues dropped in field after the achenes harvest

In this stage two operating machines were consecutively used.
The first was an agricultural tractor combined with a common hay rake operating the concentration of the product dropped in land by the combine harvester machines in suitable pathway for the intervention of the following machine.
The second was another tractor combined with a packing machine New Holland BB940A, PTO driven.
The packing machine was equipped with a pick up for the gathered product harvest and a mechanism of feeding which facilitates the entrance of the product in the compression chamber.
The machine model in question is equipped with a compression chamber with dimensions equal to 0,9 x 0,9 m; the third dimension of the bales (length) is adjustable with apposite system.

1-13: hay rake used to set in tier the residues of cultivation

1-14: packing machine New Holland BB940A

5. EVALUATION OF THE OPERATING CHARACTERISTICS OF THE HARVESTERS

In table 4 are reported the times collected during the tests of the maize chopper New Holland FX 60. As the test aimed at pointing out the performance of the system independently of the farm characteristics, only the operative times during the harvest were taken.

Tab. n.4: operating charateristic of self-propelled maize chopper New Holland FX60		
effective time TE	%	72,97
turning time TAV	%	27,02
unloading time TAS	%	0
manteinance time TAC	%	0
accessory time TA	%	27,02
operative time TO	%	100
operative efficiency Ro	η	72,97
effective speed ve	m/s	1,38
operative speed vo	m/s	1,01
effective working capacity Ce	ha/h	2,15
operative working capacity Co	ha/h	1,56

The accessory time was constituted by time in turning of the 27,2%, partly spent waiting for the end of the turning of the tractor drawing the trailer.

The operative efficiency (η), defined as effective time versus operative time, resulted equal to 0,73.

The machine, with an operative speed of 1,01 m/s, reached an operative work capacity of 1,56 ha/h.

In table 5 are reported the times taken during the tests of the packing machine New Holland BB940A.

The accessory time was constituted by the turning time of about 12,57%, the operative efficiency resulted equal to 0,87.

The machine, with an operative speed of 0,67 m/s, reached an operative work capacity of 3,13 ha/h.

The machines produced 30,17 bales /hour, corresponding to 9,65 bales/ha.

Tab. n.5: operating charateristics of baler New Holland BB940A		
effective time TE	%	87,43
turning time TAV	%	12,57
unloading time TAS	%	0
manteinance time TAC	%	0
accessory time TA	%	12,57
operative time TO	%	100
operative efficiency Ro	η	87,43
effective speed ve	m/s	0,77
operative speed vo	m/s	0,67
effective working capacity Ce	ha/h	3,57
operative working capacity Co	ha/h	3,13
bales per hectare	bales/ha	9,65
operative working capacity Co	bales/h	30,17
operative working capacity Co	m^3 bales/h	56,21

In table 6 are reported the mean characteristics relieved on the produced bales, the mean one has a dimension of 0,9 x 0,9 x 2,3 m, a mass of 281 kg and a volumetric mass of 151 kg/m^3.

Tab.n.6: bales charateristics		
height	m	0,9
width	m	0,9
length	m	2,3
volume	m^3	1,863
mass	kg	281,31
density	kg/ m^3	151

6. CONCLUSION

This work allows to appraise the performances of the cereal harvesting combine grains of the top area working on Cynara cardunculus.

The raised problems are the following:

1) the maize chopper machine does not provide for the separation of the seed, picking and chipping the whole product. The harvest system can then be used only when the product will be entirely destined to the combustion. Besides the product harvested has an extremely low density (volumetric mass) as about 80 kg/m^3, and from that the transport for long distances would be extremely expensive.
The machine allows the emission of the pappi from the head during the entrance stage of the product between the feeding rolls. That involves the scattering of light and flammable material all over the harvest yard. That material is sucked whether by the cooling system or by the engine intake causing the obstruction of the radiator and of the air filter. The settled pappus coat on mechanical parts that can reach high temperatures can be subjected to spontaneous combustion with evident problems of security.

