XVII[th] World Congress of the International Commission of Agricultural and Biosystems Engineering (CIGR)

Hosted by the Canadian Society for Bioengineering (CSBE/SCGAB)
Québec City, Canada June 13-17, 2010

QUALITATIVE AND QUANTITATIVE ASPECTS ON FIELD DRYING OF SORGHUM AND EVALUATING THE MOWER CONDITIONER PROTOTYPE DEVISED BY CRA-ING – CRESSONI

LUIGI PARI[1], ALBERTO ASSIRELLI[2], ALESSANDRO SUARDI[3]

[1]Corresponding author: Luigi Pari, CRA-ING - Agriculture Engineering Research Unit, Via della Pascolare, 16 – 00016 Monterotondo, Rome, Italy
Tel.: 0690675250; Fax: 0690675249, luigi.pari@entecra.it
[2] Alberto Assirelli, CRA-ING - Agriculture Engineering Research Unit, Monterotondo, Rome, Italy; Tel.: 0690675252; Fax: 0690675250, alberto.assirelli@entecra.it
[3] Alessandro Suardi, CRA-ING - Agriculture Engineering Research Unit, Monterotondo, Rome, Italy; Tel.: 0690675219; Fax: 0690675250, alessandro.suardi@entecra.it

CSBE101031 – Presented at Section III: Equipment Engineering for Plant Production Conference

ABSTRACT Fiber sorghum is an important crop with a large potential as an energy target related not only to energy but also to anaerobic digestion (biogas), as well as second generation bioethanol production. Structural aspects of this crop in size, strength, reduced water release in post-mowing, have often represented a limit to the harvesting mechanization as adried product. In Italy the harvesting of dried fiber sorghum has frequently been a serious problem in regards to mechanical limits of the commercial harvester in conditioning fiber sorghum that do not permit the spread of the cultivation except for silage use only. The result establshed that the crop was only established in areas able to use the fresh product, for which standard equipment is readily available on the market. To overcome the above mentioned limits, CRA-ING after harvesting, analyzed the structural aspects of the crop after the evaluation of the modified solutions available on the market. The designe and development of a prototype mower conditioner was completed in 2007 and then modified in the winter of 2008. The experimental tests were conducted nothern and central Italy. In 2009, other experimental tests with the equipment were carried out in others regions of the country, in order to define the prototype performance. In addition, investigations on the qualitative aspects of the drying by evaluating the degradation of cellulose from the early stages of harvest, were carried out. The experimental activity was conducted in collaboration with major corporations that have welcomed the proposed solution and are currently interested in developing cultivations on large-scales in regards to second-generation biofuel production.

Keywords: Fiber Sorghum, dried biomass, energy conversion, second generation ethanol.

INTRODUCTION Sorghum is an annual herbaceous species of great interest consisting of extremely diversified germ plasm in terms of morphological and functional characteristics. Various genotypes of sorghum are obtained from the production of grains,

sugar and fibre. Fibre sorghum is used for animal nutrition, and for paper, biocomposites and energy production. Many studies in the past, related to the production of sorghum for non-nutritional purposes focused on a sugary variety (sorghum vulgare var saccharatum) after an increase interest in cultivations potentially convertible to ethanol. Unlike the sugary variety, no sugary genotypes and especially those having culm with high fibre content, did not rouse great interest in the past. Moreover, after the new Common Market Organization for Sugar (CMO Sugar), the European Community agricultural policy has remarkably reduced sugar productions assigned to Italy, thereby facilitating the changeover within an agro-energetic framework of existing sugar refineries and increasing interest in cellulose cultivations (Dolciotti I. et al., 1998).
Therefore, fibre sorghum has aroused new interest as thermal biomass, whether as starting point for biogas systems or for second generation ethanol. However, transportation costs for fresh products limit the profitability of crops and they can only be overcome if the fields are located nearby the transformation centre. Otherwise, the field drying process and the subsequent baling of dry products is the only possible harvesting method that must be used to limit transportation costs and obtain a product with a humidity level enough to make it usable for combustion purposes.
CRA-ING has been involved in hay harvesting since 1994 (Barbucci P. et al., 1994), thereby evaluating machines built for haymaking of forages and analysing relevant issues and drawbacks (Assirelli A. et al., 2006). The first mower conditioner prototype was devised in 2007 mounted on an agricultural tractor (Assirelli A. et al., 2008) and was modified in 2008 (Pari L. et al., 2009). In 2009, the making of a pre-sales model was commissioned to a firm in the north of Italy by means of a call for tenders intended for agricultural machine manufacturers and in the spring of 2009, the firm manufactured the prototype according to CRA-ING's instructions.

