



Agronomic and socioeconomic effectiveness of the weed management by mechanical methods at irrigated rice crop

Efectividad agronómica y socioeconómica del manejo de arvenses por métodos mecánicos en el arroz de riego

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ABSTRACT: The present work aimed to evaluate the agronomic and socioeconomic effect of different direct seeding methods in combination with weeds management, by mechanical methods, in irrigated rice crop. Therefore, experiments were conducted in conditions of popular rice production in Madruga municipality (Mayabeque province, Cuba) on a Gley Vertic Chromic soil, during May to August. It was used a quasi-experimental design with three treatments and four repetitions, where crop yield was evaluated at 14 % grain humidity and its components. The statistical processing consisted of calculating the means confidence intervals by treatments of the variables evaluated, for a 95 % confidence level. In the economic analysis; the Gross Return, Production Cost of, the Net Return and the Benefit-Cost Ratio were determined. From the social perspective, the results socialization and the feedback were carried out in a participatory workshop with the local innovation actors. The results showed that the T₃ treatment (SDM) allowed an increase in crop yield of rice by 21 %, above the Conventional Technology and achieved the best economic results. In the participatory workshop, actors identified the aspects that could influence the adoption of the best technological alternative. It is suggested to deepen the effect of these technological alternatives on growth and development variables of the irrigated rice crop.

Key words: cultural control, farming systems research, pilot farms, waterlogging.

RESUMEN: El presente trabajo tuvo como objetivo evaluar el efecto agronómico y socioeconómico de diferentes métodos de siembra directa, en combinación con el manejo de arvenses, por métodos mecánicos, en el cultivo del arroz de riego. Para ello, se condujeron experimentos en las condiciones de la producción popular de arroz en el municipio Madruga (provincia Mayabeque, Cuba) sobre suelo Gley Vértico Crómico, durante los meses de mayo a agosto. Se utilizó un diseño cuasiexperimental con tres tratamientos y cuatro repeticiones, donde se evaluó el rendimiento agrícola al 14 % de humedad del grano y sus componentes. El procesamiento estadístico consistió en el cálculo de los intervalos de confianza de las medias por tratamiento de las variables evaluadas, para un nivel de confianza del 95 %. En el análisis económico; se determinaron los Ingresos, el Costo de Producción, la Ganancia y la Relación Beneficio-Costo. Desde la perspectiva social, la socialización de los resultados y la retroalimentación se realizaron en un taller participativo con los actores locales de la innovación. Los resultados demostraron que el tratamiento T₃ (SDM) permitió el incremento del rendimiento agrícola del arroz un 21 %, por encima de la Tecnología Convencional y alcanzó los mejores resultados económicos. En el taller participativo, los actores identificaron los aspectos que podrían incidir en la adopción de la mejor alternativa tecnológica. Se sugiere profundizar en el efecto de estas alternativas tecnológicas sobre las variables de crecimiento y desarrollo del cultivo del arroz de riego.

Palabras clave: anegamiento, control cultural, fincas experimentales, investigación sobre sistemas de producción agrícola.

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INTRODUCTION

Weed competition with economically important crops is one of the main biophysical constraints in agricultural systems. In this respect, weeds can cause significant yield reduction by affecting plant growth and development. With regard to losses caused by weed damage, studies carried out at the International Rice Research Institute (IRRI) report that, in direct-seeded rice cultivation, yield losses can reach up to 50 % (1).

In view of this situation, mechanical weed management represents an ecological and viable option for farmers with limited resources (2). This technological alternative is one of the ways used to reduce populations, particularly in the management of herbicide-resistant species (3). At the same time, different authors report levels of efficiency in the evaluation of this method, both in individual variants (4-8) and in combination with fertilization (9).

In this respect, Cuban research focuses on the evaluation of the productivity of the manual rotary weeder (10), comparisons of agricultural yields in semi-mechanized and broadcast direct sowing (11,12), the definition of the working area of the mechanical elements (13) and the evaluation of the economic and environmental impacts in various weed management systems (14). However, comprehensive studies are required to compare the above technological alternatives from an agronomic and economic point of view, due to their practical use by popular rice producers (15). Based on the above-mentioned background, this work was developed to evaluate the agronomic and socioeconomic effectiveness of different weed management, by mechanical methods, in irrigated rice cultivation.

