ANALYSIS OF THE FIELD EFFICIENCY OF SUGARCANE HARVESTERS
/
ANÁLISIS DE LA EFICIENCIA DE CAMPO DE COSECHADORAS DE CAÑA DE AZÚCAR

González-Cueto O.[1)], Castillo-Rodríguez J.A. [2)], Ávalos-Clavelo, J.L. [2)], López-Bravo E.[1)], Herrera-Suárez, M.[3)], Salcerio Salaberry[1)] [1]

[1)] Universidad Central "Marta Abreu" de las Villas, Faculty of Agricultural and Animal Sciences / Cuba;
[2)] Empresa Azucarera Villa Clara / Cuba;
[3)] Universidad Técnica de Manabí, Faculty of Mathematical, Physical and Chemical Sciences
Tel: 05342222875; E-mail: omar@uclv.edu.cu
DOI: https://doi.org/10.35633/inmateh-63-30

Keywords: *time efficiency, fuel efficiency, throughput capacity, furrow length*

ABSTRACT

Field efficiency is a main factor for obtaining high productivity of agricultural machinery. The aim of this paper was to determine the field efficiency of KTP 2M and CASE IH 8000 sugarcane harvester machines, working with different lengths of cutting fronts. The research was carried out in the Panchito Gómez Toro area of production, belonging to Sugar Enterprise, Villa Clara, during February and March 2020. The main movement times of the harvester inside the field was obtained by stop watch, as well as the fuel consumption during the works. The influence of the length of the cutting fronts on the turning time, time for completing the task and field efficiency were determined according to the sugarcane yield. The results show that lengths of cutting front less than 300 m, represent greater losses in time and higher rate of fuel consumption.Lengths of cutting fronts greater than 500 m, do not represent an increase in field efficiency.

RESUMEN

La eficiencia de campo es un factor principal para la obtención de alta productividad de maquinaria agrícola .El presente trabajo se realizó con el objetivo de determinar la eficiencia de campo de cosechadoras de caña de azúcar KTP 2M y CASE IH 8000 durante el trabajo en frentes de corte de diferentes longitudes. La investigación se llevó a cabo en áreas de producción de APA Panchito Gómez Toro de la Empresa Azucarera Villa Clara, durante los meses de febrero y marzo de 2020. Se obtuvieron mediante cronocartas los principales tiempos que componen el movimiento dentro de los campos de las cosechadoras; así como, el consumo de combustible durante la realización de los trabajos. Se determinó la influencia de la longitud de los frentes de corte en el tiempo de viraje, el tiempo para la realización de la tarea y la eficiencia de campo en función del rendimiento agrícola de la caña de azúcar. Los resultados del trabajo muestran que longitudes de frente de corte inferiores a 300 m representan mayores pérdidas de tiempo y mayor tasa de consumo de combustible. Longitudes de frentes de corte superiores a 500 m no representan incremento en la eficiencia de campo.

INTRODUCTION

In Cuba, the mechanized harvesting with harvester machines reaches 96% of the total sugarcane amount that goes to the factories for the production of sugar and other derivatives. The harvesters used are from different manufacturers and different models, such as the Cuban harvesters KTP 2M and other imported harvesters as the machines from CAMECO, AUSTOFF and the CASE IH series 7000, 8000 and 8800.

The economic technical index, that most widely characterizes the agricultural machinery performance is the direct operating cost per unit of time (*Jrobostov, 1977*). Among the factors that determine this index and determine the lower direct operating costs is the field capacity of agricultural machines. Field capacity is an index used to evaluate the performance of agricultural machinery (*Adamchuk et al., 2004*); it is also identified as the productivity of agricultural machinery. Hunt (1999), defines the field capacity as the work done by the machinery in the unit of time, it is expressed in surface such as m^2 or hectare per units of time. Theoretical field capacity *(TCC)* is the amount of work that a machine realizes by working without interruption, at its normal speed *(v)* and using its entire theoretical width *(a).* It can be expressed by the following equation $Cct = v * a$.

