

Synthesis on the application of a reference framework to determine the resilience capacities of agroecosystems to climate change

Abstract

Tropical cyclones and droughts are extreme hydrometeorological events whose effects can be disastrous in agroecosystems. Several participatory research projects have been conducted in different regions of Cuba to establish a framework for determining the resilience of agroecosystems to extreme events. The objective of this short article is to provide a synthesis of the documented results and raise awareness of their practical applicability to local climate change management. The resulting framework allows for the determination of a general resilience index for agroecosystems in the face of droughts and tropical cyclones. This index considers vulnerability variables (exposure, event risks, agroecosystem status, and sensitivity of production components) and resilience variables (resistance, recovery, and transformability). A summary of general resilience indices and evidence regarding resilience capacities in studied agroecosystems are provided. In agroecosystems, resistance is inherent to a combination of genetic traits in productive species and the technological design and management of cropping or livestock systems; while resilience is a set of comprehensive capacities in the design and management of the agroecosystem, based on its ability to systematically transform itself. Agroecosystems that have adopted agroecology demonstrate the greatest resilience to these events.

Keywords: agriculture, hydrometeorological events, vulnerability, resilience, recuperation, transformation

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Introduction

The main causes of climate change are greenhouse gas emissions, generated by various human activities since the beginning of the industrial revolution;¹ however, society's perception of it as a problem only began in the 1980s, and it gained importance among researchers and the public following the emphasis placed on it at the Rio de Janeiro Earth Summit in 1992.²

In Cuba, drought events registered a significant increase in their frequency of occurrence in the period 1961-1990 compared to 1931-1960. This increase has continued in the persistent drought events that affected the eastern half of the country from the early 1990s to the present, including the very serious event that occurred from May 2003 to May 2005. This behavior is linked to the strengthening of the anticyclonic influence over Cuba at middle and upper levels, which is associated with a strong tendency for an increase in downward vertical movements of the atmosphere.³

Regarding hurricanes, an increasing trend in activity is observed when considering a very long and reliable series, spanning from 1791 to 2017, although it is not statistically significant. Between 2001 and 2017, 12 hurricanes affected the island, 10 of which were intense. This strong activity of major hurricanes over Cuba since 2001, unprecedented since 1791, is primarily due to the high sea surface temperatures in the tropical Atlantic recorded since 1998. This variation is similar to future climate projections, which suggest that hurricanes could become more intense as sea surface temperatures rise.⁴

Climate change can exacerbate land degradation processes through increased rainfall intensity, flooding, drought frequency and severity, as well as through heat stress, drought periods, wind, sea level rise, wave action, and ice melt, the effects of which are modulated by land

management. These events clearly affect food security as a result of warming, changing precipitation patterns, and the increased frequency of some extreme events.⁵

From global strategies for adapting to climate change and mitigating its causes, countries establish policies and implement actions through programs that attempt to generate alternatives based on the specific conditions of each location. Specifically for agricultural production, programs and projects are implemented to help improve limiting factors such as soil, irrigation, varieties, breeds, and inputs; however, in many cases, the necessary structural transformations to impact the resistance capacity of production components and the resilience of the entire production system or farm are not carried out.⁶

The impact on agriculture will vary depending on the characteristics of the agricultural production system and its geographical location;⁷ in turn, thousands of traditional farmers in many rural areas have adapted to changing environments, developing diverse and resilient systems, in response to the various constraints they have faced over time.⁸

In various scientific circles, there is debate about whether the current hydrometeorological events are due to climate change, the Earth's natural cycles, or both; meanwhile, studies on future climate scenarios predict greater intensity. However, the extreme manifestation of some variables (lack of rainfall, increased temperatures, strong winds, intense rainfall), which occur non-linearly across years and affected areas, underscores the need to shift from a reactive strategy (preparation beforehand with a response afterward) to one of systematic transformation with a focus on resilience.

Internationally, conceptual updates on vulnerability and adaptation in climate change management are frequent, as seen in IPCC publications, among others. Simultaneously, theoretical and methodological proposals for adaptive and mitigation management

are being developed at different scales and across various sectors. In agricultural production, although there is a growing body of research that justifies the impacts of climate change and demonstrates adaptive and mitigation practices, there remains a demand for frameworks for resilience management in agroecosystems.

In this regard, this short article aims to raise awareness about the usefulness of reference frameworks based on Agroecology, to determine the resilience capacities of agroecosystems to climate change, based on evidence of documented innovations in Cuba.

Frameworks for determining the resilience capacity of agroecosystems

Climate change management in agroecosystems begins with determining resilience capacity, as a basis for identifying the practices needed to withstand and recover from the risks of extreme events.

