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Resilience of agricultural production systems exposed to hurricane Irma in Cuba

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Abstract

Objective: To evaluate the resilience of production systems exposed to hurricane Irma in territories of Cuba.

Materials and Methods: The general index of resilience to tropical cyclones (GIRtc) was determined, which was contrasted with the coefficient of agroecological design and management ($A_{dm}C$). They were both complemented with the evaluation of the sensitivity of productive species and the vulnerability of the cultivation and animal husbandry systems.

Results: The production systems were grouped in three clusters, with higher contribution for these groupings by their resistance capacity during the event and their permanent transformability, as well as by the design and management of the production system and structure of agrobiodiversity. The sensitivity of the cultivated species showed certain differences for the plant types in the following order: annual and temporary agricultural crops > semi-permanent crops > fruit trees > permanent herbaceous plants. The vulnerability of the cropping and animal husbandry systems in each studied production system was lower for the systems of cluster III, in which 62,5 % of the crops remained. This contrasts with cluster I, in which 38,5 % of the production was rescued during the process; while in the systems of cluster II 2,7 % could be maintained.

Conclusion: The production systems that adopted agroecology expressed different capacities of resilience, which is related to the traits contributed by the design and management of the existing cropping and animal husbandry systems, as well as the rest of the production system.

Keywords: biodiversity, climate change, cyclones

Introduction

Climate change can exacerbate the land degradation processes due to the increase in the intensity of rainfall, flooding, drought frequency and severity, as well as by thermal overload, dry seasons, wind, sea level, action of waves and thaw, whose outcomes are modulated by land management. These events evidently affect food security, as a result of warming, changing rainfall patterns and higher frequency of some extreme phenomena (IPCC, 2020).

Although it is not adequate to ascribe the occurrence of a hurricane to climate change, because this phenomenon obeys different regional factors, there is scientific evidence that proves the intensification of Atlantic Ocean hurricanes, especially those of higher category (Poveda *et al.,* 2020). In this regard, projections indicate that hurricanes during the 21st century will be more intense, due to climate change (Ting *et al.,* 2019).

An increasing trend is observed in hurricane activity over Cuba, considering a very long and reliable series, comprised between 1791 and 2017, although it is not statistically significant. Between 2001 and 2017, 12 hurricanes affected the Island, and from them 10 were intense. This strong activity of big hurricanes over Cuba since 2001, without antecedents since 1791, is conditioned by the high sea temperature values in the tropical Atlantic Ocean, recorded since 1998. This variation is similar to the projections of future climate, regarding the idea that hurricanes could be more intense, following the increase of sea temperature (CITMA, 2020).

Hurricane Irma, which occurred in 2017, sensitively affected the agricultural production in the country, whose damage reached more than 50 thousand 500 ha, mainly 26 915 ha of plantain (*Musa* sp.) and banana (*Musa* spp.), 1 900 of rice (*Oryza sativa* L.), 4 520 of cassava (*Manihot esculenta* Crantz.), 12 569 of corn (*Zea mays* L.) and 123 of citrus fruit trees (*Citrus* spp.). In animal husbandry, more than 145 thousand animals were affected: 71 800 laying birds, 1 600 cattle (mainly calves) and 866 pigs died (Naciones Unidas-Cuba, 2017).

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Few studies evaluate the strategies of resistance to hurricanes or the challenges faced by the people who manage lands to attenuate their effects. Meanwhile, the actions that are implemented in order to increase resilience against hurricanes should incorporate the local needs, align with other objectives of land management and increase general resilience to climate change and related stressful factors (Wiener *et al.,* 2020).

Cinner *et al.* (2018) identified five dominions that are necessary to develop the adaptation capacity and achieve resilience to these events. They are assets that can be utilized at moments of need, which are related to the flexibility to change a strategy, capacity of organization and collective acting, acknowledgement and response to change, and when and how to change. Previous studies have proven that the actors' adaptation capacity is determined by the interactive processes that occur at multiple scales, including belonging to farmer organizations and relations between farmers and buyers (Frank *et al.,* 2012).

Due to the importance of studying further the characteristics that confer resilience capacity to agricultural production systems against the physical effects of tropical cyclones-hurricanes, the objective of this study was to evaluate the resistance of production systems exposed to hurricane Irma in several territories of Cuba

Materials and Methods

Hurricane Irma touched Cuban land on the northern keys, in the limits between Camagüey and Ciego de Ávila, East of Romano key in the Camagüey province, since the evening of September 8, 2017. In its movement, the center was located over the Jagüey, Perros and Buena Vista bays in the first hours of September 9. It was catalogued as a hurricane category 5 in the Saffir-Simpson scale (Benedico-Rodríguez, 2017).

It moved that same day over the seas north of the country, with a movement between West and West-Northwest, over all the keys of the central region, then it began to turn slowly towards Northeast and North, between the Villa Clara and Matanzas provinces. The geographical configuration of the national territory, the trajectory described by the hurricane and the wide circulation of this system, favored that all of Cuba was affected by this phenomenon (González-Ramírez *et al.,* 2017).

After the incidence of the event, different types of agricultural production systems were studied, which were exposed to the physical effects of strong winds and intense rains of hurricane Irma, as recommended by the local authorities, in the Havana, Sancti Spíritus, Ciego de Ávila and Camagüey provinces (table 1).

In these territories, hurricane Irma had incidence in a period of relatively low agricultural production, intermediate between the end of the summer season (spring crops) and the preparations for the beginning of cold-season planting (seed beds, soil tillage, others), which is the most important in Cuba. However, some temporary, annual and permanent crops were under production.

The general methodology that was used was an approach of the quantitative and qualitative approach, complemented with participatory processes. It consisted in the exchange and tour with the farmer throughout the production system to characterize its design and agroecological management; as well as to determine its resilience capacity, sensitivity of the productive species and vulnerability of cropping and animal husbandry systems. Collective evaluations were also made in meetings with technicians and officials of the territory.

The resilience capacity of each production system (table 2) was determined through GIRtc, adapted from Vázquez *et al.* (2016).