[1] *González-Cueto O., Prof. Ph.D. Eng.; Castillo-Rodríguez J.A., Eng.; Ávalos-Clavelo, J.L., Eng.; López-Bravo E., Prof. Ph.D. Eng.; Herrera-Suárez, M., Prof. Ph.D. Eng.; Salcerio Salaberry, R.A.*

Several factors modify the ability of machines to perform at their theoretical field capacity. In soil preparation, the theoretical width of the implement is generally not reached. During the work, part of the implement overlaps previous pass, to avoid leaving spaces unworked, which makes the effective width of the implement less than the theoretical one. During operation with grain or fodder harvesters, even with experienced operators, they are seldom handled at the designed cutting width. During open row operation, the effective width is the same as the designed width, depending on the spacing of the current pass with respect to the previous one. The non-equidistant spacing of the furrows during sowing are later reflected in difficulties during the travel of the machines in the work of cultivation and harvesting (*Hunt, 1999*). Furthermore, the forward speed cannot be kept constant depending on the soil conditions.

The theoretical field capacity can be reached by a combine harvester over short distances, it is expressed in ha h^{-1} or also in Mg of product per hour (*Ortiz-Cañavate et al., 2012*). When the machine works at its designed width and travels at constant speed without interruption, it works at 100% of field capacity; interruptions in machine operations reduce the field capacity. These interruptions can be generated by turns at the end and beginning of the fields, unproductive stops waiting for transport, unloading and filling the hopper with seeds or fertilizers, etc. When the loss of field capacity due to insufficient width or speed of the machinery is taken into account, and also the time losses due to turns or other causes in the fields, the parameter is called effective field capacity (Cce).

The relation between theoretical field capacity and effective field capacity is called *field efficiency coefficient (e)* (****ASABE D497.7, 2011*). This term takes into account the working width, advance speed and time losses of the machine in the field. Travel to and from a field, major repairs, preventive maintenance, and daily service activities are not included in field time or field efficiency (*Topakci et al., 2010*). ****ASABE D497.5 (2006*) shows ranges of average and typical field efficiency for different implements, agricultural machines, and self-propelled harvesters. Field efficiency is calculated by the equation $e = (Cce/Cct) * 100$ and takes into account the time lost during operation, influenced by parameters such as: operator skills, machine operation mode, movement method and types of turns, size and shape of the fields, crop agricultural yield, and moisture and soil conditions.

For sugarcane harvesting machines the advance speed and the effective width are equal for effective and theoretical field capacity. This happen because the width is given by the distance between rows, which in the Cuban fields of sugarcane is mostly 1.6 m. Therefore, both capacities are calculated as a function of the operation times. On the other hand, the theoretical field capacity is determined by the theoretical time, necessary to realize all the work, if the theoretical field capacity could be reached. This, would be expressed as $e = (Te/(Te + Tp)) * 100$, so this indicator coincides with the time efficiency that *Grisso et al.* (*2004)* defined as a ratio of the time a machine is effectively operating to the total time the machine is committed to the operation. The time when the operator is in the machine and not actually working the field is counted as lost time. *Topakci et al. (2010)* and *Carroll (2015)*, propose time efficiency as the effective time worked by the machine, between the total theoretical time worked.

The field capacity and field efficiency are essential indicators for evaluating the performance of agricultural machines and implements. Several researches have been carried out on this subject, such as those by *Grisso et al. (2013*) on fodder packing machines, *Carroll (2015*) on combined soybean harvester, *Baio (2012*), *Ma et al. (2018*), *Santos et al. (2018)* in sugarcane harvesters.

The evaluation of the productivity of agricultural machines in Cuba is carried out by the stop watch method. The times in which the production process is carried out, and the productivity indicators are calculated. Several researches have been carried out with this objective, highlighting those carried out by *Betancourt et al.* (2016), *Diego et al. (2015*), *González-Cueto et al. (2017*), *Ramos and Lora (2013)*. Specifically, in sugarcane harvesters, researches have been conducted by *Daquinta et al. (2014), De la Rosa et al. (2014), Martinez et al. (2020)*. However, no research has been carried out, to establish the influence of the field conditions and machine movement methods in field efficiency. In this sense, the present paper aims to determine the field efficiency of KTP 2M and CASE IH 8000 sugarcane harvesters, working on different lengths of cutting fronts.

MATERIALS AND METHODS

Data on the field was measured by timing the different operations of KTP 2M and CASE IH 8000 harvester machines at the Panchito Gómez Toro farm, in Villa Clara, Cuba. By this procedure were obtained the cutting time, turning time and fuel consumption per Mg of sugarcane.

The agricultural yields (*Ra*) for KTP 2M were established: 40; 50 and 60 Mg ha^{-1}; for CASE IH 8000 were: 50 70 and 90 Mg ha^{-1}. The advance speed of KTP 2M was 5, 4.6 and 4.1 km h^{-1} for each yield, and the advance speed of CASE IH 8000 was 5.1, 4.3 and 3.7 km h^{-1} respectively. The effective field capacity of each machine was established based on the daily cutting tasks (Tc), 100 Mg for KTP 2M and 400 Mg for CASE IH 8000. The lengths of cutting front were from 100 to 1000 m with intervals of 100 m.

