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Yields and economic results of sugarcane cultivation under an alternative system compared to traditional management

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Abstract In the traditional method of managing sugarcane in Argentina, the entire field where the crop will be planted is severely ploughed, requiring large amounts of energy. In addition, during the subsequent maintenance tasks, furrows are worked at depth, reducing their yielding capacity and making them more vulnerable to traffic from farming equipment, harvesters and heavy trucks. The use of this system during prolonged periods of monoculture affects the soil physical integrity, compromising yields and the efficient use of the inputs. It was necessary, therefore, to develop an enhanced alternative management system to the traditional one in order to revert, stop or mitigate soil deterioration and improve crop economic results. A possible solution was to use energy only where it could be harnessed by the roots of the crop and maintain, without disturbing, the traffic lanes throughout the cane cycle. In order to implement this form of controlled-traffic management, an experimental scarifier for deep strip-tillage was developed and manufactured. Since 2013, trials have been carried out at EEA INTA Famaillá (Tucumán) comparing both cultivation technologies. Results indicate that, during the cane production stage, fuel consumption, energy requirements and operating times and costs can be reduced by 60-70% with this new management system. The average gross margin over five harvests was approximately 15% than that of the traditional management system, due to an increase in yields and fewer maintenance tasks required by the new technology. The new system is presented as less operationally complex, economically profitable and a more sustainable management alternative.

Key words Crop management, strip-tillage, sugarcane, sustainability, economics

INTRODUCTION

Crop management in Argentinian sugarcane continues being done in a conventional way, contrary to the majority of other crops grown in the region. Soil physical integrity has been affected by high tillage intensity and the use of heavy machinery during the harvest, as well as sustained periods of monoculture (Pankhurst *et al.* 2003; Rodríguez and Valencia 2012). Soil degradation has altered several basic processes, generating negative impacts. Reduction in soil macro-porosity has a negative effect on the dynamics of air, water and nutrients, and increases the emission of greenhouse gases (GHG) (Picone *et al*. 2015; Estévez 2016). Furthermore, the reduction in soil infiltration rate increases the risk of water erosion and nutrient losses, leading to low efficiency in the use of fertilizers. Moreno Seceña *et al.* (2016) report that, in the last 15 years, the application of nitrogen fertilization increased by 60% without an increase in cane yield.

Organic matter content has a determinant role in the conservation of the mechanical properties of soils. In fine textured soils, predominant in the Cuban sugarcane industry, a reduction of the easily oxidizable carbon makes them more susceptible to damage during tillage and they have lower capacity to support the loads applied by the machinery (Villazón-Gómez *et al*. 2017).

In Argentinian sugarcane fields, sub-superficial cone indexes greater than 6 MPa (10 cm depth) and specific drafts around 200 kPa have been measured (Tesouro *et al.* 2011). These force an increase in energy demand and fuel consumption of the mechanical planting and cultivation of sugarcane crops. According to Sopena and Terán (2008) the average fuel demand for sugarcane reaches 230 L/ha of diesel per year. Hence, sugar production presents a low-efficiency energy balance. INTA's analysis of the ethanol industry shows that Argentina produces approximately three energy units per energy consumed, while in Brazil this ratio approaches 8:1 (FMAM-5 PIF-INTA 2018).

Therefore, it was necessary to develop an alternative mechanical management system that reverses, stops or mitigates soil deterioration and improves the economic results of canegrowing. At the same time, due to lack of soil porosity, it is necessary continue some tillage, but with a lower intensity to avoid the deterioration of the resource and decreasing energy consumption. Hence, it was proposed to apply energy only to the area where the crop roots grow. Thus, an experimental prototype for deep strip tillage was designed, developed and built. Since 2013, an alternative cropping system has been tested at EEA INTA Famaillá, Tucumán. This paper presents the results obtained regarding energy consumption, crop yields and economic outcomes.

METHODOLOGY

Two cultivation systems were tested from 2013 in an area with Argiudol soils at the EEA Famaillá, Tucumán, Argentina (27°00'52.58"S, 65°22'46.78"W, 750 metres above sea level) with a long history of monoculture of sugarcane using the traditional management system of the area. The treatments were conventional management (Treatment 1) and deep strip-tillage management (Treatment 2).