To the effects of this study, it was considered that the technological approaches of production systems are different because they belong to several types of productive organizations, including those of the Program of Urban, Suburban and Family Agriculture of the Ministry of Agriculture, farmer systems of the National Association of Small Farmers (ANAP, for its initials in Spanish) and state companies. For such reason, the design-agroecological management they carry out through the agroecological design and management coefficient (AdmC) was determined, which considers traits proposed by Vázquez and Martínez (2015), validated in studies about the capacity of resilience of the farms to drought (Vázquez *et al.,* 2016; 2019) and to hurricane Mathews (Vázquez *et al.,* 2016) (table 3).

The components of the resilience capacity and of the design-management were evaluated through specific scales, which were applied to the variables that were used to evaluate the status of each component, whose final value was determined by the following expression:

$$\Sigma\ [V_1 + V_2 + V_3 + \ldots]/\ NE, \text{ where:}$$

Σ is the sum of the values obtained for each one of the variables (V)

Table 1. Studied production systems to determine the resilience to hurricane Irma in territories of Cuba.

Territories (municipality and province)	Productive organization form¥ and location zone¥¥	Studied production system and main characteristics of its design	Productive species exposed to the event
Marianao (Havana)	UBPC La Victoria (periurban)	La Victoria farm (24,48 ha). Complex design: diversified perimeter living fence, surface subdivided into management units delimited by sections of internal living fences, integration of animal husbandry, agriculture and fruit trees, several plantations of fruit trees; integration of living fences, fields in polyforages, beds of polycrops with protection (organoponic garden); semi-confined small livestock, which grazes in enclosed paddock.	Field in blocks [mulberry (*Morus alba* L.), moringa (*Moringa oleifera* Lam)], organoponic garden (vegetable seed nursery), semi-confined rearing (goats) and shed in cages (rabbits), fruit tree plantations [acerola (*Malpighia emarginata* DC.), mango (*Mangifera indica* L), coffee (*Coffea* sp.), coconut (*Cocos nucifera* L.), guava (*Psidium guajava* L.) and other 25 species
		Margaritas farm (6,3 ha). Simple design: diversified perimeter living fence, agricultural production and fields in monoculture.	Fields [guava, plantain, tomato (*Solanum lycopersicum* L.), beans (*Phaseolus vulgaris* L.)]
Habana del Este (Havana)	CCS Ana Betancourt (periurban)	El Pedregal garden (0,9 ha). Simple design: simple perimeter living fence, integration agriculture and animal husbandry, integration of living fences; polycrops in beds (organoponic garden) and small plots; rearing of semiconfined livestock.	Beds [string beans (*Vigna unguiculata* var. sesquipedalis (L.) Verdc.), capsicum (*Capsicum* spp.), lettuce (*Lactuca sativa* L., chard (*Beta vulgaris* var. cicla (L.) K. Koch]; small plots [plantain, guava, lemon (*Citrus x limon* (L.) Burm f.)]; semiconfined rearing (cattle and goats).
		Victoria contra las piedras garden (2,0 ha). Simple design: perimeter living fence, integration of agriculture, fruit trees and animal husbandry, integration of living barriers, plant beds in polycrops (organoponic garden) and in small plots and polyfruits in typical field; semi-confined and in-shed animal husbandry.	Plant beds [lettuce, string beans, carrot (*Daucus carota* L.), beet (*Beta vulgaris* L.), fragant garlic (*Allium ramosum* L.)]; plots [cassava, banana, squash (*Cucurbita maxima* L.); field [avocado (*Persea americana* Mill), mango, bitter orange (*Citrus* x *aurantium* L.), guava)]; semi-confined rearing (cattle, sheep), sheds (poultry, rabbits).
		Trece de septiembre garden (0,75 ha). Complex design: perimeter living fence, integration agricultural crops and fruit trees; integration of living barriers, polycrops in beds (organoponic gardens) and small plots, polyfruits in field.	Plant beds [lettuce, chive (*Allium schoenoprasum* L.), chard, beet)]; small plots [okra (*Abelmoschus esculentus* (L.), tomato, cucumber (*Cucumis sativus* L.), sweet potato (*Ipomoea batatas* L.), banana], field [mango, guava, sugar-apple (*Annona squamosa* L.), aguacate, cocotero, June plum (*Spondias dulcis* Parkirson)].
		El Cachón garden (1,2 ha). Complex design: simple living fence, integration agriculture and fruit trees; system subdivided into management units, delimited by sections of living fences; integration of living barriers, Chinese plant beds and beds with protection (organoponic garden) and field in polyfruits.	Beds with protection [capsicum, string beans, cucumber, apium (*Apium graveolens* L.) coriander (*Coriandrum sativum* L.)], Chinese plant beds (okra, plantain); field (coconut tree, guava, acerola, lemon and other 13 species)
Guanabacoa (Havana)	CCS Emiliano Montesdeoca (suburban)	Vista hermosa farm (47 ha). Complex design: diversified perimeter living fence, integration animal husbandry, agriculture and forages; surface subdivided into management units, delimited by internal living fences; enclosed paddocks, fields in polyforages, rearing sheds and Chinese plant beds in polycrop.	Semi-confined rearing (sheep, goats, cattle); pens-grazing (pigs); cage in shed (rabbits); pen-grazing (poultry); fields in blocks [sugarcane (*Saccharum* spp.), mulberry, Mexican sunflower (*Tithonia diversifolia* Hemsl., A. Gray), king grass (*Pennisetum purpureum* x *Pennisetum typhoides*)]; fields (sugarcane, king grass]; greenhouse (vegetables); beehives with seminatural browsing area.

Table 1. (Continuation).

