Analysis of the Agroecological Zone Method in Predicting the Impact of Climate Change on Agriculture

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Abstract—Agriculture is an activity dependent on environmental conditions and with the predicted climate changes, serious influences on crops are likely to occur, and prediction studies are important in order to minimize the impacts on agricultural production. The present work is the result of consultations to scientific works published on the proposed topic. It was found that extreme heat increases and greater risks of drought are expected in Brazil and that the Agroecological Zone Method is one of the most used for modeling in which it is desired to verify the impact of the water deficit on plant production, being of easy application, understanding and your results are close to reality. In this situation, depletion in plant production is considered only as a function of the reduction of water available to the plant, which is interesting for verifying the influence of future climate change scenarios on plant production. However, it has the disadvantage of not considering the attack of pests and diseases, which are influenced by climate changes. The importance of reinforcing resilience in agroecosystems is also highlighted, not only with plant improvement through the development of cultivars adapted to future climate scenarios, but also with management alternatives. It is concluded that the Agroecological Zone Method is a reliable alternative to verify the effect of future droughts on agricultural production, despite its limitations and that it is essential to plan and combine strategies for adapting to climate change.

I. INTRODUCTION

Agriculture is an activity that is extremely dependent on climatic elements, such as temperature, rainfall, humidity and solar radiation, and any interference with one or more of these factors can influence plant development [1].

On the other hand, water is essential for agricultural production, as it is necessary for the process of cell growth and expansion; however, 90% of the water required by terrestrial plants is not used in any biochemical route, being lost through transpiration [2] and it is through this transpiration process that the absorption of essential nutrients for the plant's development and translocation takes place. of solutes [3].

In this context, once the future scenario of climate change is confirmed, with an increase in the Earth's surface temperature and changes in rainfall patterns, the agricultural sector will certainly be affected. This, in view of the dependence of agriculture on the climate, and changes in this component will directly affect, among

others, the physiology of plants. In the case of Brazil, future projections indicate significant impacts on the extreme precipitation regime, with floods and floods; in addition to increases in extremes of heat and greater risks of drought in the country [4] [5]. Thus, agriculture may suffer from more frequent and severe abiotic stresses, such as drought and high temperatures, and biotic stresses, such as greater occurrence of pests and diseases [6]

There are regions of the country where the productivity of some agricultural crops is still below its potential, precisely because of stresses, considered limiting [6]. To minimize these impacts, research in the area of plant genetic improvement has been carried out in order to adapt agricultural production to climate change, through technologies that generate plants that are more tolerant to stresses such as water deficit, high temperatures and changes in the incidence and severity of illnesses. In this context, it is important to highlight that the cultivation of local varieties by farmers is essential, as in addition to avoiding a major crop problem, it also works as a germplasm bank, which can be used by breeders for the development of cultivars resistant to environmental conditions different, especially to climate change [7]. Thus, the loss of genetic resources and local knowledge can compromise the ability of farmers and breeders to obtain plants that will be resistant to future environmental shocks, as in the case of climate change [8].

Therefore, efforts to minimize the consequences of global warming, as well as actions and policies to adapt and reduce vulnerabilities at a local and regional scale, are essential to reduce the risks to social and environmental security. Cuadra et al. [9] mention that, from a strategic point of view, it will be extremely important to foresee how agroecosystems will meet the increased global demand for food and energy in a sustainable way and in a context in which agricultural productivity may present stagnation or associated reductions to climate change [10] [11]. Therefore, understanding how the plant responds to climatic conditions, directly influencing crop yield, is of paramount importance, as well as understanding how far it is possible to predict the resilience of agrobiodiversity to these changes.

Thus, the objective of this work is to evaluate the Agroecological Zone Method as a way to predict the impacts of climate change on agricultural crops.

II.   METHOD

The present bibliographical review was carried out by consulting scientific works and books published in areas related to the proposed theme in several databases: Scielo,

Science Direct, Scopus, Web of Science, EMBRAPA, Capes Periodicals, FAO, among others.

The following keywords were used for the survey: agrobiodiversity, agroecological zone method, effect of meteorological events, climate and plant interaction, requirement of cultivated plants and plant resilience.

Based on the works found, this review article was constructed.

III.   RESULTS AND DISCUSSION

3.1 Resilience in Agroecosystems

Resilience is the intrinsic capacity of a system to maintain its integrity over time, especially in relation to external pressures [12]. The main characteristic of a resilient system is its flexibility and ability to perceive and eventually create options to face adverse situations. The diversity of alternatives that the farmer perceives, or is able to create, is a central element in building the resilience of the agroecosystem [13].

For a better understanding of the mechanism of resilience of agroecosystems, it is essential to study the impacts of climate change on agriculture, in order to minimize production and quality losses, helping to choose strategies to overcome the problems. Among the main difficulties encountered in this type of study, there is the continuing uncertainty about the exact magnitude of climate change that will occur in the next 25 to 50 years [14].

