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SOME METHODS OF WATER CONSERVATİON IN AGRICULTURE WHICH MAY ALSO BE INTEGRATED TO ACHIEVE HİGHER PRODUCTIVITY AND QUALITY ECOLOGICALLY

II. Some Methods and Their Physiological Bases of Benefits

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Abstract

Plant growth and productivity and water use efficiency (WUE) in terms of physiology and crop productivity are the result of many interrelated and complex factors, some of which are being changed by global warming. Vast majority of plant propagators have limited power of interference and control of these factors at natural conditions, especially under pressure of cost-profit ratio and environmental concerns. It will be attempted to review some promising methods, their outstanding performances and potentials in terms of productivity and water use efficiency (WUE) within the framework of sustainable agriculture at constantly changing climatic conditions and to attract attention to the potential of integrating some of them for higher water economy and productivity to attract attention to the possible benefits of using artificial intelligence in meta-analytical approaches to the challenging meta-problems, by integrating the prospective advancements obtained by researchers all over the world. In the coming third part of the article, some prospective ecological approaches to agricultural ecosystems for integral and economic solutions to the growing problems in the era of global warming and population growth. The purpose of the study will be to draw attention to possibility of alleviation of the growing worldwide problems in agricultural production to some extend by integration of some methods, techniques deserving higher interest and wider practical applications considering billions of people living in rural areas and depending on their agricultural production, and also the locus of food production.

Keywords: Plant physiology, global warming, ecological agriculture, water economy

1.INTRODUCTION

As it is well known fact nowadays that, so called “green revolution”or “intensive agriculture”lost its prosperity and replaced by approaches like “The new Green Revolution: Sustainable intensification of agriculture by intercropping” (Martin-Guay , Paquette , Dupras *et al.* (2017). Intercropping and use of synthetic chemicals for instance, have been two of the methods getting popularity, but some other successful techniques do not seem to receive that level of attention. The aim of this study is to attract attention to some successful methods, techniques which can be assessed for higher productivity and water use efficiency (WUE) in the era of global warming, consequent climate changes and related environmental problems.

2.CLIMATE SMART AGRICULTURE

The media on the "Internet of things" (IoT) names the offered technology as "IoT for All Technology" and describes the concept named as smart, or precision agriculture, or smart farming in the article titled "Smart Farming: The Future of Agriculture" (IoT for All. Smart Farming, 2020). The description there is a management concept to provide the infrastructure to leverage advanced technology including big data, cloud and the IoT for tracking, monitoring, automating and analyzing operations by software-management, using sensors for monitoring. It was added that the importance of smart farming was growing, due to increasing global population and demand for higher crop yield, by using natural resources efficiently and sustainably. Presence of sophisticated information and communication technology offers the possibility of this development at the era of increasing need for climate-smart agriculture.

Kim, Lee, & Kim (2020) in their article titled "A Review of the Applications of the Internet of Things (IoT) for Agricultural Automation" described the benefits of the of modern Information and Communication Technologies (ICT) into agriculture. According to the author, the applications of capital-intensive and hi-tech system to smart, precision farming was increasing operational efficiency accompanied by lower costs, reduced waste, and higher yield quality. Obviously, the capability of monitoring light, humidity, temperature, soil moisture, etc. and automating the irrigation system offers very efficient water economy. It was added that this modern approach was not only applicable to conventional, large farming operations, but to other growing or common trends like organic farming, family farming performed at complex or small spaces, particular cattle and/or cultures, preservation of particular or high-quality varieties, etc. Another advantage of the method would be enhancing transparency of farming business.

Food and Agriculture Organization of United Nations (FAO) cooperated with International Atomic Energy Association (IAEA) for development of methods and techniques using stable isotopes such as N^{15}, C^{13} and necessary equipment, consumables for smart farming, smart agriculture applying intelligent operations (IAEA, 2020). The list given there covered IoT sensors and actuators for soil scanning and water, light, humidity and temperature management; telecommunications technologies such as advanced networking and geo-positioning systems (GPS), hardware and software for specialized applications and for enabling IoT-based solutions, robotics and automation, data analytics tools devices such as precision equipment, unmanned aerial vehicles (UAVs) and robots for decision making and prediction of the quantitative data collected on the weather data and changes of climate, crop yields, properties of soils, fertilizer applications, machinery and animal health etc. As seen clearly, the need for capital investment, financing operation and hiring operation, maintenance specialists are high. Additionally, it is obvious that the necessary infrastructure is not available everywhere.

IAEA mentions that satellites and drones could also be used for gathering data for entire field and forwarded to IT systems for tracking and analysis also in order to reduce overall costs, improve the quality and quantity of products, the sustainability of profitable agriculture and waste reduction, careful management of the demand forecast and delivery of goods to market in time to reduce value loss and waste. It was added that precision agriculture was concentrating on the right growing parameters to provide the right crop that was in demand. In the section of the article on the future of smart, IoT-driven farming, which is also named as "third green revolution,"referring to the combined application of information and communications technologies. It can be noted here that, there is one overlooked, neglected problem called global warming related climate changes and the related risk management solutions. The only topic related with global warming and related climate changes by IAEA was decreasing impact of agricultural activities on greenhouse gas emissions by smart agricultural practices.

Although excessive growing of global ecological footprint is closely related with technological advancements accompanied with exploiting natural resources and polluting environment, it seems that the solutions to the environmental problems will also be offered by development of sustainable, green technologies (Shaikh, 2017). As he said, "Green technologies have a promising future in meeting the needs of economic sustainability. But, environmental and social sustainability factors need to be reinforced in a mutual manner.". One way to achive this goal may be using the integration of the results of studies obtained in different disciplines, and the success obtained by utilizing the possibilities offered by the AI for early diagnosis of cancer is a good example (Huang, Yang, Fong *et al.* 2020). The researchers said that developments in statistics and computer engineering had encouraged scientists to apply computational multivariate statistical analysis to analyze the prognosis of the disease in order to increase the accuracy of diagnosis depending on empirical predictions significantly. They added that with the applications of AI, especially machine learning and deep learning in clinical cancer research, cancer prediction performance had reached new heights. Their review article aimed to present advantages of the application of AI to cancer diagnosis and prognosis, and summarizing its advantages, specifically with regard to its unprecedented accuracy, which was even higher than that of general statistical applications in oncology.

Frankfield, J. (2020) described AI as "The simulation of human intelligence in machines that are programmed to think like humans and mimic their actions. The term may also be applied to any machine that exhibits traits associated with a human mind such as learning and problem-solving.", and added that its ideal characteristic was its ability to rationalize and take actions to have the best chance of achieving a specific goal, by learning, reasoning, and perception. The author too, stressed the achievements in the healthcare industry for dosing drugs and different treatment in patients, and for surgical procedures in the operating room, and added that AI was continuously evolving to benefit many different industries. The examples given were self-driving cars, detect and flag activity in banking and finance, making trading easier by making supply, demand, and pricing of securities easier to estimate, agricultural production was not mentioned at all.

Talaviya, Shah, Patel *et al.* (2020) attracted attention to the growing supply and demand problem in agriculture sectors, and described the new automated methods as the solution of satisfaction the food requirements and provision of employment opportunities to billions of people in their review article. They added that AI technology could protect the crop yield from various factors like the climate changes, population growth, employment issues and the food security problems, referring to the projection published by UN, which was claiming that 2/3rd of world's population would be living in urban areas by 2050. The authors stated that AI would be needed to lessen the burden on the farmers by automating several processes, reducing risks and providing farmers comparatively easier and more efficient farming. They presented the main concern of their study as to audit the various applications of AI in agriculture, such as for irrigation, weeding, spraying with the help of sensors and other means embedded in robots and drones, to save the excess use of water, pesticides, herbicides, maintaining soil fertility, increasing the efficiency of man power, elevating productivity and improving the quality of the products. They also covered the weeding systems through the robots and drones, various soil water sensing methods along with automated weeding techniques, using drones for spraying and crop-monitoring, and added that the least digitalized agriculture sector would gain momentum for the development and commercialization of agricultural technologies. They referred to a study showing that AI was based on the vast domains like Biology, Linguistics, Computer Science, Mathematics, Psychology and Engineering, and attracted attention to the potential contribution to rural development, also referred to another report on a proposed system for flower and leaf identification and watering by using IOT. The AI-based technologies were helping to improve efficiency in all the fields, and managing the challenges faced by various fields in the agricultural sector like the crop yield, irrigation, soil content sensing, crop-monitoring, weeding, crop establishment. Talaviya *et al.* (2020) added that technological solutions already enabled the farmers to have more and improved the quality of output with less input, also ensured faster delivery; they also presented a projection predicting that farmers would be using 75 million connected devices, and an average farm would generate an average of 4.1 million data points every day by 2050.