The various methodologies presented herein have been tested in the field under various socioecological settings and they comprise useful tools for assessing the vulnerability of farming systems as well as the adaptive capacity of resource-poor farmers to respond to climatic events. The goal of the review was not to critically compare these methodologies, assess cross-case interpretability, or explore trade-offs between them. Rather, the objective was to synthesize field-tested assessment methodologies that provide a broad approximation to socioecological resilience in the context of resource-poor farmers in various Latin American countries. These farmers mostly neglected by extension services, urgently need tools to evaluate the preparedness of their farms to unpredictable climatic shocks.⁹

One line of research generated a methodology for the evaluation of socio-ecological resilience-MERS,¹⁰ which has been used to determine the resilience of farms in different territories of the country.¹¹

Several successive investigations carried out in territories of Cuba accumulated experiences and results that led to identifying the sensitivity of production components, vulnerability of cultivation systems and agroecological practices that contribute to adaptation capacities to droughts and tropical cyclones.^{12,13}

As a result, a general index was generated to determine the resilience capacity of agroecosystems, contrasting vulnerability variables with resilience capacities (Figure 1). Within this framework, it is assumed that as the production system is transformed through agroecological redesign, its resilience capacity to extreme hydrometeorological events progressively increases, while vulnerability also decreases.¹⁴ The results obtained in determining the aforementioned variables constitute the basis for the adaptive management of resilience in agroecosystems exposed to extreme events.

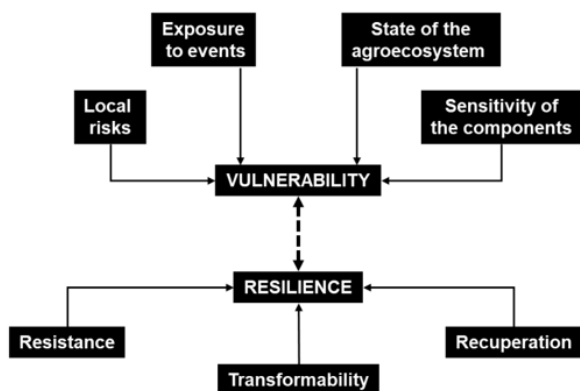


Figure 1 Framework for determining the resilience capacity of agroecosystems.¹⁴

The multiplicity of approaches and methodologies for understanding, identifying, and measuring climate resilience presents a complex landscape. As confirmed in the literature, there is a kind of “explosion of conceptual and reference frameworks for identifying and measuring resilience” across multiple fronts and dimensions (FAO 2021).

Evidence on resilience capacities in agroecosystems

In a participatory process to assess the vulnerability to drought of the main types of agroecosystems, carried out in 10 agricultural territories belonging to the western (3), central (3), and eastern (4) regions of Cuba, it was determined that vulnerability was high, above 70%, in most types of agroecosystems. This result demonstrates the high sensitivity of the exposed production components; of these, soil, growing crops, irrigation, and pest control showed the greatest sensitivity. Specifically, farms, cooperative production areas, and urban gardens, which are the most common types of agroecosystems, presented vulnerability to drought above 70%, except for coffee agroforestry systems (64.6%), and conventional livestock farming was rated as the most vulnerable (90.4%).¹³

A study conducted on 20 farms in the municipalities of Niceto Pérez and Manuel Tames in Guantánamo, to determine drought resilience, found that nine farms in Niceto Pérez and nine in Manuel Tames had General Resilience Index (GRId) values of 0.65 and 0.40, respectively. The highest resilience was achieved by farm number six in Niceto Pérez and farm number one in Manuel Tames, with the highest GRId values of 1.57 and 1.13, respectively.¹⁴

Subsequently, three suburban farms in the province of Havana were studied, and the results showed that the overall drought resilience index (GRId) was lowest for the La Victoria farm (GRId=0.66); followed by the Media Luna farm (IGRs=0.93) and the La China farm (GRId=3.21), which had the greatest resilience capacity. All three farms studied, which are in agroecological transition, showed values above the threshold (GRId>0.5), demonstrating that they are also developing resilience to this type of event.¹⁵

In these three farms it was also determined that the greatest contribution to resilience was due to the composition of agrobiodiversity, with the highest values (between 0.84-0.85) of all the indicators used, showing that during the agroecological transition process of these systems, greater progress has been made in the integration and diversification of productive species, precisely because they are livestock-based systems that have integrated agriculture and forage.¹⁵

Following Hurricane Irma, the overall tropical cyclone resilience index (GRItc) was determined for different types of agroecosystems in the provinces of Havana, Sancti Spiritus, Ciego de Ávila, and Camagüey. This index was then compared with the agroecological design and management coefficient (CdmA). A strong and direct linear relationship (correlation coefficient $r=0.835$) was found between the resilience capacity shown in response to Hurricane Irma and the agroecological design and management of the production systems studied. As the value for agroecological design and management increased, so did the resilience capacity.

