ORIGINAL ARTICLE

Machinery labor fronts. A contribution to management of mechanization in sugarcane production bases

Frentes de trabajo. Una contribución a la gestión de mecanización en las bases productivas cañeras

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ABSTRACT: Mechanization management in sugarcane production bases today faces difficulties such as the obsolescence of machinery with an average age for tractors higher than 30 years. The high dependence on external services, the duality of the harvesting system where external services are received from modern combines. and a park of old machines is operated by sugar cane production bases such as cooperatives, fragmented into teams of very low productivity, which affects the organization of logistics, technical assistance and the use of transportation. This paper theoretically demonstrates the advantages in machinery management achieved by forming labor fronts with the equipment of two or more bases, to jointly harvest the sugarcane areas. Likewise, the advantages of using the fronts as operational centers for other tasks that can be fulfilled with high quality in unison with the harvest or immediately after it is executed. The implementation of the fronts in the 2021 - 2022 harvest is described, resulting greater productivity for the harvesters grouped in the new system and demonstrating the possibility of achieving greater sugar yield.

Keywords: Obsolescence, Dependence, External Services, Harvest.

RESUMEN: La gestión de mecanización en las bases productivas cañeras hoy enfrenta como dificultades la obsolescencia de la maquinaria con edad promedio que supera los 30 años en los tractores, la alta dependencia de servicios externos, la dualidad del sistema de cosecha donde se reciben servicios de cosechadoras modernas y se opera un parque de máquinas antiguas fragmentado en pelotones de muy baja productividad, lo cual afecta la organización de la logística, la asistencia técnica y el uso del transporte. El trabajo demuestra teóricamente las ventajas en la gestión de maquinarias de la formación de frentes de trabajo que agrupen la operación de dos o más pelotones para cosechar en común las áreas cañeras de las bases productivas que los operan. Asimismo, se exponen las ventajas de utilizar los frentes como base de operaciones de otras labores que pueden realizarse con alta calidad al unísono con la cosecha o inmediatamente después de la misma. Se describe la implementación de los frentes en la zafra de 2021 a 2022, lográndose mayor productividad en los pelotones agrupados en el nuevo sistema y demostrándose la posibilidad de lograr un mayor rendimiento azucarero.

Palabras clave: obsolescencia, dependencia, servicios externos, cosecha.

INTRODUCTION

The need to introduce mechanization in Cuban sugarcane production, particularly in the harvest, stands out in statements by the country's main leaders after 1959, this activity being defined by Che Guevara as the "backbone of agriculture" and pointed out by Fidel Castro: "Since we cannot renounce the harvest, which occupies an important place in our economy, there is no other solution than using machines,…" (Castro, 1962).

The First Agrarian Reform Law Gobierno de Cuba (1959) created conditions for an accelerated development of mechanization in the agricultural production bases. The National Institute of Agrarian Reform (INRA), individually gave land only to those

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who already worked it, promoting the formation of cooperatives in the intervened large estates, with sufficient area for a rational exploitation of agricultural machines, the number of which increased rapidly.

The concentration of areas for the management of agricultural machinery allows the formation of a versatile machine park, operating in teams[†] with a greater operating load per team, thus reducing amortization, salary and technical assistance expenses for the use of machinery in general. and particularly in the harvest, where financial expenditures for the use of harvesters, tractors and means of transportation can amount up to a third of those required for sugar cane production (AZCUBA, 2021b). Expenditures for workshop services also decrease, knowing that in countries like Brazil a greaser serves about 21 pieces of equipment, a welder between 39 and 51 and a turner between 105 and 121 IDEA (1999), making these personnel underutilized if they are used in small units.

The search for efficiency in this way led to the formation of organizational units for sugarcane production, including agricultural mechanization, called “districts”, with an area between 2000 and 2500 hectares, divided into “lots” with a net area of 450 hectares, in turn formed by blocks, which are defined as compact areas of 54 to 104 ha Cuellar (2002) destined for the production of cane, with the same variety and subjected to agricultural processes in the same calendar period. Santana et al. (2014) suggest an area of 100 ha for the blocks, as convenient for the operation of the harvesting system. (Santana et al., 2014). With a view to their productive organization, the blocks were subdivided into fields.

At the same time, a network of workshops was developed in accordance with the productive structure.