MATERIALS AND METHODS

The research was carried out on the farm of the producer José Antonio Monteagudo (Figure 1), located at 22° 93' north latitude and 81° 87' west longitude at 119 m a.s.l. (16), which belongs to the Rolando Concepción Credit and Services Cooperative (Madruga municipality, Mayabeque province, Cuba).

The climate of the agro-ecosystem is tropical savannah, according to the Köppen-Geiger climate classification (17) with mean annual temperature of 23.9 °C and fluctuations of minimum and maximum values between 18.1 and

29.8 °C, respectively. Relative humidity reached 80 % and in precipitation, the cumulative value amounted to 2028 mm from May to October and corresponded to 80 % of the annual figure. Despite the variability, the climatic conditions of the experimental area were favorable for rice cultivation, as the temperature values were above 10 °C and below 35 °C; therefore, they were in the optimum range.

The soil type of the experimental area was classified as Chromic Vertic Gley, according to the New Version of the Genetic Classification of the Soils of Cuba (18). These soils are located on flat reliefs, are clayey, with $\text{pH} \geq 6.5$ and high Cation Exchange Capacity (CEC). The main formation process is gleyzation, which generates a gleyic horizon, due to saturation by a water table, either permanent or temporary, which causes oxidation-reduction phenomena in any part of the profile (19). These characteristics constitute potential for irrigated rice cultivation, although it should be noted that these soils tend to salinize.

With the advice of the municipal extensionist, three farmer-experimenters set up and conducted the experiments in a rice-silverbush successional system, during the months of May to August, with four replications (years 2011, 2012, 2013, 2014). Three no-tillage methods were evaluated in combination with mechanical weed management (Table 1), using hand implements for areas smaller than 10 ha (20).

Basic seed of the short-cycle cultivar Reforma, with 92 % germination power and from the Grain Research Institute, was used. Seed selection was carried out using the gravity method in saline solution, with a specific weight of 1.13 g cm^{-3} (21). The seeds that emerged to the surface were removed and those that remained at the bottom were used, as they corresponded to the specific weight. They were then rinsed for pre-germination for 24 hours.

The soil preparation technology used was direct drilling and direct sowing was carried out with pre-germinated seed. In the cultural attentions, irrigation was by permanent watering with a 10 cm water sheet and the rest of the work was carried out according to the technology of small-scale rice cultivation (22), with the exception of weed management, which was the subject of the study.

A quasi-experimental design was used with 1 ha per plot, a usable area of 0.96 ha and 1 m borders. The variables evaluated were agricultural yield, at 14 % grain moisture

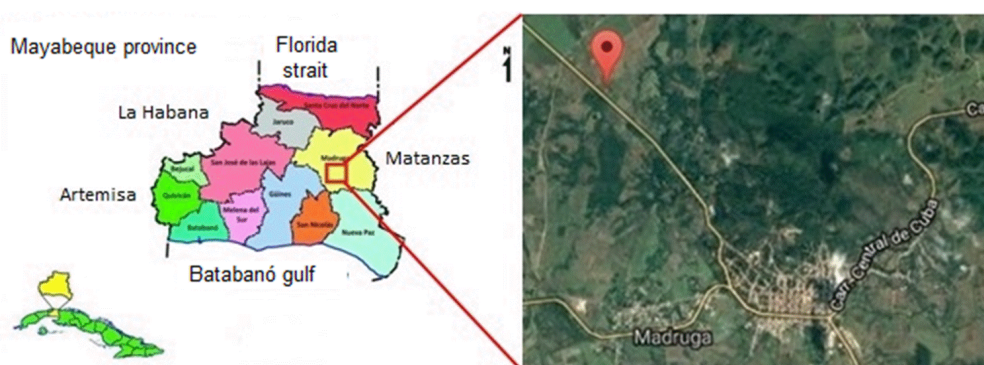


Figure 1. Location of the experimental area

(expressed in $t\ ha^{-1}$) and its components, as described in the literature (23). Statistical processing consisted of calculating the confidence intervals of the means by treatments of the variables evaluated, for a confidence level of 95 %.

