EFFECTS OF INTERACTION BETWEEN ABIOTIC STRESS AND PATHOGENS IN CEREALS IN THE CONTEXT OF CLIMATE CHANGE: AN OVERVIEW

[1]PARASCHIVU MIRELA, [2,3]COTUNA OTILIA, [1]PARASCHIVU M, [1]OLARU L.

[1]University of Craiova, Faculty of Agronomy, Department of Agriculture and Forestry Technologies, Craiova, Romania
[2]Banat`s University of Agricultural Sciences and Veterinary Medicine "King Michael I of Romania" Timisoara, Romania
[3] Station of Research and Development for Agriculture Lovrin, Timiș County, Romania
Corresponding author: paraschivumirela@yahoo.com; otiliacotuna@yahoo.com

Keywords: abiotic stress, climate change, cereals, pathogen, interaction

ABSTRACT

The scenario that climate change will lead to higher incidence of crop diseases, following geographical distribution of the host and cropping technology, suggests that can be positive, negative or neutral depending of multiple interactions between host, pathogens and abiotic stress factors. Both plants and pathogens are constantly threatened by abiotic stress factors such as high temperature, moisture, drought, salinity, soil pH, greenhouse gases, Ultraviolet-B (UVB) radiation and air pollutants. Currently the research focused on this topic is inconsistent therefore these interactions are poorly understood. In the process of adaptation to these adverse conditions, it is expected that abiotic stress factors impact pathogens into a wide range of responses such as changes in life cycles (pathogen reproduction – shorter incubation -, dispersal, survival and activity), increased incidence, modified pathogenicity, genetically recombination and aggressiveness traits. The present review is focused particularly on the impact of abiotic stress factors on cereals pathogens and all changes in their life cycles and host-pathogen interaction associated with under climate change conditions. However, our study suggest that a better understanding of interaction between pathogens and abiotic stress factors can be an important mechanism to estimate disease risk on a large scale and to introduce new understandings in developing management strategies.

INTRODUCTION

During the last decades many changes in agricultural system have contributed worldwide to significant progress in food, fiber, fuel production as a consequence of the interaction among multiple factors: world population increase, urbanization, technical progress, income growth, genetically progress, improved cropping technologies, globalization on food production, machinery revolution, markets, consumption, faster access to the information (ALEXANDRATOS and BRUINSMA, 2012; BONCIU, ELENA, 2012, 2016, 2017; DRAGOMIR, C.L. and Elena PARTAL, 2016; MATEI, GH et al., 2008, 2009, 2010; Elena PARTAL et al., 2013, 2014; POPP et al., 2013; REILLY, J. and SCHIMMELPFENNING, D., 2000). The question is if this progress is able to fix the issues of global food production and food security and for how long? Additional factors, as climate variability and climate changes come to threaten both of them when most climate projections using GCMs show warming for all continental interiors, leading to variable responses to the level of each ecosystem (Pan et al, 2004; PARRY et al., 2004).

However, the current awareness of climate change in the agriculture land use (e.g. land sparing – save some natural ecosystems from conversion into cropland), crop production and future food security appears to be high, especially due to high uncertainties about future food production (DÖÖS and SHAW, 1999) and estimations about population increase to 10 billion in 2050.

The possible increases in extreme weather events might cause higher yield variability, lower harvestable yields, reductions/extensions in land use in some areas, introduction of new crop species, changes in soil organic matter levels, in nitrate leaching risk, in soil erosion and salinization, in new crop protection challenges (BONEA DORINA, 2016; BONEA, D. and URECHEAN, V, 2017; LEIRLÓS et al., 1999, REILLY, 1994, 1999; YEO,1999; REILLY and SCHIMMELPFENNING, 1999; OLSEN and BINDI, 2002; HEYDER et al. 2011; PERKINS et al., 2011; SIN GH. and PARTAL ELENA, 2010) and also changes in crop host and pathogens and pests interaction, which will drive emergence of infectious diseases in both agricultural and non-managed ecosystems through multiple pathways (COTUNA et al., 2013 a, b; ENGLER et al., 2011; HEYDER et al., 2011; SCHERM, H., 2004; TEIXEIRA et al., 2012). Also, the effects of climate change and climate variability will impact differently food security being location-specific and societally-specific especially in the countries with low income and limited adaptive capacity facing significant threats to food security (von Brown, 2007).

The responses depend on the particularities of the agricultural systems and on the changes in the crop management. There are scenarios that climatic change will lead to a higher incidence of crop diseases (especially plant host and susceptibility, pathogen reproduction – shorter incubation - dispersal, survival and activity, host-pathogen relationship) and to a potentially larger use of pesticides (NEWTON et al., 2011; SUTHERST et al., 2011).Thus, new pathogens may occur in certain regions, while other pathogens may decreases to be economically important, following geographical distribution of the host and cropping technology (COAKLEY et al., 1999; GHINI et al., 2008; GHINI and HAMADA, 2008;). General tendency is that pathogens are likely to remain limited to their host distribution and not become disconnected from them. There is serious concern that climate zones will move faster that it is possible for plant populations to track them, which is expected to determine disproportionate extinction of local endemic species (LOARIE et al., 2009). However, many cereals pathogens exhibit considerable capacity for generating, recombining, and selecting fit combinations of variants in key pathogenicity, fitness, and aggressiveness traits that there is little doubt that any new opportunities resulting from climate change will be exploited by them.

