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Review

Sustainable and technological strategies for basic cereal crops in the face of climate change: A literature review

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At the international level, corn, wheat and rice are basic grains considered to be the most important food source for humans, as they are a fundamental part of the daily diet and represent more than 55% of the caloric intake. They make up the greater production and consumption in the world. Due to Climate Change, these highly vulnerable crops to extreme temperatures have suffered a reduction in quality and quantity of yields. In addition, there is an increase in the risk of production especially for small farmers who provide more than 75% of the world production. According to the projections for the year 2050, basic cereals will continue to be essential for food security and global survival. In turn, the temperature will continue to increase and will cause a decrease of up to 10% in yield for each increased degree celsius, in the absence of sustainable adaptation. The present work consists of a review of the literature of adaptation strategies in the face of Climate Change, which contributes to reestablishing the damage caused by the green revolution on basic cereal crops, the environment, and biodiversity, the technological strategies review was also included considering that it is a tool that offers valuable support to the farmer in the decision making inherent in the planning and improvement of their cereal crops.

Key words: Sustainable adaptation strategies, basic cereals, climate change, technological strategies.

INTRODUCTION

Basic cereals such as corn, wheat and rice are foods that are grown all over the world, are part of the daily diet of humans and constitute foods that provide more than 55% of the calories consumed worldwide. According to Reynolds et al. (2016), in per capita terms this represents the most important food in the world. About 75% of the total cereal production is generated by small farmers (Torres, 2017). Demand for basic grains will continue to

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Table 1. Yield by crop and management system caused by Climate Change.

Region	CSIRO Model	NCAR Model
Corn under irrigation		
Developing countries	-2.0	-2.8
Developed countries	-1.2	-8.7
Corn (rain)		
Developing countries	0.2	-2.9
Developed countries	0.6	-5.7
Rice under irrigation		
Developing countries	-14.4	-18.5
Developed countries	-3.5	-5.5
Rice (rain)		
Developing countries	-1.3	-1.4
Developed countries	17.3	10.3
Wheat under irrigation		
Developing countries	-28.3	-34.3
Developed countries	-5.7	-4.9
Wheat (rain)		
Developing countries	-1.4	-1.1
Developed countries	3.1	2.4

Change in % between the yield with climate of 2000 and yield with climate 2050. Weighted average.
Source: Own elaboration with data of Nelson et al. (2009).

rise (although slightly) from the years 2016 to 2025 mainly in developing countries, based on population growth with the exception of sub-Saharan Africa where it will increase by 4.9% and its consumption by 8.3% (OECD/FAO, 2017).

In line with the goal to ensure food security in the face of the threat of Climate Change, from a few years ago and nowadays, large producers in different countries were able to increase the production and yield of their cereal crops through the new agriculture identified as the green revolution. In Mexico, for example, 33% of cereal consumption is imported from the United States, a high dependence that has raised import costs (Wise and Garvey, 2012).

By 2050, the demand for basic grains will increase on the basis of world population growth and will require 800 million tonnes more than now (Reeves et al., 2016). However, the Climate Change whose origin is anthropogenic and emerges with the modern era and its processes of industrialization, according to Graß et al. (2015), will continue to cause global temperature increases, from 1.4 to 4.0°C by the year 2050. There will be extreme climatic events of greater frequency and intensity, new pests and diseases, water shortage, losses of biodiversity, among others, causing crop reduction, yield and quality FAO (2016). It is estimated that production shortfalls from a number of countries will reach 25% of the world's total (Nelson, 2009). The Table 1 shows the crop yield according to two management systems (CSIRO and NCAR), shows the difference between the one reached during the year 2000 and the projection to the year 2050.

Risks that are added to the consequences of the green revolution, which even when it provided benefits, used unsustainable adaptation strategies that require greater consumption of energy and economic resources, capable of causing damage to human health, deterioration of the environment by the excessive use of fertilizers, chemical pesticides, high cost of seeds and technology (dependence), new pests, increased water consumption and non-adaptation of traditional crops (Reeves et al. 2016). Thus, even in developed countries, Climate Change continues worsening the uncertainty and instability of cereal grain production.