The effective working time was determined by means of the equation.

$$Te = \frac{Lc}{v} \tag{1}$$

where:

Te - effective working time (h);

Lc - length to harvest for the task (km);

v – advance speed (km h^{-1}).

$$Lc = Tac\ (6250/1000) \tag{2}$$

Tac - total area to be harvested (ha).

$$Tac = \frac{Tc}{Ra} \tag{3}$$

Tc - cutting task (Mg)

Ra – crop yield (Mg ha^{-1})

The time lost in cutting task, due to turning time, was determined from the result of the measurements of turning time by means of the stopwatch method.

$$Tp = \frac{Lc * 1000}{L_{fc}} * Tv \tag{4}$$

where:

Tp - time lost in cutting task (h);

Tv – turning time (h);

L_{fc} - length of the cutting front (m)

The time necessary to carry out the cutting task is the sum of the effective working time and the time lost in the cutting task.

RESULTS

Time lost in the cutting task

In the paper, reference is made to length of cutting front, however, in many occasions this term is confused with the furrows' length. Length of cutting front refers to the longitude of one or more furrows located in the same direction in adjacent fields that are being cut one after other. As result of the stop watch it was obtained that turning time average of the KTP 2M was 0,026 h and of the CASE IH 8000 was 0.0173 h. The Figures 1 and 2 show the results of time lost in the cutting task, due to turning time, for both harvesters, working on three sugarcane yields and different lengths of the cutting front.

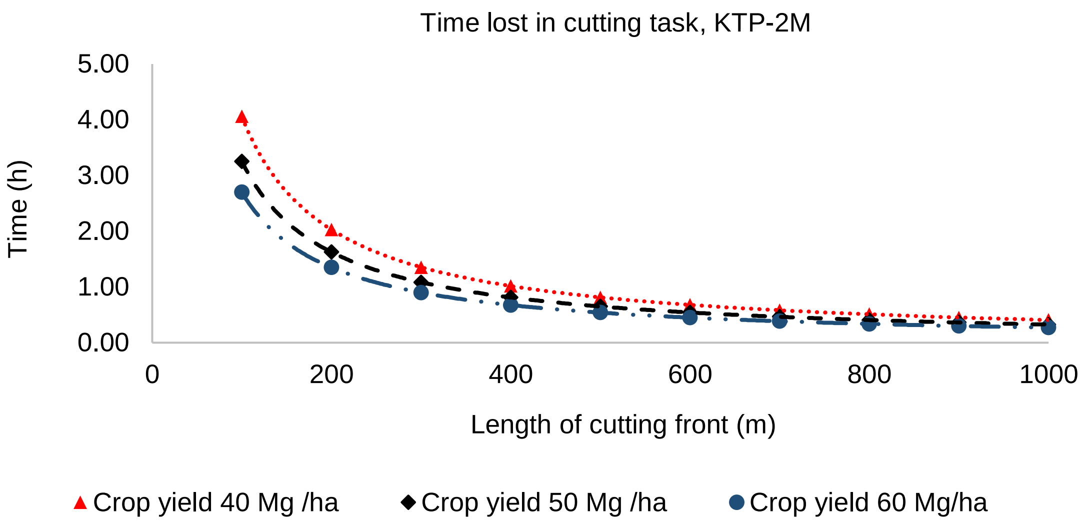

Fig. 1 - Time lost in cutting task for KTP 2M harvester, working on three sugarcane yields and different lengths of the cutting front