At the beginning of the trial, the experimental area had stubble from a soybean crop planted in 2011 over a sowing bed tilled with an offset disk harrow and a chisel plough. In treatment 1, conventional soil preparation was carried out with the following tasks: one pass of an offset disk harrow (22 disks of 610 mm diameter), two passes of a subsoiler (four shanks, 0.80 m separation between shanks, with 100 mm winged tips), a second tillage operation with the same offset disk harrow, furrowing and planting. Subsequent operations followed traditional management, consisting of chemical and mechanical control of weeds, fertilization and deep tillage of the earth furrows (inter-rows) during the crop cycle. In treatment 2, a deep tillage (only in the area where the furrows were later shaped to place the stalks) was carried out. The tillage technique used, known as strip-tillage, was carried out using a deep tillage unit (Figure 1) designed and developed in the Terramechanics and Crops Implantation Laboratory (IIR INTA). This prototype has four rigid shanks, which work together narrow sections of soil at increasing depths maintaining without disturbing the space between them (earth furrows) from the beginning and throughout the crop cycle, with the exception of the surface layer cultivation required for the mechanical control of weeds and fertilization that were carried out in a single operation. In the two management systems (treatments), the same types and dosage of agrochemicals and fertilizers were used, and stubble was not burnt.

Figure 1. Experimental prototype unit for deep strip-tillage.

The traction demand of the operations was determined using an electronic load cell of 5000 kg. Draft force data was taken at 1-second intervals. Time and distance travelled was recorded in order to determine the equipment's effective forward speed and the power demanded from the tractor on the drawbar. The energy per hectare required to perform each task was calculated. Subsequently, energy was converted to fuel consumption in litres per hectare, using a model developed in our laboratory. This model considers the type of tractor used, its tractive efficiency and the thermodynamic performance of the engine. The consumption by unit of time obtained was transformed to an area unit (hectare) according to the working capacity of each machine. Before these measurements, the bulk density, gravimetric humidity, soil resistance profiles and micro-topography were surveyed.

Based on the results obtained in the tractive force measurements, the appropriate machinery was determined for medium-sized farms for both conventional and strip management systems, in order to calculate and compare their operating costs. The expected crop cycle was that used locally, consisting of a soybean crop between cane cycles of five years. In both treatments, it was considered that soybean would be planted in a conventional manner and with the same sequence of operations. Due to its general use and simplicity in the calculations, it was assumed that machinery contractors would carry out the planting and mechanical harvesting of the cane. The cost calculation was made following the Argentinian conventional methodology (Frank 1995) considering the actual market values of different machines in new and used condition with the age equivalent to half of its useful life.

Annual yield in each plot (18 rows separated by 1.60 m and 50 m long) was estimated by counting the number and measuring the weights of stems. To count the number of stalks, six rows per plot were chosen randomly. In each one of them, 5 m was marked and the total number of the stalks was counted. The data was converted to stalks per meter of furrow (stalks/m). The weight of the stalks was determined by selecting 10 representative stalks at each sampling site. The stalks were cut, cleaned and weighed. This data was converted to weight per stalk (kg/stalk). Cane yield was calculated for 6000 linear meters of row per hectare. After sampling, the plots were harvested mechanically in a conventional manner. The sum of the yields of the sugarcane plant crop (2014) and those of first to fourth ratoons (between 2015 and 2018) were divided by the number of years in order to determine the average yield (t/ha/year) for the calculation of gross margins.

Gross margins were calculated using a gross income of USD14.75/t for cane delivered to the mill. Planting, harvesting and transport services, inputs used for the crop and direct machinery costs were deducted from the gross income.

We used a randomized complete-block (RCB) design with three replicates of each treatment. Statistical analysis of the results used an ANOVA.

RESULTS AND DISCUSSION

The initial gravimetric soil moisture was 28.8% and the profile strength was 1759 kPa, thus it was necessary to use a 118-kW tractor to subsoil at an effective depth of 0.3 m at an effective speed of 4.5 to 4.8 km/h. The unitary tractive demands were 1132 daN/shank and 882 daN/shank in the first and second passes, respectively, and in both cases, the specific draft remained in the order of 111 kPa.

The sum of the energy required by the subsoiling and the harrowing equipment for soil preparation in treatment 1 was 114 kWh/ha, with a fuel consumption of approximately 61 L/ha. In treatment 2, a 59-kW tractor was used to carry out the work with the prototype unit at an effective speed of 4.2 km/h, demanding a force of 1237 daN to plough a section of soil (strip) of 0.50 m wide by 0.50 m deep. The specific draft was reduced to 66 kPa, being almost half of that used with the subsoiler in treatment 1. Only 14.5 L/ha of fuel and 24 kWh/ha of energy were required to prepare the soil for cane planting. Differences in energy needed between treatments in order of decreasing importance were due to partial tillage of the area where the crop was to be planted, fewer tasks and increased deep-tillage efficiency.