Nelson, Valin, Sands *et al.*(2014), on the other hand, approached to the current problems by looking from different perspectives in their comprehensive review article titled "Climate Change Effects on Agriculture: Economic Responses to Biophysical Shocks"and explained the significance of the topic by indicating the presence of plausible estimates of climate change impacts on agriculture, which required integrated use of climate, crop, and economic models. They investigated the contribution of economic models to uncertainty in the impact chain by using nine economic models, which included the direction of management intensity, area, consumption, and international trade responses to harmonize crop yield shocks from climate change. They added that, as the magnitudes were differing significantly, the magnitude of differences depended on model structure, particularly to the specification of endogenous yield effects, land use change, and propensity to trade.

Nelson *et al.* (2014) criticised the results obtained by the previous studies for the substantial variations in models, scenarios, and data used; described their approach as a part of a collective effort to systematically integrate three types of models. Considering the definition of meta-analysis, it can be stated that their approach was meta-analytical; meta-analysis is defined as a quantitative statistical analysis of several separate but similar experiments or studies in order to test the pooled data for statistical significance since 1976 (Merriam-Webster, 2020). They focussed on the economic component of the assessment, investigating endogenous responses of nine global economic models of agriculture representing seven standardized climate change scenarios produced by two climate and five crop models which included adjustments in yields, area, consumption, and international trade. Parameters such as biophysical shocks derived from the IPCC's representative CO_2 concentration pathway, mean biophysical yield effect with no incremental fertilization would be a 17% reduction globally by 2050, relative to a scenario with unchanging climate were used. Endogenous economic responses were found to reduce yield up to 11%, increase area of major crops by 11%, and reduce consumption by 3%. Agricultural production, cropland area, trade, and prices would show the greatest degree of variability in response to climate change, and consumption show the lowest. The sources of the differences included model structure and specification, disagreements were on the relative responses to climate shocks, so Nelson *et al.*(2014) drew attention to the need of research activities to improve the representation of agricultural adaptation responses to climate changes. As it can be clearly seen from their conclusion, there is a need for understanding the details of the adaptation and resistance mechanisms of living organisms to changing abiotic and biotic environmental conditions within a wide range of population complexity.

Although, one of the solutions offered by biotechnological inventions is using seeds of genetically modified organisms (GMOs), this approach created some moral and legal problems, as Bouchie (2002), for instance, wrote on the topic approximately two decades ago. Lo (2013) published an article titled "Monsanto Bullies Small Farmers Over Planting Harvested GMO Seeds", and Peschard, (2019) reported recently that Monsanto won $7.7 billion lawsuit in Brazil, but farmers' were determined to continue fighting to stop its 'amoral' royalty system. More recent and attractive biotechnological innovative development, is genetical modification by using CRISPR-Cas method, Barrangou (2015), for instance, wrote on the roles of CRISPR-Cas systems in adaptive immunity and beyond to stress the prospective potential of the technique, and Cai, Chen, Liu *et al.* (2017) reported another success of CRISPR/Cas9-mediated targeted mutagenesis in delaying flowering time in soya bean. There are much more examples of course, but Cohen (2020) on the other hand, drew attention to the legal problems arised recently in the articled titled "The Latest Round in the CRISPR Patent Battle has an Apparent Victor, But the Fight Continues".

As very well known, independent from complexity, autotrophs are the starting point of ecosystems, and their sustainability depends on the adaptation and resistance mechanisms of their primary producer members. This is the reason of the increasing interest of researchers on plant ecophysiology, and focusing on physiological mechanisms of survival under global warming and related changes in climate. Acclimation as well as adaptation, tolerance and resistance can be defined as the ability of organisms to cope with stress, either natural such as temperature changes, salinity variations, oxygen level fluctuations, and plant toxins, or chemicals depending on anthropogenic inputs of many different classes of contaminants into the environment. Biagianti-Risbourg, Paris-Palacios & Mouneyrac (2013) defined acclimation or physiological adaptation as the second phase of stress, and referred to numerous papers defining adaptation as synonymous of resistance, the word that was frequently used in the scientific literature as a synonym for tolerance. They mentioned that several authors had tried to clarify these terms, but none of the proposed terms had been adopted generally. Here, the terms defined by Biagianti-Risbourg *et al.* (2013) will be used: "Acclimation as well as adaptation, resistance, or tolerance can be defined as the ability of organisms to cope with stress, either natural such as temperature changes, salinity variations, oxygen level fluctuations, and plant toxins or chemicals depending on anthropogenic inputs of many different classes of contaminants into the environment." complementary to the expression "Considering the fact that autotrophs or primary producers are the sources of energy to lotic food webs by acquiring their energy from sunlight and materials from nonliving sources, such as some bacteria and protists, algae and higher plants, their coping mechanisms to stresses should be considered as the vital ones."(Allan & Castillo, 2007).

The title of the chapter written by Surowka, Rapacs & Janowiak (2020) is "Climate Change Influences the Interactive Effects of the Simultaneous Impact of Abiotic and Biotic Stresses on Plants"is reflecting the framework of their study on the influence mechanisms covering alteration of habitats, changing the natural conditions affecting organisms and functioning of ecosystems. The influences of changes in climatic conditions on the members of fauna can be appended to their list; as a matter of fact, they covered the topics "meta-organism" and "holobiont"in their text, and stressed the importance of integral approach to all communities. They focussed on microbiota and plants, and attracted attention to the differences in combined effects of randomly interacting several natural abiotic and biotic stress factors in the fields and the controlled laboratory conditions. Such differences might lead to changes of strategies adopted by plants to susceptibility or tolerance through modifying the primary and secondary metabolisms; changes in nutrient availability, nutrition and their metabolism would cause deviations in C and N metabolisms and C/N ratio.

Dubey, Kumar, Mohammad *et al.* (2020) reminded that *Fabaceae* family members were important for sustainable agriculture and human health due to their high protein content and maintaining the nitrogen economy of the soil, especially in semi-arid and arid regions at global warming era. Therefore, they attracted attention to the need of an integral approach and identification of physiological and biochemical traits that could contribute to enhancement of legumes growth and productivity under stress conditions, which was a major challenge for the plant breeders and geneticists. Although the application of biostimulants/biofertilizers have emerged as eco-friendly solutions for tackling these problems, they said, diverse substances and microorganisms were defined as biostimulants, such as Plant- Growth-Promoting Rhizobacteria (PGPR), bacterial and fungal endophytes or endosymbionts, which were enhancing plant growth and productivity, nutrition use efficiency (NUE) and plant performance under stress conditions. Thus, they added, such microbial bioinoculants were playing a dual role as biostimulant and biocontrol agent, so theh said, global market for them had reached up to $2,200 million by 2018, with particular reference to *Fabaceae* family, but still lacking peer-reviewed scientific evaluation. So, they aimed to provide latest advances in the application of plant biostimulants and scientific information related to the nature, mechanism of action and effects of biostimulants on *Fabaceae* spp. under abiotic stress conditions.

As a matter of fact, Stepanova, Yun, Likhacheva *et al.*, (2007) for instance, attracted attention to the central role of hormones in the coordination of internal developmental processes with environmental signals. They added that a combination of physiological, genetic, cellular, and whole-genome expression profiling approaches had been employed in their study to investigate the mechanisms of interaction between two key plant hormones: ethylene and auxin. They presented results obtained by quantification of morphological effects of ethylene and auxin hormones in a variety of mutants, which indicated that auxin biosynthesis, transport, signaling, and response were required for the ethylene-induced growth inhibition in roots, but not in hypocotyls of dark-grown seedlings. Analysis of the activation of early auxin and ethylene responses at the cellular level, and global changes in gene expression in the wild type versus auxin and ethylene mutants which lead to a simple mechanistic model for the interaction between those hormones in roots. They concluded that ethylene and auxin could reciprocally regulate each other's biosyntheses. They were affecting each other's response pathways, and/or act independently on the same target genes.

Salazar, Hernández & Pino (2015) referred to the article by Netting (2000), who reviewed the literature to compare stressed and non-stressed plant metabolisms to reveal the interrelationship between pH, abscisic acid (ABA) and integration of metabolism in stress and normal conditions. Netting had evaluated cellular responses to stress and their implication for plant water relations and concluded that actively controlled physiological changes under stress conditions were leading to increase WUE and water storage in order to increase tolerance and preparation for water transport and use at cellular level by physiological and biochemical changes. Salazar *et al.* (2015) reminded in their excellent article that agriculture was severely impacted by water stress due either to excess (hypoxia/anoxia) or deficit of water availability. Hypoxia/anoxia was associated with oxygen (O_2) deficiency or depletion, inducing several anatomical, morphological, physiological, and molecular changes related with adaptation, such as changes in shoot length, aerenchyma and adventitious roots formations. They focussed on the role of association between ABA and ethylene in the major physiological responses to decreasing O_2 level and root respiration, stomatal conductance, photosynthesis, fermentation pathways in roots, changes in gene expression. The expression of ethylene receptor genes were affected, and ethylene seemed to have a crucial role in anatomical and physiological effects during hypoxia/anoxia. Ethylene accumulation was inhibiting ABA biosynthesis enzymes and also activating ABA breakdown to phaseic acid. Drought was primarily sensed by the roots, which were inducing a signal translocated to shoots triggering physiological and morphological changes. They added that several genes were regulated by osmotic stress through ABA-dependent or ABA-independent pathways; some previous studies had suggested a sharp cease in leaf growth by ethylene, and also antagonization of the control of gas exchange and leaf growth upon drought by its own and ABA accumulation.