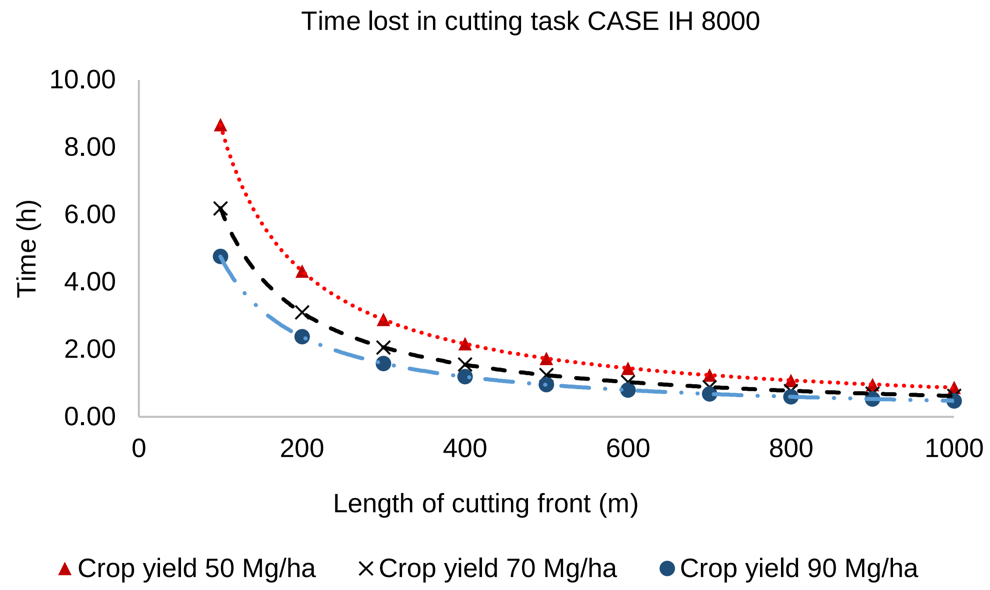

Fig. 2 - Time lost in cutting task for CASE IH 8000 harvester, working on three sugarcane yields and different lengths of the cutting front

As the Fig. 1 and 2 show, the time lost in cutting task decreases as increases the length of the cutting front independently of the agricultural yield. For small lengths of cutting fronts a significant increment of time lost in cutting task takes place. The equation of the curves of the tendency lines are of the potential type. The potential equation curves: $y = ax^{-n}$, describe the behaviour of the time lost in cutting task (y) to respect the length of cutting front (x) and agricultural yield (n). Table 1 shows the prediction equations obtained from the trend curves fits and the R^2 for time lost in cutting task in KTP 2M and CASE IH 8000 harvester machines.

Table 1

Prediction equations for time lost in cutting task for both harvester machines.

Crop yield Mg ha^{-1}	KTP 2M Equation	R^2	CASE IH 8000 Equation	R^2
40	$Y = 401.38x^{-0.998}$	1	-	
50	$Y = 325x^{-1}$	1	$Y = 867.96x^{-1}$	1
60	$Y = 269.75x^{-1}$	1	-	
70	-		$Y = 620.78x^{-1.001}$	1
90	-		$Y = 475.75x^{-1}$	1

The field dimension is one of the main factors that modify time lost due to turning time of the harvesters as shown in several researches (****SASA, 1998; Meyer, 1999; Ma et al., 2015*). The efficiency of harvesters must be taken into account for the right design of the fields during soil preparation before sugarcane plantation. The geometry of the field should offer as long as possible cutting fronts up to 500 m. As shown in Fig. 1 and 2, from 500 m the time lost during turning has an asymptotic behaviour up to 1000 m. Therefore, extremely long cutting fronts are not recommended because of the difficulty to change transport, increasing travelled distance and consequently fuel consumption.

The design of the harvester also affects the capacity to reduce time lost during turning. The harvester CASE IH 8000 has 2.96 m wheelbase, being more compact and shorter than the KTP 2M who has 3.5 m wheelbase, making the CASE IH 8000 more manoeuvrable. The turning radius of self-propelled machines depends on the wheelbase and the KTP 2M is 0.54 m higher than the CASE. Another factor that affects the manoeuvrability of the combines is the expertise of the operator (Meyer, 1999). Regarding this parameter, it should be noted that, due to the high level of automation, the training of operators of CASE machines is generally better.

The efficiency of the harvester also depends on the infield transport, because it needs to wait for the turn of the tractor with trailer or truck. As the infield transport is heavier, the trailer's wheelbase is greater, thus the turning radius is bigger and there is more time lost waiting for turning infield transport.

The preparation of the headlands to carry out the turns and the conformation of a turning strip are essential to reduce the time lost during the turn in the harvest.

The turning strip widths should be taken into account during field design, because it modifies the turning times. The study found that turning strips do not have adequate size, being a common factor in the fields of the researched area. De la Rosa *et al* (2014) found a similar result in areas of the farm Arquímedes Colina, although it is known that this situation is common in almost all fields, in Cuba.

Time for cutting task

Fig. 3 and 4 show the behaviour of the times for cutting task, this including time lost in cutting task due tuning and effective work times. The trends of the curve in the figure look similar to those of the time lost in cutting task, time for cutting increases when lengths of the cutting front are shorter. Cutting time decreases for cutting front between 400 and 500 m, after that it remains asymptotic. These results are independent of crop yield. As shown in Table 2, prediction equations from the trend of cutting time curves are potential too. The adjustments R^2 indicated that equations can be used with good results to make predictions of timing cutting task.