1-15: air filter occluded by pappi

1-16: radiator occluded by pappi

Further problems of adaptation of the machine to the new cultivation were not observed; the high performances reached permit to conclude that if the required product of the industry is the whole plant chipped, there is a needs to develop a system to compact to a high volumetric mass on the field the chopped material to avoid excessive transport cost and finding a technical solutions to avoid the obstruction of the air filter and radiator by the pappi, as the machine will permit the biomass harvest with low cost;

2) the achene harvest with the combine harvester (whether with maize or corn head) involves the successive passing on the field of the hay rake and the packing machine.

The maize head that provides only to the detachment of the capitula involves the threshing system to operate with a high achene/biomass ratio and so permits to obtain a clean seed with very little loss.

Furthermore the maize head permits the cutting of the cultivation residues, even if the system (thought for maize) operates at a too high cutting level leaving parts of the stalk standing. So it would be necessary to modify the head to allow the cut at the base of the stalk and also to provide to move the residues in the space between the front wheels, where the outlet of the threshing system will drop also the residues of the threshed capitula.

Then only the packing machine passage will be necessary.

On the other hand, the wheat head, cutting the plant to the base, will put the threshing system into conditions to operate with a very small achene/biomass ratio, obtaining then a dirty seed with high loss; but, raising the head to the level of the first fertile box (hight not easy to reach) a good threshing can be obtained; but then there is the need of a successive passage on the field of a mowing machine to cut the plants to the base.
So the adaptation of this machine for the Cynara cardunculus harvesting is considered not advisable.
The packing machine, acting on a product broken in small pieces by the maize head cutters or by the threshing system, did not show any problem of adaptability to the new cultivation. The harvested bales were well joined, compacted and with a remarkable volumetric mass. Yet, the passage on the field of many operating machines involves increasing of harvest costs and soil compaction, the last should be avoided in a poli-annual cultivation..
For this reason it was checked the possibility to harvest only the capitula for a successive threshing during the winter and, at the same time, to bale the lignocelluloses biomass.
This harvest system could permit, in the successive stage of head treshing, even to separate the pappi, by a ventilation equipment acting on the exit of the threshing device, so to get another source of cultivation income, as the pappus is made of pure cellulose.
The results of the first tests are reported in the following chapter.

CHAPTER 2
TESTS OF CAPITULA DETACHING FOR SUCCESSIVE THRESHING

1. INTRODUCTION

The research was planned to explore two main areas: the adaptability of existing harvest machines (of which was referred in the previous chapter) and the development of new systems not yet existing in commerce. This last area of intervention regarded, during the firts year of the project, the development of a prototypes of small dimensions (to reduce the development costs) to check the efficiency of the technical-mechanical choices through tests in field.

The CRA-ISMA focused its activities on the development of a mechanical system to detach the capitula for a successive threshing; the UPM developed a mowing-packing machine to roll-pack only the lignocellulosic biomass. The combination of both machines would have constituted an innovative system to check the efficiency of the adopted technologies.

2. DEVELOPMENT AND DESCRIPTION OF THE PROTOTYPE

The head to separate the capitula was designed with the aid of a 3D CAD (think3) and then its building was commissioned to an agricultural machines firm. It was chosen to build the machine by an external firm instead of by the Institute workshop to favorite from the very beginning the sharing of the results to the future utilizers and to allow, should the prototype be efficient, the marketing of the new machine.

Thus because the introduction of a new crop like the Cynara cordunculus will not be possible until the machines for its harvest will be available on the market.