Another important physiological mechanism that take part in water stress adaptation and response are the relations between some hormones and enzymes. Ullah, Manghwar, Shaban *et al.* (2018) reviewed the literature on the topic, and after mentioning the importance of understanding the mechanism of drought tolerance in enhancing acclimation, they also attracted attention to the role of phytohormones. After mentioning ABA as the main hormone intensifying drought tolerance through various morpho-physiological and molecular processes including stomata regulation, root development, and initiation of ABA-dependent pathways, they added jasmonic acid (JA), salicylic acid (SA), ethylene (ET), auxins (IAA), gibberellins (GAs), cytokinins (CKs), and brassinosteroids (BRs) as the other very important phytohormones in congregating the challenges of drought stress in their comprehensive article. Their conclusion can also be taken as another invitation to integral approaches to find efficient solutions to complicated problems.

Duque, Almeida, Silva, *et al.* (2013) referred to some articles which described the phases of physiological responses to abiotic stresses. They described the sequence as a functional decline in the alarm: stress reaction, resistance, exhaustion and regeneration phases, which could occur only if the damage was not too severe. Sensing was the first and a very complex issue, covering multiple and variable mechanisms. common to all stresses. They exemplified by some stresses directly affecting the underground parts of plant bodies, such as drought, flooding, and others like photoinbition affecting directly the aboveground structures to the necessity of having different sensing mechanisms. The researchers mentioned the most common model of sensing external stimuli, binding a ligand to a specific receptor, and added that it was suitable only for chemical stresses, such as nutrient depletion stress, not for physical stresses related with temperature and others. They also referred to experimental evidences reported pointing to the possibility of sensing cell water homeostasis, depending on isolation of a transmembrane hybride-type histidine kinase from *Arabidopsis thaliana* acting as osmosensors. Level of sugars generated by photosynthesis was given as another example, playing an important role in sensing and signaling, modulating stress responses and also growth and development through changing the source and sink tissues. Sensing was followed by one or more signaling and activation of signaling transduction cascades, preparing restitution counter reactions which would lead to resistance development, accompanied by functional declines of photosynthetic performance, transport or accumulation of metabolites and/or uptake and translocation of ions, which could lead to acute damage and death.

Duque *et al.* (2013) also covered the literature on restitution of counter reactions in their article, and attracted attention to the results showing the importance of the rate of stress imposition, more pronounced decline of physiological functions at higher dehydration rates. High rates, they said, could at least partly be related to the increased production of active oxygen species (AOS), and referred to the finding in the C_4 grass *Setaria sphacelata,* showing a decrease in the key enzyme of C_4 photosynthesis, phosphoenolpyruvate carboxylase (PEP carboxylase) after several days of water stres; but, observation of several-fold increase of its activity after a short period of acute stress.

Raza, Ashraf, Zou *et al.* (2020) also reviewed the literature on mechanisms and perspectives of plant adaptation and tolerance to environmental stresses. They covered a wide range of stresses from waterlogging, drought and salinity to chilling, freezing and high temperature, and also elevated CO_2 as the factors affecting plant and crop physiology. They also stressed the importance of differentiation of responses to single and multiple stresses, and drew attention to the variable responses at cellular, physiological and transcriptional level. Histological and anatomical responses can be added to their list, and a very similar complexity can be mentioned here: aging, senescence and programmed cell death processes also cover focussed processes transcriptional, translational, physiological changes in the cells, tissues and organs, as Woo, Masclaux-Daubresse & Lim (2018) discussed. Different physiological and biochemical processes are very well known to be altered by drought, such as water relations, gas exchange, photosynthesis and the metabolism of carbohydrates, proteins, amino acids and other organic compounds. The effects of drought on plant growth, gas exchange, water relation and osmoregulation have been widely studied for a long time as reviewed by Anjum, Xie, Wang, *et al.*(2011).

Feller & Vaseva (2014) also reviewed the literature on physiological impacts of drought and high temperature, but they covered agronomically important plants. They stressed the importance of stomatal control, which could lead to permanent closure of some of them by waxy deposits, and irreversible drop in photosynthesis rate at stressed leaves. Heat sensitivity of Rubisco activase enzyme of genera, spp. and cv.s might also become a limiting factor for photosynthesis. In addition to these effects, accumulation of reactive oxygen species (ROS) and partial conversion of free amino acids into compatible solutes such as proline, and accompanying lower rates of both nitrate reduction and de novo amino acid biosynthesis were typical developments. Induction of proteins such as dehydrins, chaperones, antioxidant enzymes and the key enzyme for proline biosynthesis were playing an important role as protective mechanisms in leaves. The effects of long-distance translocation of the solutes related with development of leaf senescence were also important. The researchers concluded that such factors were relevant for the overall performance under drought and heat, and should be considered for genotype selection and breeding programs.

Jalil & Ansari (2020) reviewed the literature on plant stresses and their implications on crop productivity, they were right to include the stresses of pesticides and toxic metals in the list of abiotic stresses. Obviously some other chemical and physical stresses can be added to the list here, such as dust pollution (Sett, 2017), combined air pollutants (Papazian & Blande, 2018), and toxic organic soil pollutants (Copaciu, Opris, Ninemets *et al.* 2016). Jalil *et al.* (2020) claimed that plant yield was affected primarily by insufficient water availability or diminished nutrient uptake. As a matter of fact, it is known since eightees that low soil potentials were depressing nutrient uptake by roots, and also subsequent translocation upwards until their adaptation (Shone & Flott, 1983), if they do not reach to permanent wilting point (PWP) under the stress of course. They found that rapid growth of nodal roots assisted by osmotic adjustment might be related to adaptive development to ensure resumption of nutrient and water uptake following the stres period. Ahanger, Morad-Talab, Abd-Allah *et al.* (2016), stressed the importance of proper supplementation of mineral elements to crop plants, which could contribute to avoid drought stress through their active participation in several defence mechanisms like osmoregulation and antioxidant systems. They added that the level of knowledge on this important subject was far away from understanding the impact of drought stress on plant mineral nutrition, although developing useful strategies that could be adopted to mitigation of the damage caused by the drought and consequent nutrient deficiency. The researchers reminded that although the deficiency of macronutrients could be readily observed and targeted, micronutrients might directly or indirectly affect the susceptibility of plants to stress factors via changing enzyme activity, modulating the signal transduction pathways and/or producing some metabolites that could not be observed easily. It may be meaningful to mention here that some micronutrients are involved in the metabolism of plant growth hormones, as the prosthetic groups of key enzymes. They are cofactors that bind tightly to proteins by a covalent bond, capable of binding the same substrate to different enzymes. As also known very well, micronutrients can also bind to some enzymes loosely, as a coenzyme, (Silva, Nogueira, Silva (2010).

Van Overbeek (1956) reviewed the physiological, practical and economical aspects of PGRs in his comprehensive article entitled "Agricultural Application of Plant Growth Regulators and Their Physiological Basis". The popularity and wide use of synthetic hormones in agricultural production was examplified and explained in terms of competitive pricing of their formulations, as it would be expected, as a matter of fact, the first subtitle of the article was Economical Aspects. His assessment was quite normal in fiftees, when the Father of Green Revolution era, Norman E Borlaug received the Nobel Peace Prize in 1970 for his work increasing crop yield and preventing hunger, or as called, Malthusian tragedy in developing countries (Muhanta, R. K. 2009). As known very well, publication of the book Silent Spring by R. Carson in 1962 triggered an environmental movement, as Taylor, P. (2016) used as the title of the article on this milestone of environmental history timeline. As he put it, "Silent Spring triggered an environmental movement" and described the triggering as "such we have known the toxic effects of chemical agriculture, basically from the very beginning. We have suffered both massive environmental damage, disease and pest resistance, and human health issues."

An earlier, less known movement actually targeting sustainability with a broader perspective was International Commission on Irrigation and Canals (ICID), which was established on 24 June 1950 by 11 founder developing countries; the aim was expressed as "Being a leading scientific, technical, and professional not-for-profit international organization working in the field of irrigation, drainage and flood management to promote and achieve sustainable agriculture water management."(International Commission on Irrigation & Drainage - ICID). This, not very well known international commission of countries from Africa and Asia, located at the center in Delhi, published an article titled Second Green Revolution (ICID, 2020). After referring to the beginning of the Green Revolution attributed to N. Borlaug, in the 1940s in Mexico depending on newly developed disease resistant high-yield wheat varieties combined with new mechanized agricultural technologies, which enabling Mexico to export wheat instead of importing half of the wheat consumed in 1960s, it was noted in the article that the Green Revolution in Mexico spread worldwide, due to this success.

