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Original article

Production *Solanum tuberosum* L. in an agroecological context on family farms in Jovellanos municipality, Matanzas

Producción de *Solanum tuberosum* L. en un contexto agroecológico en fincas familiares del municipio Jovellanos, Matanzas

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ABSTRACT: The present study was carried out with the objective of characterizing the production of *Solanum tuberosum* L. in an agroecological context in seven family farms in Jovellanos municipality, Matanzas province. The Principal Component Analysis was carried out to determine the variables that showed more variability and, on that basis, the farms were grouped by means of the Conglomerate Analysis. Morphological, agronomic and management variables (soil type, amount of irrigation and application of organic matter) were studied. High accumulated variability was found in the first five components, which explained 93.9 % of the variance. Yields varied between 6 and 17 t ha^{-1}, the tuber had 20.9 % of dry matter. Four groups were formed, one of them represented by a single farm, which showed the best results in the productive behavior of this species. The inclusion of *Solanum tuberosum* L. in the crop rotation of small producers in Jovellanos municipality is a viable and sustainable option, which contributes to the food security of the territory.

Key words: potato, agroecological practices, agrarian ecosystems.

RESUMEN: El estudio tuvo como objetivo caracterizar la producción de *Solanum tuberosum* L. (papa) en un contexto agroecológico en siete fincas familiares del municipio Jovellanos, Matanzas, Cuba. Se analizaron variables morfológicas, agronómicas y de manejo, incluyendo el tipo de suelo, cantidad de riego y aplicación de materia orgánica. Se utilizó el Análisis de Componentes Principales (ACP) para identificar las variables de mayor variación y el Análisis de Conglomerado para agrupar las fincas. Los resultados mostraron una alta variabilidad en las primeras cinco componentes, explicando el 93.9 % de la varianza. Los rendimientos variaron entre 6 y 17 t ha^{-1} y los tubérculos tuvieron un 20,9 % de materia seca. Se formaron cuatro grupos, uno de los cuales representaba una sola finca con los mejores resultados en productividad. La inclusión de *S. tuberosum* en la rotación de cultivos de pequeños productores en Jovellanos es una opción viable y sostenible, contribuyendo a la seguridad alimentaria del territorio.

Palabras clave: papa, prácticas agronómicas, ecosistemas.

INTRODUCTION

Agroecology is based on territorial processes, which helps to provide contextualized solutions to local problems (1). Agroecological innovations are based on the co-creation of knowledge by combining science with the traditional, practical and local knowledge of producers. Agroecology addresses the root causes of problems in an integrated manner and provides holistic, long-term solutions. This requires an explicit focus on the social and economic dimensions of food systems.

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In this sense, to be effective in ensuring that agricultural systems contribute to climate change adaptation and mitigation, producers need to be encouraged, be motivated and be recognized to change from high-input technologies to others with an agroecological approach, less dependent on external inputs and in harmony with the environment.

This is the case of *Solanum tuberosum* L., the fourth most important food crop worldwide after cereals (*Triticum aestivum* L., *Oryza sativa* L. and *Zea mays* L.). Annual potato production represents approximately half of the world production of all roots and tubers (2).

In Cuba, different institutions have dedicated themselves to the production of original seed to reduce, largely, the large investments for this concept (3). In this sense, the National Institute of Agricultural Sciences has carried out several investigations related to the production of seed tubers through sexual seed (4), the morphoagronomic characterization of Cuban potato germplasm (5) and the obtention of new varieties (6).

One of the fundamental aspects for which it is considered that potato is not a sustainable crop is precisely because of the high price of seed tubers and the large amount of inputs, fertilizers and pesticides used in this crop. However, by using seed produced in the country, the amount of inputs would be lower, so work has begun on the development of a production method that makes the potato a sustainable and low-input crop, being able to reduce the agrochemicals that are currently applied when seed tubers are planted (4).

To reverse this situation, the substitution of inorganic sources by organic fertilizers, such as compost, manure or biofertilizers that lead to an increase in soil fertility through the mineralization of organic matter, should be sought (7,8), which originates a greater biological activity and improvements in the physical properties of the soil (9). Hence, the objective is to characterize the production of *Solanum tuberosum* L. in an agroecological context in seven family farms from Jovellanos municipality, Matanzas province.

MATERIALS AND METHODS

Location

The study was carried out in seven farms in Jovellanos municipality, Matanzas province during 2020-2021 campaign.

Table 1 shows the general description of farms, which reflects the owner name, the productive entity to which it belongs, the area planted, soil type and some management data such as the type of irrigation used and the date of planting and harvesting.