Territories (municipality and province)	Productive organization form[¥] and location zone[¥¥]	Studied production system and main characteristics of its design	Productive species exposed to the event
Fomento (Sancti Spiritus)	CCS El Baquerito (mountain rural)	El Tamarindo farm (1,0 ha). Complex design: traditional coffee agroforestry system.	Coffee plantation with intercropped shade trees and fruit trees [avocado, mango, guava, tamarind (*Tamarindus indica* L.), lemon, plantain]
Baraguá (Ciego de Ávila)	CCS Máximo Gómez (rural)	La Ceiba farm (107,5 ha). Complex design: simple perimeter living fence; integration agriculture, fruit trees and animal husbandry; surface of the farm subdivided into management units, delimited by sections of internal and simple living fences; fields in monoculture and rearing in shed.	Fields [plantain, avocado, mamey sapote (*Pouteria sapota* Jacq.), mango]; rearing in shed (pigs).
		La Lucha farm (52 ha). Simple design: agricultural production, simple perimeter living fence, fields in monoculture.	Field [melon (*Cucumis melo* L.]
		La Esperanza farm (13,32 ha). Simple design: integration agriculture and fruit trees, simple perimeter living fence; some simple sections of internal living fences and fields in polycropping.	Fields of fruit trees (mango, avocado) with intercropping (tomato, beans, melon).
	Empresa Agropecuaria La Cuba (rural)	Farm No. 3 (120 ha). Simple design: specialized production in banana cultivation, in large fields with underground.	Blocks of fields (banana)
Majagua (Ciego de Ávila)	CCS Reynaldo Manning (rural)	Placer farm (32,0 ha). Complex design: diversified perimeter living fence, surface of the farm subdivided into management units, delimited by internal living fences; integration agriculture and fruit trees, fields in polyfruit and polycrop design, agroforestry system of coffee trees.	Fields in polyfruits [mango, avocado, mamey sapote, citrus fruits, sugar-apples, soursop (*Annona muricata* L.), cherimoya (*Annona cherimola* Mill.), canistel (*Pouteria campechiana* Baehni), caimito (*Chrysophyllum cainito* L.), coconut]; fruit tree fields (mango, guava, coconut) with intercropping [papaya (*Carica papaya* L.), pepper (*Capsicum annuum* L., staked tomato]; agroforestry system of coffee trees.
Sierra de Cubitas (Camagüey)	CCS Camilo Cienfuegos (rural)	El Alacrán farm (26,84 ha). Simple design: simple perimeter living fence, integration agriculture and animal husbandry; anti-erosion living barriers of king grass, monoculture design crops, semi-confined and in-shed animal husbandry..	Fields (papaya, cassava, corn, banana, coconut, mango, beans), semi-confined rearing with grazing in simple paddock (sheep, goats) and rearing in shed (poultry).

¥ Productive organization forms: UBPC: Basic Unit of Cooperative Production, CCS: Cooperative of credits and Services; Agricultural Enterprise
¥¥ Location zone: periurban (periphery of the city), suburban (around the city up to 10 km), rural, mountain

N is the number of variables and 4 the maximum value of the scale (adapted from Vázquez and Martínez, 2015).

El general index of resilience to tropical cyclones (GIRtc) and the agroecological design and management coefficient ($A_{dm}C$) of each production system were determined as follows:

$$\Sigma\ [C_1 + C_2 + C_3 + \ldots]/\ N, \text{ where:}$$

Σ is the sum of the values obtained for each of the components

Table 2. Components and variables used to determine the GIRtc in the studied production systems.

Component	Variable
Ex ante preparation capacity (PRa). The actions that are done upon the warning of event imminence, in order to be prepared and guarantee resources for the later recovery.	Security of productive infrastructure and support, protection of productive animals, prunning of auxiliary trees, conditioning of the drainage system, water storage capacity, feed availability for the animals, harvest of production in process and emergent access to markets.
Resistance during (RSd). Capacity of the production system to stand-absorb the physical effects of the event.	Resistance of productive species, cropping systems, animal husbandry, soil, structures of auxiliary vegetation and facilities.
Ex post recovery capacity (RCp). Capacity of the production system to recovery after the event and return to the previous productive and economic status as soon as possible.	Utilization of the damaged ongoing production, recovery of affected crops and animals, access for works on the soil, cleaning up of auxiliary trees and time of productive recovery.
Permanent transformability (TRp). Existing capacities and changes carried out during the last three years, to increase the capacity of preparation, resistance and recovery against tropical cyclones.	Funding level, participation in innovation processes, effective articulation for external support, improvements of resistance capacity in cropping and animal husbandry systems and improvements in the resistance of productive and support infrastructures.

Table 3. Components and variables used to determine the agroecological design and management coefficient (AdmC) of the studied production systems.

Component	Variable
Matrix of the agricultural landscape (MAL)	Topography, type of prevailing agriculture, physical stress factors.
Matrix of the production system (MPS)	Design of the perimeter living fence, subdivision into management units, design of the sections of the internal living fences, integration of lateral living barriers in fields of agricultural crops, integration of seminatural environments, integration of the tree as auxiliary vegetation, productive surface under exploitation.
Structure of agrobiodiversity (SAB)	Types of productive items (agriculture, animal husbandry, silviculture, ornamentals, others); subtypes of productive items (vegetables, root and tubers, grains, small fruits, plantain and banana, fruit trees, coffee and cacao (*Theobroma cacao* L.), forestry plants, herbaceous forages, shrub-tree forages, large livestock, small livestock, poultry, rabbits, pigs, flowers, ornamental plants, apiculture, others) and productive species.
Soil management and conservation (SMC)	Soil tillage, prevailing irrigation system, method of weed management, amendments; cover crops or green manures in the rotation system, crop rotation and drainage system.
Design of cultivation systems (DCS)	Large typical fields (more than 1 ha), smaller typical fields (less than 1 ha), plots (very small and irregular typical fields), fields in blocks or strips, mosaic of smaller fields or plots, garden plant beds, organoponic garden plant beds, semiprotected crops in beds or plots (cloth cover), protected crops in beds or plots (greenhouse) and agroforestry systems.
Design of animal husbandry system (DAHS)	Design of enclosed pastures or paddocks larger than 1 ha (EPLP), design of enclosed pastures or small paddocks (less than 1 ha) (EPSP), rearing in sheds (RIS) and rearing in sheds with cages (RISC).

N is the number of components (adapted from Vázquez and Martínez, 2015).

To the effects of this study, the resilience capacity of the production system (RCps) before the exposure to tropical cyclones was considered, according to the obtained values, as H-high (>0,8), MH-moderate-high (0,6-0,79), LM-low-moderate (0,4-0,59), L-low (<0,4). In the design and management of the production system (ADMps) three categories were considered: initiating the agroecological transformation (IAT)- (0,20 - 0,45), under agroecological transformation (AT) (0,46 - 0,70) and in the agroecological system in question (> 0,70), adapted from Vázquez *et al.* (2019).