Basic ingredients of this revolution was attributed to High Yielding Variety (HYV) seeds with superior genetics, use of chemicals-pesticides and fertilizers and multiple cropping system supported by the use of modern farm machinery and proper irrigation system in addition to expansion of farming areas accompanied with changes in the thinking of farmers, rural development, trade and the surplus which supported development of industries. It was added by ICID that, when world started to realize the environmental challenges, a framework for the Second Green Revolution (SGR) aligning itself with the sustainable development principles had been articulated and comprehended to cover the regions such the African Continent and and Southern part of Asia, putting emphasis on small and marginal farmers. Increasing their production sustainably by applying integrated programmes taking care of all aspects of agriculture from soil characteristics, matching seeds, grains, conversion to food and its marketing after value addition were the goals. As a network of Agriculture

Water Management professionals, it was declared that they would make a substantial contribution towards sustainable rural development in underdeveloped and developing regions by articulating how irrigation and drainage could make second green revolution a realty.

Research Center on Local and Traditional Knowledge– IPOGEA.(2017) and Traditional Knowledge Focus Group (AFCD, 2014) are also examples of scientific institutions focusing on the traditional sustainable ecosystem management and production methods, techniques. As a matter of fact, the related Article 19 of Chapter 12 of UNCCD Agenda 21 accepted in 1992 (UNCCD- UN, 2017) noted that governments, with the support of the relevant international and regional organizations, should develop land-use models based on local practices for the improvement of such practices, with a focus on preventing land degradation. Models should incorporate the interaction of both new and traditional practices to prevent land degradation and reflect the resilience of the whole ecological and social system. A very recent example has been reported by Kloppers (2020) under the title of "A small indigenous group offers an example of how to save the world", telling how Gumbi clan living in northern KwaZulu-Natal conserved the world's third most biodiverse hotspot, which had lost more than 18% of natural habitat and nearly 50% of terrestrial ecosystems were threatened, by the method named as "sharing life with nature". They had to restore 20,000 ha. of land degraded by overgrazing and abondoned and marginally suited for agriculture in the 1960's. Meli, Rey-Benayas & Brancalion (2019) wrote an article on scientific approaches to land sharing/sparing in order to discuss the way of thinking to reach decisions promising success. They discussed four questions consisting of the main focuses of restorative interventions, which restorative interventions should be implemented where; and the major factors influencing restoration outcomes. They recommended careful planning to minimize trade-offs to maximize synergies, consideration of the spatial distribution and configuration of the final land uses with its social context to find the right balance between land sharing/sparing approaches.

Leff, Bardgett & Wilkinson (2018) reminded the presence of some knowledge on the numerous ways on the influence of plants on the composition of soil communities, ans draw attention to the lack of clear information on plant community attributes could be used to predict the structure of soil communities. They performed tests in both monocultures and field-grown mixed temperate grassland communities to see whether plant attributes predict soil communities including taxonomic groups from across the tree of life covering fungi, bacteria, protists, and metazoa. The composition of all soil community groups was affected by plant species identity, both in monocultures and in mixed communities. Moreover, they said, plant community composition predicted additional variation in soil community composition beyond what could be predicted from soil abiotic characteristics. Analysis of the field for aboveground plant community and the plant roots compositions suggested that plant community attributes were better predictors of soil communities than root distributions. However, neither plant phylogeny nor plant traits were strong predictors of soil communities in either experiment. They concluded that grassland plant species were forming specific associations with soil community members and that information on plant species distributions could be used to improve predictions of soil community composition; such specific associations between plant species and complex soil communities were key determinants of biodiversity patterns in grassland soils.

Such findings have certainly lead to changes in the paradigms and inevitably affected the approaches to agricultural practices and the use of PGRs and other agricultural inputs. Hasnain, Bakhsh, Hussain et al. (2020) for instance, aimed to highlight the impact of the most popular synthetic auxin, naphthalene acetic acid (NAA) applications with some irrigation regimes on the productivity of coarse rice under agro-ecological conditions. Their field experiment was comprised of two factors with four levels (0, 60, 90, 120 mL ha-1) of NAA and irrigation at the depths (60, 75, 90 and 105 cm) of soil profile. The data was interpreted to observe the changes in plant height (cm), productive tillers (m^{-2}), sterility percentage (%), biological yield (t ha^{-1}), and grain yield (t ha^{-1}). The benefit cost ratio (BCR) was also calculated, and their results indicated the effectivity of NAA in improving paddy yield and better BCR value. The maximum yield was attained at NAA 90 mL ha^{-1} at 75 cm irrigation depth, the increase in grain yield ensured better economic returns. Several other positive effects at various applications of this synthetic auxin and its derivatives have been known since fiftees and no adverse effects of NAA and several derivatives were found by U.S. EPA in 20th century (U.S. EPA, 2004).

Hac-Wydro and Flasinski (2015) on the other hand, studied on membrane-damage effect of indole-3-acetic acid- IAA and 1-naphthaleneacetic acid-NAA PGRs on *Arabidopsis thaliana* and animal (rat liver) model membranes, considering their widely use in agriculture to control the quality of the crop. However, they said their accumulation in the environment made them hazardous for the living organisms and investigated to compare the effect of natural (IAA) vs. synthetic (NAA) auxin on the organization of plant and animal model membranes, and searched for a possible correlation between membrane-disturbing effect of these compounds and their toxicity. They evidenced that auxins caused destabilization of membranes, decreased their condensation and weakened interactions of molecules. The alterations in the morphology of model systems were seen and as expected the effects were concentration-dependent. NAA was found to act on animal vs. plant membranes more selectively than IAA, both induced the strongest disordering in model lipid system at the concentration, which was frequently reported as toxic to animal and plants. They proposed that membrane-damage effect might be important in the mechanism of toxicity and should not be ignored in further investigations, as per the rules of the "Green Revolution 2" in agricultural production.

Shifeng, Yanming , Xiao, *et al.* (2014) also attracted attention to the the hazards that had brought along with the PGRs to food safety and human health, increasingly becoming the focus of world attention. They studied on controlled release formulations (CRFs) in overcoming the drawbacks of conventional PGRs formulations by allowing usage of minimum amount of PGRs for the same activity. They prepared a controlled-release formulation of NAA and indole-3-butyric acid (IBA) by using a characterized synthetic nanohybrid material and studied their release kinetics . They found that nanohybrids of NAA and IBA simultaneously intercalated in LDHs possessed good controlled release properties, and added that the environmentalist concerns related with accumulation of residues of persistent organic chemicals or their derivatives forming in the environment had been leading the researchers to search for more eco-friendly alternatives. Pal, C., Dey,C., Kumar, S. *et al.* (2007), on the other hand, aimed to synthetise and introduce an eco-friendly PGR group and succeeded to obtain

3,3-Diindolylmethane and its derivatives, which were also tested for their PGR activities by them. But, this bioactive compound group derived from cruciferous vegetables such as broccoli, cauliflower, kale, cabbage, brussels sprouts, turnips, kohlrabi, bok choy, and radishes (Maruthanila, Poornima & Mirunalini, 2014) have been and are widely used for their anticancer potential (Isabella, 2016), not for agricultural practice.

Westfall, Muehler & Jez, (2013) are also in the group of research teams who have reviewed the enzyme actions in the regulation of plant hormone responses; they exemplified the contribution of amino acid metabolism to the synthesis of ethylene, auxin, and salicylic acid (SA), stimulation of ethylene production, by cyclization of *S*-adenosyl-L-methionine (AdoMet) into 1-aminocyclopropane-1-carboxylic acid (ACC) by ACC synthase and subsequent oxidation into ethylene by ACC oxidase, and regulation of ACC synthase, which was controlling ethylene production. Aromatic amino acids were precursors of auxins and salicylic acid (SA) synthesis, biosynthesis of indole-3-acetic acid (IAA) auxin from tryptophan was catalyzed by tryptophan aminotransferase and YUCCA flavin monooxygenase. YUCCA (YUC) flavin-containing monooxygenases (FMOs), which were catalyzing a rate-limiting step in auxin biosynthesis and that YUCs were essential for many developmental processes. Maintenance of bioactive IAA levels were required a balance of synthesis, storage, degradation, transport, and modification. SA was playing a critical role in plant responses to biotrophic pathogens, and SA synthesis required chorismate amino acid as the processor. Hanafy, Khalil., Ei-Rahman *et al.*(2012) showed the relations between the IAA synthesis processor tryptophane, Zn trace element and IAA levels once more at field studies on orange trees. As pointed out by them, plants were undergoing several physiological and biochemical changes in response to stress, such as changes in relative water content, photosynthesis, metabolism of carbohydrates, proteins, amino acids and enzyme activity.

