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RESEARCH ON TENSILE STRENGTH AND SPECIFIC FUEL CONSUMPTION FOR A MISCANTHUS RHIZOME PLANTER IN DIFFERENT EQUIPPING CONDITIONS AT THE FOUR ROW

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Abstract

A four-section miscanthus rhizome planter machine was equipped with a ploughshare and cover discs at the outer units and with ploughshare and compaction wheels arranged in V at the central units of the machine. Under these conditions, experimental determinations were made regarding the tensile strength (kN), the power required for towing (kW) and fuel consumption (l/ha), for three working depths (6, 9 and 12 cm) and different working speeds (between 1.27 and 2.65 m/s).
Field results showed traction force values between 4.90-8.51 kN for planting depths of 6 cm, respectively between 6.90-8.35 kN for depths of 9 cm and between 8.38-8.52 kN for 12 cm depths. Fuel consumption showed values between 2.96-5.18 l/ha at planting depths of 6 cm, between 3.30-4.07 l/ha for depths of 9 cm, respectively between 4.4-5.2 l/ha for planting depths of 12 cm. It was found that there is no well-defined rule regarding variation of traction parameters with planting depth, especially since the average travel speed could not be maintained at the same value for each sample, and the soil probably had wetter areas or with different resistance to the opening of the trench.

Key words*: miscanthus rhizome planter, planting depth, working speed, tensile strength, specific fuel consumption.*

INTRODUCTION

Among the species of energy plants there are also some species of *Miscanthus x giganteus* which are characterized by high biomass yields and relatively low costs, there is a growing interest for use in bioenergy production (Boersma et al., 2017; Daraban et al, 2015; Peric et al., 2018, Smeets et al., 2009; Dumitru et al., 2017).

There have written whole books and numerous papers on miscanthus culture and other energy crops capable of replacing petroleum energy and its products in the near future, but also other fossil fuels. Replacing lignite and wood with miscanthus briquettes would also lead to the protection of the environment through significant reduction of CO_2 equivalents (eq), SO_2 eq, P eq, N eq, 1,4 dichlorobenzene (1,4-DB) eq, non-methane volatile organic compound (NMVOC), PM10 eq and U235 eq emissions (Peric et al., 2018).

But many unknowns about these cultures remain, how they are set up, the land on which they should be cultivated, agrotechnics used, as well as the methods of use after harvest, either they are used as solid fuels, either by biorefinery in the form of liquid fuels (Xiu et al., 2017; Wang et al., 2018). By using the components and by-products resulting after biorefining, the economic efficiency of these plants can increase substantially.

Low division efficiency (1:10) it makes the demand for large planting rhizomes large, increasing the costs of setting up miscanthus crops. For this reason, various technologies have been developed to increase the rate of division or multiplication by seeds, but the costs are still relatively high. The authors analysed several published papers in the field and found that the highest costs are related to the establishment of miscanthus crops, the other costs of the management, harvesting, storage and transport phases (Pyter et al., 2010)

being relatively similar since the third year of growth. Establishing rhizome crops requires about average costs 3375.7 €/ha, compared to establishing crops by seeds that are about 1508.5 €/ha (Xue et al., 2015).
However, the method of setting up miscanthus crops through rhizomes remains the only method used in Romania (Sorica, 2015).
Because of the perennial character, the miscanthus does not enter the desolation, but it is cultivated extensively on certain soils less suitable for other crops, where it can remain 15-20 years, including on mining soils (Ussiri and Lal, 2014). Perennial culture has the advantage of reducing the costs of preparing the land and planting it. The miscanthus goes well after any crop plant (Sorica et al., 2009).
Rhizomes should be planted at the beginning of spring (March-April) when soil moisture is high, at a depth of 8-10 cm. The complete establishment of a miscanthus culture lasts 3 years. The oldest commercial rhizome planting machine was developed by the former company BICAL and Hvidsted Energy Forest (Huisman and Kortleve, 1994). Later farmers and private companies (ex. Tomax Ltd., Portlaw Co., ADAS Ltd.) developed automatic rhizome planters and rhizome mechanical harvesting machines (Anderson et al., 2011). On small areas, potato planters can also be successfully used (Adamchuk et al., 2019).
The preparation must be done in the fall, starting with the application of a broad spectrum herbicide, to combat any perennial weed, because weeds have a significant influence on plant development (implicitly also on biomass production), especially in the initial growth and development phase (Maksimovic et al., 2016).
The planting material consists of rhizomes between two and three years old. Rhizomes can be replanted to produce new plants, but it is preferable to have at least 2-3 sprigs, it is recommended to be commercially certified to avoid the transmission of pathogens in soil between different areas, that is, they are not affected by fungal species (*Fusarium avenaceum, Fusarium oxysporum and Mucor hiemali*) which causes rhizome rot (Covarelli et al., 2012). The best result is obtained when the rhizomes are replanted within 24 hours of harvesting (Figure 1).
Planting distance, respectively the density of plants, varies depending on soil fertility and the amount of nitrogen applied (Zivanovic et al., 2014). Thus, on fertile soils where the stems grow tall, it is recommended that the distance between rhizomes be 1 m, and between rows it should be 1 m, the middle ones 50/100 cm (15000 plants/ha.), and the poor 50/50 cm (20000 plants/ha) (Sorica, 2009; 2015).