In addition, in treatment 2, the deep tillage of earth furrows was eliminated. The main reasons for this change was to improve soil conservation and obtain better traffic conditions for the cultivating and harvesting machinery. Therefore, the first tillage with the disk (triple equipment) could also be eliminated, as its main objective is to reduce the amount of stubble and reduce jamming of the scarifiers (chisels or subsoilers) used for the subsequent deep tillage. By not performing these tasks, the energy demanded in the cultivation stage was approximately 32 kWh/ha less than with conventional management.

Differences in the demanded energy, for planting and tillage stages, were important between treatments. Treatment 1 used two tractors to carry out the planned work, while for treatment 2, only one tractor was enough, although it has been necessary to increase the power to 66 kW to carry out the tillage with chisel ploughs in the soybean seedbed preparation.

Table 1 summarizes the sequence of tasks and the main operating results for both treatments. Note that in case of the soybean crop there are differences only in the tillage operation time because the work widths were adapted to the power of each tractor, but the machine type and working conditions were kept constant, in accordance with the results obtained at Famaillá. Figure 2 shows the average annual direct costs corresponding to cane fields ranging from 100 to 300 ha. Differences between treatments fluctuated between 50 and 100 USD/ha per year. Maximum costs were for field sizes of 100 ha, corresponding to the transition zone between small and medium producers. Within productive units less than 150 ha, there may be surplus power in the machinery when using conventional management.

Mechanization Index (IM) relates power and area and is useful to determine the size of the field machinery needed. IM for traditional sugarcane tillage fluctuates between 1.18 and 1.77 kW/ha and seems excessive for this system of cropping. In this situation, different strategies to reduce costs could be evaluated. Some of them would be: take advantage of the idle capacity of the equipment to provide services to third parties; contracting the subsoiling service, which would allow to reduce the power of the main tractor reducing it to the tillage machines working widths; or eliminate the main tractor and contract all the tillage. When evaluating the convenience of replacing the farmer's own machinery by contracting, the influence of the timing and quality of work done on the economic performance of the farm should also be considered. With the Strip-tillage management, these alternatives are not necessary, since the IM reaches 0.66 kW/ha for farms of 100 ha and all the work can be carried out with on-farm equipment at low cost.

Table 1. Equipment used and operating results for both treatments.

Traditional management						Strip-tillage					
Soybean crop											
Field operation	Tractor	Energy kWh/ha	F. C. L/ha	O. T. h/ha	Passes Nº/ha	Field operation	Tractor	Energy kWh/ha	F. C. L/ha	O. T. h/ha	Passes Nº/ha
Grubbing up(1)		13.92	6.8	0.39	1	Grubbing up(10)		13.92	6.8	1.16	1
Harrowing(1)		16.63	8.1	0.50	1	Harrowing(10)		16.63	8.1	0.94	1
Chiselling(2)	118 kW	32.52	17.8	0.60	1	Chiselling(11)		32.52	17.8	0.95	1
Chiselling(2)		29.27	16.0	0.58	1	Chiselling(11)	66 kW	29.27	16.0	0.92	1
Harrowing(1)		23.73	11.6	0.39	1	Harrowing(10)		23.73	11.6	0.73	1
Sowing(3)	59 kW	12.15	5.9	0.43	1	Sowing(3)		12.15	5.9	0.43	1
Spraying(4)		2.13	1.5	0.24	4	Spraying(4)		2.13	1.5	0.24	4
Harvesting		Contractor				Harvesting		Contractor			
Plant-cane crop											
Field operation	Tractor	Energy kWh/ha	F. C. L/ha	O. T. h/ha	Passes Nº/ha	Field operation	Tractor	Energy kWh/ha	F. C. L/ha	O. T. h/ha	Passes Nº/ha
Harrowing(1)		15.98	9.6	0.42	1	Strip-tillage(12)	66 kW	23.96	14.5	1.67	1
Subsoiling(5)	118 kW	44.14	21.5	0.81	1						
Subsoiling(5)		34.36	18.3	0.76	1						
Harrowing(1)		19.32	11.3	0.42	1						
Planting		Contractor				Planting		Contractor			
Cultivating(6)	59 kW	8.65	6.0	1.16	2	Cultivating(6)	66 kW	10.81	6.8	1.16	1
Spraying(4)		2.13	1.5	0.24	2	Spraying(4)		2.13	1.5	0.24	2
Ratoon crop											
Field operation	Tractor	Energy kWh/ha	F. C. L/ha	O. T. h/ha	Passes Nº/ha	Field operation	Tractor	Energy kWh/ha	F. C. L/ha	O. T. h/ha	Passes Nº/ha
Cultivating(7)	59 kW	9.73	6.4	0.73	1	Fertilizing(9)	66 kW	12.16	7.0	1.09	1
Cultivating(8)	118 kW	22.00	11.6	0.89	1	Spraying(4)		2.13	1.5	0.24	2
Fertilizing(9)	59 kW	11.19	6.8	1.09	1						
Spraying(4)		2.13	1.5	0.24	2						
Harvesting		Contractor				Harvesting		Contractor			