MATERIALS AND METHODS

Machine description The firm Cressoni from Volta Mantovana (MN) won the tender for the realisation of a prototype and looked after the manufacturing process directly from its own facilities. The machine is semi-mounted on the rear of an agricultural tractor with reversible drive and power of at least 90 kW; it has a width of 3.77 meters, a high of 0.86 meters, a depth of 1.75 meters and weight of 1400 kg (see figure 1).

Figure 1. Prototype of Cressoni/CRA-ING mower-conditioner

The frame of the machine consists of two diagonal beams with length of 3.77 meters, wherein the parts of the mower conditioner are mounted and where 2 idle wheels are mounted right below it on the wheels of the tractor, having a diameter of 400 mm and width of 150 mm, which serve to support the machine under operation and to adjust the cutting height of plants, therefore acting as a fulcrum for the extension of the top-link cylinder, preferably hydraulic. The device use for cutting the base of stems comprises a cutting blade with oscillating motion, having a length of 3.45 meters, used to cut 7 seeded rows at 0.5 meters apart from each other. The cutting process of plants coincide with the mower conditioner's operation, thereby enabling the mower conditioner to hold the stem firmly. Furthermore, the cutting device can shift forward and backwards in order to adapt the machine to different cultivation conditions. The machine can operate on 7 rows; each row is grabbed by one mower conditioner module and each single module consists of two shafts with length of 0.9 and a counter-rotating diameter of 50 mm. The motion is driven by a through chain located on the upper side of the crown of a shaft and on the lower side of the crown of the another shaft; therefore, it synchronises and inverts the rotation of the two shafts. The shafts are mounted on two bearings coupled into two beams constituting the frame and positioned at 0.2 meters from each other in order to carry the two shafts (length of 0.7 m) to the front, which are also supported by another bearing positioned on the top of the shaft.

There are two screws mounted on each shaft, the first one has the shaft's length of 0.5m, enough to favour the movement of the produce to the machine; the second one has a length of 0.2 meters, which is counter-rotating as opposed to the first one and serves to move the non-conditioned produce forward, hence preventing any build-up on the end part of the mower conditioner devices. The screws mounted on the 2 shafts with diameter of 250 mm and pitch of 100 mm, coincide with each other for 70 mm, wherein the conditioning of stems takes place. This is carried out by means of bulges mounted on the 2 screws in such a way as to allow the passage of the stem between the two bulges and crush them against the roller, thereby conditioning throughout the entire plant. If a product breaks on the upper part of the screws (as it could happen when using soft materials such as multi-mowing fibre sorghum) it will anyhow be conditioned as it will be pushed back by the counter-rotating screws and it should therefore pass through the conditioning sections (see figure 2).

Figura 2. Screws conditioning elements

The conditioned product is dropped to the ground along the entire width of the machine in order to form a bed comprising conditioned plants that rests on the base of the cut-off stems so that they can dry within the shortest possible time, depending on weather conditions. The main dimensions are specified in table 1.

Figure 3. Cressoni/CRA-ING prototype at work

Table 1. Technical data of CRA-ING prototype

Description	Unit of measurement	Values
Width	m	3,77
Length	m	1,75
Height	m	0,86
Weight	kg	1400
Number of conditioning sections	n	7
Elements inter-row	m	0,5
Cutting blade length	m	3,45

Testing area The initial mechanical harvest tests were conducted in experimental fields pertaining to the group Co.Pro.B. from Minerbio (BO) located in Mirandola di Modena (MO), where the position of the land is flat and consists of a medium textured clayey soil. Three varieties of sorghum were cultivated in the testing field in a total surface area of 3,6241 ha. The experiment examined the varieties of fibre sorghum H133, produced by the firm Syngenta. The company was involved in precession farming in wheat in 2008 and in corn in 2007; the land was tilled in the summer (2008) at a depth of 0.4 m, followed by weeding in September and surface harrowing (0.1 m) before sowing in the spring. The main characteristics are specified in table 2.