According to Pinho et al. [15], climate changes are due to the increase in the global average temperature expected for the next decades until the end of the century, which, in turn, is related to the increase in the concentration of greenhouse gases (GHG), leading to a reduction the resilience of ecosystems in all biomes, incurring in loss of biodiversity and ecosystem services and increased exposure and socio-environmental vulnerabilities. Initially, in Brazil, the Caatinga biome is the most resilient to global temperature increase, and the Amazon, Atlantic Forest and Cerrado are the most susceptible to loss of resilience. For the Caatinga, the aridization process is enhanced [16] and spatially advances to other possible areas occupied by the Atlantic Forest, especially in the coastal region [17].

To ensure greater resilience and adaptability to climate risks, it will be important to quantify the risk that agroecosystems will be subject to in different ecoregions in Brazil. This task is extremely complex given the continental dimension of the country, the diversity of crops, production systems and availability of natural resources. Objectively measuring ecological resilience is not a trivial task [18], especially at large spatial scales [19]

and it is in this context that the tools used come into play. To assess the responses of agricultural productivity to climatic conditions, empirical (statistical) models and models based on biophysical processes that simulate agricultural productivity and its interactions with the environment and management practices are used [20] [21].

The possibility of adapting agriculture varies depending on the characteristics of each system and the different foreseen future scenarios. There are few analyzes in this regard in Brazil [22]. Andrioli and Sentelhas [23] determined the sensitivity of maize genotypes (*Zea mays*) to water deficit using an Agroecological Zone Model. The model's performance was acceptable for the evaluation of the real yield, whose estimated mean errors for each genotype ranged from -5.7 to +5.8%, and whose overall mean absolute error was 960 kg ha^{-1} (10%).

Barbieri et al. [24] carried out the zoning of sugarcane expansion areas, validating the model with irrigated sugarcane data. The model was effective in estimating the productivity of irrigated sugarcane, in both year and year and a half crops, with the possibility of being used for forecasts throughout the harvest. Monteiro [25] used the same model, associating the penalty of productivity with water deficit, to develop a procedure for obtaining classes of production environments for sugarcane cultivation, in 178 locations in the state of São Paulo. As a result, it obtained satisfactory performance, enabling, together with the use of a geographic information system, to obtain the climatic classes of the production environments, which can support the planning of plants regarding varietal and operational management of sugarcane fields.

Despite great advances in recent decades, development, parameterization and validation on a regional, national and global scale are still insufficient. Initiatives such as The Agricultural Model Intercomparison and Improvement Project (AgMIP) and the Intercomparison, Improvement and Adaptation of Agricultural Crops Simulation Models for Climate Change Application (AgMIP-BR) project, coordinated by Embrapa, have sought to accelerate advances in parameterization and validation of these models [9].

There are other practices that reinforce the resilience of agroecosystems, such as: management alternatives, through the recommendation of more favorable times for the implantation of various agricultural crops [26] [27]; genetic improvement of plants, as it has a fundamental role in the development of cultivars adapted to the projected conditions of climate change [10]; animal production, adapted to heat and humidity, in conventional or integrated production systems, contributes to the reduction of thermal stress; intensive and integrated agricultural, livestock and forestry production systems (crop-livestock-forest integration – CLFI) allows for the intensification of land use for productivity gains in food and energy [28]; ecological systems, which make intelligent use of the natural functionalities offered by ecosystems [29], with the objective of designing multifunctional agroecosystems; fish farming, through the adaptation of aquaculture through integration with plant production for small producers [30], also called aquaponics [31].

It is important to emphasize that the diversity of alternatives to strengthen the resilience of agroecosystems is possible, through access to knowledge in various areas, including technical, ecological, cultural, the construction of concrete solutions in the environment, constructed and/or permitted biological diversity, characterized as a centerpiece in the resilience of an agroecosystem.

3.2 Plant behavior against water deficit

The water deficit in plants is due to a higher transpiration rate than water absorption, which can happen by different mechanisms, such as drought, salinity and low temperatures [32]. Thus, there is a stress on the plant that causes changes in its behavior, and the irreversibility of the situation will depend on the species, genotype, duration of stress, plant development stage and the nature of this stress [33].

Basically, water stress resistance mechanisms involve limiting growth in order to minimize water loss; morphological adaptations; physiological adaptations; and metabolic alterations [34]. However, the most accentuated response of plants to water deficit is the decrease in leaf area production, stomata closure, acceleration of senescence and leaf abscission [35] [36]. At the cellular level, when the plant is subjected to water deficit, the changes involve the concentration of solutes inside the cells, changes in the volume and shape of the plasma membrane, loss of turgor and protein denaturation [32]. Taiz and Zeiger [37] claim that as the stomata close during the initial stages of water stress, the efficiency of water use can increase, that is, more CO_2 can be absorbed per unit of transpired water, because stomatal closure it more inhibits transpiration which decreases the intercellular concentrations of CO_2. As stress becomes more severe, however, dehydration of mesophyll cells inhibits photosynthesis, mesophyll metabolism is impaired, and water use efficiency generally decreases.