The economic analysis was carried out in Cuban pesos (CUP), based on the experimental results. The proposal described in the Text of Agricultural Economics of the Agrarian University of Havana (24), allowed the calculation of the following indicators: Income, Cost of Production, Profit and Profit-Cost Ratio; therefore, the product of the agricultural yield and the selling price of wet paddy rice (expressed in $\$ t^{-1}$), according to the Accounting and Prices Directorate of the Ministry of Agriculture (25) specified the value of the income (expressed in $\$ ha^{-1}$).

The cost sheet for each treatment provided the Cost of Production (expressed in $\$ ha^{-1}$). The difference between Income and Cost of Production reflected the value of Profit (expressed in $\$ ha^{-1}$); while the division of Income and Cost of Production determined the Benefit-Cost Ratio.

Finally, the socialization of the experimentation results was carried out in a participatory workshop. In addition, feedback was given, where the main criteria about the advantages and disadvantages of the use of mechanical weed management, which can influence the adoption of the best technological alternative, were quantified. The workshop was attended by 38 local innovation stakeholders (30 farmers, three farmer-feeders, one municipal extension worker and four decision-makers) and two agricultural science researchers. It took place at the time of physiological maturity of the rice crop and was methodologically based on the experiences of the Project to Support the Agricultural Extension System in Cuba (26).

RESULTS AND DISCUSSION

The analysis of 95 % confidence intervals for the yield components showed that the means of the treatments did

not differ statistically, according to the experimental results shown in Table 2.

However, it was evidenced that treatments T2 (SDE) and T3 (SDM) achieved higher agricultural yield results of 19 and 21 %, in relation to Conventional Technology T1 (SVE), respectively, and the increase in yields was motivated by the contribution of the number of panicles/ m^2 and filled grains/panicle.

Although the confidence interval for the mean number of panicles/ m^2 and filled grains/panicle of treatment T2 (SDE) comprised the values of these components in the rest of treatments, it was found that the number of panicles/ m^2 in treatment T3 (SDM) was 0.8 and 9 % higher compared to T2 (SDE) and T1 (SVE) and the number of filled grains showed similarities with increases of 2 and 16 %, respectively.

Related to this topic, similar works carried out in popular rice (11) indicate that direct sowing in line increases the number of panicles/ m^2 by 9 % compared to broadcast sowing, with the peculiarity of not finding significant differences in the rainy period, which coincides with results of this research.

On the other hand, the high population density in the Conventional Technology T1 (SVE) in comparison with the remaining treatments, could have caused the affectation by harmful organisms that cause the grain to become vain and stained, which affects the decrease in the number of full grains/panicle and limits the obtaining of high yields (12).

Also, from the physiological point of view, the significant differences in the agricultural yield of the T3 (SDM) treatments with the Conventional Technology T1 (SVE) could be attributed to several causes. Among them, the literature points out that the spatial arrangement of the crop in rows allows the appropriate location and rapid emergence of the seed. This aspect, together with the softening and aeration of the soil, resulting from the action of weed management by mechanical methods, specifically

Table 1. Description of treatments

Treatment	Direct seeding method	Sowing standard (kg ha^{-1})	Management of weeds by mechanical methods
T ₁ (SVE)	By hand (broadcast)	120	Manual weeding
T ₂ (SDE)	In-line and semi-mechanized broadcasting	75	Manual weeding
T ₃ (SDM)	In-line and semi-mechanized broadcasting (rice seed drill SAM-160)	75	With Machine (manual rotary weeder ER-15)

SVE (stands for Conventional Technology): direct seeding by hand broadcasting at a norm of $120\ kg\ ha^{-1}$ and hand weeding. SDE: direct seeding in line and manual broadcasting at a standard of $75\ kg\ ha^{-1}$ and manual weeding. SDM: direct seeding in line and by hand with the manual rice seeder SAM-160 at a standard of $75\ kg\ ha^{-1}$ and weed management by machine with the manual rotary weeder ER-15