In drought-stricken areas of Guaimaro and Jimaguayú, Camagüey province, a process designed according to the agroecological approach to climate change resilience¹⁷ was implemented, involving 41 farms. Among its objectives was determining the sensitivity of production components, as well as the vulnerability and resilience of these agricultural production systems to extreme weather events. As a result, in the municipality of Guaimaro, twenty farms belonging to

five cooperatives were studied. The General Resilience Index (GRI) was as follows: eight farms with values below 0.6, nine farms with values between 0.6 and 0.8, and three farms with values above 0.8. In the municipality of Jimaguayu, twenty-one farms belonging to five cooperatives were studied. As a result, the General Resilience Index (GRI) was as follows: twelve farms with values less than 0.6, seven farms with values between 0.6-0.8 and two farms with values greater than 0.8.¹⁸

A socioecological resilience study based on technological and efficiency criteria, carried out on 15 family farms in five provinces of Cuba, determined an average resilience, since although the farms were self-sufficient in food, mostly with good productivity per hectare per year and high capacity for technological change, they showed an index of dependence on external inputs that influenced the unfavorable results shown by several efficiency indicators.¹⁹

Criteria and practices in agroecosystem resilience

Exposure to a hydrometeorological event can be predicted (e.g., tropical cyclone) or through an early warning system (e.g., drought); it can also be determined by the warning system when a tropical cyclone forms (Civil Defense 2010, 2017). The likelihood of such an event occurring in different territories and the exposure of the agroecosystem are relative, as they depend on its location, among other geomorphological factors.

The definition provided by the IPCC has become a benchmark for vulnerability analyses and brings to the forefront the concepts of exposure, sensitivity, and adaptive capacity. Therefore, the vulnerability of a system depends on the extent to which the system is exposed and how sensitive it is to the effects of climate change and is inversely proportional to its capacity to adapt to these effects.⁵ When assessing the vulnerability of agricultural production, it is necessary to consider the state of the agroecosystem, and this is significantly influenced by the prevailing technological approach.¹⁴

In conventional agricultural production, production factors (variety, seed, energy, water, agrochemicals, and other inputs) are considered the determining factors; whereas, the agroecological transition toward sustainable systems is determined by production components: soil, productive species, reproductive material, crop growth and development, water and irrigation, plant health management, nutrition management, crop flowering and fruiting, harvest, and post-harvest. These components can exhibit sensitivity, tolerance, or resistance to extreme hydrometeorological events.^{15,16}

The sensitivity of productive species is expressed in injuries or direct damage to their tissues or organs, alterations in their physiology, reduced growth, decreased productive yields or their quality for the market, among other criteria.¹³

An agricultural species and variety may be sensitive to the physical effects of an event; however, it may suffer less damage thanks to the resistance or absorption capacity conferred by the design and management of the cropping system.²⁰ Therefore, the need for adaptive capacity to adopt a resilience approach is being argued, which has two dimensions: resistance and recovery capacity.²¹ A system is resilient if it is able to continue producing despite the significant challenge of an extreme weather event.²²

In agricultural production, resilience to drought goes beyond simply having more water available for plants and livestock; it also requires creating a microclimate that mitigates its effects, optimizes water use, and reduces energy expenditure through evapotranspiration, all of which is possible through the multifunctional redesign of farms.¹⁴

The capacity to withstand the prolonged physical effects of drought is jointly determined by the tolerance or adaptive capacity of productive species, good production practices, the conservation status of natural resources, and the design and management practices implemented at the scale of cropping, livestock, and overall production systems. A suitable interpretation is that resistance-absorption is a capacity of the system, not of the isolated elements that comprise it.¹⁵

The tolerance, and even the resistance, of cultivated plants to the biophysical effects of cyclones and hurricanes depends primarily on the consistency of their tissues and structure. These characteristics can also vary depending on the type of cropping system, whose design and management can impart the following functional traits: a) soil quality, b) planting depth, c) planting distance, d) regulation of plant height, e) regulation of branch growth, f) regulation of plant structure, g) soil preparation system, h) intercropping with crops of different structures, i) crop nutritional status, j) crop health status, k) type of irrigation system, l) integration of auxiliary vegetation (cover and living barriers), among others.¹⁶

Production systems structured into several management units, delimited by internal living fences, which integrate trees into living fences, plant lateral living barriers, and implement polyculture designs, offer greater systemic associative resistance to the physical effects of strong winds. This resistance is expressed in traits capable of attenuating, resisting, and deflecting these winds. Furthermore, these systems provide a spatial structure for the vegetation, both cultivated and auxiliary, which translates into greater soil resistance to the physical effects of rain and water runoff. This is not achieved in production systems with a simpler structure, which are more vulnerable.¹⁶

The design of the farm's structural matrix is fundamental for drought resistance, where the integration of trees, whether in crop fields or in different parts of the farm, makes the greatest contribution. This is because trees promote different strata which, together with the diversity of crops integrated into the system, increase the capacity of both the crops and the soil to withstand the direct effects of solar radiation and increase moisture retention.¹⁴