This review aims to discuss mainly the impact of climate change on wheat pathogens and hostpathogen relationship which is very important to demonstrate that wheat pathogens can adapt to new environment, despite the fact that currently we are not able to predict accurately the trajectory of each pathosystem under climate change. However, in the last decade the evidence for the measured climate change on cereal crops and their associated pathogens is starting to be documented.

CLIMATE CHANGE AND INTERACTION BETWEEN CEREALS HOST AND PATHOGENS

There are reports of climatic factors affecting the interaction between cereals and pathogens changing host-pathogen relationship. Thus, extreme temperatures (warmer than long-term means, or including lack of, or occurrence of, unseasonal frosts), precipitation (including snow, hail or extreme intensity), wind, light (lack of intensity due to cloud or dust), humidity, CO_2 and other greenhouse gasses have been associated with changes in pathogens life cycles, increased incidence, pathogenicity, genetically recombination and aggressiveness traits, which involves the urge to rethink the integrated management strategies. These become more difficult when rapid changes in the climate caused by extreme events are likely to lead to disease epidemics because control measures are difficult to apply quickly enough or on a sufficiently large scale to contain the problem. However, there is evidence that, stress conditions stimulate the activity of retrotransposons enhancing the generation of variability in pathogens, enhancing mutation rate and new traits aggressiveness (ANAYA N and RONCERO MIG,1996; NEWTON A.C., 1988; Halterman D.A. et al., 2003). Clearly these and other post-translational regulatory mechanisms may contribute to adaptive response to climate of pathogens.

There are other examples where the distribution ranges of pathogens have been shown to change in response to climatic variables such as, for example, *Puccinia striiformis* f.sp. *tritici* in response to rainfall patterns in South Africa (BOSHOFF et al., 2002). Changes in crop rotations in response to climate change may also influence the future importance of specific pathogens. For example, if warming of northern latitudes enables forage maize to be grown in the rotation then this will leave residues in which pathogens such as Fusarium Head Blight (FHB) could build up high levels of inoculum for subsequent wheat and barley crops (MAIORANO et al., 2008).

However, enhancing crop resilience to the effects of climatic stress, and stresses in general, might be the solution to improve crop performance in the relationship with pathogens (NEWTON et al., 2009).

CO_2, other greenhouse gasses and UV-B radiation effects

Carbon dioxide (CO_2), ozone (O_3) and other greenhouse gasses along UV_B radiation are individual climate change factors that have direct effects on plants and biotic agents (GUDERIAN et al., 1985; DOWING, 1988; KRUPA and MANNING, 1988; MANNING and KEANE, 1988; BAZZAZ, 1990; ASHMORE and BELL, 1991; COLLS and UNSWORTH, 1992; BAKER and ALLEN, 1994; ROGERS et al., 1994, RUNECKLES and KRUPA, 1994;)

The changes in the chemical composition of atmosphere such as increases of carbon dioxide (CO_2), chlorofluorocarbons (CFCs), methane (Ch_4) and ozone (O_3) concentrations, along with increased solar UV-B radiation have been wildly reported (BISHOF et al., 1985; KRUPA and KICKERT, 1989; CRUTZEN, 1992; SECKMEYER and MCKENZIE, 1992; KERR and MCELROY, 1993). There is estimated that tropospheric CO_2 concentration are projected to increase from 355 ppm to 710 ppm, by the year 2050.

Changes in CO_2 concentration increase plant photosynthesis, transpiration rate per unit leaf area and resources use efficiency for water and nitrogen, enhancing wheat canopy, which impact both yield (increases in crop yield are 10-20% for C3 crops and 0-10% for C4 crops according with AINSWORTH and LONG (2005) and wheat-pathogen relationship (THOMSON et al.,1993; THOMPSON and DRAKE, 1994; COAKLEY et al. 1999; PRITCHARD et al., 1999; DOWNING et al., 2000, JONES and CURTIS, 2000; LOLADZE, 2002; LI et al. 2003; PANGGA et al., 2013). Thus, some types of resistance can be more affected in some diseases in wheat (e.g. reduced expression of induced resistance (PLESSL et al., 2005), due to changes in host physiology and in pathogen cycles (e.g. higher spore production) leading to epidemics (CHAKRABORTY et al., 2003; GHINI et al., 2008). Analyzing the effects of the increased CO_2 concentration on wheat pathogens, MANNING and TIEDEMANN (1995) emphasized that wheat rusts, powdery mildew, leaf spots and blights incidence increase due to the effect of carbohydrate contents which stimulates sugar-dependent pathogens. Also, the amount of primary inoculum due to greater overwintering crop debris would be also increased. An early study on the effects of CO_2 effects on cereals rusts showed that optimal concentration of carbon dioxide for growth of stem rust and stripe rust on wheat were higher (0,3-0,75%) than for crown rust on oats, leaf rust on rye and wheat (0,15-0,5%) (GASSNER and STRAIB,1930).