Jorge (2015) describes the existence of moments of maximum ripening in the development of sugarcane, while Rodríguez (2022) explains how the high variability of the climate in sugarcane producing units puts these moments out of phase with respect to what was planned. Consequently, if the harvesting equipment of a unit operates throughout the campaign, the increase in the number of blocks and area to be harvested defines the number of moments of maximum ripening distributed over time and therefore adds possibilities of operating in fields with high potential sugar yield.

According to AZCUBA (2023), the potential sugar yield of cane is estimated by the expression:

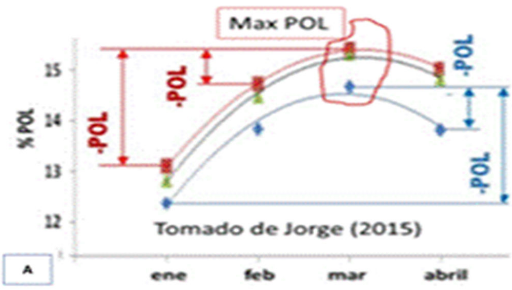

FIGURE 1. Variation of POL in varieties from the CALESA company in Panama.

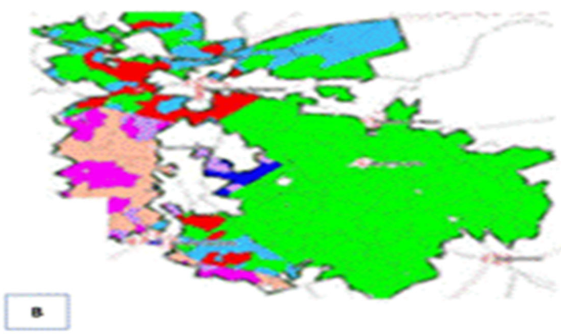

FIGURE 2. Climatic zones of the A. Sánchez company (Information from E. Pérez).

$$RPC = 1{,}5 * POL(1 - (Fiber + 6{,}5)/100) - 0{,}5 * Brix(1 - (Fibra + 3)/100) \quad (1)$$

And the net price of cane according to:

$$PCN = RPC * FF \quad (peso/t) \quad (2)$$

Where: FF is a fixed factor equivalent for year 2023 to 71.89, which determines income considering the RPC of net cane.[††]

Harvesting cane with the highest POL and Brix at the lowest cost summarizes the objectives of planning the harvest machinery and the increase in the number of blocks or moments of maximum ripening correlates with them. In the 90 s, the disintegration of the socialist camp affected the foundations of the Cuban sugar agroindustry, which was not sustainable in a context of low sugar prices in the market. This forced it to increase its resilience, reducing the number of sugar factories to 61, the area destined for sugarcane production to 886,470 ha and the number of tractors and harvesters to about 1.5 units per 100 ha ONEI (2020) with low technical availability due to insufficient renewal, shortage of parts and supplies and progressive decapitalization of the workshop network. Changes were made in the forms of agricultural management and mechanization, reshaping the productive base from mostly state-owned with its management concentrated in districts

[†]Platoon - specialized group of personnel, agricultural machines and technical assistance means that work with the same location, objective and direction.

[††]Net cane - cane without foreign matter.

to mostly agricultural cooperatives. In this way, the advantages of the state form of production on district and company scale, designed for conditions of resource sufficiency, were partially renounced by a new management system, enhancing the sense of responsibility over resources being property of the cooperative members, and greater quality demands for the labors. Figure 3 illustrates the variability of the area of the 1008 productive bases with sugarcane production (AZCUBA, 2022). It shows that in 53.5% of them it does not exceed 540 hectares and in 87% it does not exceed 1080 hectares, which implies a significant reduction with respect to the area of the old districts.

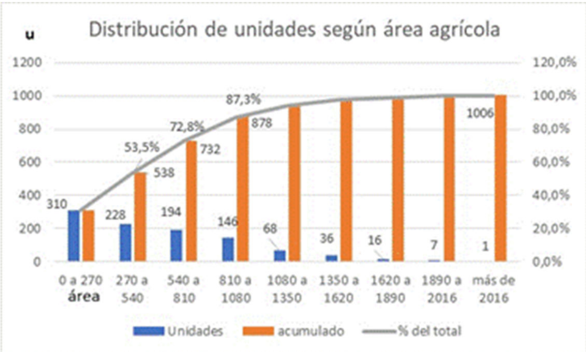

FIGURE 3. Productive units structure of according to their agricultural area.