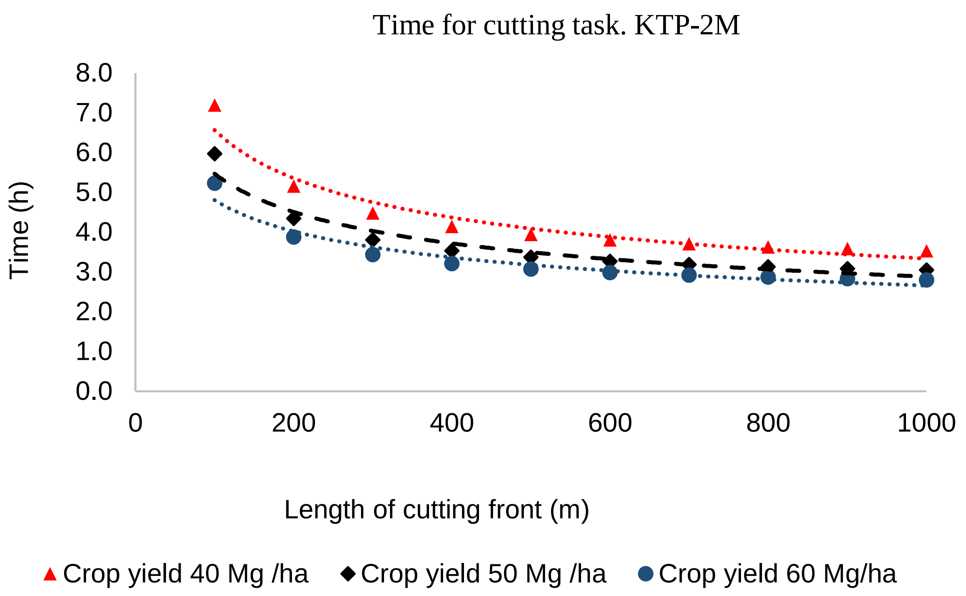

Fig. 3 - Times for cutting task for KTP 2M harvester, working on three sugarcane yields and different lengths of the cutting front.

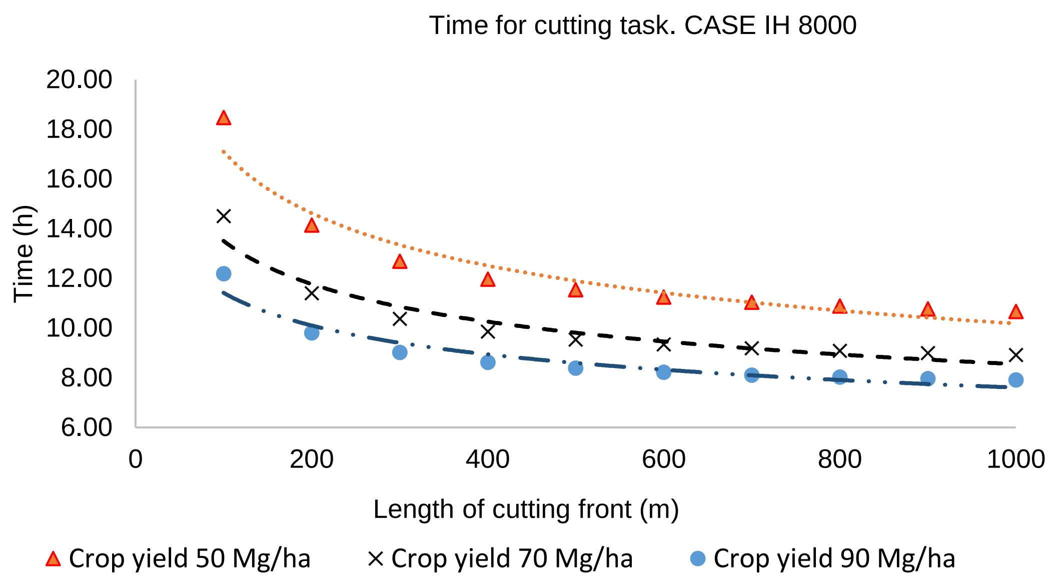

Fig. 4 - Times for cutting task for CASE IH 8000 harvester, working on three sugarcane yields and different lengths of the cutting front

Table 2

Prediction equations for time cutting task for both harvester machines.