In order to determine whether there were types of production systems, according to their resilience capacity (GIRtc) and agroecological design-management (AdmC), an analysis of hierarchical clusters was done, using the Euclidian distance, with a full link method and also through the linear correlation method (StatSoft, Inc., 2011).

The sensitivity of the agricultural species exposed to hurricane Irma was determined through a scale elaborated in this study, which is based on the symptoms that are observed in the plants: 1) very slight, barely perceptible; 2) some organs with visible damage, without importance; 3) damaged or destroyed organs (leaves, flowers, fruits or branches) are immediately observed; 4) destroyed plants. This scale (prevailing value) was applied to fields and groups of dispersed plants. The sensitivity index to tropical cyclones was used, according to the following expression, adapted from Vázquez *et al* (2019):

$ISTc = \Sigma\ [(1*n) + (2 * n) + (3 * n) + (4 * n)]/4\ (N)$, where:

1, 2, 3, 4, are the scale values
n is the number of crop fields and groups of dispersed plants with each scale value
N is the total crop fields and groups of dispersed plants
4 is the maximum value of the scale

Vulnerability was determined for the existing cultivation and animal husbandry systems in each studied production system, considering that the lost surface of crops (non-recoverable), with regards to the planted or sown one at the moment the event occurred, for fruit trees that are planted in groups, destroyed quantity from the existing total and productive animals, quantity that was lost (deaths or strays) from the existing total. According to the affected surface or quantity from the existing one, vulnerability was grouped into 0 %; 0,1-30 %, 31-60 % and 61-100 %.

Results and Discussion

Production systems were grouped into three clusters (figure 1), according to the resilience capacity (GIRtc) showed in the face of hurricane Irma and the characteristics of their agroecological design and management (AdmC), with higher contribution for these groupings due to the capacity of resistance during the event (RSd) and of permanent transformability (TRp), as well as because of the design and management of the matrix of the production system (MPS) and the structure of agrobiodiversity (SAB).

A strong and direct linear relation was proven (correlation coefficient r=0,835) between the shown capacity of resilience to hurricane Irma (GIRtc) and the agroecological design and management of the studied production systems (AdmC) (fig. 2 left). As the value in the agroecological design and management increased, the resilience capacity also increased, with the exception of the El Cachón garden. This facility, in spite of having a higher AdmC than others, as it is very close to the coast (less than 10 m), was extremely exposed to the rains, winds and sea penetration (fig. 2 right).

From the nine production systems with lower GIRtc, grouped in cluster II, five are rural peasant farms ($A_{dm}C$=0,36-0,43), three periurban gardens ($A_{dm}C$=0,44-0,51), besides a conventional rural farm ($A_{dm}C$=0,35), which turned out to be the one with lower index of resilience among all the studied systems. It is followed by three systems of cluster I: one farm, a periurban garden and a rural peasant farm ($A_{dm}C$=0,52-0,58). The systems of higher resilience index (cluster III) were two private farms: a rural and a periurban one ($A_{dm}C$=0,73).

A similar result was obtained by Vázquez *et al.* (2019) in a study conducted in three suburban farms close to Havana, in which it was concluded that the agroecological transition of agricultural production towards sustainable systems is convergent with the transformation towards drought-resilient systems. This evidence reinforces the contribution of agroecology to the management of the climate change, in which considering the social functions that grant transformability capacity is fundamental.

Casimiro-Rodríguez *et al.* (2020) from technological and efficiency criteria, conducted a study to determine the socioecological resilience of 15 family farms in five provinces of Cuba. These authors reported moderate resilience as average, because although the farms were self-supplied with food, most of

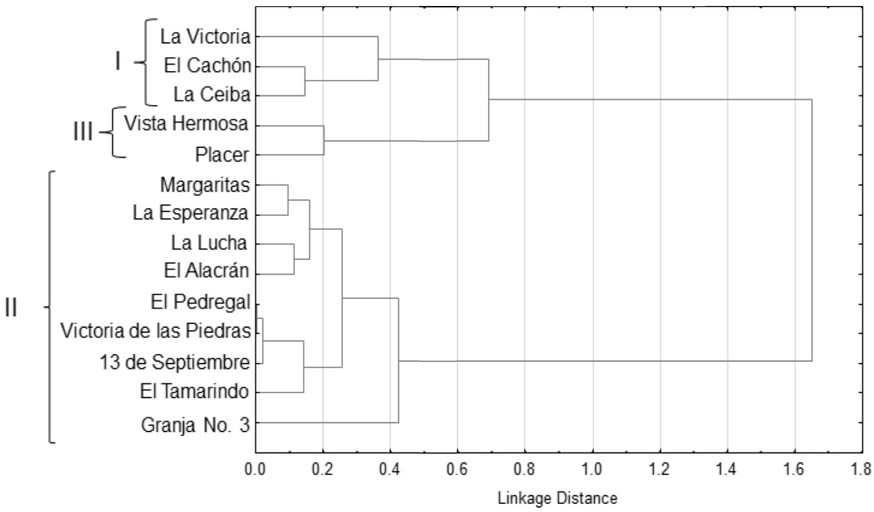

Figure 1. Dendrogram of the cluster analysis to group the production systems, according to the GIRtc and AdmC.