In 2008, a process of recovery of sugarcane agriculture began, which includes mechanization activity, acquiring new equipment to be operated in the harvest and other activities by state service units, among them: more productive combines Case 7000 models, 7700 and later 8800, along with trucks and trailers with 20 t loading capacity and high-power tractors and modern agricultural implements. This resulted in the creation of a new harvesting system and the formation of machinery specialized groups for farming activities and cultural services. However, the service capacity created with the new combines covered only about 50% of the needs, and the new system had to coexist with the old one, formed by the numerous groups of obsolete KTP2M model combines with very low productivity, which became managed by the productive bases when the districts were fragmented, with a very narrow horizon for programming, limited to the fields that are not harvested with the modern system, in the environment of the cooperative unit that operates them. This makes it difficult to carry out opportunity planning throughout the campaign, where the use of the harvesters coincides with the optimal moment to execute the processes. An example of the dispersion of resources caused by the elimination of the districts is that in the 2020 to 2021 harvest, the operation of 481 KTP2M groups included 85 with a single machine and 340 with two (AZCUBA, 2021a). This not only leads to planning difficulties, it also makes technical assistance and the distribution of parts fuel and other supplies difficult, in addition to affecting transport management.

The lack of renewal of the machinery of the productive bases makes them extremely dependent on the service units, a situation that must change at least in cultivation labors, where there is a preference in the productive bases to carry them out with their own resources (CNCA-AZCUBA, 2020). For this reason, they are gradually being equipped with medium-power Belarus 1025 model tractors and new implements, such as the AZ301 fertilizer cultivator (see Figure 4), which simultaneously carries out fertilization and traditional cultivation and, unlike the implements used until now by these bases, they have a high passage capacity between the stubble of the recently harvested cane.

However, the small areas of most of the cooperatives[†††] makes the organization of machinery groups to carry out labors in addition to harvesting economically ineffective and prevents using the advantages this form of organization represents for the control of activities, technical assistance of equipment, logistical attention and protection of machinery.

FIGURE 4. AZ301 Cultivator Fertilizer.

On the other hand, the rate of harvesting areas by the KTP2M combine harvester teams is very low in comparison with the cultivation teams, which affects the organization of those cultivation activities that should be carried out immediately. after harvest, regardless of the equipment's ability to avoid clogging with residue from that operation. The main objective of this paper is to establish labor fronts that integrate the harvesting teams and other equipment and resources of two or more production bases, including the following tasks.

1. Harvest the area of the units integrated in the front as a whole, achieving with the increase of total area

[†††]CPA - agricultural production cooperative; UBPC - Basic unit of cooperative production. In the CPA, farmers are owners of the land, in the UBPC - usufructuaries.

in plan, an adequate varietal and planting strategy, the increase of alternatives to harvest fields with maximum sugarcane maturity.

2. Increase the productivity of harvesters and reduce harvesting expenses through better use of transportation, together with greater availability and technical security, based on the fact that the concentration of machinery makes technical assistance and distribution of parts and supplies easier.
3. Integrate in the labor front the cultivation activities that must be carried out simultaneously with the harvest or immediately after, which include:
4. The application of hormonal herbicides using the “harvest and apply” method, which consists of installing a sprinkler mechanism on the harvester itself, with the particularity that the herbicides are deposited on the ground when the agricultural residues are still inside the harvester.
   a. Fertilization and first cultivation, considering that the introduction of the AZ301 fertilizer cultivator with high passage capacity and the increase in productivity of the set of machines as a result of the integration of teams, creates conditions for this purpose.

This work does not delve into the third task because:

a. The “harvest and apply” method or system is a technology already evaluated as effective and is in the process of generalization, whose presence in a work front is fully justified.
b. Cultivation and fertilization immediately after harvest is agronomically based by different authors (Martín et al., 1987; MINAZ-Cuba, 2000; Santana et al., 2014), the technical reasons that prevented its application in those conditions are They are eliminated with the formation of the fronts and introduction of the AZ301 high-throughput fertilizer cultivator. The construction innovations that characterize it will be the subject of other works.

Theoretical and methodological fundaments

Figure 5 shows the conception of the front in a block diagram, where the input factors are N1 -the number of harvesters with “harvest and application” systems, N2 - a group of transport resources, the necessary maintenance, direction and fire protection systems. and an AZ301 fertilizer cultivator. As output factors stand the profit for a better price due to harvesting cane with higher sugar content (I1), lower expenses for harvesting and transportation (I2), lower expenses for carrying out chemical weed control together with the harvest (I3). , as well as overall cultivation and fertilization (I4), and benefits from being able to carry out cultural operations at an ideal time (I5) and from facilities in supply and external technical assistance due to the concentration of equipment (I6), all in specific climate, soil and territory conditions.