Soil characteristics

In the farms where the crop was planted, six corresponded to a Ferrallitic Red leached soil and one to a Brown soil with Carbonates (Table 1).

Crop nutrition

The first fertilization was carried out at planting time, with the application of organic fertilizers according to the availability of each producer at the bottom of the furrow during soil preparation. In some cases, they used AGROMENAS-G, an organic-mineral fertilizer of national production, which is applied at the bottom of the furrow before planting at a rate of 3 t ha^{-1}. The second fertilization was carried out after 50 days with the CBFERT product.

For the experiment, seed tubers of the Romano variety, of national production, recommended by the Provincial Directorate of Agriculture, were used; those of 35-45 mm caliber were selected. The multiple sprouting of the crop from the refrigerator was eliminated and a selection was made for the elimination of the damaged tuber. At planting time, another selection was made to eliminate unfit tubers.

Soil preparation

The soil was prepared by conventional tillage with a plow, harrow and rotovator, and then was furrowed for planting. The decomposed organic matter was applied at the base of the furrow where the tuber was deposited before planting.

Planting

Planting was carried out in furrows separated by 90 cm from the row and 4 tubers were placed per linear meter, that is, 25 cm between tubers; the planting depth was 10 cm. Subsequently, the planting bed was mechanically covered and a manual mulching was carried out when necessary. All

Table 1. Characteristics of areas by farms

Farm	Producer	Productive entity	Area	Soil	Irrigation	Sowing date	Time of harvest
F1	Carlos Cruzata	CCS Leonel Fraguela	0.9	Red ferrallitic	Surface	December 22 de	March 25. 2021
F2	Rodrigo Rodríguez Rodríguez	CCS Leonel Fraguela	0.4	Red ferrallitic	Sprinkler	December 26	April 3. 2021
F3	Fernando Martínez Junco	CCS Leonel Fraguela	1.0	Red ferrallitic	Surface	December 22	March 25. 2021
F4	Yeni Mosquera Niño	CCS Leonel Fraguela	0.8	Red ferrallitic	Sprinkler	January 9	March 31. 2021
F5	Julio César Quinta Simón	CCS Massety	1.0	Red ferrallitic	Surface	January 9	
F6	Arsenio Devora	CCS Massety	1.0	Red ferrallitic	Surface	December 26	March 23. 2021
F7	Héctor Correa Almeida	CCS Nicomedes Nodarse	0.4	Brown with carbonates	Sprinkler	December 26	March 24. 2021

cultural attentions were carried out according to the technical standards for this crop.

Seed inoculation

To inoculate the seeds at the time of planting, they were placed in a 200 L tank with 20 L of IHPLUS® BF, 20 kg of EcoMic® and 25 mL of BIOBRAS-16®. The tank was then filled with water not treated with chlorine and the bag was submerged in this solution for 10 minutes, after which it was left to orate in the shade and then planted.

Cultural care

Irrigation, cultivation, weed control and the application of bioproducts were carried out according to the crop cycle (Table 2). If after the ninth application, the crop had not yet reached maturity, then applications similar to the ninth application were continued until the crop reached maturity, which was around 100 days.

Measurements

Measurements were made 65 days after planting the crop; they were made on plants found in a 1 m^2 (4-5) and replicated twice, except for pests which were checked daily to the entire field. The following variables were evaluated:

- Number of tubers per plant: number of total tubers among plant number.
- Average tuber weight (kg): total weight of tubers among tuber number.
- Number of stems per plant. The number of stems in 1 m^2 was counted.
- Stem diameter per plant (cm). It was measured at a height of 10 cm from the ground.
- Tuber caliber. The number of tubers per caliper was counted.
- Tuber diameter. It was done in the middle transverse zone of the tuber.
- Tuber weight. The tubers were weighed for each caliber.
- Yield per plant (kg): total weight of tubers divided by the number of plants.
- Total yield (t ha^{-1}): yield per plant multiplied by the total number of plants in one hectare and divided by one thousand (one ton).
- Stem length (cm). It was measured from the base of the soil to the apical bud.
- Dry matter (%): Based on wet weight and dry weight at 65 days.