According to Larcher [38], a plant organism goes through a succession of characteristic phases when subjected to stress: the alarm phase, the resistance and exhaustion phase. In the first phase, there is a loss of stability in the structures and reactions responsible for

maintaining vital functions, and the plant can react and recover from this stress. In the second phase, of resistance, which is increased under continuous stress, a rusticity process begins and, depending on the duration, the plant can adapt through osmotic adjustment. Finally, in the exhaustion phase, which occurs when stress is too long or its intensity increases rapidly, the plant is susceptible to infections that occur as a consequence of the decrease of the host's defenses and leading to premature collapse.

The frequency and intensity of the water deficit are the main factors limiting agricultural production, accounting for 60 to 70% of the final variability of production [39]. This highlights the importance of knowing the local climatic conditions and the genotype to be used, in order to develop management strategies that make it possible to reduce the effects caused by water deficit [3]. In this context, the assessment of the degree of tolerance and susceptibility of genotypes is an important point to consider in studies involving the tolerance of plants to water deficit [40].

The impacts of climate change can constitute a serious threat to agriculture, as it puts the preservation of current agricultural systems at risk, as well as becoming an opportunity for the development of other systems [14]. In this context, Smit and Singles [41] and Bray [32] state that adequate knowledge of how vegetables respond to water stress is one of the main requirements for choosing both the best variety and the best management practices, aiming, above all, improve the exploitation of natural resources.

Thus, changes in the rainfall regime, which trigger droughts, may negatively influence agricultural regions, and it is important to foresee future scenarios in order to develop measures that help in the resilience of crops.

3.3 Use of the Agroecological Zone Method

Simulation models have been widely applied in agronomy as a research tool, enabling the understanding of plant responses to different environments and, consequently, predicting crop productivity [42]. Through these models, it is possible to simulate different management conditions over several years and locations, using historical or synthetic climate data [43] [44].

The application of mathematical-physiological models has been increasingly used in agriculture, with regard to the provision of tools for decision-making support systems, aiming at real simulations of future processes to be able to face events [25] [45]. According to Streck and Alberto [46], mathematical models are a simplification of reality that allow describing the complicated interactions that exist in agroecosystems and, in this way, indicate the possible impact of changes in meteorological elements and

climate on agroecosystems. Thus, the FAO Agroecological Zone Model (AZM) is one of the most used in research aimed at estimating the agricultural productivity of crops[47] [23], having, however, wide application in agroclimatic zoning studies and in determining the most appropriate times for planting and sowing [25].

This model makes a correlation between the relative fall in productivity and the water deficit in each phenological phase, through a crop response coefficient and, although generic, it can be applied in crop forecasting systems as it is a simple model and presents very satisfactory results [42]. Thus, with the application of this method, the potential and attainable productivity of agricultural crops is estimated, through the input of meteorological variables, determining that the depletion of productivity occurs as a function of the relative water deficit, through a coefficient of response to the water deficit. Such data on the response coefficient to water deficit exist in the literature and are derived from a linear regression between the evapotranspiration deficit (relation between the actual and maximum evapotranspiration of the crop) and the relative loss of productivity (relation between the attainable and potential productivity) [3]. As for the reference evapotranspiration, it can be estimated by methodologies such as Thornthwaite & Mather [48] and the maximum crop evapotranspiration through methods such as the Penman-Moneith [49] or the Class A tank [50], for example, using the crop coefficient (Kc) data obtained in the literature. Reichardt [51] defines the maximum evapotranspiration (ETm) as the maximum water loss that a given crop suffers in a development stage, when there is no soil water restriction and also states that the real evapotranspiration (ETr) is the one that fact occurs. Above all, it emphasizes that if there is water available in the soil and the water flow in the plant meets the atmospheric demand, the ETr will be equal to the ETm.