If we continue without sustainable adaptation strategies that contribute to restoring optimal cultivation conditions, the catastrophic scenarios that can be seen in the year 2050, in the immediate future could become a reality. They include loss of human health, production and yield deficits, irreversible damage to environment and food security, loss of biodiversity, global adverse socioeconomic losses (Ye et al., 2013; Tesfaye et al., 2015; Jones and Phillips, 2016).

LITERATURE REVIEW

The cereal sector and climate change

Of the world's basic diet foods, one of the most important groups are basic cereals and are grown worldwide. Family farmers or small farmers provide up to 75% of total food production (Eitzinger et al., 2013; Reeves et al., 2016).

Due to the strong dependence between Climate Change and crop development, cereal species are among the most affected by extreme temperatures (Jones and Phillips, 2016).

In Mexico, a third of the national consumption of basic grains such as corn and wheat is imported mainly from the United States and this strong dependence of Mexico (34% from 2006 to 2008) has led to an increase in import costs (Cal and Ciesas, 2012). Even though in the first half of the century the projections may seem to be favorable in economic and food terms for some countries, this is not the case for the world (OECD/FAO, 2017).

Satisfactory results of the green revolution have nevertheless caused serious damage of various kinds in environmental and soil aspects, such as land degradation, depletion of soil micronutrients, increased soil toxicity, high incidence and resistance of pests and diseases and increased greenhouse gas emissions, which in the medium term will contribute to the disappearance of fields and cereal species, due to the inherent consequences of the green revolution and exhaustive use of the technology (Reeves et al., 201.6). Research and the construction of sustainable adaptation strategies continue to be a priority task at the international level, however, most of the work developed shows valuable local orientations. However studies with a global focus are still required (Arnell, 2016).

Impact of Climate Change on crop development

Due to the need of the cereal sector to provide and protect their crops in a sustainable way, the participation of researchers has been fundamental to the scientific demonstration of phenological stages of greater resistance and sensitivity to Climate Change and extreme factors, identifying anthesis with greater sensitivity, observing a decrease in yield, growth and physiological indicators.

The omission of crops that require timely attention, will lead to problems of yield and quality (Rawson and Macpherson, 2001). Frederiks et al. (2015) evaluated damage caused by radiant frost, identifying it after the emergency phase; Crimp (2016) studied frost using the Stevenson screen at 2°C at ground level and temperature threshold; similar work is done by Perry et al. (2017), who used evaluation sensors before achieving it with the naked eye. As mentioned earlier, the results consisted of identifying the most sensitive and the most resistant stages. However, the study is unable to provide data related to the time of early evaluation. In summary, the results of these studies were able to identify those stages of greater sensitivity and those of greater resistance to meteorological factors.

Ji et al. (2017) analyzed the impact of low temperatures on wheat yield, identified the stages of ear formation and grain filling as being of greater sensitivity in cultivars of controlled environment. With the same conclusions but for high temperatures, Pimentel et al. (2015) observed the 79% reduction in yield. Boutraa et al. (2015) evaluated the growth of Saudi wheat under heat stress in a controlled environment, observing a reduction in physiological and growth indicators. Sanad et al. (2016) evaluated spring wheat in the drought, concluding greater phenological resistance during emergence and sensitivity in anthesis, under controlled conditions.

Sharifi et al. (2016) evaluated the effect of the temperature depending on the stage and found out that the time from the rice planting to the initiation of the panicle is more sensitive. Ihsan et al. (2016) analyzed the phenological development of wheat crops, their growth, yield and water use efficiency in arid soil in Western Arabia, observing the relationship between growth and yield at the beginning of the reproduction phase and also observed greater sensitivity to drought and to the dates of planting during anthesis.