The main parameter of the front consists of the number of combines (N1). In order to simplify the analysis of its dimensions, the ratio of transport and harvesters (N2/N1) is assumed to be constant, as well as that the described front has a basic level, where the dimensions of the direction, maintenance system, fire protection system are also proportional to the number of harvesters (N1)[††††], as are the expenses incurred in their operation.

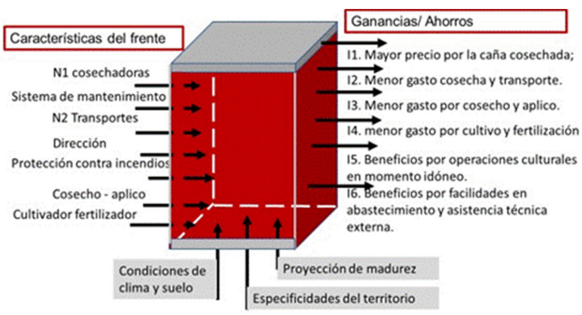

FIGURE 5. The front in block diagram.

Obtained information is not enough to estimate the dimensions of I5 and I6 and therefore they are not considered in this paper, although they appear in the block diagram since their existence is evident.

The dimension of the front is generally established considering the average areas destined for harvest, having reached maximum maturity and this in turn is the result of a planting strategy where distant and nearby blocks are balanced, avoiding transport overloads and considering possible effects of early rainfall on the transit capacity of harvesting and transportation means. In order to obtain lower harvesting expenses on the fronts, the aim is to increase the operating time of the combines, which is the only "measurable" time with the technical limitations of the production base based on knowledge of the total engine hours and transportation hours.

[††††] In a fundamentally cooperative productive base, the fronts are formed by the union of machines from different cooperatives under the conditions that they agree upon and with common use of cane transport, in order to coincide in the areas with greater sugar cane maturity defined in the plan of the company. A higher level of front arises when the parties agree to achieve savings, by reducing other means and equipment by giving common use to existing ones.

$$T_{02} = h \quad motor_{total} - h \quad motor_{transit\ between\ fields} \qquad (3)$$

and in the absence of recording equipment it is easier to estimate. The average value of the set of combines in the front can be expressed as:

$$\sum_{i=1}^{N} T_{02i} = \sum_{i=1}^{N} h \quad motor_{total\ i} - \sum_{i=1}^{N} h \quad motor_{ttransit\ between\ fields\ i} \qquad (4)$$

The operational effectiveness criteria (E_{02}) is proposed, which is equivalent to the relationship between operating time and exploitation time or productivities in both times.

$$E_{02} = \frac{T_{02}}{T_{07}} = \frac{W_{07}}{W_{02}} \qquad (5)$$

Where W_{02} y W_{07} – , productivity in operational and exploitative times respectively.

So, the productivity in exploitative time becomes:

$$W_{07} = W_{02} \times E_{02,} \quad t/h_{exploitation} \qquad (6)$$

By forming the front it is estimated to obtain a greater value of $E_{02,}$ due to the facilities obtained by concentrating machines regarding supply and external technical assistance, as well as better use of transportation.

It is necessary to point out that an excessive increase in the dimension of the front leads to an increase in travel time, affecting operating time and productivity in exploitation time, which subtracts operating time and can contribute to the opposite effect, reducing $E_{02,}$ and consequently I2, which is admissible as long as this reduction is compensated by increases in I1, I3, I4. considering that:

$$(I1 + I2 + I3 + I4) \rightarrow Max \quad (peso/t) \qquad (7)$$

The front as a facilitator of increased operational effectiveness

The system of harvesting and supplying cane to the sugar mill can be considered as part of a chain production system, where according to Rodríguez-López et al. (2020) [16], citing Kletskin, Pavlovki, Saakian, Finov and Tsinan, Jodosh, Zhalnin, Puskariov and Iglesias, a system of this type with several links, requires that the following expression on flow continuity be fulfilled:

$$X_1 \leq X_2 \leq X_3 \leq X_4 \qquad (8)$$

In these: X_1,X_2, X_3, X_4, are equivalent to the average productivities of each link in the system at each moment of the day, which are equal to the sum of the productivities of the set of j pieces of equipment intended for the same purpose.

$$X_i = \sum_{j=1}^{n} W_{ij}$$

From them: X_1 – harvest productivity; X_2 – transportation productivity in the field to the cleaning center; X_3 –in the cleaning center; X_4 - on the railway.