Table 2. Range of agricultural yield and its components in the evaluation of treatment effect

Treatments	Panicles / m^2	Full grains/panicle	Mass of 1000 grains (grams)	Agricultural yield at 14 % grain moisture ($t\ ha^{-1}$)
T ₁ (SVE)	280.2 \pm 40.51	49.8 \pm 9.01	26.93 \pm 1.45	3.88 \pm 0.26
T ₂ (SDE)	305.6 \pm 82.90	57.8 \pm 19.85	27.22 \pm 1.88	4.79 \pm 0.90
T ₃ (SDM)	308 \pm 37.38	59.2 \pm 12.82	26.11 \pm 2.54	4.90 \pm 0.73

\pm represents the confidence interval of the means, $n=5$

with manual machines, generates beneficial effects on plant height, growth and the emission of fertile stems (27-29).

In a general sense, the results of the economic analysis revealed that indicators evaluated show different values, according to the characteristics of each treatment in terms of cultural attentions, use of labor force and inputs required, which are recorded in Tables 3 and 4.

In spite of the expenses incurred in the soil preparation works, it was evidenced that in the plot where the T3 treatment (SDM) was applied, it showed a reduction of the production costs in 774.00 \$ ha⁻¹ and the yield was increased in 1.02 t ha⁻¹ with respect to the Conventional Technology T1 (SVE). This was due to the decrease in costs by 259.00 \$ ha⁻¹ where different concepts such as labor force, the acquisition of external inputs (seed), the establishment of the crop in the semi-mechanized sowing and the management of weeds, by mechanical methods, with the use of manual machines, had an impact. Consequently, treatment T3 (SDM) obtained an increase in profit of 5 053.84 \$ ha⁻¹.

A similar situation was found in the comparison of treatment T3 (SDM) with treatment T2 (SDE). In this case, the higher costs of treatment T2 (SDE) were due to the intensification of manual activities in row planting and hand weeding, which led to the hiring of more workers for these tasks.

It was interesting to note that treatment T3 (SDM) achieved the highest Benefit:Cost ratio, due to the use of the manual planter together with the management of weeds with the weeder, which allowed the humanization of the cultural attentions, which had an impact on the reduction of production costs by 70 and 88 % compared to treatments T2 (SDE) and T1 (SVE), respectively. These results corroborate similar research in the literature (11,12) on the

economic importance of mechanical weed management in direct-seeded rice under irrigated conditions.

Reducing the cost of production is the essential basis for increasing economic efficiency in the agricultural sector, and the introduction of advances in science and technology is one of the ways to achieve this objective (24). Particularly in this research, the use of the cultivar Reforma (with resistance to the rice mite *Steneotarsonemus spinki* Smiley) contributes to the elimination of all kinds of losses and losses due to the affectation by this harmful organism.

Other avenues lead to the same objective and these are: increased yields of agricultural crops, reduction of labor and external input costs (seed), and correct use of scientifically argued standards in the development of cultural care, and cost reduction through mechanization.

In the feedback during the participatory workshop, more than half of the stakeholders' criteria agreed that the advantages and disadvantages are centered on two concrete aspects: the implementation of the technological alternative (defined by usefulness, easy operation of the agricultural equipment and competitiveness) and the possibilities of acquisition, respectively.

With reference to the implementation, 76 % of actors (with a predominance of 21 farmers) highlighted the practical usefulness of the T3 treatment (SDM) as an advantage and agroecological alternative, motivated by the management of weeds without external inputs (herbicides). Another positive criterion, mentioned as an advantage by 92 % of the stakeholders (including 29 farmers), was the ease of operation of the manual rice seeder SAM-160 and the manual rotary weeder ER-15.