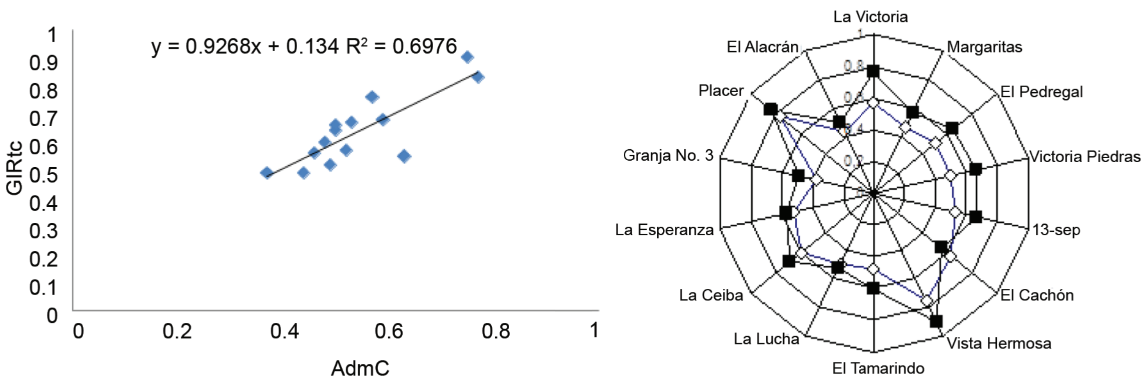

Figure 2. Correlation coefficient (left) and agroecological design and management coefficient-AdmC (white triangles) and general index of resilience-GIRtc (black squares) to hurricane Irma (right).

them with good productivity per hectare per year and high capacity of technological change, they showed an index of dependence on external inputs that influenced the unfavorable results presented by several efficiency indicators.

The production systems of cluster I are considered under agroecological transformation (table 4). Nevertheless, the resilience capacity was moderate-high for the farms La Victoria and La Ceiba and low-moderate for the El Cachón garden (table 5). This last one is a system of urban agriculture, which has as limiting external factor its closeness to a beach.

La Victoria farm, which obtained a moderate-high capacity of resistance during (RSd=0,75) the post-event recovery (RCp=0,96) and permanent transformability (TRp=0,85), integrates animal husbandry, forages, agricultural crops and fruit trees. In such activities no affectations were recorded. Its main item is goat milk.

From the systems grouped in cluster II, four are initiating the agroecological transformation, and four are under agroecological transformation. One system (farm 3) is still considered conventional (table 4). The resilience capacity is also different (table 5): low-moderate for four systems and moderate-high for four of them: El Pedregal, Trece de Septiembre and El Tamarindo. The systems El Pedregal, Victoria de las Piedras, Trece de Septiembre and El Tamarindo, stood out for their high capacity of recovery after the event.

The systems of cluster III are considered agroecological (table 4), with high resilience capacity.

Table 4. Agroecological design and management coefficient of the production systems.

Production systems	MAL	MPS	SAB	SMC	DCS	DSG	$A_{dm}C$	ADMps[¥]
Cluster I								
La Victoria	0,69	0,57	0,58	0,41	0,25	0,67	0,53	AT
El Cachón	0,63	0,54	0,58	0,56	0,58	0	0,58	AT
La Ceiba	0,69	0,25	0,58	0,41	0,66	0,50	0,52	AT
Cluster II								
Margaritas	0,75	0,29	0,33	0,38	0,38	0	0,43	IAT
La Esperanza	0,69	0,54	0,42	0,41	0,63	0	0,54	AT
La Lucha	0,69	0,29	0,42	0,41	0,42	0	0,45	IAT
El Alacrán	0,44	0,29	0,42	0,44	0,33	0,25	0,36	IAT
El Pedregal	0,75	0,36	0,42	0,44	0,5	0,50	0,50	AT
Victoria piedras	0,69	0,36	0,42	0,44	0,31	0	0,44	IAT
13 septiembre	0,75	0,36	0,50	0,44	0,5	0	0,51	AT
El Tamarindo	0,75	0,29	0,42	0,22	1,0	0	0,54	AT
Granja No. 3	0,69	0,25	0,25	0,28	0,25	0	0,35	-
Cluster III								
Vista Hermosa	0,81	0,71	0,92	0,66	0,6	0,69	0,73	A
Placer	0,75	0,71	0,75	0,53	0,88	0,75	0,73	A

MAL: matrix of the agricultural landscape, MPS: matrix of the production system, SAB: Structure of Agrobiodiversity, SMC: soil management and conservation, DCS: design of cropping systems, $A_{dm}C$: agroecological design and management coefficient, ADMps: agroecological design and management of the production system.
[¥]IAT-Initiating the Agroecological Transformation (0,20-0,45), AT-under Agroecological Transformation (0,46-0,70) and A-Agroecological (>0,70).

The capacity of later recovery and of permanent transformation stands out in them (table 5).

Agricultural biodiversity, as it is used by traditional farmers, contributes to resilience through several strategies which, often, are used combined: the protection and restoration of the landscape matrix, soil and water conservation, diversification of agricultural systems with polycrops, agroforestry systems and integration of animals and the diverse adjustment in the practices of cultivation and use of stress-tolerant native varieties (Altieri and Nicholls, 2018).

It was proven that the preparation capacity (PRa) of production systems in the face of the imminence of this event was relatively similar, with values from low to moderate for most of the systems, except for the Vista Hermosa farm, of cluster III, which was slightly higher (table 5).

Most of the production systems had very low capacity to prepare upon the warning of an event of this type. They limited to collecting some production under process and protect the animals and facilities, among other emergent actions, expecting the hurricane to hit, and then utilize what was not completely lost. However, although the energy generated by this type of event is highly destructive, it could be proven that the losses due to production under process would have been less, if there were capacities for the harvest, commercialization and fast processing of the productions that could be recovered, among others that depend on an effective articulation at local scale.

To the effects of this study, coinciding with Vázquez *et al.* (2020), preparation is considered a component of resilience that values the preliminaries in the face of the warning of imminence for a certain territory. This stage is very important to protect physical and animal resources and harvest the production under process that can be utilizable, among other emergent actions that are intrinsic of agricultural production systems, and which are in the trajectory of a tropical cyclone or hurricane. These actions are justified by the intensity of the combination of strong winds and intense rains to which such systems can be exposed.