Hassan, Aamer, Chattha *el al.* (2020) reviewed the effects of drought stress on plant physiological and biochemical processes, also affecting stomatal conductance, which was increasing leaf temperature, decreasing plant growth, development and crop productivity. They mentioned the changes in membrane permeability, nutrient uptake and chlorophyll and assimilation. They added that there were some management approaches that could provide quick solutions to this problem, such as understanding the role of nutrition on drought tolerance, and exemplify the role of zinc, although they said its role in plant growth and development under normal conditions was well understood, conversely its role in drought tolerance was poorly understood. Zn was an important component of carbonic anhydrase and a stimulator of aldolase, which were involved in carbon metabolism, an integral component of several biomolecules such as lipids, proteins and co-factor of auxins; therefore, it was playing an important role in plant nucleic acid metabolism. However, there was lack of information regarding Zn-induced mechanisms conferring drought tolerance in plants. Therefore, they said the review would address different effects of drought stress on plants and show the pending research gaps in plant physiological, biochemical and molecular aspects and Zn cross talk with other molecules in Zn-induced drought stress tolerance. They also supported the literature claiming that the hormones were playing a role of paramount relevance in regulating several plant processes and ABA was the most prominent plant hormone in response to water deficit conditions. They added that it was primarily synthesized in the vascular system, and transported to the target tissues by xylem and phloem, permitting bi-directional transport between roots and shoots.

However, Hassan, *et al.* (2020) said, under drought stress, pH was significantly increasing in the apoplast, and ceasing ABA translocation. ABA was known to serve as a root-to-shoot signal reducing transpiration by inducing embryogenesis abundant (LEA) proteins accumulation and consequent plant adaptation to drought. So, this decrease in ABA translocation was accompanied by a rapid reduction of cytokinin and gibberellin levels; as cytokinins were delaying leaf senescence, and improving plant resilience under drought stress, this development was meaning a loss in resilience against drought stress. They added that plants were accumulating various substances including proteins and amino acids in response to drought stress, and altering, generally decreasing the amount of proteins; increasing the accumulation of osmolytes as proline by increasing its synthesis or by reducing the activities of degrading enzymes. Its and other osmolytes accumulation were reducing cell water potential, and increasing WUE, and protection of delicate cell components from oxidative stres. Proline biosynthesis was playing a vital role in the energy balance between chloroplasts and mitochondria; in conclusion, they said drought was disrupting various physiological, biochemical and molecular processes determining reductions in growth, yield and quality. Zinc availability, uptake and transport mechanisms were one group of the key parameters involved in the related developments in adaptation and acclimation success of plants, which were reviewed thoroughly in the comprehensive review article by Hassan, *el al.* (2020).
Plants possessing the ability to acquire and retain more water have high WUE, and can withstand drought conditions better than the others; however, response of plants to drought stress largely depended on the severity of drought, as well as the growth stage of plant, according to Medrano, Tomas, Flexas *et al.* (2015). They drew attention to the measurement of WUE at leaves by portable instruments measuring leaf gas exchange rates and displaying the values related with photosynthesis and transpiration, which might or not reflect the daily integrals or whole plant status. They considered the results of the tests on grapevines were showing the worse part of the discrepancy, and the lowest correlations found in midday measurements, when the water stress was reaching a peak. So, they sought to evaluate the importance of spatial and temporal variation in carbon and water balances at the leaf and plant levels. The results showed them that the position of the leaves, that were governing average light interception in the canopy, showed a marked effect on instantaneous and daily integrals of leaf WUE. They also evaluated night transpiration and respiration rates and contribution of respiration values to total carbon balance. This approach enabled them to identify two main components, which were removing the discrepancy between leaf and whole plant WUE affecting daily carbon gain and water loss, and leading to the large flux of carbon losses by dark respiration. Their practically very important conclusion was the need to revise the WUE evaluations among genotypes or treatments.

As Silva, Nogueira & Silva (2010) also mentioned, under drought conditions nutrient uptake was impaired as a result of reduced soil moisture, which was leading to decrease in the soil nutrient availability and translocation from roots to the shoots and leaves; decrease in transpiration rate created an imbalance in active transport and membrane permeability. They added that the inevitable changes in different physiological processes needed to be understood as much as possible, in order to develop better management strategies to cope with drought stress and consequent nutrient deficiency.

As all of the stresses, plant response to water stress is known to depend mainly on the severity and duration of the stress and the growth stage of the plant, but its management is closely related with the physical and chemical properties of the soil (Geng, Yan, Zhang, *et al.*, 2015). Their approach to address the question was different, they designed experiments with maize to identify changing tendencies of microbial biomass carbon content and the proportion of microbial biomass carbon in soil organic carbon under different drought conditions by measuring the content of microbial biomass carbon. They collected soil samples about 10 cm far away from the rhizosphere of the maize, and measured microbial carbon quantities to identify effects of extreme drought on agriculture soil ecosystem. They showed that the optimum mass water content of soil for microbial biomass carbon was 19.5 %, and the demarcation point of microbial biomass carbon to drought was 14.3 %, which could be used to demonstrate alters and degradation of soil ecosystem and the irrigation requirement of crops. The researchers also evaluated sustainability of different drought soil ecosystems after rainstorm with rehabilitation, and found that soil ecosystem could recover after interfered by moderate drought; its tolerance to drought, in terms of its function and activity were also improved. They added that soil systems could not adapt to severe drought stress, could barely recover and restore from extreme drought within a few days with their damaged function and structure. Their conclusion was related with the mass water content of soil, it should be kept above 10 % to maintain soil system function and structure, and these soil ecosystem should be watered when mass water content was lower than 14.3 %, which provided reference for improving the soil to increase the grain output. Actually similar decrease in soil fertility is known to occur following erosion, eroded and transferred soils lose their fertility to some extent (Zhao, Shao, Omran *et al*., 2011).

It must be mentioned here that, optimization of such plant-soil-water-nutrition relations at field conditions is not as easy as it seems; as a matter of fact, Fahad, Bajwa , Nazir *et al.* (2017) provided a detailed account of plant responses to heat and drought stresses with special focus on highlighting the number of commonalities and differences in their review article. They also attracted attention to the level of the complexity involved, and stated that only a holistic approach taking the different management options into account could deal with heat and drought stress simultaneously could offer a win-win approach in future. Their aim was described as covering conventional and modern management strategies, and presenting a critical discussion on salient responses to them. They referred to a study presenting the analysis of the global data covering studies published from 1980 to 2015, which showed up to 21% wheat and 40% yield loss in maize due to drought, and another report showing that global wheat production was simulated to decline by 6% for each ^{o}C rise in average temperature. They added that, in spite of the expectation of increase in crop production in some cooler regions overall impact of increasing temperatures on global food security would still be negative, and the severity of the damage was generally unpredictable, because of the complexity. But, earlier studies they referred showed them that impaired radiation use efficiency and decreased harvest index were the major yield reducing factors under limited supply of soil moisture. They also mentioned some earlier reports showing oxidative damages in addition to damages to protein metabolism and enzyme activities and cell membranes.

Fahad *et al.* (2017) added that the yield to be obtained was basically depending on the complex integration of different physiological processes, which were mostly affected negatively by drought stress. As known, and mentioned by them, the negative impacts of drought on the yield mainly depended upon the severity of the stress and the plant growth stage; drought at the pre-anthesis stage would shorten the time to anthesis, but after anthesis it would reduce the period of grain filling in cereals. So, they included evaluation of some studies on the enzymatic control of grain filling in cereals, which showed the role of four major enzymes; decreases in their activities under the drought conditions were leading to losses in the yield of major cereals. Another reference cited in their article was reporting that exposure to drought stress at the flowering stage was leading to complete sterility due to disturbed assimilate supply to the developing ear. The seed filling could be accelerated and would lead to poor quality and reduced yield. In short, the outcome was poor germination and stand establishment, scorching of the twigs and leaves with sunburn and senescence, floret sterility inhibited fruit growth. Depending on the development stage of cereals, adverse effects would vary with the timing, duration, and sternness of the heat stress. Inside a floret, anthers, and pollens were more susceptible to high temperature than ovules, and at ≥30°C could lead to reduction in the growth and net assimilation rate, consequent low biomass accumulation along with early leaf senescence.

Fahad *et al.* (2017) also presented some data on the drought induced reduction in the yields of some major field crops, and added that drought and heat stress were definitely causing significant reductions in growth. The extent of the damages were depending on growth stage and severity of the stress; generally higher sensitivity of reproductive phase was causing a substantial reduction in the yield. Drought stress was disturbing certain parameters including the leaf water potential (LWP), leaf and canopy temperature, transpiration rate, and especially stomatal conductance; low stomatal conductance was leading to increased the leaf and canopy temperature and WUE. Actually, as Reddy (2019) pointed out leaf water potential (LWP) was known as the indication of the whole plant water status, and maintenance of LWP at high values was found to be associated with dehydration avoidance mechanisms; so, Reddy suggested that its levels might be used as an easy and fast way to screen sorghum genotypes for drought avoidance.