In contrast to conventional approaches, agroecology proposes that designing resilient agriculture requires reincorporating agrobiodiversity (varietal mixtures, polycultures, agroforestry, animal integration, etc.) into agricultural plots, along with organic soil management practices, water conservation and harvesting, and the restoration of surrounding landscapes. At the landscape level, diversification of the crop matrix must be accompanied by a series of complementary activities to achieve the objectives of socio-ecological resilience.²³

Observations of agricultural performance after extreme weather events, conducted over the past two decades, have revealed that resilience to the effects of climate disasters is closely related to farm biodiversity levels.^{24,25} In this regard, Altieri and Nicholls²² consider that vulnerability can be defined as the possibility or imminence of loss of biodiversity, resources (soil, water), or productivity of an agroecosystem or its key socio-cultural characteristics in the face of an occurring or imminent threatening process.

In fact, forty days after Hurricane Ike struck Cuba in 2008, diversified farms were found to have experienced 50% losses compared to the 90% to 100% losses recorded by neighboring monoculture farms. Similarly, farms managed agroecologically showed a faster recovery in production (80-90%) 40 days after the hurricane, compared to monoculture farms.²⁶

Recovery is the system's capacity to recover after an event, the speed at which this recovery is achieved, and the degree to which it reaches its previous state. This capacity can be enhanced with the support of local entities or cooperative networks among farmers. Recovery is closely linked to the capital endowment of the production system: natural, physical, human, social, and financial.¹⁴

In systems that were exposed to Hurricane Irma, the productive recovery variable, which means the time it takes for the production system to recover the production levels it had before the event, showed the best values for integrated and diversified systems, whether for traditional peasant farms or for urban agriculture gardens.¹⁶

Transformability means that climate change adaptation management must be a continuous process, going beyond simply preparing for an imminent extreme event. Actions must be taken gradually to improve resilience and recovery capacity. This capacity also depends on capital assets. The transformability achieved by a production system is closely related to local innovation capacity.¹⁴ It depends primarily on the human, physical, financial, and natural capital of the production system; however, the contribution of social capital (local public administration, various institutions, private sector entities, and organizations of different types) is fundamental in the transition to resilient systems.¹²

Studies conducted to determine the drought resilience of suburban farms showed a greater contribution to transformability, due to the education level of their workers, gender equity, and participation in reciprocal exchanges and innovations.¹⁵

However, in areas with steeper slopes, the difference in agroecological resilience between diversified farms and conventional monocultures were less clear as the combination of rainfall intensity and slope became so great that differences in resilience between the two types of farms were no longer apparent. Although factors such as exposure, farm design and management practices mitigated impact, on average agroecological farms suffered as much damage as conventional farms.²⁷

In many areas of the world, farmers have developed agricultural systems adapted to local conditions, enabling them to maintain the continuous production necessary for subsistence, despite cultivating in marginal land environments with unpredictable climate variability and very low use of external inputs. Part of this success is related to the high level of agrobiodiversity that characterizes traditional agroecosystems, which has positive effects on their functioning. Diversification is, therefore, an important strategy for managing production risk in small-scale farming systems.⁸

Final comments

While the principles of climate resilience recognize that, broadly speaking, adaptation to climate change is what is done (actions) to achieve resilience to climate change (a condition or state), the concepts are combined and uniformly referred to as climate resilience.²⁸

Although an overwhelming number of studies demonstrate that these agroecological designs and practices are associated with greater farm-level resilience, it is important to recognize the limits of resilience. The aim of this paper is to assess the limitations of agroecological practices in enhancing the ability of agroecosystems to adapt to climate change under extended drought stress which may overwhelm crops' adaptation response. A set of agroecological practices that can extend such limits under prolonged water stress scenarios are described.²⁹

Adaptation is the process of adjusting to the current or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or take advantage of beneficial opportunities. In some natural systems, human intervention can facilitate adjustment to the expected climate and its effects. Resilience is the capacity of social, economic, and environmental systems to cope with a hazardous event, trend, or disturbance by responding or reorganizing themselves in ways that maintain their essential function, identity, and structure, while also maintaining the capacity for adaptation, learning, and transformation (IPCC 2014).

Society as a whole must seriously consider the possibility of further promoting resilience in socio-ecological systems and exploring options for the deliberate transformation of vulnerable socio-ecological systems.³⁰

In agricultural production, which takes place in different types of agroecosystems, resistance is inherent to a combination of genetic traits in the productive species and the technological design and management of cropping or livestock systems; whereas resilience is a set of comprehensive capacities in the design and management of the agroecosystem.^{14,31-33}

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Conflict of interest

Authors declare that there is no conflict of interest.

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