Ozone is likely to have adverse effects on plant growth and diseases incidence (MANNING et al., 1969; DOHMEN, 1988; MANNING and KEANE, 1988; TIEDEMANN, 1922). Thus, TIEDEMANN and FIRSCHING (2000) analyzed the combined effect of increased CO_2 and O_3 in wheat leaf rust (*Puccinia recondita* f.sp. *tritici*) and observed that wheat leaf rust was strongly inhibited by O_3, but unaffected by high CO_2 concentration. Barley powdery mildew was found to be relatively ozone tolerant and only inhibited by elevated ozone doses acting during germ-tube growth (HEAGLE and STRICKLAND, 1972). Rusts on cereals have been found to be insensitive to elevated doses of ozone. (HEAGLE, 1970; HEAGLE and KEY, 1973).

High level of SO_2 emissions seems to be correlated with incidence of *Phaeosphaeria nodorum* and *Mycosphaerella graminicola* in wheat (BEARCHELL et al., 2005; FITT et al., 2011). SHOW et al. (2008) reported that fluctuations in amounts of *P. nodorum* in grain were related to changes in spring rainfall, summer temperature and national SO_2 emission. Also, in leaves, annual variation in spring rainfall affected both pathogens similarly, but SO_2 had opposite effects. Higher canopy growth will promote higher residue amount which favors necrotrophic pathogens development, while increased roots biomass will favor soil-born diseases occurrence. However, there is less knowledge about potential impact of climate change on soil-borne pathogens compared to foliar pathogens (EASTBURN et al., 2011). Previous studies emphasized that the exposure to high CO_2 concentration affects the defensive response in plants against pathogens (BRAGA et al., 2006), altering cultivar resistance. Wheat pathogens and wheat-pathogen relationship are affected by CO_2 changes, which also interfere with uptake of systemic fungicides, with both positive and negative effects on efficacy (COAKLEY et al., 1999; GHINI et al., 2008). Studying the impact of increased atmospheric CO_2 concentration plant viruses, MALMSTRÖM and FIELD (1997) observed that CO_2 enrichment may increase the size of plants affected by barley yellow dwarf virus (BYDV) attenuating the dwarfing symptom due to the increase in root biomass and to the water-use efficiency by diseased plants, positively impacting the disease severity. Also, changes in plant growth and physiology resulting from higher atmospheric CO_2 concentration associated with changes in temperature and precipitation conditions, can affect the efficacy of systemic fungicides altering their penetration, translocation an mode of action into the plants. Changes in cultivars susceptibility can determine a new fungicide application calendar (CHAKRABORTY and PANGGA, 2004; PRITCHARD and AMTHOR, 2005). MADGWICK et al. (2010) predicted that by the 2050s the risk of FHB epidemics and the number of crops where mycotoxin levels would exceed the limit set by the EU will increase across the whole of the UK. VÁRY et al. (2015) investigated the effects of elevated CO2 on Septoria tritici blotch (STB), which infects leaves and Fusarium head blight (FHB), which infects flowers. The results showed that elevated CO2 increased the severity of both diseases and the acclimation of the pathogens and the plant worsened disease development. Thus, for FHB, the highest disease levels were found for plants that had been acclimated under elevated CO2 infected by pathogens that had also been acclimated at elevated levels affecting yield and reducing the number of grains by 76% and the weight of grain by 59%. In case of a resistant wheat variety it was observed that elevated CO_2 lead to 27% lower number of grains produced was also and 20% lower weight of grain due to FHB. Also, increasing crop biomass by an average 17% by elevated CO_2 (AINSWORTH and LONG, 2005) will further increase the amount of pathogen inoculum in stubble and crop residues. However, further new studies are needed to be done about the effect of CO_2 and other green gases concentrations on plant diseases in both controlled and field trials under cumulated action of other abiotic constrainers.

Relatively little work has been done on the effects of increased UV-B on the occurrence and severity of cereal diseases, and contradictory results showed that UV-B lead to increased (BIGGS et al., 1984), decreased infection (ORTH et al., 1990) or have no effect.