Crop yield Mg ha[-1]	KTP 2M Equation	R^2	CASE IH 8000 Equation	R^2
40	$Y = 25.439x^{-0.294}$	R² = 0,9476	-	
50	$Y = 19.695x^{-0.278}$	R² = 0,9457	$Y = 48.235x^{-0.225}$	R² = 0,9374
60	$Y = 15.727x^{-0.257}$	R² = 0,9425	-	
70	-		$Y = 33.72x^{-0.199}$	R² = 0,9331
90	-		$Y = 25.752x^{-0.177}$	R² = 0,9294

Field efficiency

As shown in Figure 5, for KTP 2M, at cutting lengths of 300 m, for the three yields, the harvester has a field efficiencies of approximately 70% or less. Only the time losses per turning time will be 30%, when adding the other time losses that always occur in the field, the efficiency will be less than 70%. In fields with cutting fronts of 200 m or less, the efficiency is below 60%. The behaviour is the same for CASE IH 8000 (Figure 6) at cutting lengths less than 200 m.

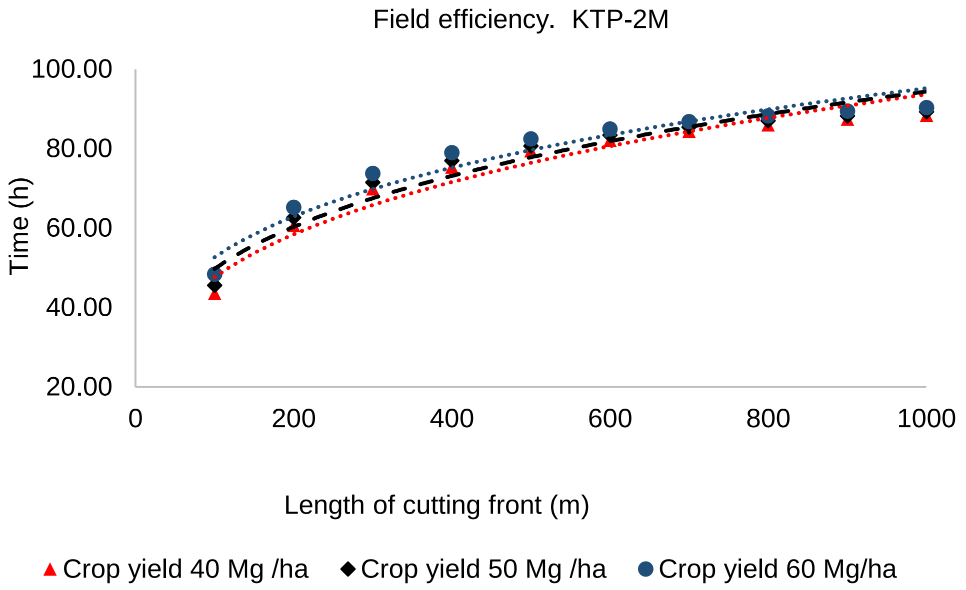

Fig. 5 - Field efficiency for KTP 2M harvester, working on three sugarcane yields and different lengths of the cutting front

