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An innovative flexible head for the harvesting of cardoon (*Cynara cardunculus* L.) in stony lands

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ABSTRACT

Cardoon (*Cynara cardunculus* L.) is a promising crop for utilizing marginal lands. In these terrains, the lack of adequate tillage or soil levelling and the excessive presence of stones requires a high cutting height during harvesting, with remarkable biomass loss occurring. CREA-ING designed a new flexible bar driven by a system for sensing and signalling the presence of obstacles during the forward of motion of a combine harvester. A test-track was prepared to monitor the activation sequence of three sensor systems placed on the cutter bar as follows: four piston transducers measuring the flexion of the blade and counter-blade, two opposite wire transducers computing the movements of the blade-holder hinged on the left and right side of the frame, and one wire transducer placed between the head and the combine for measuring the lifting of the head operated by the hydraulic system. The combine was driven at an average speed of 0.7 km h^{-1} on a row of progressively higher obstacles (from 10 to 40 cm) placed in lateral, intermediate and central positions. The tests were carried out in the left half of the cutter bar.

The output sent by the different sensors varied as a function of their position and the position of the obstacle, thus highlighting that the presence of an obstacle was correctly perceived by the sensor system. The signals originated from the left and right transducers had opposite trends. At the narrow "bell-shape" showed by the graph of the left transducer corresponded to a "reversed" bell generated by the right transducer, thus representing graphically the flexibility of the bar. The four piston transducers detected the necessary flexion, then lift and return the cutter bar to the starting point in response to each obstacle.

The head lifting varied from 1.25 s to 2.51 s, but a threshold value could be observed as follows: below 25 cm the lifting occurred between 1.0 s and 1.5 s, while for higher obstacles the head lifting required 2.0–2.5 s. Such movement was the result of the signals sent by the sensors to the control unit before the head lifting began. The difference between the input sent by the transducers and the head lifting ranged from 1.22 s to 2.54 s in relation to the position of the obstacle.

The tests showed that the head elements activated efficiently during the overcoming of an obstacle. However, if increasing speeds are needed, the reduction of Δ_{Act} or D_{sig} will require a modification of the electrohydraulic components.

1. Introduction

Crop harvesting is a crucial stage in the supply chain of biomass production because it affects both product quality and efficiency. Specifically, some energy crops might require innovative solutions for assuring their integral exploitation and the profitability of cultivation.

Cardoon (*Cynara cardunculus* L.) is one of the most interesting non-food crops for biomass production. It is a perennial species with an annual development cycle that can be repeated for more than 10 years (Angelini et al., 2009; Gherbin et al., 2001). The plant can reach a height of 3 m and the rooting system can reach a depth up to 7 m (Fernández et al., 2006). Cardoon is well adapted to the xerothermic conditions of southern Europe and Mediterranean climatic-type areas (Tuck et al., 2006; Grammelis et al., 2008), and could be preferred to others crops (fibre sorghum, giant reed, miscanthus, switchgrass) when water is a limiting factor (Solano et al., 2010). Recently, the growth of cardoon in marginal areas of South (Sicily region) or Central (Latium region) Italy has been studied, where the crop improved the soil fertility of degraded lands (Mauromicale et al., 2014; Francaviglia et al., 2016).

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In terms of energy conversion, the main products are the lignocellulosic biomass for energy production (Fernández et al., 2006; Gominho et al., 2009) and the oil extracted from seeds for biodiesel production (Gominho et al., 2011; Sengo et al., 2010), similar to other botanically related oil crops, such as the sunflower or the safflower (Fernández and Manzanares, 1990).

New systems for the separation of lignocellulosic biomass and seeds were studied to aid in the development of the crop (Pari et al., 2008, 2009a,b, 2011). Such systems integrate the components of a maize head with those of a classic wheat head (Pari et al., 2011). The upper portion, derived from a maize head, provides for the detachment of the capitula and then transports it to the threshing operation. In the lower portion (developed from a wheat head), the aboveground biomass is mowed, conditioned and windrowed. The capitula residue is released in the windrow, while the seeds are collected from the combine harvester.

During previous harvesting trials performed in stony areas of Sardinia (Italy), the traditional head for wheat with a rigid cutter bar showed high susceptibility to stone damage, forcing operators to increase the cutting height to 40 cm, which resulted in excessive harvesting losses.