Figure 1. Rhizomes of Miscanthus

The main operations to be performed by planters, regardless of culture, are:

- to ensure the opening of gutters, pits or nests;
- to distribute the planting material evenly at the regulated depth and distance;
- to ensure that the planting material is covered with soil and that soil is squeezed near it;
- not to cause injury to the planting material, when deposited in the soil.

In this regard, the planters are provided with ploughshares for opening the gutters, distribution systems for planting material in the gutter opened by ploughshare, coating systems and, eventually, soil compaction wheel cover. The highest energy consumption is given by the ploughshares, these being designed in different types of construction to reduce tensile strength (Altuntas et al., 2006; Troger et al., 2012; Benjaphragairat et al., 2010).
Thus, shoe type gutter opener with the distance between rows of 0.25 m showed tensile strengths of 10.5 N/row, for moving speed 1.68 km/h when planting garlic (Benjaphragairat et al., 2010). For a depth of planting of 0.12 m, tensile strength can increase more than 100 times, especially if the fence opener is not properly designed or is planted directly in the stem (Troger et al., 2012).
They cannot be neglected, like the other resistance to the movement of the planting machine.

In this context, the paper presents an analysis of the displacement resistances and the fuel consumption for a rhizome planting machine, on four rows, with different equipment in the marginal sections compared to the central sections. It is desired to highlight the energy indices of the planting machine for different planting depths, at three speed classes of machine, without being followed the indications of quality of the work, and possibly the participation of each working body in the energy index analysed.

MATERIALS AND METHODS

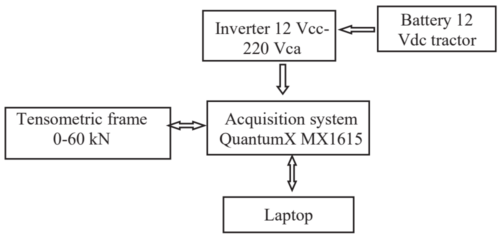
The MPM-4 machine was used to characterize the tensile behaviour of the miscanthus rhizome planting machine (designed and realized by the INMA Institute of Bucharest) in aggregate with the 80 HP New Holland TD80D tractor (Figure 3). The determinations were made on the experimental field of the institute (4000 m^2) using a five-channel tensometric frame and Quantum MX 1615 - HBM data acquisition and amplification system between the tractor and the machine, and for the fuel consumption a device equipped with Flowtronic 215-217 type tester was used (Figure 2).

Figure 2. Tensometric frame for measuring tensile strength

The land was plowed in autumn at 0.25 m depth, and in the spring it was dug with a disc harrow at a depth of 0.15 m and levelled with a combiner. The soil of the experimental field of INMA Bucharest is of a reddish-brown type of forest, characteristic soil within the research institute. It is characterized as having high saturated hydraulic conductivity (0.01-0.035 m/h), in the layer 0-0.25 m, low penetration resistance (1.0-2.5 MPa) and large field capacity (25-30% in volume), in the same top layer (Dumitru et al., 2011). At the time of the experiments, soil moisture had values between 13.4-20.9% (medium value 17.86%), and the penetration resistance was between 0.67-2.25 MPa (average 1.47 MPa), in layer 0-0.25 m.

The miscanthus rhizome planter was designed to work with a number of sections, each equipped in two variants: ploughshare-disc cover-compaction wheel, respectively ploughshare-disc cover-wheels with V-fins.

For the experimental samples were calibrated, first, tensometric frame transducers on the traction-compression machine inside the INMA laboratory, after which they were mounted on the miscanthus planting machine. Then the movement was made in the field, where the plots of 90 m long were laid out, on each plot, carrying out an experiment as trial.



The tests were carried out, the parameters being followed: tensile strength, fuel consumption per hectare and movement speed of tractor. There were several rehearsals, with different movement speeds, with different combinations of ploughshares and cover discs (or wheels with wings) in the processed agricultural land.