Table 2. Sequence of applications of byproducts in the crop

Application number	Byproducts
First	• IHPLUS® BF, 20 L ha^{-1} • *Trichoderma harzianum*, 5 kg ha^{-1}
Second	• IHPLUS® BF, 20 L ha^{-1} • FitoMas-E, 2 L ha^{-1} • *Bacillus thuringiensis*, 26 o 24, 10 kg-L ha^{-1} • BIOBRAS-16® **,** 25 mL ha^{-1}
Third	• IHPLUS® BF, 20 L ha^{-1} • *Trichoderma harzianum*, 5 kg ha^{-1} • *Bacillus thuringiensis*, 26 o 24, 10 kg-L ha^{-1}
Fourth	• IHPLUS® BF, 20 L ha^{-1} • FitoMas-E, 2 L ha^{-1} • BIOBRAS-16®, 25 mL ha^{-1}
Fifth	• IHPLUS® BF, 20 L ha^{-1} • *Trichoderma harzianum*, 5 kg ha^{-1} • *Bacillus thuringiensis*, 26 o 24, 10 kg-L ha^{-1}
Sixth	• IHPLUS® BF, 20 L ha^{-1}
Seventh	• IHPLUS® BF, 20 L ha^{-1} • *Trichoderma harzianum*, 5 kg ha^{-1}
Eighth	• IHPLUS® BF, 20 L ha^{-1}
Ninth	• IHPLUS® BF, 20 L ha^{-1} • *Trichoderma harzianum*, 5 kg ha^{-1}

- Leaf length (cm). From the insertion of the petiole with the stem to the apex of the central leaflet.
- Leaf width (cm). Measured at the second pair of leaflets.

Mathematical analysis

The results were processed by means of principal component analysis (PCA) (10), in which the analysis criteria were those principal components that presented eigenvalues greater than 1 and sum or preponderance factors greater than 0.70.

To group the farms and select those with the most prominent similar characteristics, Cluster Analysis was used, based on the results obtained in the PCA. The Euclidean distance and Ward's method were used as grouping criteria as a form of ascending hierarchical aggregation (11). The cut-off line for the formation of the groups was based on the researcher's criteria (12) and the mean and standard deviation statistics were determined for the variables analyzed in these farms.

It was established, as a principle, to select the best farm or farms in terms of their behavior based on all the variables studied. In this way, groups were formed that allowed a true analysis of the behavior of the farms in the groups formed. All analyses were carried out using the SPSS® statistical program version 11.5 for Microsoft® Windows® (13).

RESULTS AND DISCUSSION

The PCA (Table 3) showed high cumulative variability in the first five components, which explained 93.9 % of the variance, based on the variables included in the study.

Regarding the variance in the principal components (PC), PC1 reached a value of 28.58 % and the variables that most influenced the variance extracted were stem diameter (0.916), tuber number (0.961) and stem number (0.698), all positively related to each other.

In PC2, with 22.43 % variance, irrigation type (-0.961), tuber diameter (0.967) and yield (0.699) were more involved, the latter variables being positively related to each other, but inversely related to irrigation type. This means that the type of irrigation, which as shown in Table 1, was of different forms (surface and sprinkler), had an influence on tuber yield and diameter.

In PC3, the highest values were for the application of organic matter (-0.965), although it was inversely related to the other variables, except for soil type, which means that no matter what the soil classification was, organic matter benefited it and the variance explained by this component was 16.32 %. While in PC4 and PC5, the variables that contributed most to the total variance were leaf length (0.947) and tuber weight (0.940), with 13.59 and 12.99 % of the variance, respectively.

The results described above allow us considering that there was greater differentiation between farms, depending on the variables present in PC1, PC2, PC3, and was much less for the variables of PC4 and PC5.

This means that the variables that make up the first two components should not be left unstudied in experiments similar to this one, since they are the ones that contribute to the variability of yield behavior, independently of the influence of other biotic and abiotic factors.

In correspondence with the high value reached by the accumulated variance and the eigenvalue of the PCs, it is possible to assume that the phenotypic variability was sufficiently favorable for these indicators to be included, in their totality, in the cluster analysis, and thus determine the differentiation or similarity between species and accessions.

The cluster analysis, based on the results of the PCA, allowed the formation of four groups. Producers belonging to each of them are shown in Table 4, as well as the mean and standard deviation of each of the groups formed.

Table 3. PCA results and relationship between variables

Variable	Component				
	1	2	3	4	5
Soil type	-0.501	0.307	-0.118	0.606	-0.500
Application of organic matter	-0.001	-0.073	**-0.965**	0.008	-0.090
Type of irrigation	-0.033	**-0.961**	0.093	-0.161	0.180
Stem length	0.458	0.593	0.397	-0.095	0.447
Stem diameter	**0.916**	0.276	0.025	0.140	0.041
Number of stems	**0.698**	-0.032	0.627	0.111	0.284
Leaf length	0.178	0.034	0.026	**0.947**	-0.041
Leaf width	0.454	0.059	0.475	0.632	0.351
Number of tubers	**0.961**	0.062	0.153	0.097	0.182
Number of titins	0.526	-0.175	0.600	0.157	-0.229
Tuber diameter	0.058	**0.967**	0.027	0.007	0.101
Tuber weight	0.106	0.024	0.042	-0.001	**0.940**
Yield	0.691	**0.699**	0.067	0.027	0.105
% variance	28.583	22.435	16.319	13.586	12.995
% cumulative	28.583	51.019	67.338	80.924	93.919