Temperature effects

Higher temperatures are expected to occur in northern areas which will expand the cropping area for cereals by 2050; further more increased diseases severity and Area Under the Diseased Curve are expected too (GHINI et al., 2008). HARVELL et al (2002) argue three hypotheses how pathogens will be influenced by climate change. He suggested that that rising temperatures will (i) increase pathogen development transmission, and generation number; (ii) increase overwinter survival and reduce growth restrictions during this period and (iii) alter host susceptibility. Warmer climates are more favorable for virus-vectors proliferation, because they can complete a greater number of reproductive cycles and additional insect generations which suggests higher incidence of virus diseases in wheat (CAMMEL AND KNIGHT, 1992; NEILSON AND BOAG, 1996, HARRINGTON, 2002; NEWMAN, 2004; HARRINGTON ET AL., 2007; DOBSON, 2009). NEWMAN (2004) pointed out the simultaneous effect of higher temperatures and elevated CO_2 concentration lead to 10% earlier timing of cereal aphids peaks (as much as a month earlier) and to 10% increase in winged forms, which results in greater spread and incidence of *Barley yellow dwarf virus* for which the aphid is the vector. Warmer winter temperatures may also allow wheat pathogens to overwinter in areas where they are limited now by cold, increasing the primary inoculum amount and causing greater and earlier infections during the following crop season. Also, warmer temperatures associated with cropping practices appear to have been associated with shifts in plant hosts for some pathogens, particularly when talking on long-term view (MADGWICK et al., 2011; WEST et al., 2012). Thus, Fusarium Head Blight (FHB) is expected to enhance higher levels of inoculum for subsequent wheat and barley crops in warmer northern latitudes due to introduction of forage maize in crop rotation (MAIORANO et al., 2008). For example, disease incidence of Fusarium head blight in the United Kingdom and Germany might increase middle of this century, whereas disease severity of Septoria tritici blotch might decrease in France end of this century (JUROSZEK and VON TIEDEMANN, 2013). Also, it is expected that wheat flowering will be around 2 weeks earlier by the 2050s (4 weeks earlier if we switch to using „Mediteranean-type‟ cultivars) and harvest will be 3 weeks earlier (or 5 weeks). Consideration of these altered growth stages is important because without it we would conclude that the incidence of fusarium ear blight will reduce substantially due to a decrease in occurrence of suitable wet conditions for infection occurring in early flowering stage (date) (JUROSZEK. P., VON TIEDEMANN, A., 2013). In the case of *F. graminearum*, warmer spring weather will increase spore production and additional spore release from maize debris is likely to lead to an overall increase in fusarium ear blight on wheat. This is an example of an indirect effect of climate change on a crop disease. Climate change also has an impact on food safety, particularly on the incidence and prevalence of mycotoxins. The main consequence of FHB is that trichothecene mycotoxins, such as deoxynivalenol (DON), accumulate in the grain, presenting a food safety risk and health hazard to humans and animals (GOSWAMI and KISTLER, 2004).

Temperature can also affect disease resistance in plants, thus affecting the incidence and severity of the diseases. Ambient temperature perception in plants is well recognized and plants have been shown to be able to detect temperature changes as little as 1°C (ARGYRIS et al., 2005). The efficacy of current resistance genes may be compromised under more extreme and variable climatic conditions. Thus, previous findings emphasized that under drought stress, resistance expression can be reduced or lost temporary, as well as reduced disease symptoms (BITA and GERATS, 2013). Also, some organisms enhance their ability to generate variants as an adaptive response to climate change (because pathogens exert very intensive selection over few generations), changes which can later become fixed through conventional mutation and recombination (HOVMØLLER et al., 2016). For example, there is an increased range of stem rust a possible explanation is that enhanced levels of free radicals were found under drought stressed conditions.

The same breakdown problem occurred in response to cold stress, rainfall stress, but not salt stress (STEWART, 2002).

CONCLUSIONS

Anthropogenic activities on the environment have intensified in the last century resulting in a devastating increase in greenhouse gases and triggering global climate oscillation. In the coming years, there could be more changes in the biosecurity of food crops due to escalating global climate change. Along with climate impact a range of regional and global political and economic factors intensify food insecurity and long term vulnerability in certain regions.

The impact of climate change also need to be considered along with other factors that affect crop yields, such as specific biotic constrainers (pathogens) and its impact on the host-pathogen relationship.

Moreover extreme temperatures and precipitation have been associated with changes in pathogens life cycles, increased incidence, pathogenicity, genetically recombination and aggressiveness traits.Co2 concentrations will continue to increase and we need to know more about elevated CO_2 effects on disease incidence and severity. The climate change may affect not only the optimal conditions for infection but also host specificity and mechanisms of plant infection. Changes in the abiotic conditions are known to affect the microclimate surrounding plants and the susceptibility of plants to disease.

Although, many previous studies have emphasized the sensitivity of plants to various biotic constrainers, the host-pathogen interactions are poorly understood in the context of climatic change. Therefore, the response of pathosystems to climate change is of high interest currently in order to estimate disease risk on a large scale and to introduce new understandings in developing management strategies in this new reality.

On this terms new models of crop and pest and pathogens interractions linked with more performant climate forcasting monitoring systems, breeding for durable resistance in wheat and improving modelling of the many interacting processes, would be an essential investment for future food security.

BIBLIOGRAPHY

1.Ainsworth, E.A., Long, S.P., 2005 - *What have we learned from 15 years of free-air CO2 enrichment? A meta-analytic review of the responses of photosynthesis, canopy properties, canopy properties and plant production to rising CO2*. New Phytopathologist, vol. 165, p.351-371.

2.Alexandratos, N., J. Bruinsma, 2012**-** *World agriculture towards 2030/2050: the 2012 revision*. ESA Working paper No. 12-03. Rome, FAO.

3.Anaya N, Roncero MIG, 1996- *Stress-induced rearrangement of Fusarium retrotransposon sequences*. Molecular and General Genetics, 1996, vol. 253, p. 89-94.

4.Argyris, J., Truco, M.J., Ochoa, O., Knapp, S.J., Still, D.W., Lenssen, G.M., Schut, J.W., Michelmore, R.W., Bradford, K.J.-2005.*Quantitative trait loci associated with seed and seedling traits in Lactuca.* Theor. Appl. Genet.111, p.1365–1376.

5.Ashmore M.R., Bell J.N.B., 1991 – *The role of ozone in global change.* Annals of Botany, vol.67, p.39-48.

6.Backer J.T., Allen L.H.Jr., 1994 – *Assessment of the impact of rising carbon dioxide and other potential climate changes on vegetation*. Environment Pollution, vol. 83, p.223-235.