The concept of equal or higher productivity in successive stages$X_i \leq X_{i+1}$, defines the system's capacity to face eventualities.

Expression (8) presents a limited vision of the requirement of balance since it does not analyze the variation in productivity in the links due to the preceding link and the first link - the harvest.

The combine´s principal-time productivity can be expressed as:

$$W_1 = 0{,}1 * V_C * B * R_a \quad (\mathrm{t/h}) \qquad (9)$$

Where: V - working speed; B - working width; R_a - agricultural performance.

Productivity in operation time can be defined as:

$$W_{02} = 0{,}1 \times B \times V_c \times R_a \times K_{02} \quad (\mathrm{t/h}) \qquad (10)$$

Where: K_{02} - coefficient showing the relation of principal and operation times. $K_{02} = \frac{T_1}{T_{02}}$

In turn, productivity in exploitation time is expressed as:

$$W_{07} = 0{,}1 * V * B * R_a * K_{07} \quad (\mathrm{ha/h}) \qquad (11)$$

Where: K_{07} - coefficient for the use of exploitative time, relating principal and exploitative times. $K_{07} = \frac{T_1}{T_{07}}$

T_1, T_{02}, T_{07}, K_{02}, K_{07}, correspond as symbols with current standards and procedures (Iagric:-Cuba, 2013).

An analysis of expressions 9, 10 and 11 shows the high variability of X_1, given that:

a. Working speed of the combines depends on the relationship between the cane mass input capacity that the machine allows with its working width and the agricultural yield Matos-Rodríguez (2012); Matos-Ramírez et al. (2014), which generally ranges between 15 and 80 t/ha and the preparation of the field to ensure the cutting quality Díaz (2011); Norris (2014), which is generally unsatisfactory.

b. K_{07} depends on very diverse factors such as the conformation of the fields, the technical and technological safety of the equipment and maintenance times, in addition to the humidity of the environment and the level of weeds, factors of work organization and availability of transportation to unload the mass of harvested cane, which may be insufficient.

Considering the above, expression (8) must take the form:

$$(\overline{X_1} + \Delta x_1) \leq (\overline{X_2} + \Delta x_2) \leq (\overline{X_3} + \Delta x_1) \leq (\overline{X_4} + \Delta x_4) \quad (12)$$

Harvest	Transportation to Cleaning Center	Process Center: Cleaning	Rail transport

For 95% of the events in a normal distribution, the productivity deviation in a platoon of "n" machines are within a predictable limit by integrating the standard deviation of the productivity of the different machines.

$$\Delta x_1 \leq 2 * \sigma_{xp} = 2 * \sqrt{\sigma_{xa1}{}^2 + \sigma_{xa2}{}^2 + \sigma_{xa3}{}^2 \ldots\ldots \sigma_{xan}{}^2} \quad (13)$$

Similarly, the deviation of the productivity of the group of harvest teams and therefore of the harvest productivity, which must be assimilated by the rest of the links in the production chain can be estimated as:

$$\Delta x_1 \leq 2 * \sqrt{\sigma_{xp1}{}^2 + \sigma_{xp2}{}^2 + \sigma_{xp3}{}^2 \ldots\ldots \sigma_{xpn}{}^2} \quad (14)$$

Considering an ideal condition, where all platoons work in a close area, the amount of transportation required to assimilate the maximum expected variation in productivity would be:

$$\Delta x_{2.1} \geq TU * 2 * \sqrt{\sigma_{xp1}{}^2 + \sigma_{xp2}{}^2 + \sigma_{xp3}{}^2 \ldots\ldots \sigma_{xpn}{}^2} \quad (15)$$

Where: TU is the amount of transportation required per unit of mass harvested.

However, if the teams work in areas not close to each other, then the transport must compensate for the variations of each independent team:

$$\Delta x_{2.2} \geq TU * 2 * (\sigma_{xp1} + \sigma_{xp2} + \sigma_{xp3} + \sigma_{xp4}) \quad (16)$$

Being evident that: $\Delta x_{2.2} \geq \Delta x_{2.1}$ so, that the grouping of teams in fronts, where this is possible, allows a balance of machinery with a smaller amount of transport and consequently greater operational efficiency.

By forming labor fronts, it is possible to reduce the moments of failure, where transportation is paralyzed due to being no harvesters available.