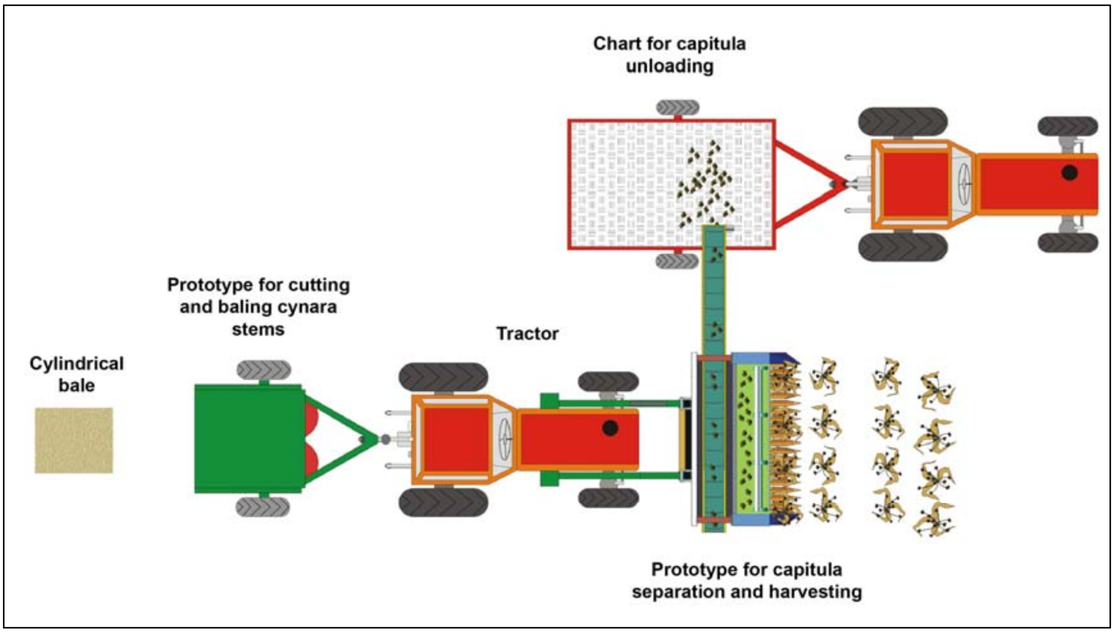
The machine project aimed at "teasing" the area where the capitula are present. As they are in the same plant at different heights and the plants do have different heights, a harvest system with a fixed mower will provoke the loss of the low capitula and the harvest of the higher ones with a considerable portion of stalk.

The suggested system allows the introduction of points (teeth of comb) among the heads, the traction towards the soil of the stalk also trough a rotating roll, the removal of possible residues of the stalk by a mowing lever, and the conveyance towards a wagon through a belt conveyor.