7.Bazzaz F.A., 1990 – *The response of natural ecosystems to the rising global CO_2 levels.* Annual Rev. Ecol. Syst. Vol. 21, p.167-196.

8.Bearchell. S.J., Fraaije, B.A., Shaw, M.W., Fitt, B.D.L., 2005 – *Wheat archive links long-term fungal pathogen population dynamics to air pollution*. Proceedings of the National Academy of Sciences USA, vol.102, p.5438-5442.

9.Biggs R.H., Webb P.G., Garrard L.A., Sinclair T.R., West S.H., 1984 – *The effects of Enhanced Ultraviolet B radiation on rice, wheat, corn, citrus, and duckweed.* US EPA Interim Report 80, p.8075-03, US EPA, Washington, D.C.

10.Bishof W., Borchers R., Fabian p., Kruger B.C., 1985 – *Increased concentration and vertical distribution of carbon dioxide in the stratoshere.* Nature, vol. 316, p.708-710.

11.Bita, C.E., Gerats, T. 2013 – *Plant tolerance to high temperature in a changing environment: scientific fundamentals and production of heat stress-tolerant crops*. Front Plant Science, vol. 4, p. 273.

12.Bonciu Elena, 2012 - *Agricultural biotechnologies, balance factor for the sustainable development of the socio-economic system*. Annales of the University of Craiova, Series Biology, Horticulture, Food Produce Processing Technology, Vol. 17(1), p.69-74.

13.Bonciu Elena, 2016 **-** *Basic raw materials used in processing of the snack food (ecological/non ecological) and their expanding capacity.* Annals of the University of Craiova - Agriculture, Montanology, Cadastre Series, Vol. 46(1), p. 42-47.

14.Bonciu Elena, 2017 - *Food processing, a necessity for the modern world in the context of food safety: a Review*. Annals of the University of Craiova - Agriculture, Montanology, Cadastre Series, Vol. 47(1), p. 391-398.

15.Bonea Dorina, 2016 - *The effect of climatic conditions on the yield and quality of maize in the central part of Oltenia*. Annals of the University of Craiova - Agriculture, Montanology, Cadastre Series, 46(1), p.48-55.

16.Bonea D., Urechean V., 2017 **-** *Study on the selection for drought tolerance of some semi-late maize hybrids cultivated at A.R.D.S. SIMNIC.* Annals of the University of Craiova, Agriculture, Montanology,Cadastre Series, 47(1), p.34- 40.

17.Boshoff W.H.P., Pretorius Z.A., Niekerk BD.,2002 - Establishment, distribution, and pathogenicity of Puccinia striiformis f.sp. tritici in South Africa, Plant Disease, vol. 86, p. 485-492.

18.Braga, M.R., Aidar, M.P.M., Marabesl, M.A., Goday, J.R.L., 2006 – *Effects of elevated CO2 on the phytoalexin production of two soybean cultivars differing in the resistance to* *stem canker disease.* Environmental and Experimental Botany, vol. 58, p.85-92.

19.Chakraborty, S., Pangga, I.B., 2004 – *Plant diseases and climate change.* In: Gillians, M., Holmes, A (Ed.) Plant microbiology. London:BIOS Scientific, p. 163-180.

20.Coakley, S.M., Scherm, H., Chakraborty, S., 1999 – *Climate change and plant diseases management*. Ann.Rev. Phytopathology, vol. 37, p.399-426.

21.Colls J.H., Unsworth M.H., 1992 – *Air pollution interactions with natural stressors*. In *Air Pollution Effects on Biodiversity*, ed. J.R.Backer &D.T.Tingey, Van Nostrand Reinhold, New York, p.93-108.

22.Cotuna O., Sarateanu V., Durau, C., Paraschivu M., Rusalin Gabriela, 2013a – *Resistance reaction of some winter wheat genotypes to the attack of Fusarium graminearum L.Schw. in the climatic conditions of Banat plain*. Research Journal of Agricultural Science, vol.45 (1), p.117-122.

23.Cotuna O., Sarateanu V., Paraschivu M., Durau C., Micu L. – 2013b. *Researches on the comportment of some foreign winter wheat to the attack of the pathogen Drechslera tritici repentis (Died.) Shoemaker*. Research Journal of Agricultural Science, vol.45 (1) 2013, p. 123-128.

24.Crutzen P.J., 1992 – *Ultraviolet on the increase. Nature*, vol. 356, p.104-105.

25.Dohmen P.G., 1988 – *Indirect effects of air pollutants: Changes in plant/parasite interactions.* Environment Pollution, vol. 3, p.197-207.

26.Dowding P., 1988 – *Air pollutant effects on plant pathogens*. In Air Pollution and Plant Metabolism, ed. S.Schulte-Hostede et al., Elsevier, London, p.329-355.

27.Downing, T.E., Barrow, E.M., Brooks, R.J., Butterfield, R.E., Carter, T.R., Hulme, M., Olesen, J.E.,Porter, J.R., Schellberg, J., Semenov, M.A., Vinther, F.P., Wheeler, T.R., Wolf, J., 2000 – *Quantification of uncertainty in climate change impact assessment*. In: Dowing, T.E., Harrison, P.A., Butterfield, R.E., Lonsdale, K.G. (Eds.), *Climate Change, Climatic Variability and Agriculture in Europe*. Environmental Change Unit. University of Oxford, UK, 415-434.