Data processing was done using spreadsheet tools, EXCEL and MathCad math computing software. Diagrams of the tracked sizes were obtained, tensile strength, in relation to the time and the average values of these sizes for each repetition.

Figure 3. Equip of the planting machine on each work section

The determinations were made for three working depths (0.06, 0.09, 0.12 m) and three speed stages (with small variations within the step due to the specificity of the experiments), average 1.29, 1.78 and 2.6 m/s.

The tensile force was calculated from the force records of the two lateral and central straps, also representing itself graphically (Figures 4 and 5). Was obtained, thus, the variation of the tensile force during each experiment, in the equipment variant specified for miscanthus planting machine sections.

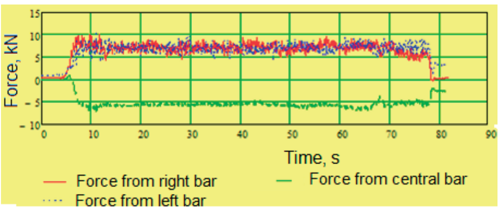


Figure 4. Signal recorded in experiment 20

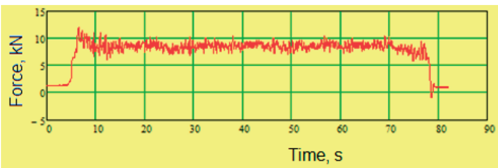


Figure 5. Variation of the total tensile strength

As for the power required for traction, it was calculated as a product between the travel speed and the traction force, for each working depth.

RESULTS AND DISCUSSIONS

The results obtained in the experiments are presented in Table 1.

Table 1. Traction force, fuel consumption and traction power at the planting unit

Sample	Work depth (m)	Work speed (m/s)	Traction force (kN)	Fuel consumption (l/ha)	Required power (kW)
1		1.27	7.039	5.18	8.92
2		1.28	6.919	4.44	8.88
3		1.32	5.971	4.44	7.89
4		1.76	6.423	3.33	11.33
5	0.06	1.76	7.309	3.70	12.89
6		1.84	6.857	3.33	12.59
7		2.57	6.056	2.96	15.56
8		2.57	4.898	3.33	12.59
9		2.65	8.513	3.33	22.54
10		1.38	7.682	4.07	10.63
11		1.32	6.113	4.07	8.08
12		1.34	7.240	3.70	9.71
13		1.73	8.283	4.07	14.33
14	0.09	1.73	7.701	4.07	13.33
15		1.76	6.911	3.70	12.19
16		2.37	8.053	3.70	19.06
17		2.64	6.338	3.30	16.76
18		2.50	8.318	3.70	20.80
19		1.32	8.380	5.18	11.08
20	0.12	1.30	8.516	4.40	11.09
21		1.27	8.379	4.40	10.61

Analysis on sets of experiments of the energy parameters of rhizome planting aggregate involves determining their average values, for average values of the working speed of the machine and the same working depth (Table 2).

Table 2. The experimental average values of the energy parameters of planting unit

Depth (m)	Speed (m/s)	Force (kN)	Consumption (l/ha)	Power (kW)
0.06 (9 sample)	1.290	6.643	4.687	8.563
	1.787	6.863	3.453	12.270
	2.597	6.489	3.207	16.897
0.09 (9 sample)	1.347	7.012	3.947	9.473
	1.740	7.632	3.947	13.283
	2.503	7.570	3.567	18.873
0.12 (3 sample)	1.297	8.425	4.660	10.927

From the analysis of data from Table 1 and Table 2 it is found that the traction force does not necessarily have a connection with the speed of movement, this having a random variation, but the power required to tow the machine increases with increasing working speed. The power required to tow the machine showed variations within the limits 7.9-22.5 kW for planting depths of 0.06 m and between 8.1-20.1 kW, at the depth of 0.09 m, for speeds from 1.29 to 2.6 m/s, respectively between 10.6-11.1 kW for the depth of 0.12 m, but in the latter case the travel speeds were about 1.3 m/s.

Variation of the average values of the energetic and working parameters of the planting unit, obtained in the experiments, depending on the working depth, is shown in Figure 6.

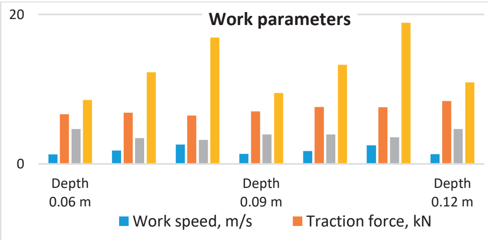


Figure 6. Variation of average energy parameters in experiments

One can easily observe the increasing variation of the average values of the working speed for the first two sets of experiments, as well as the power required to tow the planter. Also, the decreasing variation in fuel consumption per hectare is observed for each set of experiments (Figure 6).