The capacity to resist or absorb (RSd) the physical effects of the event was high for the two production systems of cluster III; while several systems of clusters I and II showed moderate-

Table 5. General index of resilience of production systems to tropical cyclones

Production systems	Components of resilience				GIRtc	RCps¥
	PRa	RSd	RCp	TRp		
Cluster I						
La Victoria	0,47	0,75	0,96	0,85	0,76	MH
El Cachón	0,38	0,45	0,70	0,65	0,55	LM
La Ceiba	0,43	0,79	0,75	0,75	0,68	MH
Cluster II						
Margaritas	0,43	0,65	0,50	0,65	0,56	LM
La Esperanza	0,50	0,75	0,58	0,45	0,57	LM
La Lucha	0,42	0,45	0,70	0,50	0,52	LM
El Alacrán	0,33	0,58	0,63	0,40	0,49	LM
El Pedregal	0,33	0,63	0,96	0,65	0,64	MH
Victoria Piedras	0,38	0,63	0,96	0,65	0,66	MH
Trece de septiembre	0,42	0,65	0,95	0,65	0,67	MH
El Tamarindo	0,33	0,75	0,85	0,45	0,60	MH
Granja No. 3	0,46	0,50	0,50	0,50	0,49	LM
Cluster III						
Vista Hermosa	0,64	0,96	1,0	1,0	0,90	H
Placer	0,53	0,85	0,95	1,0	0,83	H

PRa: preparation capacity, RSd: resistance during the cyclone, RCp: *ex post* recovery, TRp: permanent transformability, GIRtc: general index of resilience to tropical cyclones, RCps: resilience capacity
¥H-high (>0,8), MH-moderate-high (0,6-0,79), LM-low-moderate (0,4-0,59), L-low (<0,4)

high resistance (table 5). This result was in correspondence with the structural design of the production system matrix, tree integration, design and management of perimeter and internal living fences, as well as complexity in the design and management of cropping systems.

From the six production systems that expressed the highest resistance capacity during the exposure to this event (RSd > 0,7), La Victoria farm, which is from periurban agriculture, and the others, which are peasant farms, have as common characteristics that they are diversified systems. These systems are structured into several management units, delimited by internal living fences, in which trees are integrated in living fences, lateral living barriers are sown and polycrop designs are done.

These characteristics, which are achieved by the design and management, offer higher associative systemic resistance against the physical effects of strong winds, expressed in characters with capacities of buffering, withstanding and diverting them. In turn, they grant a spatial structure of cultivated or auxiliary vegetation, which is expressed in higher soil resistance to the physical effects of rain and water currents. This is not achieved in production systems with simple structure, which are more vulnerable.

The above-cited studies prove the importance of increasing the diversity of vegetation, its complexity and multifunctionality in agricultural systems, to reduce their vulnerability to extreme climate events. These observations reinforce the report by Altieri *et al.* (2015). These authors acknowledge that biodiversity is essential to maintain the functioning of ecosystems, and points at the crop diversification strategies, used by traditional farmers, as an important strategy to increase resilience in agroecosystems.

In contrast with conventional proposals, agroecology states that for the design of resilient agriculture it is necessary to reincorporate agrobiodiversity in the agricultural plots (mixtures of varieties, polycrops, agroforestry, animal integration, among others), along with practices of organic soil management, water conservation and harvest, besides the restoration of the surrounding landscapes. At landscape level, the matrix diversification must be accompanied by a series of complementary activities to reach the objectives of socioecological resilience (Nicholls and Altieri, 2017).

The recovery capacity post-event (RCp) was higher for the traditional private farms of cluster III, followed by the systems of cluster I. In cluster II, it was higher for the gardens of urban agriculture (table 5). The diversification of productive species, agriculture-animal husbandry integration and financial capacity were determinant for recovery.

The variable productive recovery, which means the time in which the production system is able to recover the production levels it had before the incidence of the event, showed the best values for the integrated and diversified systems (table 4), for traditional private farms as well as for gardens of urban agriculture.

The above-explained fact became particularly evident in the periurban gardens, which manage small short-cycle vegetables, where although Irma completely destroyed the production under process, they had the capacity to prepare rapidly the plant beds or plots and plant or sow, to recover their productions and incomes in several months.

The same happens in the farms of traditional farmer agriculture, which integrate diversity of productive agricultural, fruit and animal husbandry species, so that they have more options, because not all the productions were lost or because they have the capacity to plant anew rapidly, achieving productive recovery in less than one year.

However, the production systems with simple design, such as the farm specialized in plantain cultivation in Ciego de Ávila, where the winds tore down all the production under process, and whose partial recovery was estimated from 8 to 10 months, achieved the productive recovery in the second harvest (approximately one year or more).

Forty days after hurricane Ike battered Cuba in 2008, several researchers made a survey in the farms of the Holguín and Las Tunas provinces. They found that the diversified farms showed losses of 50 % with regards to 90 and 100 % recorded by the neighboring farms with monocultures. Likewise, agroecologically-managed exploitations showed a faster recovery of production (80-90 %) 40 days after the hurricane, compared with the farms with monocultures (Rosset *et al.,* 2011).

Permanent transformability (TRp) was a component that showed different values for each of the clusters (table 5), which were influenced mainly by the capacity of access to different funding sources and participation in innovation processes, with approach of resilience and effective articulation for external supports. The variables of this component, which are often associated to the preparation and resistance capacity, also influenced the recovery capacity and, in general, are determinant of the resilience of the production system. Precisely, the two systems of cluster III, which obtained the highest resilience index, showed the highest permanent transformability (TRp = 1,0). They were followed by La Victoria farm (TRp = 0,85), because part of the incomes of this facility was aimed at improving the capacities; besides the fact that it participates in projects that facilitate transformative innovations.

Studies conducted to determine the resilience to drought of suburban farms showed higher contribution to transformability, due to the educational level of their workers, to gender equity and to the participation in reciprocal exchange and innovations (Vázquez *et al.*, 2019).

The agricultural species that were exposed to the incidence of hurricane Irma showed different sensitivity to its physical effects (fig. 3). It was proven that the crops with herbaceous structure, such as vegetables, beans, corn, plantain and banana, independently from the variety and age, are highly sensitive (IStc>0,9). Papaya and cassava were also very sensitive (IStc > 0,8); while sweet potato and okra showed lower sensitivity (IStc= 0,5-0,7). Fruit trees had different sensitivity levels soursop (IStc > 0,9), avocado, cherimoya (*Annona cherimola* Mill.), coconut and June plum (IStc= 0,5), mango and mamey sapote (IStc of 0,4-0,5) and orange and guava (IStc= 0,25).