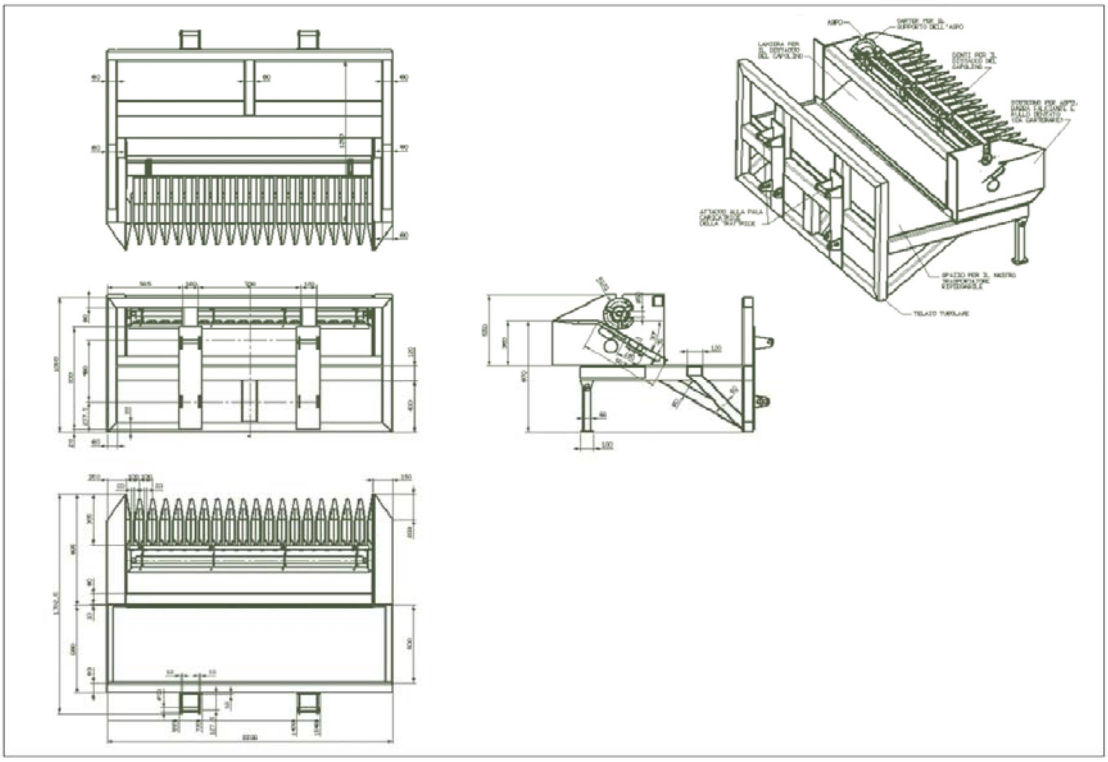
The points were composed by a series of shaped sheets, about 30 mm away one from each other, under which a mowing lever and a toothed roll act, and overhung by a pickup reel.

At the back, a belt conveyor, pliable during the transportation, permits the discharge of the product on a wagon beside. During the tests the prototype was put on the front lifter of a tractor, equipped with a hydraulic circuit connected to the tracot's one for the operating parts power needs.

The machine operates the detachments of the capitula by a simple traction (from tests done in field the necessary strength was found to be 220N). The mower acts on those plants on which the detachment did not take place, helped by the rotating roll that operates the traction toward the stalk below.



2-1: ISMA prototype



2-2: ISMA prototype

2-3: ISMA prototype

2-4: ISMA prototype

3. HARVEST TESTS

The machine, built in Italy, was moved to 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 e Innovación Tecnológica de la Comunidad de Madrid in El Encìn, near Alcalà De Henarez.

The plantation where the tests were done was set up many years ago, where the alternative cultivations were implanted in the marginal lands, the less fertile of the farm.

The plants were definitely under-developed because of the presence of a stony substrate in the soil, which did not allow the roots to grow deeply.

2-5: experimental fields

The first test pointed out that the toothed roll prevents the mower action because of their respective positions. So it was decided to remove the toothed roll to check the improvement of machine performances.

A change to the transmission was necessary: initially the toothed roll dragged the pickup reel; a shaft with a smaller diameter replaced the toothed roll and the connection to the motor and the gear were readapted.

Following tests showed good results but also some problems:

- the detachment does not always take place by simple traction, as very often the mower accomplishes the task;
- the space between the shaped sheets (teeth) resulted too narrow; as a matter of fact on taller plants the points act on the stalk before it branches out; in that case the uprooting of the plant is quite likely;
- some capitula, cut by the mower therefore with part of the stalk still attached, stop in the area included between the rear of the mower and the connection of the teeth to the frame: in that area the pickup reel cannot act, so clogging becomes possible.

3.1. Necessary changes to the prototype pointed out during the tests

To solve the problems pointed out by the first harvest tests, the prototype must be changed as follow:

- the teeth will be modified to have a wider section for the passage, possibly using mobile sheets instead of fixed ones;
- the area that follows the reel will be redesigned by removing the dead space and tilting the sheet to obtain a slope favouring the discharge of the capitula on the belt conveyor;
- the pickup reel will be modified with the bands wrapped in the opposite direction compared to the present, because it caused some clogging between the rotating bands and the fixed protection casing;
- the belt will be widened and the reported edges will be removed and integrated in the carrying structure;
- the present transmission system will be changed, by removing the roll that was part of it.