If the harvesters are: **Operational** or **Non-Operational** and the probability of occurrence of both events in a machine is known: Pr("operational") and Pr("non-operational"), then the probability of a combination x with i operational machines in a team of N machines would be:

$$\Pr(i\ operational) = \Pr(\text{"operational"})^{i} * Pr\ (\text{"non operational"})^{N-i} \quad (16)$$

The set of possible combinations with operational and non-operational machines in a team of N machines is:

$$C = 2^{N-1}$$

The probability that i equals the number of operating machines, considering the total number of combinations with these characteristics is:

$$Pr\ \ total(i\ \ operational) = \sum_{x=1}^{j} Pr\ \ (i\ \ operational)_x \quad (17)$$

Where: j is the number of combinations with i operating machines.

The graph in figure 6 illustrates the above said, where pton equals team.

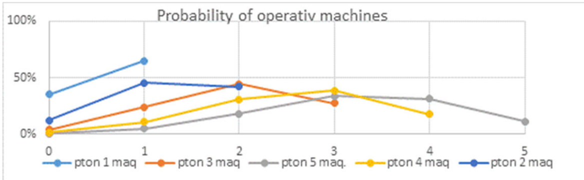

FIGURE 6. Probability of having operational machines

It is built, considering that the lack of technical availability, breakages and the execution of maintenance occupies 35% of the combine's working day, observing that if the team is made up of a single isolated machine, the probability of not being operational is 35%, if it is two - the probability that none is available is 12.25%, if it is three - 4.29% and if it is five - 0.53%.

Evaluation methodology

In order to evaluate the benefits of integrating harvest teams into fronts, during the 2021 to 2022 harvest, a set of tests were carried out at Antonio Sánchez EAAZ, forming three labor fronts and maintaining two productive bases without integration as in the previous campaign

Front 1 Bases Antero Reglado + Regadío. Área with s. caña - 2034 ha.

Front 2 Bases Desquite + Rev. de Octubre. Área growing s, cane - 2053 ha.

Front 3 Bases Victoria + Chapeo. Área con caña - 2365 ha.

Team 1. Base Vietnam. Área con caña - 2034 ha.

Team 2. Base 21 de Septiembre. Área con caña - 2034 ha.

Witness 2

The attached table shows the equipment that both the fronts and witnesses had.

The aspects evaluated were the following:

Fronts formation to increase sugar cane yield at harvest time.

TABLE 1. Equipment of fronts and witnesses

Equipo 	**Frente 1 - Antero Regalado +Regadío**	**Testigo 1. Vietnam**	**Testigo 2. CPA 21 de Septiembre**	**Frente 2. -Desquite + R. Octubre**	**Frente 3. -Victoria + Chapeo**
Harvesters KTP2M	5	3	2	5	5
Trucks	10	5	2	7	9
truck trailers	10	5	3	7	9
moving tractors	2	2	1	2	3
daily cutting task	500 t	500 t	140 t	380 t	520 t

The potential sugar yield of cane was compared in the fortnights of January and February of 2021 and 2022 based on laboratory tests of the plantations in the planning phase of their harvest, determining the POL, Brix and amount of fiber and calculating their potential performance by expression (1). What was done constitutes a two-level evaluation. Level A represents the results of harvesters working in 2021 without forming teams. The average cane surface of all units within independent teams turned to be 1262 ha.

Level B represents the results of harvesters working in 2022. Average Cane surface of the units that took part in the 2022 campaign, turned out to be 2062 ha with an increase of 63%. where those that formed fronts were considered as a single unit.

The actual performance of the mill was not analyzed, as it was seriously affected by factors unrelated to the harvest schedule.

Evaluation of the exploitation of harvesting machinery.

The results in the exploitation of harvesters forming fronts and team's machinery was compared based on four parameters:

a. The average productivity of the combines per workday
b. The technical availability of the machines 'according to $DT = 100 * \frac{d_r}{DE}$, relating actual work days of the combines versus effective days.
c. Operational efficiency of combines (E_{02}) according to expression (5).
d. The relationship between the time lost due to transportation and the mass harvested, considering it as a productive dimension of the group of machines.

Data obtained was subjected to simple variance analysis.

Economic Impact Assessment.

Economic impact is analyzed from the profit obtained by comparing the price of cane according to its RPC in 2022 and 2021 according to expression (2) and from the greater productivity of the machines at the same time, considering the established hourly rates (3).