Based on data from Table 1, the correlation table between the main working parameters with the planting unit was created (Table 3).

Table 3. Working parameters correlations matrix for the miscanthus planting unit

Parameter	Work speed	Traction force	Fuel consumption	Required power
Depth = 0.06 m				
Work speed	1	-0.057	-0.821	0.830
Traction force	-0.057	1	0.113	0.502
Fuel consumption	-0.821	0.113	1	-0.651
Required power	0.830	0.502	-0.651	1
Depth = 0.09 m				
Work speed	1	0.189	-0.714	0.925
Traction force	0.189	1	0.279	0.535
Fuel consumption	-0.714	0.279	1	-0.490
Required power	0.925	0.535	-0.490	1
Depth = 0.12 m (only working speed = 1.3 m/s)				
Work speed	1	0.121	0.803	0.910
Traction force	0.121	1	-0.495	0.521
Fuel consumption	0.803	-0.495	1	0.484
Required power	0.910	0.521	0.484	1

It can be stated that for values above 0.8, analysed parameters (two by two) has a strong correlation, for values between 0.5-0.8 the correlation is good, for values 0.3-0.5 the correlation is weak, and for values below 0.3 the two parameters have an insignificant correlation. It can be seen, so, that, for all working depths used, the traction force has a negligible correlation with the working speed, but it has a good correlation with the power required to move the machine. Furthermore, working speed correlates very well with specific fuel consumption (l/ha) and with the actuating power (values above 0.8 in most cases). Still, at the working depths of 0.06-0.09 m, the correlation of speed with fuel consumption per hectare is negative, that is, the two parameters are inversely proportional, as shown in Figure 7.

A strong correlation is found between the working speed and the power required to move the planting unit, in all cases it having values above 0.83 (mostly above 0.91). It is noticed, also, a good correlation of the power required for the traction force (values over 0.5), but also with fuel consumption per hectare (values over 0.49), though presented globally, for each working depth, the correlation seems mostly negative than positive (Table 3).

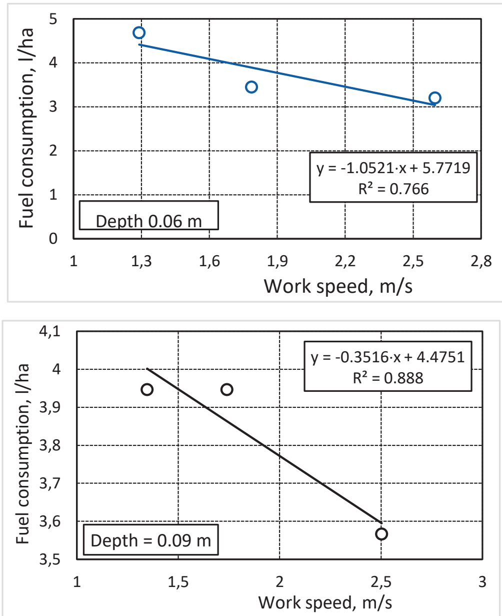


Figure 7. Variation of fuel consumption with working speed, at depths of 0.06 m and 0.09 m

Figure 8 shows the correlation of fuel consumption per hectare with the traction force, taking into account their average values within each planting depth, a correlation that seems logical, that is, a directly proportional variation of the two parameters.

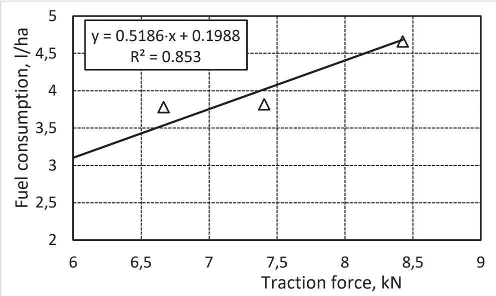


Figure 8. Variation of fuel consumption with traction force, for their average values

Also, taking into account the average values of the traction force (within each working depth), its variation with depth seems, again, a logical one: tensile strength increases with increasing working depth, no matter how fast the planter moves (Figure 9).