Related to this criterion, the actors argued that this issue could be a determinant element to guarantee a fast diffusion of the technological alternative, in the scenario of popular rice production. This reasoning reinforces the intrinsic

Table 3. Production costs for each treatment

Concept	Treatments		
	T1 (SVE)	T2 (SDE)	T3 (SDM)
Work force	1 790.00	2 372.00	1 329.00
Rental of machinery and fuel consumption for soil preparation	2 085.00	2 304.00	2 304.00
Inputs	786.00	527.00	527.00
Irrigation	340.00	340.00	340.00
Sowing/seeding and transplanting	723.00	642.00	642.00
Plant nutrition	155.00	155.00	155.00
Management of pests			
	weeds	576.00	1 026.00
	harmful organisms	89.00	89.00
Total	6 544.00	7 455.00	5 770.00

Table 4. Effect of planting methods and weed management by mechanical methods on production costs, income, profit and Benefit:Cost ratio

Treatments	Agricultural yield at 14 % grain moisture (t ha ⁻¹)	Inputs (\$ ha ⁻¹)	Production Costs (\$ ha ⁻¹)	Profit (\$ ha ⁻¹)	Benefit:Cost Ratio
T ₁ (SVE)	3.88	16 280.17	6 544.00	9 736.17	2.49
T ₂ (SDE)	4.79	20 098.46	7 455.00	12 643.46	2.70
T ₃ (SDM)	4.90	20 560.01	5 770.00	14 790.01	3.56

characteristics of this production form in Cuba, which is carried out on a small and medium scale with extensive use of manual labor and, in addition, mainly employs agro-technical methods of crop management in order to reduce competition from weeds (15).

Related to this criterion, actors argued that this issue could be a determining element to guarantee a rapid diffusion of the technological alternative, in the scenario of popular rice production. This reasoning reinforces the intrinsic characteristics of this production form in Cuba, which is carried out on a small and medium scale with extensive use of manual labor, and in addition, agro-technical methods of crop management are used fundamentally in order to reduce competition from weeds (15).

Although experimentation has shown that the uniformity of the population in the T3 treatment (SDM) allows yields of over 4 t ha⁻¹ with lower production costs, there are other practical methods such as the Intensive System of Rice Cultivation (SICA) with yields of over 6 t ha⁻¹. For these reasons, only 58 % of the stakeholders (including 17 farmers) indicated that this technological alternative is very competitive for small-scale rice production, in case they do not have sufficient labor force for transplanting and cultural attentions.

This point of view coincides with the literature (10-12) on the validation of this technological alternative in Cuban scenarios. On the other hand, the management of weeds by mechanical methods is widely used in Asia and Africa, due to its advantages in agronomic response, the labor reduction and the damage minimization to the rice crop (30-32).

Finally, 87 % of the stakeholders (with a preponderance of 27 farmers) stated, as a disadvantage, the existence of difficulties in acquiring the implements used in the T3 treatment (SDM), as they are not manufactured on a large scale. In reference to this criterion, construction with recyclable materials could be a proposed solution to this problem (10).

Therefore, one of the challenges of agricultural extension is the evolution towards flexibility in its organization, where the interrelation between agricultural technical services such as the repair of agricultural machinery and implements with agricultural extension at the municipal level, with the aim of finding solutions to the demands of farmers, with endogenous resources of the locality (33).

The analysis of the criteria issued by actors revealed that the T3 Treatment (SDM) could be accepted by popular rice producers with an area larger than 1 ha, because of the economic and social benefits of semi-mechanized sowing and the management of weeds with easily operated manual machines, which imply lower labor costs, higher labor productivity and low use of external inputs that can affect the environment.

CONCLUSIONS AND RECOMMENDATIONS

- The method of direct sowing in line and in a semi-mechanized drip with the management of weeds with manual machines represents an opportunity for Cuban farmers, since it produced increases of 21 % in rice yields and higher profits of \$5000.00 compared to conventional technology.
- The main advantages that, according to local stakeholders, favor the adoption of this technological alternative are the practical utility, the ease of operation of agricultural equipment and competitiveness, while the acquisition of implements is considered a restrictive aspect.
- Further research is needed on the combined effect of direct seeding methods and mechanical weed management on growth and development as well as on the emergence of fertile stems in irrigated rice.

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