The cutter bar is one of the most important elements affecting the combine performance since it is the first mechanical contact with the crop and the first point where the yield losses occur. The use of a flexible header was reported as a popular method for the harvesting of pulses, with particular reference to soybean harvesting (Hirai et al., 2005; Hummel, 1983; Zyla et al., 2002). The idea of using a flexible cutting system for reducing the harvesting losses of traditional combines dates back to 70's (Quick and Buchele, 1974). The authors observed that approximately 85 percent of combine losses were borne from the head, mostly due to the action of the reciprocating cutter bar. Floating, flexible and floating flexible cutter bars follow the contour of the ground, thus minimizing the loss of low hanging pods (Siemens, 2006; Glancey, 1997). As a result, the harvesting losses were reduced by 3–10% of the total yield (Hummel, 1983; Nave et al., 1977; Quick and Buchele, 1974). A particular case for using the flexible cutter bar was recently proposed by Mahmoodi et al. (2007) for harvesting of furrow-hill plantings. The bar was composed of multiple sections hinged to each other and regulated by a leveller to the shapes and sizes of furrows and hills.

To find a technical solution for reducing losses in stony soil, CREA-ING designed a new flexible bar driven by a system for sensing and signalling the presence of obstacles. The present work reports the results obtained in a test-track prepared for monitoring the behaviour of the flexible bar and the ability of the sensors system to detect obstacles of different heights. The goal of the work was to analyse the timing of the sensor system in detecting the obstacles and to verify their ability to correctly overcome the obstacle while maintaining the height of the cut at the minimum distance from the soil.

2. Materials and methods

2.1. Description of the head

The new head for the harvesting of cardoon in stony lands was designed by CREA-ING in collaboration with the company Cressoni Ltd. The head has three different elements which are activated by the presence of obstacles.

The first element is a cutting bar fixed on a harmonic steel structure, which allows for an oscillation up to 150 mm high. Such a blade is capable of following the profile of the ground surface, keeping the height of the cut at the minimum distance from the ground, and flexing when a stone is encountered.

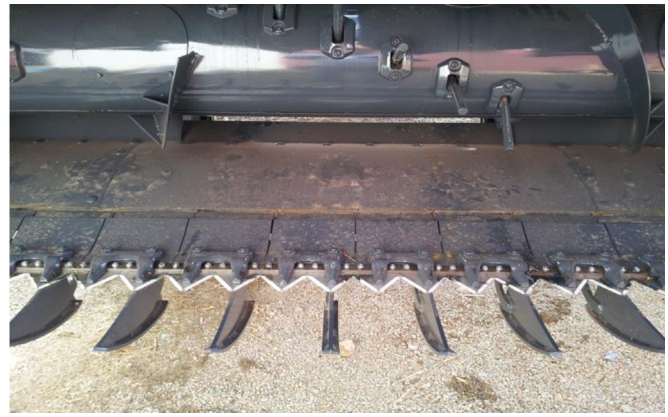

Fig. 1. Boot-shaped coulters of the self-leveling head.

The second element is represented by the structure that supports the blade. It is hinged on both sides of the head's main body and is free to move vertically, following the contours of the ground. The lower part of the structure contains 28 coulters, fitted with 20 mm wide sleds shaped to climb the stones, while avoiding their contact with the blade (Fig. 1).

Behind the coulters, a structure consisting of six articulated sections in wear-resistant steel, protects the moving parts from rubbing with stones and rocks.

Since each arm can float independently from the other, the blade can flex, adapting itself to the roughness of the ground also in the transverse direction. To this aim, the housing of the lower auger (fixed part) is connected to the mobile part by a lamina of harmonic steel. The task of the lower auger (300 mm diameter) is to convey the cardoon stalks towards the centre of the head and to discharge them to the ground between the wheels forming the windrow. The lower auger moves with the mobile part through a sliding system between metal sheets.

For overcoming the obstacles, the three systems act independently and sequentially. When the head encounters an obstacle, the sleds prevent its contact with the blade by lifting it from the ground in response to the contact point. Subsequently, when the blade reaches the highest point allowed by its flexibility, the mobile part hinged on the sides of the head and supporting the blade raises.

The oscillations of the mobile portion are measured by angular transducers installed on both oscillating arms and transmitted to the control unit of the combine. When the lifting exceeds a threshold, the control unit commands the hydraulic system to lift the whole head while the signal persists. When the obstacle is overcome, the interruption of the electrical signal causes the lowering of the head. Then, the mobile portion drops as well and the blade straightens (Fig. 2).

A corn head is mounted above the flexible cutter bar, which provides for the detachment and separation of the capitula. It is composed of 9 groups spaced 500 mm apart. In each group, a pair of chains transfers the capitula to an upper auger. Below the chains, two detachment blades can be regulated hydraulically according to the diameter of both the capitula and the apical portion of the stem. Underlying these are the counter-rotating harvesting rollers. Equipped with 4 blades, the stem is simultaneously pulled down and comminution occurs until the capitula is detached by the blades.

The first prototype for cardoon harvesting was designed as part of the BIOCARD Project (Pari et al., 2008, 2009a,b, 2011). The head used in this study is the second version developed by CREA-ING in collaboration with Cressoni Ltd. in the framework of the BIT3G project for developing operation in the marginal stony fields of the Sardinia Region (Pari et al., 2014).