Chen et al. (2017) analyzed growth time and leaf area index of the winter wheat crop in their reproductive phase under extreme temperatures from 2001 to 2008 in China and detected shortening of reproductive growing, acceleration of senescence and damages to leaf area.

Impact of Climate Change on yield and quality of basic cereals

The OECD/FAO (2016) predict that the increase in cereal production will correspond to a 90% increase in yield, which, like the quality of the seed depends on the climate of production or environment, in addition to the genotype (Sosa et al., 2015). However, the relationship between Climate Change and yield levels and quality of basic cereal crops is the reverse, Figure 1 expresses this in the case of rice in agronomic areas of America, as temperature increases the yield goes down (Higuera and Monroy, 2014).

In the world, 21% of the yield variability of basic cereal crops is explained by the increase in temperatures that exceed the optimal margins (Iizumi and Ramankutty, 2016). Nowadays basic grains are among the species most affected by extreme temperatures according to Jones and Phillips (2016). Recently Crimp et al. (2016) in Australia, observed that the risk of wheat production has increased by 30% due to Climate Change. Drastic changes in temperature have resulted in decreased yields and quality of corn, wheat and rice crops, as well as economic losses in various parts of the world (Giroux et al., 2016).

At the international level, however, projections indicate that crop yields in cereals will benefit in some cases during the first half of the century (Krimly et al., 2016). Since the year 2014, an increase was observed that broke record, however, most of the crop was obtained in few but large production areas, where farmers pay the consequences of the intensive monoculture, with the degradation of soils, reduction of groundwater, marked reduction of yield increase, plus major damage to the environment with effect on their crops (Reeves et al., 2016).

In other regions of North America and the Caribbean, declining yields are expected according to Pérez and Omar (2015), in North Africa declining wheat, according to Chourghal et al. (2016), corn in the United States (from 1.6 to 2.7% per decade) according to Basche et al. (2016), as well as in some regions of Europe where there will be an increase in the frequency of extreme events and population of the continent (Trnka et al., 2015).

In other countries, the decline in yield is expected from 2050, in the case of West Africa according to Ahmed et al. (2015), some regions of Canada at the end of this century. According to Rose et al. (2016), supported by

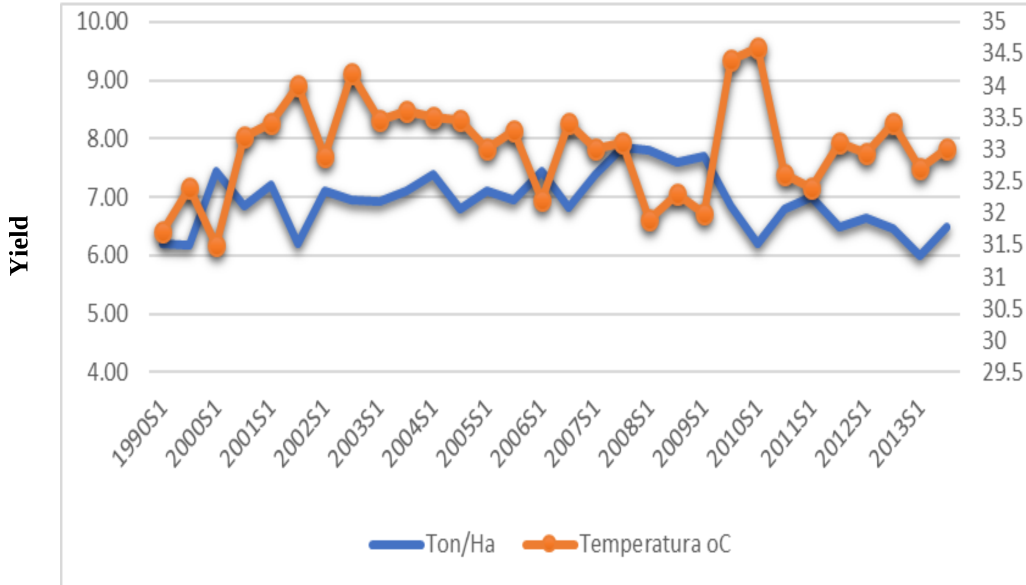

Figure 1. Temperature vs Yield.
Source: own elaboration with data of Higuera and Monroy (2014).