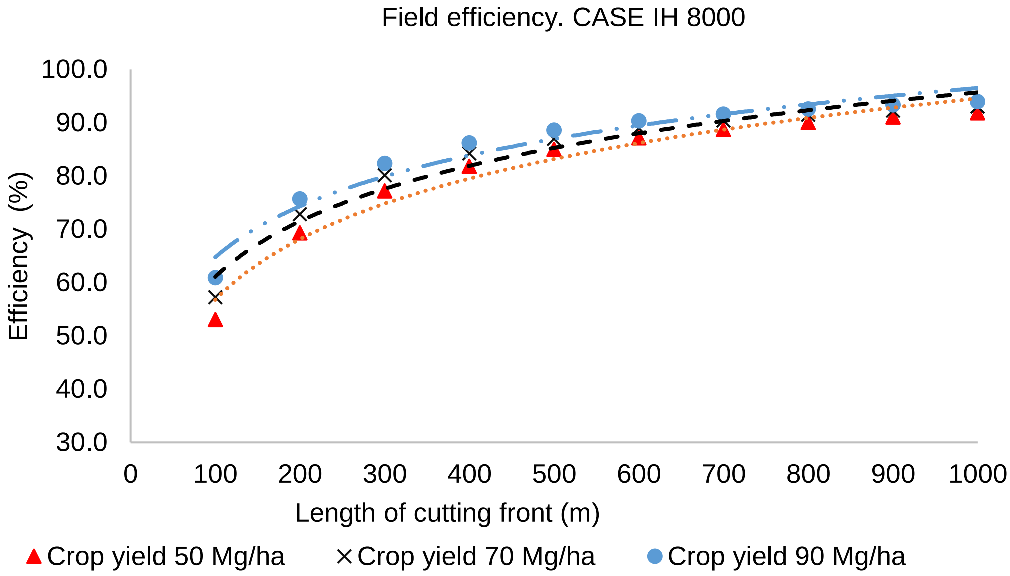

Fig. 6 - Field efficiency for CASE IH 8000 harvester, working on three sugarcane yields and different lengths of the cutting front

For both harvesters, the increases in crop yield modify field efficiency a little; this result could be explained by the narrow range of agricultural yield researched. Although, the greatest difference is found in cutting front lengths up to 400 m, in longer lengths the difference in field efficiency decreases. The length of cutting front increases field efficiency more than agricultural yield. The logarithmic prediction equations were obtained from the trend curves (Table 3), also R^2 of each curve is bigger than 96%, showing excellent fit between measurements and prediction. The typical values of field efficiency in harvesting machines have a range between 65 and 80% (*ASABE D497.5, 2006*). In a review by *Abd-El Mawla and Hemeida (2015)* of sugarcane harvesters, the KTP-1 reported field efficiency of 80%; *Ma et al. (2015)* in harvester John Deere 3522 obtained field efficiencies of 86.2% in energy cane, 80.6% harvesting banagrass, and 59.6% harvesting sugar cane. *Baio (2012)* determined field efficiencies of 80% in a CASE 7700. The authors coincide on the relation of field efficiency with factors such as: manoeuvrability of the machines, skills of the operators and turn time at the headlands. Other factors are the organization of the machines in the field, minimum distance travelled during the turns, the design of the fields, length of the cutting front, irregularly in shape of the fields and low crop yield.

Table 3

Equation of prediction curves for field efficiency

Crop yield Mg ha^{-1}	KTP 2M Equation	R^2	CASE IH 8000 Equation	R^2
40	$Y = 19.279\ln(x) - 42.19$	0,9824	-	
50	$Y = 18.725\ln(x) - 37.431$	0,9797	$Y = 16.41\ln(x) - 18.806$	0,9687
60	$Y = 17.873\ln(x) - 30.458$	0,9757	-	
70	-		$Y = 15.029\ln(x) - 8.1295$	0,9624
90	-		$Y = 13.794\ln(x) + 1.228$	0,9566

CONCLUSIONS

The time lost in cutting task, for harvesters under investigation decreases as increases yield and the length of cutting front up to 500 m, from this length the time lost during turning has an asymptotic behaviour. Similar behaviour was found in time for cutting task; it increases when lengths of the cutting front are shorter. The time for cutting task is also affected by the organization of the harvest and shape of the field. For both harvesters increases in agricultural yield have low impact on field efficiency. On the other hand, the length of the cutting front increases field efficiency more than agricultural yield. The length of the cutting front in a field of sugarcane is a fundamental parameter to achieve high field efficiency of the harvesters. Lengths of cutting front less than 500 m increase time losses. At cutting lengths of 300 m or less, the combines showed a field efficiency less than 70%, reaching 50% in fields of 100 m, which shows the importance of shaping fields with lengths of up to 500 m. Prediction equations were obtained from the trend curves with R^2 greater than 96%, showing excellent fit between measurements and prediction.

REFERENCES

[1] Abd-El Mawla, H. A., Hemeida, B. E. (2015). "Sugarcane mechanical harvesting-evaluation of local aplications", J.Soil Sci. And Agric. Eng., 6 (1): 129-141. https://doi.org/10.21608/jssae.2015.41814.

[2] Adamchuk, V. I., Grisso, R., Kocher, M. F. (2004). Machinery performance assessment based on records of geographic position. *Proceedings of ASAE / CSAE Annual International Meeting*.

[3] Baio, F. H. R. (2012). "Evaluation of an auto-guidance system operating on a sugar cane harvester", *Precision Agriculture*, 13: 141-147. https://doi.org/10.1007/s11119-011-9241-6

[4] Betancourt, Y., Rodríguez, M., Churches C. E., Gómez, J. R., García, I. (2016). "Indexes of three primary tillage implements in soil with mound surface and covering of vegetables residues", *Revista Ciencias Técnicas Agropecuarias*, 25(1): 17-22.