Notes: F.C. fuel consumption per hectare; O.T.: operating times; (1) offset disk harrow with 32 disks 24"; (2): chisel plough with 11 shanks at 0.28 m (3) single seed drill, 7 row units at 0.70 m; (4) field crop sprayer of working width 6.40 m (5) subsoiler with 4 shanks at 0.80 m; Cultivation (6): ridge lowering and weed mechanical control with a ploughing equipment of 12 disks in four units plus a fertilizer accessory (*triple equipment*); Cultivation (7): earth furrow cultivation and stubble chopping with the triple equipment; Cultivation (8): deep tillage of the earth furrow with chisel cultivator of 6 shanks; (9): triple equipment; (10) offset disk harrow 22 disks 24"; (11) chisel plough with 7 shanks at 0.28 m; (12) prototype for deep strip-tillage.

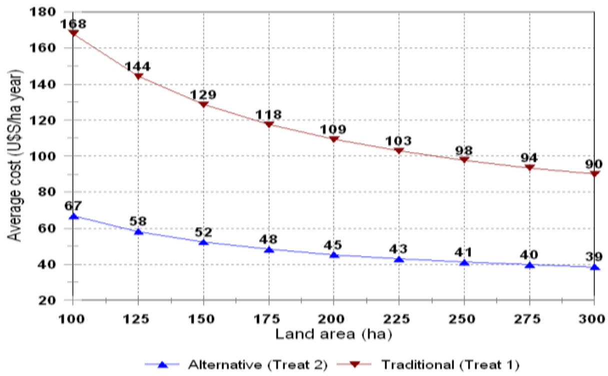

Figure 2. Average annual direct cost of machinery for different sugarcane field sizes.

IM differences between treatments for all field sizes gives a measure of the increase in mechanization efficiency. Another comparison is the differences between treatments for similar IM values. An IM of 0.66 kW/ha for the alternative strategy (100 ha) is the same as for a field size in conventional management of 275 ha (0.64 kW/ha). The average annual cost is still higher in conventional management, although differences were reduced to USD26.7/year.

However, the operating times and the annual worked area (which can be calculated with the information in Table 1) must be considered. In a 275-ha field under conventional management, 1650 ha are worked each year, which implies 971 hours of machinery use, with 351 hours using the tractor of 118 kW and 620 hours with the 59 kW. According to the work schedule, 65% of the annual use of the second tractor, corresponding to 403 hours, must be carried out between the second half of August and the end of October. Conversely, when dealing with 100-150 ha under conventional management, this IM of 0.64 kW/ha is now difficult to achieve, since the work needed may not be possible in the available times. With the alternative management, in a field of 275 ha, 1100 ha are worked each year, a reduction of 1/3 in the worked area. The annual use of the tractor is 648 hours and, maintaining the same work schedule, 48% of the total time is in the critical period, equivalent to 311 hours. The difference between the two systems of management represents 9 days each of 10 hours of work.

From 2014 (cane plant) to 2018 (fourth ratoon), 424.0 t/ha were harvested in Treatment 1 and 431.4 t/ha in Treatment 2, resulting in average yields of 84.8 t/ha/year for conventional management and 86.3 t/ha/year for the alternative – these were not significantly different. Gross income was USD1250.8/year and USD1272.6/year, respectively. The inputs and services used for the planting and maintenance were identical in both treatments, an average value of USD183.3/year. Harvest and transport costs were USD461.3/ha and USD469.4/ha for treatments 1 and 2, respectively. Figure 3 shows the gross margins and the annual income obtained with the management systems.

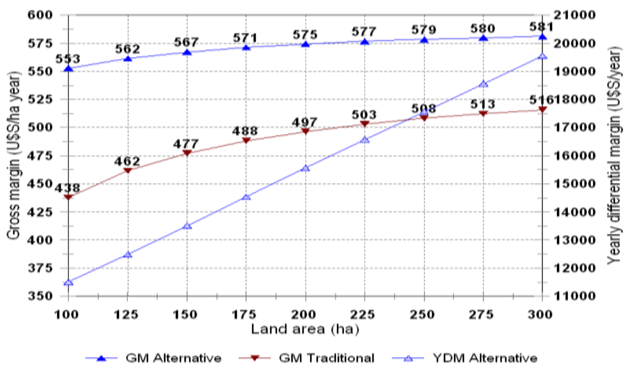

Figure 3. Economic results of the treatments. GM Alternative: gross margin of the alternative management system (Treatment 2); Conventional GM: gross margin of the conventional management system (Treatment 1). YDM Alternative: alternative differential margin: increase in the field annual income due to alternative management.