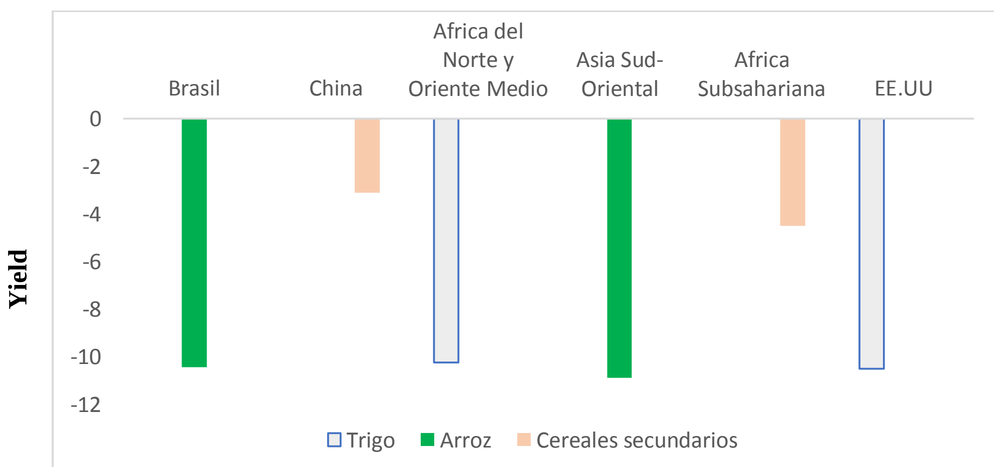

Figure 2. The projected decline in cereal yields due to Climate Change in 2050, without adaptation (%).
Source: Own elaboration with data of Reeves et al. (2016).

Zhao et al. (2017), there will be a decrease in world cereal yield greater than 10% and adverse socioeconomic consequences on the cereal sector according to Pérez and Omar (2015) of greater intensity for small farmers (Eitzinger et al., 2013).

Worldwide, wheat yield has decreased by 5.5% and corn by 3.8%, since 1980 due to Climate Change. By the year 2050, unadapted cereal yields will be reduced even further in developed and developing countries (Figure 2).

Particularly in the case of corn, when it is basically dry, its yield will decrease due to droughts and floods in sub-Saharan Africa and Asia, as well as incidence, severity and distribution of diseases. Similar situation to rice in the tropics since the current high yield varieties are intolerant to abiotic tensions, probably intensified by Climate Change, threatened by an increase in thunderstorms.

Wheat yield at high-temperature frequency will have serious effects, as crops in South, West Asia and North Africa will suffer from heat stress, water shortage, pest increase and soil pathogens, even in the Indo-Gangetic plains by 2050. Climate Change could reduce nutritional content of cereal (Reeves et al., 2016).

Sustainable adaptation strategies

Sustainable adaptation research agrees to support the small farmer and traditional crop management as the strategy with the greatest possibilities at a global level, whose objective is the adaptation and at the same time the mitigation of the Climate Change in a sustainable way, taking care of the environment and increasing the crops resilience, practice based on the experience and customs of the region, preserved from centuries ago (García and Del Fabro, 2015).

Roncancio et al. (2016), support polyculture systems, Reeves et al. (2016) propose the guide based on the Food and Agriculture Organization (FAO) model "Save for growth" in basic crops such as corn, rice and wheat, through ecosystem-based agricultural systems, with participation and support for family farmers, increasing cereal yield and resilience to Climate Change, a proposal that has been implemented in several countries with favorable adaptation and mitigation results.