Fahad *et al.*2017 also exemplified the importance of this parameter by referring to a report which indicated that higher WUE of drought resistance of wheat cv.s was mainly due to the decreased accumulation of the dry matter by the lower rate of transpiration through stomata. They added that this also greatly impacted the nutrient relations of the plants; since nutrients including N, Si, Mg, and Ca uptake was performed by diffusion and mass flow. They referred to another study showing that plants were trying to adapt by increasing the length and surface area of roots, changing their architecture into capturing such less mobile nutrients. Another study they referred was on the reduction of less mobile nutrients such as P at soil moisture deficit times by reducing growth of the roots. Although they did not mention in their excellent review, any retardation of root growth would lead to decrease in the synthesis and upward translocation of cytokinin hormones, which took part in regulating a variety of biological processes implicated in plant development and stress responses (Liu, Zhao & Zhang, 2019). As they put it, cytokinins (CKs) were mobile adenine derivatives, acting as chemical signals regulating a variety of biological processes implicated in plant development and stress responses by a complicated intracellular traffic, intercellular movement, and in short- and long-distance translocation. They were also serving as hormonal signals functioning in processes such as cell division and differentiation, seed germination, apical dominance, leaf senescence, root growth, branching and nodulation, nutrient homeostasis, and stress responses. The researchers referred to a study which showed that CKs were synthesized in different cell types in both roots and shoots, and cross-talk with other phytohormones, particularly auxins, to regulate plant growth and development. This hormone group were also acting as chemical signals mediating both local and long-distance communications, and were transported between neighbour cells or translocated as acropetal and basipetal messengers in long distance between roots and shoots.

Ahmad, Jaleel, Salem, *et al.(*2010) reviewed another aspect of physiological developments related with abiotic stresses, changes in enzymatic and nonenzymatic antioxidants and their roles in adaptation and resistance. Reactive oxygen species (ROS) were produced in plants as byproducts even by photosynthesis and respiration processes, and their accumulation could lead to oxidative stress by creating an imbalance between the production of ROS and antioxidant defense. As ROS caused rapid cell damage by triggering a chain reaction, they add, cells were evolving enzymatic and nonenzymatic antioxidants to scavenge the indigenously generated ROS. Ahmad *et al.*(2010) reviewed the studies that reported the results obtained by manipulating various enzymes in order to study the role of the antioxidant systems. They covered enhancement of changes in environmental stress tolerance by over expressed or downregulated enzymatic and nonenzymatic antioxidants and also topics such as signaling performances of ROS, redox, Ca, growth and transpiration inhibitor ABA.

The primary effects of abiotic stress was defined by them as ion imbalance and hyperosmotic stresses leading to a cascade of the molecular network activating stress responsive mechanisms to re-establish homeostasis and to protect and repair damaged proteins and membranes, by turning a number of genes. It can be added here that, hormones trigger a series of biochemical and physiological changes in different organs and tissues,by changing composition of active genes, enzyme concentrations and activities or their activators and inhibitors.

Ahmad *et al.* also referred to the studies evidenting the transfer of electrons at a high-energy to molecular oxygen (O_2) to form ROS, such as singlet oxygen ($^1O_2$), superoxide ions (O_2-) and peroxides (O_2^{2-}). They mentioned that ROS targets were high-molecular mass molecules, such as membrane lipids or mitochondrial DNA, or nucleotide peroxides, especially at the level of thymine. So, they referred to a study showing that ROS could induce damage to
almost all macromolecules, and mitochondrial DNA was more sensitive than nuclear one. They added that, in stress conditions ROS concentration was elevating to damaging levels in chloroplasts, mitochondria, and peroxisomes, limitation of CO_2 fixation in turn decrease oxidized NADP+, which serves as an electron acceptor in photosynthesis. This limitation wass leading to overreduction of ferrodoxin during photosynthetic electron transfer, and capture of the electrons by O_2 to form superoxide radicals (O_2-), which were triggering chain reactions generating more aggressive oxygen radicals, their accumulation to lipid peroxidation, ultimately membrane deterioration and cell death. They referred to studies that showed H_2O_2 production in peroxisomes during photorespiration and the polyunsaturated fatty acids (PUFAs) were the major ones in the plant cell membranes that were particularly susceptible to

attack giving rise to complex mixtures of lipid hydroperoxides. Extensive PUFA peroxidation was decreasing the fluidity of the membrane, increasing leakiness, and caused a secondary damage to membrane proteins; there were studies indicating that DNA could also be modified by ROS in many different ways, HO- was the most reactive, damages of $_{mt}$DNA and $_{n}$DNA were not completely random, as mutation clusters at hot spots, and indirect modifications of DNA had been observed. Oxidative DNA modifications, which had also evidented, could lead to changes in methylation of cytosines, which were important for regulating gene expression. Protein oxidation induction by ROS or byproducts was a widespread phenomenon and often used as a diagnostic marker for oxidative stress, since ROS were predominantly implicated in causing cell damage and playing a major physiological role in intracellular signaling and regulation, and interfering with the expression of a number of genes and signal transduction pathways as reported in earlier studies referred by Ahmad *et al*. All of the toxic effects of ROS were counteracted by enzymatic and nonenzymatic antioxidative system such as: superoxide dismutase (SOD), catalase (CAT), ascorbate peroxidase (APX), glutathione reductase (GR), ascorbic acid (AsA), tocopherol, glutathione and phenolic compounds etc. which were contained in groups in each of cellular compartments.

Boivin, Fonouni-Farde & Frugier (2010) drew attention to another related and important topic in their review article titled “How Auxin and Cytokinin Phytohormones Modulate Root Microbe Interactions”. As, they said, large range of microorganisms could associate with plants, and make neutral, friendly or hostile interactions; the ability of plants to recognize compatible and incompatible microorganisms, to limit or promote their colonization was crucial for their survival, and elaborated communication networks were determinants in this association. Phytohormones were modulating the associations and coordinating cellular and metabolic responses associated to the progression of microorganisms across different plant tissues. They reviewed hormonal regulations by focusing on auxins and cytokinins, considering their involvement in the symbiotic or pathogenic interactions between roots and soil bacteria and fungi associations, to highlight similarities and differences in cytokinin/auxin functions amongst various compatible versus incompatible ones. It may be meaningful to add only some points to their valuable contributions here; as mentioned above by referring to several studies, roles of some other hormones and inhibitors also deserve to be studied in future.

3.CONCLUSION

As mentioned in the first part of the review, and supporting references presented also in this article, several researchers have found it relevant to stress the need to integral approaches to the problem imposed by climate change and its effects on agricultural production. Although some technological advancements offer some effective solutions to the existing problems, they need considerable capital investments, increased in operational costs that cannot be defrayed by the farmers of many countries. Insufficiency of necessary infrastructure and/or qualified human power may be the reason of impracticability and frustration of purpose. As put forward and discussed by FAO in the publication titled “Putting Farmers at the Center to achieve the Sustainable Development Goals – SDGs” rural poverty was a major problem (FAO). Almost 80 percent of the world’s poor and food insecure were living in rural areas, mostly depending on agricultural production for their subsistence, most of the rural poor were small-scale family food producers, who were depending on agriculture and aquaculture for their food and income but were facing many difficulties accessing productive resources, opportunities and markets. There were more than 600 million farms and more than 90 percent of farms were running by an individual or a family who were relying primarily on family labor, occupying around 70–80 percent of farmland and producing more than 80 percent of the world's food in value terms.

Considering these bitter facts, some methods, techniques must be developed and presented to agricultural production sector, which are affordable and profitable for more of the people producing food for themselves and consumers. As known, there are industries using various plant products as raw materials. In the third coming part of the article, an attempt will be made to review some prospective approaches which are fitting in this framework.

References

AFCD (2014) Biodiversity Strategy and Action Plan (BSAP) Awareness, Mainstreaming and Sustainability Working Group Traditional Knowledge Focus Group-Final Report (English Summary) https://www.afcd.gov.hk/english/conservation/Con_hkbsap/bsap_links_to_resources/files/Final_Report_Traditional_Knowledge_FG_eng_summary.pdf *Accessed 6 Nov. 2020*

Ahanger, M. A., Morad-Talab, N., Abd-Allah, E.F. *et al.* (2016) Plant growth under drought stress: Significance of mineral nutrients. In: Ahmad, P. (Ed.)*Water Stress and Crop Plants: A Sustainable Approach, Vol. 2. Ch. 37, pp. 649-668*. John Wiley & Sons, Ltd. DOI - 10.1002/9781119054450.ch37 https://www.researchgate.net/publication/304479896

Ahmad, P., Jaleel, C. A. Salem, M. A.*et al*.(2010) Roles of enzymatic and nonenzymatic antioxidants in plants during abiotic stres. *Critical Reviews in Biotechnology*, 30: 161–175. ISSN 1549-7801 online. DOI: 10.3109/07388550903524243

Allan, J. D. & Castillo, M. M. Ed.s (2007) *Primary Producers.* In: Stream Ecology. Springer, Dordrecht. https://doi.org/10.1007/978-1-4020-5583-6 https://link.springer.com/chapter/10.1007%2F978-1-4020-5583-6_6

Anjum, S. A. , Xie, X., Wang, L. et al.(2011) Morphological, physiological and biochemical responses of plants to drought stres. *African Journal of Agricultural Research Vol. 6, pp. 2026-2032.* DOI: 10.5897/AJAR10.027 ISSN 1991-637X, http://www.academicjournals.org/AJAR

Barrangou, R. (2015) The roles of CRISPR-Cas systems in adaptive immunity and beyond. *Current Opinion in Immunology*. 32: 36–41. doi:10. 1016/j.coi.2014.12.008. PMID 25574773.