Table 4. Distribution of producers and the mean according to Cluster Analysis

Variable	Group			
	I	**II**	**III**	**IV**
Soil type	1	1	1	2
Application of organic matter	2	3	2	4
Type of irrigation	2.0	1.5	1.0	1.5
Height. Cm	36.5	41.6	54.1	29.4
Stem diameter. cm	0.8	0.7	0.9	0.7
Number of stems	4.7	3.9	5.0	3.2
Leaf length. mm	20.9	19.5	21.0	20.3
Leaf width. mm	12.8	11.6	13.9	11.1
Number of tubers	6.7	4.8	8.5	4.3
Number of titins	1.4	0.7	1.5	0.9
Tuber diameter. cm	3.9	4.1	4.3	4.0
Tuber weight. kg	0.4	0.5	0.4	0.3
Yield. t ha^{-1}	9.0	9.5	18.0	7.5

Group	**Amount of producers**	**Farm**
I	3	1. 3 y 6
II	2	2 y 5
III	1	4
IV	1	7

According to the results of the table, there were 3 producers in-group I, 2 in-group II and 1 each in groups III and IV. The producers of group I were characterized, in their majority, by having the Ferrallitic Red soil; but they applied organic matter, and achieved an average of 4.7 stems and 6.7 tubers, as well as an average yield of 9.0 t ha^{-1}.

Group III, is formed by one producer (4), with the best performance in the morphoagronomic variables. It had a number of stems of 5 and an average of 8.5 tubers plant, and a yield of 18 t ha^{-1}. This producer applied organic matter and Agromenas-G at a rate of 8 and 4.5 t ha^{-1}respectively. The amount of organic fertilizers influences tuber yield. This behavior is considered acceptable due to the combination of organic matter with the organ-mineral used. In this regard, it is worth mentioning that Agromenas-G has nutritional properties, and that with its applications it has been possible to increase crop yields and replace at least 50 % of chemical fertilizers (14).

On the other hand, organic fertilizers provide organic matter, nutrients and microorganisms, which favor soil fertility and plant nutrition. Their application also increases the activity of phosphatases by stimulating microbial biomass and root secretion (15); in addition to enhancing soil biodiversity and optimizing edaphic variables linked to soil conservation.

In relation to this, increases in potato yield were found by the addition of increasing doses of organic fertilizers, presenting a quadratic tendency; the increase in yield between the absolute control and 15.0 t ha^{-1} of organic fertilizer was 20.8 t ha^{-1} (16).

On the other hand, one producer formed group IV; the behavior of the variety on this farm was the one with the lowest response of the morphoagronomic variables, including the yield, which was 7.5 t ha^{-1}.

The analysis of some morphobotanical indicators of the Romano variety showed differences in stem length, stem diameter, leaf length, and leaf width. The highest stem length was found in-group III, which is located in farm 4, and the lowest value was obtained in-group IV, which is located in farm 7. The analysis of stem diameter showed, a behavior very similar to that described above.

In general, the diameter of the stem varied between 0.6 to 0.9 cm, values lower than those obtained with the Spunta variety (12 cm), when some of the components of growth and yield were evaluated in plants of *Solanum tuberosum* L. subjected to foliar application of different doses of QuitoMax® (17).

These results were similar to those obtained when evaluating the effect of four planting distances and three tuber-seed calibers on some morphoproductive characteristics of the Romano variety (0.7 and 1.1 cm) (18).

The number of stems varied between 3 and 5. However, the productive yield is also directly proportional to the number of stems per seedling, a condition that is fulfilled in this study, since the highest number of stems was in the farm that reported the highest yield in the variety under study (19).

The number of stems coincided with those obtained when studying alternatives of biofertilization in the cultivation of *Solanum tuberosum* L. cv. Superchola, in Andisol soils of Carchi, Ecuador (20). Furthermore, they were higher than those found when evaluating the yield of *Solanum tuberosum* L. under three doses of chemical fertilization and two doses of organic fertilization, which was 2.57 (21).

There is a close relationship between the length and stem number, because when increasing these in the plant, the height is reduced, which, among other factors. It is related to the possibilities that the seed tuber has to provide the new plant with its reserves; when having to share them with a smaller quantity of stems, these will be favored in their growth (18).