Similarly, Sapkota et al. (2015), among other authors, support conservation farming that is attentive to the soil, profitable and sustainable, protecting the environment, supporting sustainability. Conde (2014) proposed the eco-friendly farming that reduces ecological impact and intelligent farming that seeks sustainable increase of production and income, greater resilience, adaptation and mitigation.

Unsustainable adaptation strategies

On the other hand, biotechnology is an alternative with several proposals for the improvement of seed that increases yield, but not its quality. However, the disadvantages exist and the risks to crop, environment, biodiversity and even to human health are generally serious. However, biotechnology has been widely implemented in the cereal sector and today they experience the consequences (Reeves et al., 2016).

Trigo (2015) worked in the development of new corn and wheat varieties with greater resistance. He et al. (2014) assert that the use of germplasm in the production of cereals and the use of molecular technologies will be useful for cereal production in the future. Robles et al. (2015) analyzed the hybrid corn and proposed the use of improved seed. Constantinescu (2017) developed a neuro-diffuse system based on environmental factors that proposes the appropriate corn hybrid per year.

In general, strategies for adaptation are observed that promote increased production and economic income, but avoid those that cause damage to the life and to the planet.

Technological strategies

In support of the cereal sector the technological strategies implemented at the local level have been multiple, and have made use of traditional technologies (mathematics and statistics) and intelligent technologies (based on Artificial intelligence techniques) basically. The approaches are oriented to obtain information of support to the farmer in the decisive decision making that contributes to reducing the vulnerability of its crops, all supported in information technologies. The most used forecasting approach has made possible the reduction of uncertainty about future events, a priority for the proper management of crops and the development of contingency plans.

Traditional technological strategies

Planning models have been used to analyze temporal variables of corn in order to identify adequate planting dates and increase crop yields in Mexico (Covarrubias et al., 2014).

Prediction models have been used to obtain timely information that favors the development of appropriate action plans. Wallach et al. (2017) predicted the impact of climate warming on rice development time, estimating the mean squared error (MSE), use generalized least squares and statistical analysis that separates model uncertainty with MSE. On the other hand, Bogard et al. (2014) constructed a model to predict the locally adapted wheat ideotype according to its phenology, based on ecophysiological models and statistical analyzes.

Prediction based on plant phenology provides accurate information for its protection. Torres et al. (2012) developed a mathematical prediction model for corn and armyworm to reduce pest damage supported by the measuring instruments, Sakamoto et al. (2013) made predictions of the same crop through statistical analysis. Lv et al. (2015) used mathematical analysis and a wheat phenology model to estimate parameters of specific cultivars and predict their development.

The models of crop simulation, of wide antiquity and use, have provided possible scenarios and very useful data, even when they show weaknesses, such as lack of data, basic parameters not considered or considered static when in fact they are dynamic. The CERES system, developed in 1896, updated today, is the most used to evaluate corn and wheat crops, considering two scenarios of Climate Change. Gallo (2015) performed daily calculations on phenological aspects, growth index, distribution of biomass, the HERMES model of Kersebaum in 1989, simulated monocultures and double corn cultivation along with predictions regarding the year 2100 as well as a decrease in yield in summer periods from 2050 (Graß et al., 2015).

The DSSAT deterministic model (Decision Support System for Agrotechnology Transfer) of the International Consortium for Agricultural Systems Applications (ICASA) more than 25 years ago, updated today, simulates corn growth, nitrogen dynamics in soil, water and temperature at the global field scale. The WOFOST model of quantitative analysis of annual crop production based on physio-ecological processes considers phenology, transpiration, respiration, CO_2 absorption, water simulation and daily growth.

Basche et al. (2016) analyzes the Simulator model of Agricultural Production Systems (APSIM), simulate the behavior of the production of corn in winter for a period of 45 years, associating temperature variability to decreased performance per decade. The deterministic mathematical model AquaCrop simulates the development of corn cultivation for various regions of the world, considers total and deficit irrigation, determines optimal planting dates, and simulates biomass and yield according to water availability (Bernal et al., 2013).