Table 2. Features of the experimental field

Location	44°53’07.98” N	11°10’42.07” E
Description	Unit of measurement	Values
Length	m	162
Width	m	138
Surface	ha	2,23
Sowing date	day/month/year	06/05/2009
Sowing inter-row distance	m	0,5
Sowing intra-row distance	m	0,107
Sowing depth	m	0,025
Varieties		H133

Harrowing was done several weeks before seeding, but due to rainfall it was postponed to a week later as opposed to the traditional local season. A mechanical precision seeder (generally used for sugar beet) manufactured by an Italian agricultural firm along with a double-drive Fiat tractor model 45-66 with power of 33.6 kW were used to seed the land.

Preparing the harvesting site A special machine was chosen for harvesting the site, where it can combine lightness with easy handling for mowing-conditioning. Lightness plays a major role considering the fact that at least 2 rows of crops are trampled-on by the wheels of the machine after every passage. The tractor used was devised by the firm BM Tractors from Zocca (MO) and has double steering on both axles, reduced total mass and can be fitted with wide section wheels without intake caps; this type of tyres are mostly used in maintenance operations of decorative green areas. The main technical characteristics of the tractor are specified in table 3.

Table 3. Technical features of the tractor unit

Description	Unit of measurement	Values
Type		BM Tractors
Model		Better 130
Engine power output	kW	93
Total mass	kg	3500
Length	m	4,56
Width	m	2,45
Height	m	2,77
Tyres front/rear	type	Floating 500/60-22.5

The first version of the prototype did not include devices to keep a constant height of the plants. Therefore, two rear level wheels were added to the prototype to drop part of the machine’s weight on the ground, hence reducing the overhanging volume of the tractor. The reversible drive on the tractor facilitated the driving significantly.
The productivity of the site was evaluated by measuring the collection times according to the classification layout on working times in farming, agreed during the C.I.O.S.T.A. (Commission Internationale de l’Organisation scientifique du travail en agriculture) and according to the recommendations of the Italian Association of Genio Rurale (A.I.G.R.) 3° R1, whereas information on the conditioned product was gathered according to the

operative protocol CEN (European Committee for Standardization)/TS (Technical Specification) 15414-1:2006.
Before conducting tests, a weather station (manufactured by the firm Oregon Scientific model WMR200) was installed nearby the field to gather and store information on temperature, humidity, wind and rain. This helped monitor the drying cycle accurately in the field containing scythed and conditioned sorghum, starting from the water content of the product upon the mowing-conditioning process up until accomplishing suitable humidity values for baling, transportation and conservation. The testing field was divided in three sections whereby samples of the products were gathered to evaluate the drying process. Two samples were gathered from each sector at 1:30 pm and 8:00 pm everyday, they were subsequently weighted and sent to the oven.

RESULTS AND DISCUSSION

Work capacity The first experiments with the site consisting of the BM Tractor and the CRA-ING prototype were conducted from the last week of July 2009 at the Co.Pro.B. testing field of Mirandola.
Fibre sorghum cultivation had a uniform distribution level during harvesting. The main characteristics of the cultivation are specified in table 4.

Table 4. Sorghum crop features at the harvesting time

Description	Unit of measurement	Values
Variety		H133
Inter-row distance	m	0,5
Crop height	m	2,88
Basal diameter	mm	16,75
Crop density	n°/m2	14
Crop bending	%	0
Weeds	%	0

The machine ran for the entire testing period without major flooding issues or nuisances (see figure 3). As there were no breaks or dead time, the only extra time was due to turnings quantified at 19.47% of the total time. The major working parameters of the mowing conditioning process are specified in table 5.

Table 5. Performance of CRA-ING prototype

Description	Unit of measurement	Values
Engine revolution speed	rpm	454
Feed rate	m/s-km/h	1,71-6,15
Operative working capacity	ha/h	2,15
Effective working capacity	ha/h	1,74
Machine availability	%	80,63
Cutting height	mm	30

The plants were uniformly scattered throughout the front part of the machine after the mowing conditioning process and effectively conditioned up to the top of the plant (see figure 4). The effect of the mower conditioner parts fixed on the screws were particularly

visible, where the stem had little elastic structure and progressively became less aggressive as the diameter of the stem decreased.