[5] Carroll, J. (2015). *Using Precision Agriculture Field Data to Evaluate Combine Harvesting Efficiency,* Agricultural Education, Communications and Technology Undergraduate Honours Theses. 4.

[6] Daquinta, A., Dominguez, J., Pérez, C., Fernández, M. (2014). "Operating technical indicators for the sugar cane harvesting machines CASE-IH 7000 & 8000 in Ciego de Avila province", *Revista Ingeniería Agrícola*, 4(3): 3-8.

[7] De la Rosa, A. A, Ventura, L., Calzada, I., Suárez, O. (2014). "Valuation of mechanized harvests of the sugar cane process, by means of the harvesters, CASE IH (A 7000), in the Sugar Mill "Arquímedes Colina Antunez", *Revista Ingeniería Agrícola*, 4(4): 30-34.

[8] Diego, F., Herrera, M., González, O. García de la Figal, A. E. (2015) "Performance assessment of two animal traction plough in Oaxaca milpa environment", *Revista Ingeniería Agrícola*, 5(1): 46-51.

[9] González-Cueto, O., Machado-Trujilllo, N., González-Álvarez, J. A., Acevedo-Pérez, M., Acevedo-Darias, M., Herrera-Suárez, M. (2017). "Technological and economical evaluation of the tractor XTZ-150K-09 during soil tillage", *Revista Ingeniería Agrícola*, 7(1): 49-54.

[10] Grisso, R. D., Kocher, M. F., Adamchuk, V. I., Jasa, P. J., Schroeder, M. A. (2004). "Field efficiency determination using traffic pattern indices", *Applied Engineering in Agriculture*, 20(5): 563−572.

[11] Grisso, R. D., Webb, E. G., Cundiff, J. S., Sokhansanj, S. (2013). Parametric Study of Machinery Management Relationships on Forage Equipment. *Proceedings of ASABE Annual International Meeting*.

[12] Hunt, D. R. (1999). "2.5. Cost Analysis", in *CIGR Handbook of Agricultural Engineering Volume III. Plant Production Engineering*. American Society of Agricultural Engineers, St. Joseph.

[13] Jrobostov, S. N. (1977). Operation of the fleet of tractors and machines (Explotación del parque de tractores y máquinas). MIR, Moscú.

[14] Ma, S., Karkee, M., Scharf, P. A., Zhang, Q. (2018). "Adaptability of chopper harvester in harvesting sugarcane, energy cane, and banagrass". Transactions of the ASABE, 61(1), 27-35. https://doi.org/10.13031/trans.12038

[15] Martínez, R., Acevedo, M., Yanes, M. R., González-Cueto, O. (2020). "Operation Indicators of the CASE IH Austoft 8800 sugar cane harvest". *Revista Ingeniería Agrícola,* 10**,** 28-32.

[16] Meyer, E. (1999). Some measurements of mechanical sugarcane harvester performance. *Proceedings of South African Sugar Technology Association*.

[17] Ortiz-Cañavate, J., Barreiro, P., Diezma, B., Garcia, F. J., Gil, J., Moya, A., Ortiz, C., Ruiz, M., Ruiz, L., Valero, C. (2012). *Agricultural machines and their application* (Las máquinas agrícolas y su aplicación). Mundi-Prensa.

[18] Ramos, R., Lora, D. (2013)." Determination of operating and economic parameters in cutting different forage harvesters", *Revista Ingeniería Agrícola*, 3(2): 31-38.

[19] Santos, N. B., Teixeira, M. M., Fernandes, H. C., Gadanha Júnior, C. D. (2018). "Analysis of times and efficiencies of the mechanized harvest of sugarcane (Saccharum spp.)", Nucleus, 15(1), 181-188. https://doi.org/10.3738/1982.2278.2794

[20] Topakci, M., Unal, I., Canakci, M., Yigit, M., Karayel, D. (2010). "Improvement of field efficiency measurement system based on GPS for precision agriculture applications", *Journal of Food, Agriculture & Environment*, 8(3&4): 288-292.

[21] ***ASABE D497.5. (2006). *Agricultural Machinery Management Data,* American Society of Agricultural and Biological Engineers, St. Joseph. Michigan.

[22] ***ASABE D497.7. (2011). *Agricultural machinery management data.* American Society of Agricultural and Biological Engineers, St. Joseph. Michigan.

[23] ***SASA. (1998). Factors to consider when implementing a mechanised cane harvesting system, Information sheet, South African Sugar Association, Durban, SA.