Biagianti-Risbourg, S., Paris-Palacios, S., Mouneyrac C., et al. (2013) *Pollution Acclimation, Adaptation, Resistance, and Tolerance in Ecotoxicology.* In: Férard J. F. & Blaise C. (eds) Encyclopedia of Aquatic Ecotoxicology. Springer, Dordrecht https://doi.org/10.1007/978-94-007-5704-2_81

Boivin, S., Fonouni-Farde, C. & Frugier, F. (2010) How Auxin and Cytokinin Phytohormones Modulate Root Microbe Interactions. *Frontiers in Plant Sci.* https://doi.org/10.3389/fpls.2016.01240 https://www.frontiersin.org/articles/10.3389/fpls.2016.01240/full

Bouchie, A. (2002) Organic farmers sue GMO producers. *Nature Biotechnology.20:210, Business &Regulatory News.* https://www.nature.com/articles/nbt0302-210.pdf

Cai, Y., Chen, L., Liu, X. et al. (2017) CRISPR/Cas9-mediated targeted mutagenesis of *GmFT2a* delays flowering time in soya bean. *Plant Biotechnology Jour.* https://doi.org/10.1111/pbi.12758 https://onlinelibrary.wiley.com/doi/full/10.1111/pbi.12758

Cohen, J.(2020) The latest round in the CRISPR patent battle has an apparent victor, but the fight continues https://www.sciencemag.org/news/2020/09/latest-round-crispr-patent-battle-has-apparent-victor-fight-continues *Accessed 6 Nov. 2020*

Copaciu, F. O. Opriş, Ü. Niinemets, *et al.* (2016) Toxic influence of key organic soil pollutants on the total flavonoid content in wheat leaves. *Water Air Soil Pollut. ; 227: 196.* doi:10.1007/s11270-016-2888-x www.ncbi.nlm.nih.gov› pmc › articles › PMC5788277

Dubey, A., Kumar, A. & Khan, M. A. (2020) *Biology and Physiological Responses to Environmental Stresses* In: Hasanuzzaman, M., Araújo, S & Gill, S. S. (Eds.) The Plant Family Fabaceae, https://doi.org/10.1007/978-981-15-4752-2 ; https://link.springer.com/book/10.1007/978-981-15-4752-2

Duque, A. S., Almeida, A. M, Silva, A. B. et al. (2013) *Abiotic Stress Responses in Plants: Unraveling the Complexity of Genes and Networks to Survive*. In "Abiotic Stress" Vahdati, K. & Leslie, C. Eds. Plant Responses and Applications in Agriculture. http://dx.doi.org/10.5772/52779. https://www.intechopen.com/books/abiotic-stress-plant-responses-and-applications-in-agriculture/abiotic-stress-responses-in-plants-unraveling-the-complexity-of-genes-and-networks-to-survive

Fahad, S., Bajwa A. A., Nazir, U. et al. (2017) Crop Production under Drought and Heat Stress: Plant Responses and Management Options. *Front. Plant Sci.*, https://doi.org/10.3389/fpls.2017.01147, www.academia.edu› Crop_Production_under_Drought_and Heat Stress: Plant Responses and Mana gement Options.

FAO – Food and Agriculture Organization. Putting Farmers at the Center to achieve the Sustainable.Development.Goals– SDGs. FAO http://www.fao.org/3/ca4532en/CA4532EN.pdf

Feller, U & Vaseva, I (2014) *Frontiers in Environmental Science/Agroecology and Land Use Systems, 2: 1-17* doi: 10.3389/fenvs.2014.00039

Frankfield, J. (2020) Artificial Intelligence (AI). Investopedia. https://www.investopedia.com/terms/a/artificial-intelligence-ai.asp. *Accessed 6 November 2020*

Geng, S., Yan, D., Zhang, T. *et al.*(2015). Effects of drought stress on agriculture soil. Natural Hazards 75. doi 10.1007/s11069-014-1409-8. https://www.researchgate.net/publication/269577984_Effects_of_drought_stress_on_agriculture_soil

Hac-Wydro and Flasinski (2015) The studies on the toxicity mechanism of environmentally hazardous natural (IAA) and synthetic (NAA) auxin – The experiments on model Arabidopsis thaliana and rat liver plasma membranes. *Colloids and surfaces B: Biointerfaces 130.* DOI: 10.1016/j.colsurfb.2015.03.064

Hanafy A., Khalil, M.K., Ei-Rahman, A.M. *et al.* (2012) Effect of zinc, tryptophan and indole acetic acid on growth, yield and chemical composition of Valencia orange trees. *Journal of Applied Sciences Research. 8. 901-914*. ISSN 1819-544X https://www.researchgate.net/publicatio/287466965

Hasnain, Z.; Bakhsh, I; Hussain, A. et al. (2020) Naphthalene Acetic Acid and Irrigation Regimes Influence Paddy Yield and its Economics under Arid Conditions. *Planta daninha 38. On-line version* ISSN.1806-9681 http://orcid.org/0000-0001-7089-5784;.https://doi.org/10.1590/s0100-3582020380100007

Hassan, M. U., Aamer, M., Chattha, M., U. *el al.* (2020) The Critical Role of Zinc in Plants Facing the Drought Stress. *Agriculture, 10, 0396*; doi:10.3390/agriculture10090396 www.mdpi.com/journal/agriculture

Huang, S., Yang, J., Fong, S. et al. (2020) Artificial intelligence in cancer diagnosis and prognosis: Opportunities and challenges. Cancer Letters, 471; 61-71. https://doi.org/10.1016/j.canlet.2019.12.007 https://www.sciencedirect.com/science/article/pii/S0304383519306135

IAEA – International Atomic Energy Agency (2020) *Smart farming Technologies.* https://www.iaea.org/topics/development-of-smart-agricultural-practices *Accessed 7 November 2020*

ICID (2020) International Commission on Irrigation & Drainage. *Second Green Revolution.* https://www.icid.org/second_g_revolution.html *Accessed 7 November 2020*

IPOGEA (2017) Research Center on Local and Traditional Knowledge, *Curriculum and Methodology* https://www.ipogea.org/wp-content/uploads/2017/06/curriculum-ipogea-bassa-2.pdf *Accessed 7 November 2020*

IoT for All. Smart Farming. *The Future of Agriculture* (2020) https://www.iotforall.com/smart-farming-future-of-agriculture/ *Accessed 7 November 2020*

Isabella, S. (2016) Chemotherapeutic effect of 3, 3′-Diindolylmethane encapsulated chitosan nanoparticles on 7, 12-Dimethylbenz (a) anthracene induced mammary cancer – A dose dependent study. *New Horizons in Translational Medicine*. *3: pp. 1-8.* https://doi.org/10.1016/j.nhtm.2016.04.001

Jalil, S. U. & Ansari, M. I. (2020) Stress Implications and Crop Productivity. *Pp. 74-82.* In: Plant Ecophysiology and Adaptation under Climate Change: Mechanisms and Perspectives Vol. I.; H., Mirza (Ed.) ISBN 978-981-15-2156-0. https://www.springer.com/gp/book/9789811521553

Kloppers, R. (2020) In South Africa, the Gumbi have not only conserved essential biodiversity but created plenty of jobs in the process. https://africanarguments.org/2020/07/22/a-small-indigenous-group-offers-an-example-of-how-to-save-the-world *Accessed 7 November 2020*

Leff, J. W., Bardgett,R. D., Wilkinson, A. et al. (2018) Predicting the structure of soil communities from plant community taxonomy, phylogeny, and traits. *The ISME Journal 12(7)* DOI:10.1038/s41396-018-0089-x https://www.researchgate.net/publication/323664571

Liu, C-J., Zhao,Y. & Zhang, K.(2019) Cytokinin Transporters: Multisite Players in Cytokinin Homeostasis and Signal Distribution. *Front Plant Sci. 2019; 10: 693.* doi:10.3389/fpls.2019.00693 PMCID:PMC 6555093, PMID: 31214217

Lo, P. (2013) Monsanto Bullies Small Farmers Over Planting Harvested GMO Seeds. Corpwatch. https://corpwatch.org/article/monsanto-bullies-small-farmers-over-planting-harvested-gmo-seeds *Accessed 7 November 2020*

Maruthanila, V. L., Poornima, J. & Mirunalini, S. (2014) Attenuation of Carcinogenesis and the Mechanism Underlying by the Influence of Indole-3-carbinol and Its Metabolite 3,3'-Diindolylmethane: A Therapeutic Marvel . *Adv. Pharmacol. Sci. 832161.* doi: 10.1155/2014/832161

Martin-Guay, M. , Paquette, A., Dupras, J, et al. (2017) The new Green Revolution: Sustainable Intensification of Agriculture by Intercropping. *Science of the Total Environment, 615, 767–772.* https://doi.org/10.1016/j.scitotenv.2017.10.024 0048-9697