Figure 4. Post mowing crop condition

The mowing conditioning process caused deep cracks along the stem where the external tissue was discharged at intervals of 150 mm. This distance is directly linked with the rotation speed of the mower conditioner and the feed rate of the machine (see figure 5).

Figure 5. Detail of Fiber Sorghum plant after mower conditioner passage

Conditioning efficiency The data gathered by the control unit installed in the field allowed us to evaluate the progress of weather parameters during the entire drying period of conditioned sorghum. Several parameters gathered are specified in table 6.

Table 6. Average daily atmosphere conditions (temperature, wind, rain) during the drying period

Date/Unit of measur.	temperature °C	relative humidity %	wind m/s	rain mm(H20)
29/07/2009	33,69	54,04	0,58	0,00
30/07/2009	29,73	50,25	0,41	0,00
31/07/2009	28,28	54,46	1,98	0,00
01/08/2009	28,82	52,17	0,75	0,00
02/08/2009	29,30	53,58	0,51	0,00

The manner in which conditioned plants are released on the ground through the conditioning device plays a major role considering the high volume of biomass to dry. Moreover, when collecting the samples, the drying process revealed dissimilarity between the plant and portions of plants exposed directly to solar radiation compared to those that were only exposed partially.

The initial humidity level of the cultivation was 73.4% (10:30 am on 29/07/2009). After 8 hours (8:00 pm on 29/07/2009) said value decreased to 57.2% and then reached 28% 75 hours after mowing, which is considered an acceptable value for baling (see diagram 1).

Moreover, diagram 1 shows the field drying progress of sorghum treated with the new mower conditioner devised by CRA-ING. Despite the fact that the required humidity for baling was accomplished on the evening of 31/07/2009, sun exposure was prolonged until the 5th day (8:00 pm on 02/08/2009) where the humidity content of the biomass decreased even further to 20.3%.

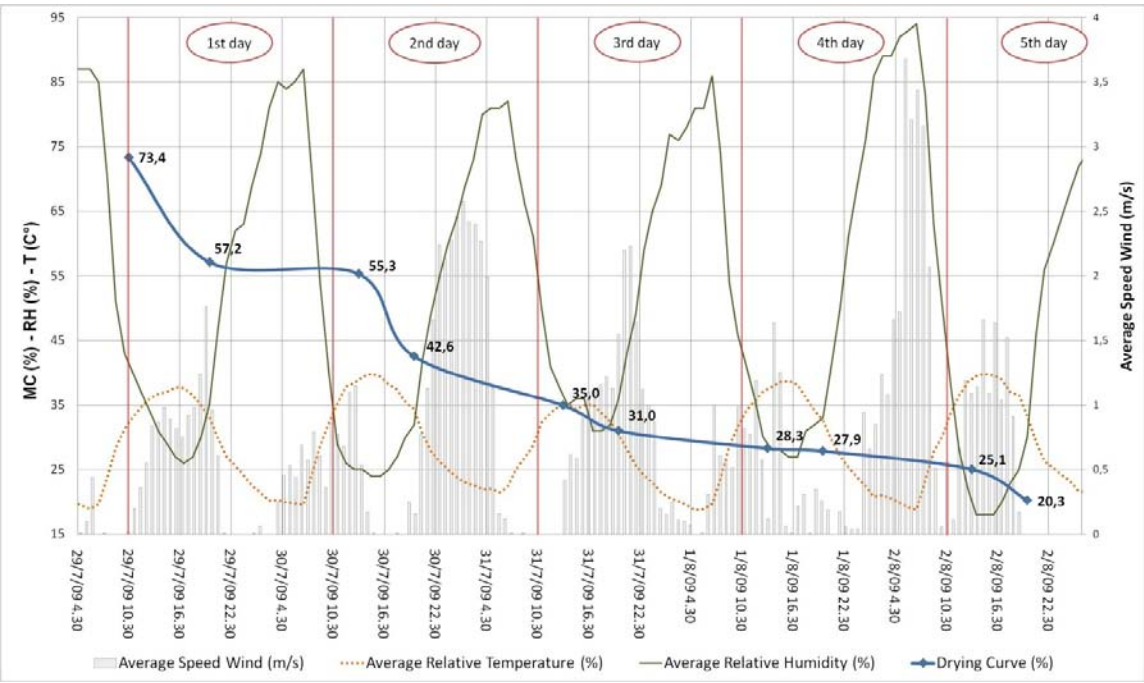

Diagram 1. Moisture content (%) of the biomass during the field drying - Mirandola (MO)

The uniform surface outline of the ground enabled us to operate at a cutting height of just 30 mm, therefore limiting significant losses of non-conditioned produce. Therefore, after baling, ground losses of un-baled biomass equalled to 5.18%, considering a production of the actual harvest of 14 t/ha of hay sorghum with humidity of 29.5% (see figure 6).