CONCLUSIONS

The alternative management system has the potential for substantial energy savings with the consequent reduction of operating costs, maintaining high yields of the crop and surpassing the profitability obtained with the traditional system.

The power demand of the strip-tillage unit makes this technology technically and economically feasible to adopt in a wide variety of field sizes, including by small producers.

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Rendements et résultats économiques d'une culture de la canne à sucre dans un système alternatif au mode opératoire traditionnel

Résumé. En Argentine, traditionnellement, en culture de canne à sucre, l'ensemble d'un champ à planter connait des opérations lourdes de préparation de sol, nécessitant beaucoup d'énergie. Puis, à l'étape suivante, la réalisation de sillons profonds réduit le potentiel de rendement car ils sont plus sensibles au passage des récolteuses et des engins lourds. Ce système pendant de longues phases de monoculture affecte l'intégrité physique du sol, compromettant les rendements et la valorisation des intrants. Il était donc nécessaire de développer un mode de gestion alternatif pour améliorer le système traditionnel afin d'inverser, d'arrêter ou d'atténuer la dégradation des sols et aboutir à de meilleurs résultats économiques. Une solution possible a consisté à utiliser de l'énergie uniquement là où elle pouvait être exploitée par les racines de la culture et maintenir, sans les travailler, des voies de circulation pendant tout le cycle de la canne. Afin de mettre en œuvre cette pratique du trafic contrôlé, un scarificateur expérimental pour un labour en bandes profondes a été conçu et fabriqué. Depuis 2013, des essais ont été réalisés à l'EEA INTA Famaillá (Tucumán) en comparant les deux modes de culture. Les résultats indiquent que la nouvelle pratique réduit de 60 à 70% la consommation en carburant, les besoins énergétiques ainsi que les temps de travail. La marge brute moyenne sur cinq récoltes a été d'environ 15% par rapport au système traditionnel, du fait de l'augmentation des rendements et de la diminution des tâches de maintenance requises par la nouvelle pratique. Le nouveau système est présenté comme une solution moins complexe sur le plan opérationnel, économiquement rentable et plus durable.

Mots-clés: Gestion des cultures, travail du sol en bandes, canne à sucre, durabilité, économie

Rendimiento y resultado economico del cultivo de caña bajo un sistema de manejo alternativo al tradicional

Resumen. En la forma tradicional de manejo de la caña de azúcar en Argentina, se rotura intensamente toda la superficie donde se implantará el cultivo, demandando grandes aportes de energía. Además, durante las tareas de mantenimiento posteriores, los entresurcos son laboreados en profundidad, reduciendo su capacidad portante y tornándolos más vulnerables al tránsito de equipos de cultivo, cosechadoras y camiones de gran peso. El uso continuo de este sistema durante prolongados períodos de monocultivo afecta la integridad física del suelo, comprometiendo el aprovechamiento eficiente de los insumos y los rendimientos. Era necesario entonces generar una alternativa de manejo superadora a la tradicional a fin de revertir, detener o mitigar el deterioro del suelo y mejorar el resultado económico del cultivo. Se especuló que, una posible solución sería, aplicar la energía solamente donde pudiese ser aprovechada por las raíces del cultivo y mantener sin disturbar los sitios de tránsito a lo largo de todo el ciclo de la caña. Para poder implementar esta forma de manejo fue desarrollado y fabricado un escarificador experimental para labranza profunda en franjas. Desde el año 2013 se lleva a cabo un ensayo en la EEA INTA Famaillá (Tucumán) comparando ambas tecnologías de cultivo. Los resultados indican que, durante la etapa de implantación de la caña, pueden reducirse entre un 60 y 70% el consumo de combustible, el requerimiento energético y los tiempos y costos operativos con esta nueva alternativa de manejo. El margen bruto medio de las cinco cosechas realizadas superó en aproximadamente un 15% al obtenido con el manejo tradicional, debido al aumento en los rendimientos y a la menor cantidad de labores de mantenimiento requeridas por la nueva tecnología. El nuevo sistema se presenta como una alternativa de manejo de menor complejidad operativa, económicamente rentable y de mayor sustentabilidad.

Palabras clave: Manejo de cultivo, labranza en franjas, caña de azúcar, sustentabilidad, resultados económicos