The sensitivity of the cultivated species showed certain differences for the plant types in the following order: annual and temporary agricultural crops > semipermanent agricultural crops > fruit trees > permanent herbaceous plants. These differences are directly related to several contrasting structural characteristics: a) herbaceous or woody, b) low to medium or high to very high size, c) surface or shallow root, d) fine and small or thick and large leaves, e) plant with vertical growth that covers the soil, which are traits that should be considered in the design and management of cultivation systems.

In the Caribbean, different agricultural products are affected by hurricanes, and there is substantial heterogeneity in the resistance of crops to these events. A higher diversification in the agricultural sector can increase resilience to hurricanes in the region (Mohan, 2017).

It was proven that tolerance, and even resistance of cultivated plants to the biophysical effects of

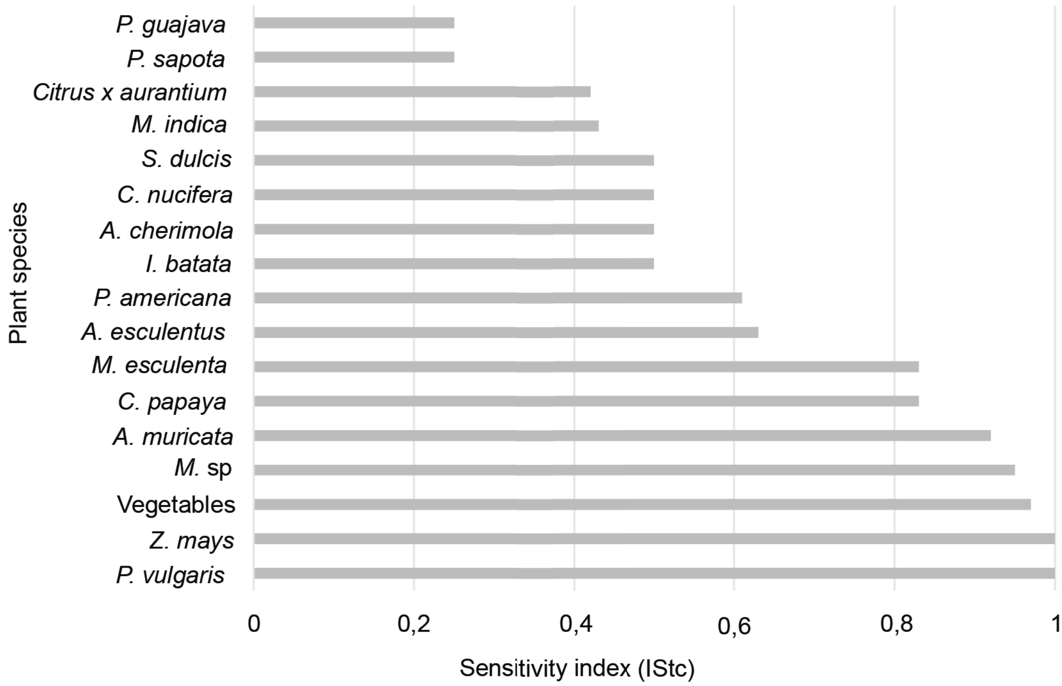

Figure 3. Sensitivity of agricultural species and fruit trees in production systems exposed to hurricane Irma.

cyclones-hurricanes, basically depend on the consistency on their tissues and structure. They can also vary for the different types of cultivation systems, whose design and management can grant the following functional traits: a) soil quality, b) depth of sowing or planting, c) sowing or planting distance, d) regulation of plant height, e) regulation of branch growth, f) regulation of the plant structure, g) soil preparation system, h) companionship with crops of different structure, i) nutritional status of the crop, j) health status of the crop, k) type of irrigation system, l) integration of auxiliary vegetation (cover and living barrier), among others.

The vulnerability of cropping and animal husbandry systems, expressed in the agricultural and livestock losses of each studied system (percentage of the surface or quantity of production under process), was lower for the systems of cluster III, with 62,5 % of crops or animals that were not lost. In contrast, in cluster I, 38,5 % of the production under process was rescued; while in II 2,7 % was preserved (fig. 4).

In the production systems with resilience capacity losses of the production under process can appear, due to three factors, mainly: the cultivation systems do not achieve the sufficient functions to withstand the physical effects of these events; in the composition of species an varieties that are managed in the season of occurrence of these events those that, as a whole, have higher physical capacity to resist are not integrated with priority; and the inappropriate agrotechnical management of the crop, which is a determinant factor of the resistance capacity.

In particular, the plantain and banana crops, which are highly sensitive to winds, express higher vulnerability in specialized cropping systems (monoculture) and the management of the clump is not well-structured with successors of different ages. However, when dwarf clones are used in high density (semipermanent crop) or they are intercropped in fruit fields or agroforestry coffee systems, express lower vulnerability. A very similar situation was observed in fruit trees, whose systems with design in monoculture were more vulnerable compared with the polyfruit design. The trees, whose plantation hole was deeper and the crown was well-regulated, were less affected. These characteristics justify the contribution of mixed cultivation systems and good phytotechnical practices to the resistance of cropping systems.

The use of polycrops can generate very complex landscapes, because it reduces the risk of total loss. The systems with polycrops are capable of responding to extreme external events, besides