The soil-plant-atmosphere systems for corn were developed with the objective of maximizing yield and minimizing the water used during evapotranspiration (Serio, 2015).

Prediction models are used with different approaches as predicting crop yield is the most exploited. Farjam et al. (2014) estimated the yield of corn seeds and grains on 144 farms using Artificial Neural Network models (ANN) taking into consideration fertilizers, biocides, seeds, human work, gas oil and machinery. Matsumura et al. (2015) developed a model based on precipitation and fertilizers; also, Lv et al. (2015) constructed a Neuronal Gray Network for rice and corn, as well as Gandhi et al. (2016), for rice.

Tripathi et al. (2015) created a model for wheat considering soil types and pond ash; Bose et al. (2016) constructed the Neuronal Score Network for the basic crops and Ravari et al. (2016) predicted yield variability index as well as wheat tolerance to soil salinity.

In the occurrence of weeds, prediction models are also developed for rice crops according to Barrero et al. (2016) for wheat crops by Mansourian et al. (2017).

In quality aspects, Al-Mahasneh et al. (2014) developed a collective prediction model of moisture absorption isotherms for 12 cereals and 5 legumes. Also, Lal and Varma (2014) constructed a model to identify functional aspects of cereal proteins according to structural composition.

Goyal (2013) mentions the great support that ANN's represent for the cereal sector, as well as intelligent models that have superiority of precision of results on the traditional models (Beigi et al., 2016; Mansourian et al., 2017).

In the classification, the intelligent models have supported the identification of quality wheat grains by means of ANN developed by Khoshroo et al. (2014), as well as Zhang et al. (2014) for damaged grains of wheat according to parameters of shape, color and texture.

Other models used are those oriented to monitoring and estimation. Mao et al. (2014) created a model that measures protein content in wheat, using particle swarm optimization algorithm, by grain analysis and internal composition. Yang et al. (2016) created an ANN for Nitrogen content in rice leaf, as related to production, whereas Nuñez et al. (2016) performed optimization of the culture medium that maximizes the production of amylase in wheat bran through an ANN and genetic algorithm.

Donné et al. (2016) performed segmentation of the corn plant using a convolutional ANN. Shi et al. (2016) analyzed losses of quality and quantity of wheat seeds due to insects and created internal infestation detection model by means of pattern recognition techniques. Other technologies and systems of agroclimatic monitoring, systems of monitoring of anomalies through image processing are also employed (Mora et al., 2016).

CONCLUSIONS

Climate Change is still a present and future threat to the world's basic cereal crops because their healthy development depends on having the best meteorological conditions. The forecasts indicate that the Climate Change will continue its course and if there is no adaptation and mitigation, it will leave consequences of greater intensity over time.

Large producers and developed countries have been able to compensate the effects of Climate Change on their crops and increase their production, achieving yield trends upwards for the next 10 years at least; however, their management of the crop called the green revolution has given rise to risks greater for biodiversity, food security, human health and of course for crops.

Because of this, farmers now face two challenges: the adverse effects of the Climate Change and the consequences of the green revolution, which far from reducing the problem has increased it. The planet therefore requires adaptation strategies that not only increase production but also avoid risks and damages to the environment and reestablish optimal conditions of cultivation. Otherwise catastrophic forecasts will become a reality in the immediate future.

The literature states that only some of the proposed strategies respond to the needs of the planet, for example, those that coincide in support to the environment, the small farmer and traditional practices, which makes them sustainable and capable of contributing to mitigation.

Technological strategies (more precisely intelligent models) offer the valuable farmer data and a broader picture of the behavior of his crops before the Climate Change.

Therefore, sustainable adaptation strategies should be used in a complementary way with the technological strategies to increase the success in the results considering that the farmer acts in present time according to his knowledge and experience. In turn, the technological strategy show data and future possibilities of broad support even for farmers with little or no experience, joint alternatives suitable to achieve adaptation to Climate Change and contribute to the mitigation of Greenhouse Gases.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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