Medrano, H., Tomas, S., Flexas, E. H. *et al.* (2015) From leaf to whole-plant water use efficiency (WUE) in complex canopies: Limitations of leaf WUE as a selection target. *The Crop Journal 3: 220-228.* https://doi.org/10.1016/j.cj.2015.04.002

Merriam-Webster. Meta-analysis. Definition of Meta-analysis by Merriam-Webster. www.merriam-webster.com ›dictionary › meta-analysis *Accessed 7 November 2020*

Meli, P., Rey-Benayas, J.M. & Brancalion, P. H. S. (2019) Balancing land sharing and sparing approaches to promote forest and landscape restoration in agricultural landscapes: Land approaches for forest landscape restoration. *Perspectives in Ecology and Conservation. 17, 201-205.* https://doi.org/10.1016/j.pecon.2019.09.002;https://www.sciencedirect.com/science/article/pii/S2530064419300100

Muhanta, R. K. (2009) Norman Borlaug and Green Revolution. *Agriculture Today, Dec. 56-57* https://www.researchgate.net/publication/275019368_Norman_Borlaug_and_Green_Revolution

Nelson, G. C., Valin, H., Sands, R. D. et al.(2014) Climate change effects on agriculture: Economic responses to biophysical shocks. *Proceedings of National Academy of Sciences (PNAS) 111: 3274–3279* www.pnas.org/cgi/doi/10.1073/pnas.1222465110

Netting, A.G. (2000) pH, abscisic acid and the integration of metabolism in plants under stressed and non-stressed conditions: cellular responses to stress and their implication for plant water relations. *Journal of Experimental Botany*, 51: 147–158, https://doi.org/10.1093/jexbot/51.343.147 https://academic.oup.com/jxb/article/51/343/147/481122

Pal, C., Dey,C., Kumar, S. et al. (2007) Eco-friendly synthesis and study of new plant growth promoters: 3,3'-Diindolylmethane and its derivatives. *Bioorg Med Chem Lett. 17: 4924-8*. doi: 10.1016/j.bmcl.2007.06.025. PMID: 17583501. https://pubmed.ncbi.nlm.nih.gov/17583501/

Papazian, S. & Blande, J. D. (2018) Dynamics of plant responses to combinations of air pollutants. *Plant Biology,22:* 68-83. https://doi.org/10.1111/plb.12953
https://onlinelibrary.wiley.com/doi/abs/10.1111/plb.12953

Peschard, K. E. (2019) Monsanto wins $7.7b lawsuit in Brazil – but farmers' fight to stop its 'amoral' royalty system will continue. https://theconversation.com/monsanto-wins-7-7b-lawsuit-in-brazil-but-farmers-fight-to-stop-its-amoral-royalty-system-will-continue-125471

Raza, E., Ashraf, F. Zou, X. et al. (2020) *Plant Adaptation and Tolerance to Environmental Stresses: Mechanisms and Perspectives.* In: Plant Ecophysiology and Adaptation under Climate Change: Mechanisms and Perspectives Vol. I.; pp. 118-136. H., Mirza (Ed.) ISBN 978-981-15-2156-0. https://www.springer.com/gp/book/9789811521553

Reddy, P. S. (2019) *Breeding for Abiotic Stress Resistance in Sorghum.* In: Breeding Sorghum for Diverse End Uses, In: Eds. Aruna, C., Visarada, K. B. R. S. & Tonapi, V. A., Woodhead Publishing Series in Food Science, Technology and Nutrition. Pages 325-340
https://doi.org/10.1016/B978-0-08-101879-8.00020-6
https://www.sciencedirect.com/science/article/pii/B9780081018798000206

Salazar, C., Hernández C., Pino, M. T. (2015) Plant water stress: Associations between ethylene and abscisic acid response. *Chilean J. Agric..Res. 75 supl.1Chillán ago. Versión.On-line. ISSN 0718-5839* http://dx.doi.org/10.4067/S0718-58392015000300008

Sett, R. (2017) Responses in plants exposed to dust pollution. *Horticult. Internat. Jour. 1: 53-56.*
https://medcraveonline.com/HIJ/responses-in-plants-exposed-to-dust-pollution.html
DOI:10.15406/hij.2017.01.00010

Shaikh, Z. A. (2017) Towards Sustainable Development: A Review of Green Technologies. Tr. Ren. Energy, 4, 1-14. DOI: 10.17737/tre.2018.4.1.0044 https://www.researchgate.net/publication/321437473.

Shifeng L., Yanming S., Xiao M.,et al. (2014) Simultaneous Intercalation of 1-Naphthylacetic Acid and Indole-3-butyric Acid into Layered Double Hydroxides and Controlled Release Properties. *Journal of Nanomaterials, Article ID 862491, 9 pages.* https://www.hindawi.com/journals/jnm/2014/862491; https://doi.org/10.1155/2014/862491

Shone, M.G.T. & Flott, A. V. (1983) Effects of Periods of Localized Water Stress on Subsequent Nutrient Uptake by Barley Roots and Their Adaptation by Osmotic Adjustment. *New Phytologist, 94: 561-572.* nph.onlinelibrary.wiley.com › j.1469-8137.1983.tb04865.x

Silva, I. C., Nogueira, R. J. M. C., Silva, M.A. (2010) *Drought Stress and Plant Nutrition.* In Plant Science Books, pp. 32-39. Global Science Books. http://www.globalsciencebooks.info
https://www.researchgate.net/publication/209959355_Drought_Stress_and_Plant_Nutrition

Stepanova, A. N., Yun, J., Likhacheva, A. V. *et al.* (2007) Multilevel Interactions between Ethylene and Auxin in Arabidopsis Roots. *The Plant Cell, Vol. 19: 2169–2185,* www.plantcell.org. American Society of Plant Biologists. DOI: https://doi.org/10.1105/tpc.107.052068

Surowka, E., Rapacs, M. & Janowiak, F. (2020) *Climate Change Influences the Interactive Effects of Simultaneous Impact of Abiotic and Biotic Stresses on Plants. Pp. 1-50.* In: Plant Ecophysiology and Adaptation under Climate Change: Mechanisms and Perspectives Vol. I.; H., Mirza (Ed.) ISBN 978-981-15-2156-0. https://www.springer.com/gp/book/9789811521553

Talaviya, T., Shah, D., Patel, N. *et al.* (2020) Implementation of artificial intelligence in agriculture for optimisation of irrigation and application of pesticides and herbicides. *Artificial Intelligence in Agriculture,.4:58-73.*https://doi.org/10.1016/j.aiia.2020.04.002
https://www.sciencedirect.com/science/article/pii/S258972172030012X

Taylor, P (2016) Silent Spring' Triggered an Environmental Movement. *Permaculture News of Permaculture Res. Institute 06, 20.* https://www.permaculturenews.org/2016/06/20/silent-spring-environmental-movement *Accessed 7 November 2020*

Ullah, A., Manghwar, H. Shaban, M. (2018) Phytohormones enhanced drought tolerance in plants: a coping strategy. *Environmental.Science.and.Pollution.Research 25: 33103–33118.* https://doi.org/10.1007/s11356-018-3364-5 ; https://link.springer.com/article/10.1007/s11356-018-3364-5

UNCCD Agenda 21 Chapter 12.pdf - United Nations (2017) https://www.unccd.int/sites/default/files/relevant-links/2017-06/UNCCD_Agenda21Chapter12_0.pdf *Accessed 7 November 2020*

U.S. EPA (2004) Reregistration Eligibility Decision (RED) Naphtaleneacetic Acid, Its Salts, Ester, and Acetamide. Prevention, Pesticides and Toxic Substance (7508C) *EPA 738-R-04-07016*. https://www3.epa.gov/pesticides/chem_search/reg_actions/reregistration/red_G-91_26-May-04.pdf

Van Overbeek, J. (1956) Absorption and Translocation of Plant Regulators. *Annual Review of Plant Physiology, 7: 355-72.* https://www.annualreviews.org/doi/abs/10.1146/annurev.pp.07.060156.002035

Westfall, C. S., Muehler, A. M., Jez, J. M. (2013) Enzyme Action in the Regulation of Plant Hormone Responses. *Journal Biological Chemistry 288: 19304–19311*. doi: 10.1074/jbc.R113.475160 *www.ncbi.nlm.nih.gov*› pmc › articles › PMC3707634

Woo, H., R., Masclaux-Daubresse, C. & Lim, P. O. (2018). Plant senescence: how plants know when and how to die. *Journal of Experimental Botany*, 69: 715–718, https://doi.org/10.1093/jxb/ery011 https://academic.oup.com/jxb/article/69/4/715/4851198

Zhao, P., Shao, M. A., Omran, W. *et al.*, (2011) Effects of erosion and deposition on particle size distribution of deposited farmland soils on the chinese loess plateau. Rev. Bras. Ciênc. Solo 35 . *On-line version ISSN 1806-9657* http://dx.doi.org/10.1590/S0100-06832011000600028