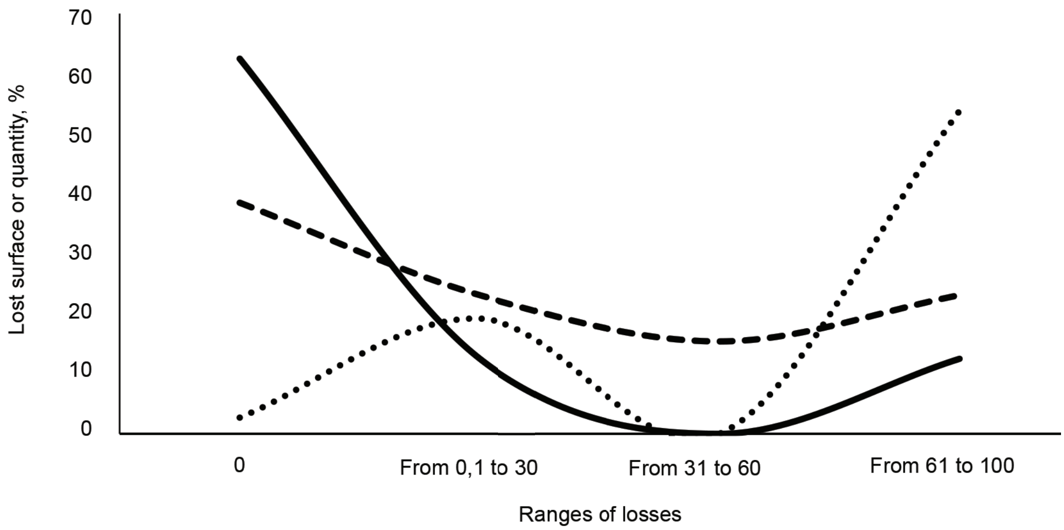

Figure 4. Vulnerability of cropping and animal husbandry systems for clusters I, II, III.

increasing productivity, when the combinations are adequate (Córdoba-Vargas and León-Sicard, 2013).

Regarding the livestock species, no losses appeared because in the studied systems they were protected, as part of the preparation before the warning of the event. Nevertheless, several vulnerability factors were identified: a) species that are reared in sheds (pigs, poultry) and cages (rabbits), as well as the semiconfined ones (cattle, sheep, goats) can risk becoming sick due to breaking of the roof covers, inundation of floors or lateral entrance of water; b) not guaranteeing the water and feed supply during the incidence of the event can sensitively affect the animals; c) the grazing species can have feed limitations after the event, due to affectations in trees of living fences, when in the paddocks there is no diversity of integrated forage species; d) apiculture can be highly affected, if the beehives are not safe and the vegetation of the browsing area is very sensitive to the physical effects of the event.

The conservation or widening of agrobiodiversity and, particularly, of the functional connections among the different species, favors the self-regulation of agroecosystems, their homeostatic capacities and the complexity of the trophic levels associated to the energy and nutrient flows. The resilience of agroecosystems is benefitted from landscapes or surroundings, with a more complex environmental matrix, but requires sociocultural contexts with capacity of reaction, mobilization or collective action, and adaptation to changing circumstances, social cohesion, networks and organizations, sense of belonging and cultural identity (Samper, 2019).

Little has been done to increase the adaptability of industrial agriculture to changing and extreme climate events, except the "magical solutions" that have been implemented, such as genetic modification, with which it is expected that bred crops yield in stressful environments. Almost no work has been done to design management practices that increase the resilience of monocultures to climate change (Nicholls and Altieri, 2012).

A study conducted on the slopes of Central America after hurricane Mitch in 1998 revealed that the farmers who used diversification practices such as cover crops, intercropped systems and agroforestry systems, suffered less damage than their neighbors with conventional monocultures. The study showed that after the hurricane, the diversified (sustainable) plots had 20-40 % more topsoil, higher humidity, less erosion, and experienced lower economic losses than their conventional neighbors (Holt-Giménez, 2002).

There are many studies about the meteorological and physical aspects of these storms, and only recently the huge impact they have on ecological systems has become part of the general literature. Agriculture, in particular, is highly affected by hurricanes in the region. Recent estimations place the export losses due to hurricanes between 18 and 80 % for itemized and for aggregated data, respectively (Mohan, 2017).

The results obtained in different studies justify that the processes of agroecological transformation of the farms and other agricultural production systems, which are positioned as promising to reach capacities of resilience to events of climate change, must be conducted from a deep understanding of the physical effects of these events on the elements of the agroecosystem and the landscape, understood as a socioecosystem to identify the socioecosystemic functions that must be achieved with agricultural, animal husbandry and forestry practices (designs and managements), farmers' self-management, participatory articulation in local networks and governance of the policies that facilitate it. A different acting can lead to the inefficiency of these processes, expressed in costs and losses of different types, which constitute the vicious cycle that currently characterizes most of the existing adaptation programs.

In the last decades much has been written about the use of sustainable agriculture to improve the resilience of ecosystem services to climate change. Nevertheless, there is no tangible and systematic evidence of how agriculture would participate in the relief of the climate impact on vulnerable rural communities (El Chami *et al.*, 2020).

The concept of resilience gained strength in the academic, political and development speech in recent years, but its conceptualization and application at farm level has received little attention. For example, the recommendations in recent policies show agricultural resilience as a miraculous solution to face the risks and agricultural uncertainty and to achieve sustainable agrifood systems. Yet, the issue of what determines agricultural resilience in an environment of small agriculture is still confusing. Approaches are recommended that increase the entrepreneurial spirit of farmers, support farmers' organizations and enhance the relations between farmers and buyers (Kangogo *et al.*, 2020).

Conclusions

Resilience is increased as the complexity of the agroecological design and management of the production system and the agrobiodiversity structure increase, with higher contribution by the capacity of resistance during the event and of permanent transformability.

The agroecological systems expressed high resilience capacity to the effects of hurricane Irma, followed by the systems under agroecological transformation, whose capacity was moderate-high. The systems that were initiating the agroecological transformation expressed low-moderate resilience capacity, which was also obtained by the conventional system, but with the lowest value.

The farms of peasant agriculture, whose design and management is traditional, are more resilient compared with those which, in spite of being originally peasant, have received influences from conventional systems, mainly in territories where this type of agriculture prevails.

The integration and productive diversification was one of the most important capacities to achieve a fast recovery after the incidence of the event, which was evident in the periurban gardens and in the farms of traditional peasant agriculture, because they integrate diversity of agricultural, fruit and animal species. Thus, they have more options, as not all the productions were lost or because they had the capacity to make new plantings rapidly.

The losses of production under process could be less, if there were capacities for their harvest, commercialization and processing, before and after the incidence of the event.

The annual and temporary crops were very sensitive. However, the fruit trees, mainly the well-managed polyfruits (plantation hole and crown) and the permanent herbaceous plants, especially polyforages that were more resilient, were less affected.

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Conflict of interests

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Authors' contribution

- Luis L. Vázquez-Moreno. Elaborated and wrote the document.

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