4. FUTURE PROSPECTS

The matured experiences whether testing the business harvesting machines or exploring the possibility to provide the head detachment on the field with the prototype focalized, had found two operative lines on which the efforts will concentrated on the next years: the development of a self-propelled mowing-baling machine equipped with a beheaded band and the change of the maize harvest head to provide to a lignocelluloses biomass speed so that to avoid excessive harvest of earthy material during the successive stage of packing.

4.1. Development of a self-propelled mower-baling machine equipped with a special head

It is to be expected that different herbaceous biomasses from various vegetables species will stoke power plants.

Today, in addition to the Cynara cardunculus, the other vegetable species that will be cultivated for energy are the Miscanthus, the Panicum Virgatum, the Arundo Donax and the fibre sorghum. Except for the fibre sorghum, the other species can be harvested and baled at the same time because of their low hydric content.

The fibre sorghum, with a hydric content superior to 70%, must be mowed and left to dry in field, hay raked and finally baled.

To harvest and bale at the same time gives a better product, less contaminated by inorganic material because it is avoided any contact with the soil.

Hence the idea of the self-propelled mower-baling machine, today not existing in commerce: the amortization will be favoured by the possibility of using the machine with different species at different times during the year.

A scheme of the machine is shown in figure 3.

The frontal part consists of a Kemper head that cut the plants to the base and send them to the feeder rolls: during this stage, the special head positioned over the Kemper head detaches the capitula by simple traction and direct them to a container that will be turned at the hedge of the field to transfer the heads in a suitable agricultural wagon.

The plants, already without head, pass inside the conveyor rolls and a successive couple of counter-rotating conditioning rolls to be finally sent to the compression chamber of a baler.

This machine, raising (or dismounting) the head can be used to pack the miscanthus, the Arundo donax and the panicum virgatum.

4.2. Change to the maize head to tier the lignocellulosic biomass

In the previous chapter it was observed how the 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.

The harvest head of New Holland CX720 tested in Portugal can be modified to allow the cut to the base of the stalk and its successive tier in the space between the front wheels, where successively the discharge system of the threshing device will provide to drop the residues of the capitula threshing.

The changes should be the following:

- the removal of the cutting blade under the squeezing rolls;
- the change of the aggressiveness of the squeezing rolls to drop to the ground conditioned stalks, not broken into fragments;

- the positioning under the first section of the squeezing rolls of a mower for the cut of the stalk to the base;
- the development of cut and conditioned stalk directing system, from the lateral toward 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 will be dropped. Successively the widrow will be picked up by a baling machine.

The research activities in 2007 will be focused on the developing of a maize head to harvest the capitula and to put in window the biomass for a subsequent baling.

5. CONCLUSION

The harvest experiences conduced during the first year of the project activity and the exchange of ideas and opinions between the project partners have permitted to outline the necessary development areas. The constructing firms must be involved since this first stage, as they must provide realization and marketing of the operative machines. For this reason, in occasion of the international show of the agricultural machine, which took place in Bologna from 15 to 19 November 2006 several meetings and activities aiming at enticing the builders' interest took place.

In concomitance with the show the "sole 24 ore" reported an interview to Dr Pari regarding the Biocard project (enclosure 1) and the magazine " L'Informatore Agrario" an informative article regarding the project (enclosure 2).

A meeting with the "Ente Nazionale Macchine Agricole" was organized and contacts and agreements were taken with the following agricultural machines firms:

New Holland Italy **-** changes of maize head and development of mower-baling machine;

Gallignani - development of mower baling machine;

Cressoni - changes of maize head and development of the head to detach capitula;

Wolagri - development of mower baling machine

Spapperi - development of the head to detach capitula.