28.Döös, B.R., Shaw, R. 1999 – *Can we predict the future food production?A sensitive analysis*. Global Environ. Change.vol. 9, p.261-283.

29.Dragomir, C.L., Partal Elena – 2016. *influence of different levels of water supply on production and economic efficiency under maize cultivated in Dobrogea region of Romania.* Scientific Papers. Series A. Agronomy, Vol. LIX, 2016, p. 289-293.

30.Eastburn, D.M., Mcelrone, A.J., Bilgin, D.D., 2011 – *Influence of atmospheric andclimatic change on plant pathogen interactions.* Plant pathology, 60, p.54-69.

31.Engler, R., Randin, C.F., Thuiller, W., Dullinger, S., Zimmermann, N.E., Araujo, M.B., 2011 – *21st century climate change threatens mountain flora unequally across Europe*. Global Change Biology, vol. 17, p.2330-2341.

32.Fitt B.D.L., Fraaije B.A., Chandramohan, P., Shaw, M.W., 2011 – *Impacts of changing air composition on severity of arable crop disease epidemics*. Plant pathology, vol. 60, p.44-53.

33.Gassner G., Straib W., 1930- *Untersuchungen uber die Abbangigkeit des Infektionsverhaltens der Getreiderostpilze vom Kohlensauregehalt der Luft*. J. Phytopathol., vol.1, p.1-30.

34.Gheorghe Matei, Eugen Petrescu, Cătălin Aurelian Roşculete, 2008 - *Research regarding the influence of the npk fertilization to the cultural hygiene at the winter wheat cultivated in the caracal plain.* Jurnal Research Journal of Agricultural Science, vol. 40, Numărul 1, p.123-126.

35.Gheorghe Matei, E. Petrescu, Elena Roşculete, C. Roşculete, 2009 - *Influence of fertilization on maize yield and quality under conditions of sustainable agriculture on agric* *chernozem from CSDA Caracal.* Jurnal USAMY, Series A, vol. 52, p.232-238.

36.Gheorghe Matei, G. Păunescu, F. Imbrea, Elena Roşculete, C Roşculete, 2010 - *Rotation and fertilization-factors in increasing wheat production and improving the agro productive features of the brown reddish soil from central area of Oltenia.* Jurnal Research Journal of Agricultural Science, vol. 42, Numărul 1, p.182-189.

37.Ghini, R., Hamada, E., 2008**.** *Mudanças climaticas: impactos sobre doenças de plantas no Brasil*. Brasilia: Embrapa/SCT, 331.

38.Ghini, R., Hamada, E., Bettiol, W., 2008 – *Climate Change and Plant Diseases*. Sci. Agric. vol. 65, special issue, p.98-107.

39.Guderian R, Tingey D.T., Rabe R., 1985 – *Effects of photochemical oxidants on plants*. In *Air pollution by Photochemical Oxudants*, ed. R.Guderian, Springer-Verlag, Berlin, p.129-296.

40.Juroszek, P., von Tiedemann, A., 2013- *Climate change and potential future risks through wheat diseases: a review.* European Journal of Plant Pathology, vol. 136, p.21-33

41.Halterman D.A., Wei F.S., Wise R.P., 2003 - *Powdery mildew-induced Mla mRNAs are alternatively spliced and contain multiple upstream open reading frames*. Plant Physiology, 2003, vol. 131 p. 558-567.

42.Harvell, C. D., Mitchell, C. E., Ward, J. R., Altizer, S., Dobson, A. P., Ostfeld, R. S., Samuel, M. D., 2002 - *Climate warming and disease risks for terrestrial and marine biota*. Science, vol. 296(5576), p. 2158-2162.

43.Heagle A.S., 1970 – *Effect of low ozone fumigation on crown rust of oats*. Phytopathology, vol. 60, p.252-254.

44.Heagle A.S., Strickland A., 1972- *Reaction of Erysiphe graminis f.sp. hordei to low levels of ozone*. Phytopathology, vol.62, p.1144-1148.

45.Heyder, U., Schaphoff, S., Gerten, D., Lucht, W., 2011 – *Risk of severe climate change impact on the terrestrial biosphere*. Environmental Research Letters, 6.

46.Hovmøller, M.S., Walter, S., Bayles, R., Hubbard, A., Flath, K., Sommerfeldt, N., Leconte, M., RodrigueZ-Algaba, J., Hansen, J.G., Lassen, P., Justesen, A.F., Ali, S., de Vallavieille-Pope, C., 2016 - *Replacement of the european wheat yellow rust population by new races from the centre of diversity in the near-himalayan region*. Plant Pathology vol. 65, p.402-411.

47.Jones, M.H., Curtis, P.S., 2000 – *Bibliography on CO2 effects on vegetation and ecosystems*: 1990-1999 literature. http://cdiac.esd.ornl.gov/epubs/cdiac/cdiac129/cdiac129.html.Accesed 10.09.2019

48.Kerr J.B., McElroy C.T., 1993 – *Evidence for large upward trends of ultraviolet-B radiation linked to ozone depletion*. Science. vol.262, p.1032-1034.