Figure 6. Post harvest field conditions

The windrow was made using a pick-up semi-mounted windrower with conveying belts, manufactured by the firm Roc model RT 950, with an operating front of 9.5 meters, made up of three sectors, among which the central sector with a width of 2.5 meters and two lateral sectors of 3 meters, which are revolving and swivelling.
A baler manufactured by the firm Feraboli was used to bale the product, model Extreme 280 with adjustable belt-driven chamber, fitted with a Rotocut shredder device that produces cylindrical bales with size of 1.2 x 1.6 meters.

CONCLUSION The mower conditioner prototype manufactured by CRA-ING in collaboration with the firm Cressoni, has provided a solution to a major problem in hay harvesting fibre sorghum. Experiments conducted during the two-year period 2007-2008 with the first prototype provided a series of useful information on problems encountered with crops during hay harvesting operations, thereby allowing us to gather the necessary devices into the prototype in order to maintain high conditioning efficiency and reduce issues linked to flooding or polluting the produce.
In the initial experiments, the prototype provided an operation speed of 6.15 km/n with erect crop of 1.71 (m/s) and an operational capacity of 2.15 ha/h.
The crops treated in this manner and under weather conditions revealed in the summer period, reached a harvest and conservation humidity within a few hours following the third day of mowing.
The evaluation of the prototype continued in September and October 2009 in Piemonte and confirmed the results achieved previously; therefore, it concluded the prototype phase of the machine with further evaluations in prolonged operations. The machine should available in the market in spring/summer 2010.

Acknowledgements. This study was supported by the Co.Pro.B Society of Minerbio (BO – Italy)

REFERENCES

Assirelli A., Bentini M., Zucchelli M. (2006) L'importanza della raccolta per le colture da biomassa. L'Informatore Agrario, 41: 117-123

Assirelli A., Fedrizzi M., Ciriello A., Pari L.. 2008. Fiber sorghum haymaking for Energy purpose: an innovative equipment for fast drying, 16th European Biomass Conference & Exhibition, Valencia, Spain.

Barbucci P., Andreuccetti P., Frati G., Bacchiet P., Vannucci D., Pari L..1994. Energy Crops Harvesting: Fiber Sorghum, Kenaf, Arundo donax Mischantus, Cynara cardunculus – Biomass for Energy and Industry – 7th E.C. Conference – Bocum, Pages 38-43

Bentini M., Zucchelli M.. Biomasse per la combustione diretta in caldaie, MMW n.1/2008, Pages 32-39

Bentini M., Zucchelli M. Pasini P.. 2008. Coltivazione e raccolta meccanica del sorgo da fibra, Agricoltura, Luglio/Agosto 2008

Dolciotti I., Mambelli S., Grandi S., Venturi G.. 1998. Industrial Crops and Products Volume 7, Issues 2-3, January, Pages 265-272

Guiducci M. . Manuale di corretta prassi per la produzione integrata del sorgo – Progetto per la Valorizzazione delle Produzioni Agroalimentari Umbre, Pages 5-7

Klinner W. E., Shepperson G.. 1975. The state of haymaking technology - Grass and Forage Science – Volume 30 Issue 3 – Pages 259-266

Pari L., Assirelli A., Suardi A.. 2009. Migliorato il condizionamento del sorgo da fibra alla raccolta. Informatore Agrario n.29 del 17/23 luglio 2009 – Supplemento Agroenergie - Pages 16-18

Pari L., Vannucci D. (1992) Energy crops harvesting: fibre sorghum, kenaf, Arundo Donax, Miscantus, Cynara cardunculus. 7th European Conference on biomass for energy and environmental, agriculture and industry. Firenze 5-9 ottobre