RESULT AND DISCUSSION

The formation of labor fronts significantly increased the possibility of harvesting cane with a higher degree of ripeness by the CPA and UBPC that formed these fronts. Figure 7 compares the POL, Brix and Fiber obtained in the two fortnights of January and the two of February of the year 2021 and 2022, also presenting the calculation of the RPC, which turned out to be 2.15 points higher in the first half of January and between 1.19 and 1.35 points in the rest, demonstrating the goodness of planning the harvest when the total area to be harvested by a given group of machines is greater. The possibility of a bias in the results due to climatic differences in the years compared was assessed, proving that in the stage before the harvest and in the months of January and February they were similar.

The conditions in which the 2022 campaign was developed with a lack of fuel, lubricants, mechanical components, in addition to industrial failures make it difficult to accurately evaluate some advantages to be obtained by the grouping of harvest platoons as a better use of technical assistance and logistics. However, in the conditions of the harvest itself at Antonio Sánchez EAAZ, where the available transportation ranged between 50 and 75% of that defined in the pre-harvest balance, the probabilistic analysis carried out when theoretically basing the constitution of the fronts, associating or merging the small platoons was effective. There was a consensus among the managers that without the formation of fronts the mechanized harvest of 2022 in that company would have had great difficulties. Figures 8 (a, b) show the advantages in productivity and technical availability of the fronts compared to the control platoons in 2022.

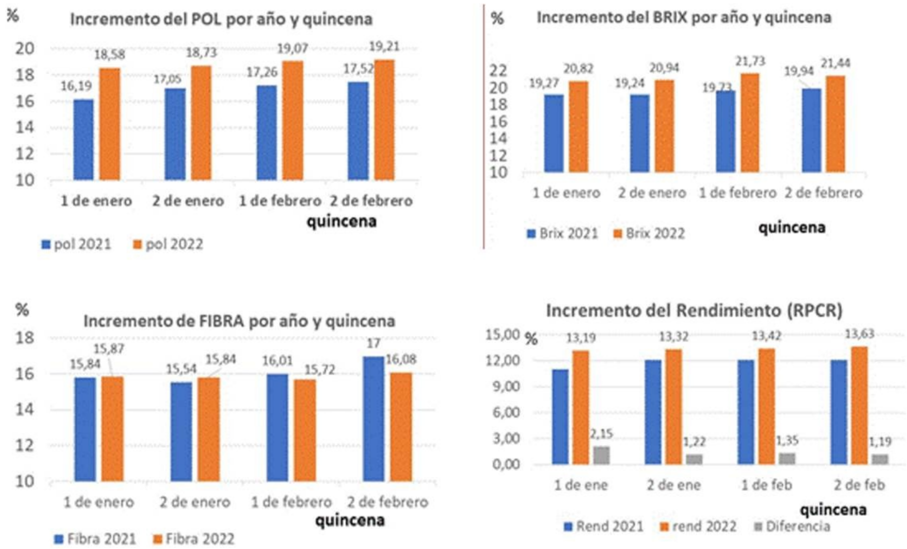

FIGURE 7. Increase in the potential yield of the cane.

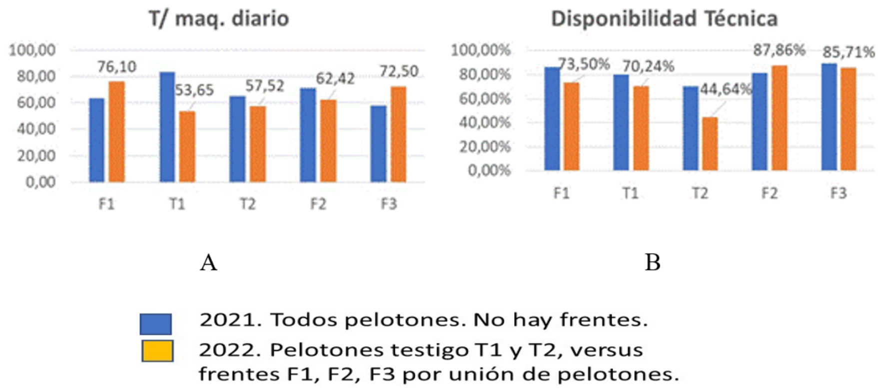

FIGURE 8. Comparison of fronts and witnesses.8A compares productivity per day; 8B compares technical availability.