49.Krupa, S.V., Kickert, R.N., 1989 – *The greehouse effect: Impacts of ultraviolet-B (UV-B) radiation, carbon dioxide (CO_2) and ozone (O_3) on vegetation*. Envirolment Pollution, vol. 61, p.263-392.

50.Krupa S.V., Manning W.J., 1988 – *Atmospheric ozone: Formation and effects on vegetation*. Environ Pollut., vol. 50, p.101-137.

51.Leirlós, M.C., Trasar-Cepeda, C., Seoane, S., Gil-Sotres, F., 1999 – *Dependence of mineralization of soil organic matter on temperature and moisture*. Soil Biol. Biochemistry, vol. 31, p.327-335.

52.Li, F., Kang, S., Zhang, J., Cohen, S., 2003 – *Effects of atmospheric CO2 enrichment, water status and applied nitrogen on water and nitrogen-use efficiencies of wheat*. Plant and Soil, vol. 254, p.279-289.

53.Loladze, L.R., 2002 – *Risisng atmospheric CO2 and human nutrition: toward globally imbalanced plant stoichiometry?* Trends in Ecology and Evolution, vol. 17,p.457-461.

54.Madgwick, J.W.,West, J.S., White, R.P. et al., 2010 - *Impacts of climate* *change on wheat anthesis and fusarium ear blight in the UK*. European Journal of Plant Pathology vol.129, (in press).

55.Madgwick, J.W., West, J.S., White, R.P., Semenov, M.A., Townsend J.A., Turner, J.A., 2011 – *Impacts of climate change on wheat anthesis and Fusarium ear blight in the UK*. European Journalof Plant Pathology, vol. 130, p.117-131.

56.Maiorano A., Blandino M., Reyneri A., Vanara F., 2008 - *Effects of maize residues on the Fusarium spp. infection and deoxynivalenol (DON) contamination of wheat grain*. Crop Protection, vol. 27 p. 182-188.

57.Malmström, C.M., Field, C.B., 1997 – *Virus-induced differences in the response of oat plants to elevated carbon dioxide.* Plant, cell and Environment, vol. 20, p.178-188.

58.Manning W.J., Feder W.A., Perkins I., 1969 – *Ozone injury increases infection of geranium leaves by Botrytis cinerea*. Phytopathology, vol. 60, p.669-670.

59.Manning W.J and Keane K.D., 1988 – *Effects of air pollutants on interactions between plants, insects and pathogens*. In *Assessment of Crop Loss from Air Pollutants*, ed. W.Heck et al., Elsevier, London, p.365-386.

60.Manning W.J and von Tiederman A., 1995 – *Climate change: potential effects of increased atmospheric carbon dioxide* (CO_2), *ozone* (O_3) *and ultraviolet –B (UV-B) radiation on plant diseases*. Environmental Pollution. vol.88, p.219-245.

61.Newman, J.A., 2004 – *Climate change and cereal aphids: the relative effects of increasing CO2 and temperature onaphid population dynamics*. Global Change Biology, vol. 10, p.5-15.

62.Newton A.C., 1988 - Mutant instability in Septoria nodorum, Transactions of the British Mycological Society, vol. 91, p. 607-610.

63.Newton A.C., Begg G., Swanston J.S., 2009 - Deployment of diversity for enhanced crop function, Annals of Applied Biology, (in press).

64.Newton, A.C., Johnson, S.N., Gregory, P.J. 2011 – *Implications of climate change for diseases, crop yields and food security*. Euphytica, vol.179, p.3-18. NOAA report, Jan. 2017.

65.Olsen, Jǿrgen E., Bindi, M., 2002 – *Consequences of climate change for European agricultural Productivity and use and policy*. European Journal of Agronomy, vol. 16, p. 239-262.

66.Orth A.B., Teramura A.H., Sisler H.D., 1990 – *Effects of ultraviolet –B radiation on fungal disease development in Cucumis sativus*. Am. J. Bot., vol.77, p.1188-1192.

67.Pangga, I.B., Hanan, J., Chakraborty, S. 2013 - *Climate change impacts on plant canopy architecture: implications for pest and pathogen management*. European Journal of Plant Pathology vol.135, p.595–610

68.Parry ML, Rosenzweig C, Iglesias A, Livermore M, Fischer G., 2004 - *Effects of climate change on global food production under SRES emissions and socio-economic scenarios*, Global Environmental Change, vol. 14, p. 53-67.

69.Partal Elena, Sin, Gh., Alionte Eliana - 2013. *The effect of management practices on the quality of wheat and maize harvest.* Annals of the Academy of Romanian Scientists. Series on Agriculture, Silviculture and Veterinary Medicine Sciences. Volume 2, Number 1/2013. p. 82-89.

70.Partal Elena, Paraschivu Mirela, Cotuna Otilia – 2014. *Influence of seeds treatment on the cereales production.* Research Journal of Agricultural Science, vol. 46 (2) 2014, p. 270-276.

71.Pan Z.,. Arritt R. W, Takle E. S., Gutowski Jr. W. J., Anderson C. J., and Moti Segal - 2004. *Altered hydrologic feedback in a warming climate introduces a "warming hole"* Geophysical Research Letters, vol. 31, p.1-4.

72.Perkins, L.B., Leger, E.A., Nowak, R.S., 2011 – *Invasion triangle: an organizational framework for species invasion*. Ecology and Evolution, 1,p.610-625.