When analyzing the length and width of the leaves, differences were found among the plantations; the highest values for length were obtained in group III, I and IV, while the lowest values were reported in group II. On the other hand, for leaf width, the highest values were found in groups III, I. The lowest values were found in groups II and IV.

The variables previously analyzed are important, since they form the foliar surface and this is one of the important variables related to the studies of plant growth, because its magnitude is associated with the capacity of the plant to carry out the photosynthetic process, since there is a direct relation in this sense (22).

For the number of tuber among the farms, it can be seen, that the highest number was obtained in F4 (8.5), and those with the lowest number of tubers were F2 and F5 and F7, belonging to groups II and IV, respectively.

The number of tubers varied from 4.0 to 8.5 and were similar to other investigations, where 288 cultivated accessions of Cuban potato germplasm were studied (23). These authors found a mean number of tubers of 6.3 per plant, with a maximum value of 15.0 and a minimum of two for this variable. They also found a high variability with a coefficient of variation of 44.3 %.

When evaluating the yield of *Solanum tuberosum* L. with three doses of chemical fertilization and two of organic fertilization, similar results were found when analyzing the variable number of tubers per plant; an average value of seven tubers per plant was found with a variation coefficient of 22.05 % (21).

Obtaining a good relation of tubers-seeds is one of the ways to achieve higher yields (11).

When performing a punctual analysis of the yield per hectare in each of the farms, it can be observed that in Figure 1 of the seven farms in the study, the highest value was obtained in F4 (18 t ha^{-1}), where the highest number of stems (5) and tubers (8.5) were also found, as mentioned previously.

In the farm of producers 2 and 4, higher values were obtained than those found in similar studies, when evaluating the responses in yield, product of temperature variations during the crop cycle (24); plantations of the Romano variety were carried out and reached a total and commercial yield (12.5 t ha^{-1}) in 2015.

The differences found among the farms may be due to the conditions in which the evaluations were carried out with different cultural attention and management; since, although all the farms had optimal environmental conditions for crop development, at the time of planting, the amounts of organic matter used were not the same in all of them. In the case of farm 4, organic matter (cattle excreta) was applied, in addition to Agromenas-G.

It is significant to point out that organic matter has an effect in improving the physicochemical properties of the soil, in addition to gradually releasing the different nutrients (25); and that it has been proven that the potato crop reacts favorably to organic fertilizers.

Sometimes, even when environmental conditions are adequate for crop development, it is also possible to find low yields, which depends on the cultural attention (especially nutrition) given to the crop (26), as well as on the genotype-environment interaction.

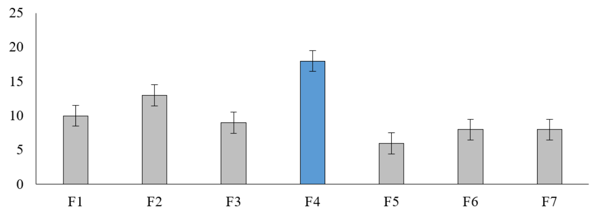

Figura 1. Rendimiento del cultivo de la papa por productor (t ha^{-1})

Figure 2 shows some indicators of the bromatological composition of the tuber of the seven farms under study; the average dry matter was 20.9 %, with a humidity of 79.1 %; while the tuber weight was 358.9 g.

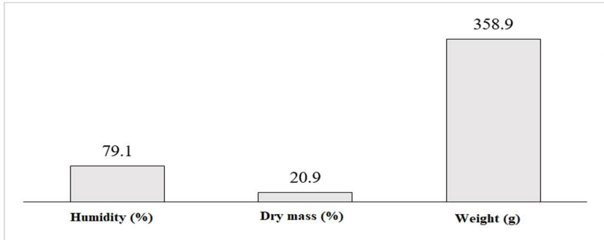

Figure 2. Dry matter value and dry weight of agroecological potato

Moisture values are higher than those ones found for some authors (27) for the Romano variety (74.0-65.7 %) at the beginning of storage; the differences found in this value were at 65 days after planting (27).

The dry weight obtained was similar to that found when evaluating at 40 and 70 days the behavior of the accumulation and distribution of dry mass among the different organs of the plant of three potato varieties (Call White, Santana and Spunta) (24).

CONCLUSIONS

- The inclusion of *S. tuberosum* in the crop rotation of smallholder farms in Jovellanos municipality allowed the development of the crop, which contributes to the food security of the territory.
- The low yields obtained in farms 6 and 7 are closely related to the agronomic management provided by the farmers, who applied 5 t ha of organic matter, in addition to the fact that these farmers had no experience in the management of this crop, which, due to the speed of its cycle, requires adequate attention to achieve good results.

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