The AZM model comprises two stages: the first deals with the estimation of potential productivity (Yp) and the second with the penalty for this by the water deficit, thus obtaining the attainable/estimated productivity (Ye), according to the following formula:

$$\text{Ye} = Yp \left[1 - ky \left(1 - \frac{ET}{ETC} \right) \right]$$

Where,

Ye= estimated productivity (kg.ha^{-1})

Yp= potential crop productivity (kg.ha^{-1})

Ky= water penalty coefficient

ET= real evapotranspiration (mm.d^{-1})

ETc= crop evapotranspiration (mm.d^{-1})

$$ETc = ETo \cdot Kc$$

Where,

ETc= crop evapotranspiration (mm.d^{-1})

ETo= reference evapotranspiration (mm.d^{-1})

Kc= crop coefficient

The potential productivity is obtained by a highly productive variety, well adapted to the growing environment, without water, nutritional, phytosanitary stress and salinity problems, the following characteristics being fundamental for its calculation: duration of the growth cycle; leaf area index (LAI) associated with maximum growth rate; harvest index; culture adaptability group and; sensitivity of the duration of the crop growth cycle to the thermal sum of degree days. Subsequently, this potential productivity is penalized with the application of the productivity sensitivity coefficient to the water deficit, since this factor is one of the factors that most affect crop productivity, it is essential to include this variable in the productivity estimation models. Thus, the elements rain and evapotranspiration are associated with productivity values, for the different phenological stages of the crop [42].

In this model, the potential yield drop is directly related to the relative water deficit of the crop, which considers the reference and maximum evapotranspiration, taking into account a crop response coefficient to the water deficit (ky) in each phenological phase of the crop cycle. Thus, the attainable productivity of the crop is estimated [54]. Regarding the meteorological data used in this methodology, the following are required: average air temperature; precipitation (mm), extraterrestrial solar radiation, photoperiod and insolation [3].

Although it requires information on climate and culture, the Agroecological Zone Method is easy to apply in operational terms, in addition to being easy to understand and the results closer to reality [53]. According to Thompson [54], precipitation is the meteorological element most used in the development of models that estimate crop productivity. However, the AZM model has some limitations, as it does not consider the occurrence of pests and diseases and soil fertility [53]. The biological system is complex and the lack of knowledge regarding some processes results in an imperfect or incomplete modeling. This is also due to the great capacity of plants to adapt to different edaphoclimatic conditions [55].

The improvement in the productivity of a crop may be related to greater tolerance to environmental stresses and thus result in an increase in productive stability. Simulation models of soil-plant-atmosphere systems are an appropriate tool for studies involving applications under conditions of great environmental variability, as it is possible to determine the risks that permeate agricultural production due to the main components of production [56] [57]. Some studies indicate that the development of agricultural zoning is a tool that aims to minimize the most recurrent risks that the crop may be subjected to from planting to harvest [58].

Thus, crop forecasting systems using agrometeorological models are present in works of great national relevance, in the case of large crops such as soybean [47] [59], corn [23] and sugar cane [60] [24] [61]. According to Santos and Oliveira [62], the agroclimatic productivity method [63] proved to be efficient in estimating corn productivity, since it elucidates parameters that can influence the reduction of the producer's yield.

In this way, the AZM is an auxiliary tool for experiments with studies on the impacts of climate change on agricultural crops, which constitute a simplification of the reality of agroecosystems [46]. Climate modeling analyzes for Brazil, covering the 1970 to 2050 baseline scenario, considering the cumulative effects of climatic and non-climatic vectors on species loss, indicate that land use changes have a preponderant historical role in biome changes Amazon, Cerrado, Caatinga, Atlantic Forest and marine environments [64]. And, it is also highlighted that climate change started to have an increasing participation in the loss of biodiversity from 1970, resulting, in the year 2050, in significant risks to the provision of ecosystem services [65].

As already mentioned, climate change projections for Brazil point to significant impacts in changing the extreme precipitation regime in the form of floods and floods, in addition to greater risks of drought and increased aridity [4] [5]. In this context, it is essential to recognize the temperature, precipitation and humidity thresholds by which ecosystems will incur in inflection points in order to anticipate and manage emerging risks [66]. Recent scientific evidence demonstrates that current climate conditions and projected changes impose relevant environmental, economic and social burdens, especially on tropical countries in the Global South, such as Brazil, which have suffered non-linear and heterogeneous economic impacts and risks [67]. However, economic losses and socio-environmental costs could be minimized through the implementation of adaptation strategies [68].

IV.   CONCLUSION

Cultivated plants, in general, are quite sensitive to water deficit, which is considered the main factor in modeling, thus, through modeling it is possible to predict

the impact of water deficit on crop yields. Although the AZM model is one of the most applied simulation models, it has flaws because it does not consider soil fertility and diseases, and in this context, when climate changes occur, major changes can occur in relation to phytopathology, such as redistribution and the emergence of new ones. of pests.

Furthermore, it is emphasized that the preservation of ecosystems is essential to ensure life on Earth, and it is essential to plan management strategies for a planned long-term adaptation to maintain genetic diversity.

Thus, adapting to climate change and minimizing its effects requires the adoption of the "precautionary principle" and the maintenance of agrobiodiversity, it being essential to strengthen the resilience of ecosystems so that they contribute to facing the future climate crisis.

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