On February 2021, when the UBPC and CPA that made up the new fronts operated independently, the first place in machine productivity (t/day - machine in operation) and production per machine (t/machine) corresponded to witness T1. (UBPC Vietnam) formed in both the 2021 and 2022 campaigns by a single platoon of three machines, while in the 2022 campaign the best results were obtained by the 1st, 4th and 5th fronts formed by uniting platoons of units with five and four harvesters respectively, relegating the witnesses made up of isolated platoons.

FIGURE 9. Comparison of the Operational Effectiveness of fronts and teams.

In turn, figure 9 compares the operational effectiveness of teams and fronts, highlighting front 1 with $E_{02} = 0.48$. All fronts evaluated had an operational efficiency 3% to 15% higher than that of the best control team (UBPC Vietnam).

An important cause of the changes in the positioning of the fronts lies in a better use of transportation, which as demonstrated significantly influences operational effectiveness. Table 2 illustrates this by showing the time lost due to transportation of fronts one and three and control T1. The table provides data on the total time lost, relating it to the cane harvested given that these are groups with different work results.

As a result of the increase in RCP shown in Figure 7, with the formation of fronts a higher price

TABLE 2. Stop time due to lack of transportation

Evaluated parameter	Fronts and witnesses		
	A. Regalado + Regadío (F1)	Vietnam (T1)	Victoria + Chapeo (F3)
Fronts and witnesses (t)	14881,7	7596,12	15230
Hours lost due to transportation	398:57:12	225:50:12	286:30:00
Ratio of time lost due to transportation/harvested mass	0:01:37	0:01:47	0:01:08
Percentage advantage	9,83%	---	36,73%

for sugarcane was estimated. Figure 10 shows a comparison of the months of January and February for the two campaigns evaluated. The additional potential income (IPA) from the sale of net cane for the productive bases in 2022 was 85 to 154 pesos/t with an average value of 119 pesos/tcn. Assuming 15% impurities, this would be 101 pesos per ton of raw cane.

Considering the experimental results, for a yield of 30 to 40 t/ha (average value 35 t/ha), if E_{02} =0,42, it can be estimated that $W_{07} =$ 6,9 t raw cane/h with 15% foreign matter, which considering the hourly rate of the harvester AZCUBA (2021 b) [3], leads to an expense of 80.8 pesos/t gross cane (tcb) and 95 pesos/t net cane (tcn). The experimental results show that the fronts allowed an increase in operational efficiency between 2.8% and 13.5% compared to the best indicator of the control platoons, which is directly reflected in the productivity of the combines. Likewise, the increase in the latter according to the data reflected in figure 8 ranges between 8 and 32%, where the performance of the fields influences.

Considering that the activity in fronts allowed an increase in productivity of 8%, there is an expense per ton of raw cane of 74.8 pesos with a reduction of 6 pesos/tcb and 88 pesos per net ton for a reduction of 7 pesos. /tcn, which can be considered as minimal impacts of the use of harvesters on fronts, which taken to harvested area is equivalent to 245 pesos/ha.

It can be seen that the income from better harvest scheduling is between 5 and 15 times greater than that obtained from better exploitation of the machinery.

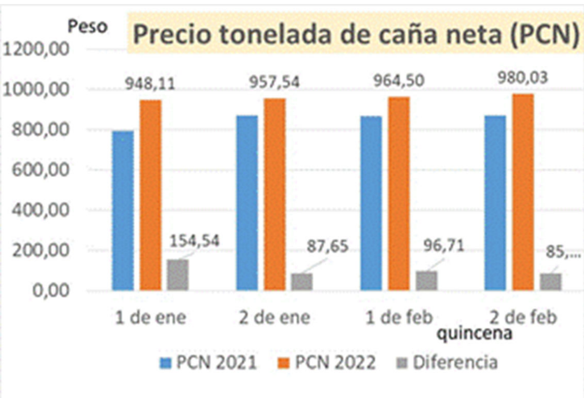

FIGURE 10. Comparison of income per net cane.

CONCLUSIONS

- The theoretical and experimental investigations showed the effectiveness of the work fronts in harvesting the cane with greater maturity, achieving the harvest with a RPC of the cane higher by 1.19 to 2.25 points compared to the platoons.
- KTP2M combines operating in fronts turned out to be between 8 and 32% more productive than those grouped in teams, achieving greater technical availability and operational efficiency, in addition to better use of transportation, higher technical availability, consequently higher operational efficiency.
- As a result of the formation of fronts, additional income of 101 pesos/t gross cane or 119 pesos/t net cane is estimated due to higher sugar yield and of no less than 7 pesos/t net cane and 6 pesos/gross cane due to the increase in machine productivity.

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