73.Plessl, M., Heller, W., Payer, H.D., Elstner, E.F., Habermeyer, J., Heiser, I., 2005 – *Growth parameters and resistance against Drechslera teres of spring barley grown at elevated ozone and carbon dioxide concentrations*. Plant Biology, vol. 7, p.694-705.

74.Pritchard, S.C., Rogers, H.H., Prior, S.A., Peterson, C.M., 1999 – *Elevated CO2 and plant structure: a review*. Global Change Biology, vol. 5, p.807-837.

75.Pritchard, S.C., Amthor, J.S., 2005 – *Crops and environmental change*. Brighamton: Food Products Press, 421.

76.Popp, J., Petö, K., NagY, J., 2013 – *Pesticide productivity and food security. A review.* Agronomy for Sustainable Development, vol. 33 (1), p.243-255.

77.Reilly, J., 1994 – *Crops and climate change*. Nature, vol. 367, p.118-119.

78.Reilly, J., 1999 – *What does climate change mean for agriculture in developing countries?* A comment on Mandelsohn and Dinar. World Bank Obs. vol.14, p.295-305.

79.Reilly, J., Schimmelpfenning, D., 1999 – *Agricultural impact assessment, vulnerability and the scope for adaptation*. Climate Change vol. 43, p.745-788.

80.Rogers H.H., Runion G.B., Krupa S.V., 1994 – *Plant responses to atmospheric CO_2 enrichment with emphasis on roots and the rhizosphere*. Environ. Pollut., vol. 83, p. 155-189.

81.Runeckles V.C., Krupa S.V., 1994 – *The impact of UV-B radiation and ozone on terrestrial vegetation*. Environ. Pollut, vol. 83, p. 191-213.

82.Scherm, H., 2004 – *Climate change: can we predict the impacts on plant pathology and pest management?* Canadian Journal of Plant pathology, vol. 26, p.267-273.

83.Seckmeyer G., McKenzie R.L., 1992 – *Increased ultraviolet radiation in New Zealand (45°S) relative to Germany (48°N)*. Nature, vol.359, p.135-137.

84.Shaw, M.W., Bearchell, S.J., Fitt, B.D., Fraaije, B.A., 2008 - *Long-term relationships between environment and abundance in wheat of Phaeosphaeria nodorum and Mycosphaerella graminicola.* New Phytol, vol. 177 (1), p.229-238.

85.Sin, Gh., Partal Elena – 2010. *Influenţa rotaţiei şi a fertilizării asupra producţiilor de grâu şi porumb în contextul variaţiilor climatice. an. i.n.c.d.a. fundulea*, VOL. LXXVIII, NR. I, p. 101-107.

86.Sutherst, R.W., ConstablE, F., Finlay, K. J., Harrington, R., Luck, J., Zalucki, M.P., 2011 – *Adapting to crop pest and pathogen risks under a changing climate*. Wiley Interdisciplinary Reviews – Climate Change, vol. 2, p.220-237.

87.Stewart, K.J., 2002 – *Abiotic stress and mlo-resistance breakdown to barley powdery mildew*. Dphil Thesis, University of Oxford.

88.Teixeira, E.I., Fischer, G Van VelthuizeN, H., Walter, C., Ewert, F. 2012 – *Global hot-spots of heat stress on agricultural crops due to climate change*. Agricultural and Forest meteorology, in pressdoi:10.1016/j.agrformet.2011.09.002

89.Thomson, G.B., Brown, J.K.M., Woodward, F.I., 1993 – *The effects of host carbon dioxide, nitrogen and water supply on the infection of wheat by powdery mildew and aphids*. Plant, Cell and Environment, vol. 16, p.687-694.

90.Thomson, G.B., Drake, B.G., 1994 – *Insects and fungi on a C3 sedge and a C4 grass exposed to elevated atmospheric CO2 concentrations in open-top chambers in the field*. Plant, Cell and Environment, vol. 17, p.1161-1167.

91.Tiedemann, A.V., 1992 – *Ozone effects on fungal leaf diseases of wheat in relation to epidemiology. I. Necrotrophic pathogens.* J. Pathology, vol. 134., p.177-186.

92.Tiedemann, A.V., Firsching, K.H., 2000 – *Interactive effects of elevated ozone and carbone dioxide on growth and yield of leaf rust-infected versus non-infected wheat*. Environmental Pollution, vol. 108, p.357-363.

93.Váry, Z., Mullins, E., MCelwain, J. C. and Doohan, F. M., 2015 - *The severity of wheat diseases increases when plants and pathogens are acclimatized to* *elevated carbon dioxide*. Global Change Biology, vol. 21, p.2661–2669.

94.Von Braun J., 2007 - The world food situation: new driving forces and required actions, Washington, DC, USA International Food Policy Research Institute.

West, J.S., Holdgate, S., Townsend, J.A., Edwards, S.G., JenningS, P., Fitt, B.D.L., 2012 - *Impacts of changing climate and agronomic factors on fusarium ear blight of wheat in UK*. Fungal Ecology, vol. 5, p.53-61.

95.Yeo, A., 1999 – *Predicting the interaction between the effects of salinity and climate change on crops plants*. Sci. Hort. vol. 78, p.159-174.