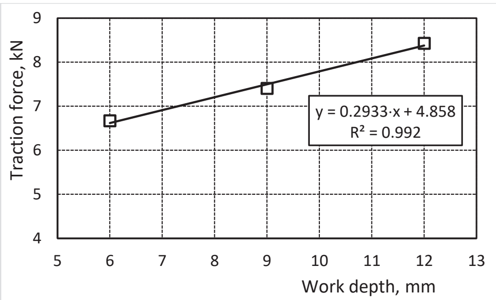


Figure 9. Traction force variation with working depth, at average force values for each depth

Matched with Voicu et al. (2015), tensile strength of the MPM-4 planter equipped only with ploughshare for opening gutters, to all four sections, is about average 7.761 kN, and the fuel consumption and power required for towing have average values of 4.44 l/ha, respective 10.56 kW, for the working depth of 0.06 m and travel speed of 1.36 m/s. Also, for the same speed regime and the same working depth, experiments show average values of 4.165 kN for tensile strength, respective 4.07 l/ha and 5.51 kW, for fuel consumption and towing power, if the planting machine is provided with two ploughshares and two cover/compaction V-wheels (only at the outer sections). At the same speed and same equipment of the machine, but at a depth of 0.09 m, the results show average values of 5.085 kN, 3.33 l/ha and 6.84 kW, for the three specified energy parameters. If the machine is equipped with ploughshares and cover discs, only at the outer sections, at the working depth of 0.06 m and average speeds 1.4 m/s, experiments showed values of 3.737 kN, 3.33 l/ha and 5.25 kW, for tensile strength, specific fuel consumption, respectively the towing power.

It can be stated, in these conditions, that the covering discs require a lower traction force than the covering / tapping wheels, but for the planting process to be complete the work sections must be equipped with additional tapping wheels. However, a small surplus of speed can lead to greater traction power and increased fuel consumption, to the same way of equipping the sections.

It has been observed that at a lower working speed, fuel consumption per hectare increases, and the V-cover wheels with flaps have a lower fuel consumption than the machine ploughshares. The same can be said about the contribution of the covering discs to the fuel consumption of the machine in relation to the contribution of the ploughshares. More, the fuel consumption of the coating discs is lower compared to the fuel consumption of the coating/tapping V-wheels, at the same speed regime and the same working depth. Also, the aforementioned are also valid in the case of the traction power required, which is greater as the speed of work and depth of planting increases. Thus, if a ploughshare has a fuel consumption of 1.2-1.3 l/ha, at a speed of 1.3 m/s and a working depth of 0.06 m, then a pair of wheels with V-fins gives fuel consumption of 0.65-0.80 l/ha, and a pair of cover discs gives a fuel consumption of 0.55-0.65 l/ha. It must be said that the contribution to the overall fuel consumption of the weight of the machine and its rolling system was not taken into account.

The same way, having regard to the present paper and the papers presented by Voicu et al. (2015) and Poenaru et al. (2015), estimates could be made on the power required by the working organs of the planting machine at towing, for the speed regime 1.3-1.35 m/s and working depth of 0.06 m. It is estimated that a ploughshare demands a power of 1.75-1.9 kW, while a pair of V-shaped wheels has a contribution of approximate 0.25-0.3 kW, and a pair of cover disks requires only a traction power of 0.1-0.2 kW. It is obvious that all these values of the energy indices presented by each working body increase with increasing working depth, but it shows variations and depending on the speed it is moving and the characteristics of the land where the planting takes place.

CONCLUSIONS

The estimation of the energy indices of a miscanthus rhizomes planting machine can be done only by experimental determinations in the field. The machine can be equipped in several variants, but in this paper the machine presented two sections with ploughshare and tapping / cover wheels arranged in V, with wings, and two sections with ploughshare and cover discs. For experiments performed at different planting depths (between 0.06-0.12 m) and speeds within limits 1.3-2.6 m/s, energy indices of the work (tensile strength, fuel consumption per hectare and the power required for towing) presented different variations, depending on the input parameters chosen.

A particular finding is that fuel consumption per hectare decreases with increasing working speed. (e.g. from 3.9 l/ha, for speeds of approx. 1.35 m/s, to 3.6 l/ha for speeds 2.5 m/s, at the planting depth of 0.09 m). Power required to tow the machine (calculated as a product between working speed and traction force) it has grown both with increasing planting depth, but also with increasing working speed (e.g. from 8.56 kW for planting depth of 0.06 m/s, to 9.47 kW for the depth of 0.09 m/s and at 10.92 kW for the depth of 0.12 m, all for the same speed regime - 1.3-1.35 m/s).

However, the values of the energy indices of a planting machine depend to a large extent on the way of equipping the machine, as well as the preparation of the land, for the same input parameters (travel speed and working depth).

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