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

III. Some Beneficial Practices and Their Prospective and Additive Potentials

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Abstract

As it is very well known, and mentioned in the previous articles of the present author, vast majority of billions of plant propagators have limited power of interference and control of the complex factors affecting crop productivity at natural conditions, especially under the pressure of cost-profit ratio and environmental concerns at the global warming era.

Here it will be attempted to review some locally proven promising performances of some practices and their potentials in terms of productivity and water use efficiency (WUE) within the framework of sustainable agriculture at changing climatic and environmental conditions. The aim here is attracting attention to the higher potential of integrating some of them for higher water economy and productivity.

Considering the considerable differences in popularity of practices in different countries, regions, academical and practice oriented literature showing the time lost for the reflection of academic advancements to practice, or neglecting them for some reasons in spite of the tremendously increased worldwide communication possibilities, it will be attempted to attract attention to the possible benefits of using meta-analytical approaches to the challenging complicated problems related with global warming stimulated climate changes.

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

Introduction

Feller & Vaseva (2014) reviewed the literature on the impacts of drought and high temperature on physiological processes in agronomically important plants, considering the predictions made by climate models for the present and the next decades, which were indicating more frequent and more severe extreme events, such as heat waves, severe and extended drought periods, and flooding in many regions. Actually, as known well and also recently reported by Kim, Iizumi & Nishimori (2019), such impacts of global warming started to affect agricultural production in many regions in earlier decades. The relationship of global warming and increase in wildfires at the termination of ice age has long been known, as Pyne (2020) described as “From Pleistocene to Pyrocene: Fire Replaces Ice” in the title of his article on the history of anthropogenic wildfires.

National Drought Mitigation Center (NDMC) of U.S., which is recently operating at University of Nebraska, issued a text titled “Why Plan For Drought?” (NDMC, 2021), providing justification for the necessity of a plan as avoiding unpleasant surprises and enjoy the benefits of normal or rainy years. They reminded that the center had been commissioned the artwork in the late 1990s to show how drought, as a slow-moving natural disaster, tending to emerge and intensify. It is added that The Federal Emergency Management Agency (FEMA) had estimated in 1995 that drought was costing the U. S. an average of $6 to 8 billion a year. The NDMC had assembled a list of “Billion Dollar Weather Disasters” since 1980, and the 90 incidents listed till 2008, 14 of them were drought and wildfire. Drought in 1980, for instance costed $55.4 billion loss, caused about 10,000 heat-related deaths; in 1988, the loss was $71.2 billion with about 7,500 heat-related deaths. It was said that FEMA was calculating the benefits of mitigation, taking precautinary steps to prevent known impacts from a natural disaster was saving $4 for every $1 expended, which is clearly more efficient and effective than taking measures in crisis mode. It was added that after-the-fact assistance to farmers was expensive and might not reach to the right people. Ultimately, costs were spread more widely to other parts of the food system, taxpayers and consumers; in developing countries, droghts were leading to social and economical problems. Growing populations in areas that were dependent on regular rains, were contributing to vulnerability to drought. Plans that were prepared in wet years, decades might be built in part on unrealistic expectations of water supply. As urban water supplies in some areas were strained, recognition of the need to balance environmental, urban, agricultural water use, protection of fish stocks and aqueous wildlife were increasing.

NDMC drew attention to the need of conducting drought planning at all levels of decision-making authorities over water, agriculture, environment and natural resources, health, water suppliers and municipalities. Farmers, ranchers, and others whose livelihoods depending on regular rain should also know their options and have plans. It was also added that people were tending to forget about it and to resume business as usual, although climatology was evidenting that drought would happen again. It is worth to add once more here that global warming is known to increase the frequency and intensity of the climatic incidents (NASEM, 2019), which are more challenging than commonly assumed. Even the title of final chapter of the publication by IPCC (2018), “Adaptation Complex Interactions among Climate Events, Exposure, and Vulnerability”stressed the level of complications involved.

Discussion

In accordance with the complexity of the issue, Feller et al. (2014) focussed on drought and heat effects on physiological status and productivity of agronomically important plants in their review article, considering the growing food security issues. They drew attention to importance of stomatal opening in the regulatory mechanisms during drought and heat stress, simultaneously influencing water loss via transpiration and CO_2 diffusion into the leaf apoplast. They added that along with the reversible short-term control of stomatal opening, stomata and leaf epidermis might produce waxy deposits and irreversibly down-regulate the stomatal conductance and non-stomatal transpiration and photosynthesis at the leaves under stress. Actually, the effect of transpiration on cooling leaves can be added to the influences mentioned by them. Consequently, they said, heat sensitive key enzyme of Calvin cycle, Rubiscoactivase might become another limiting factor to the accumulation of reactive oxygen species (ROS). Drought and heat were causing accumulation of free amino acids, which were partially converted into compatible solutes such as proline, while rates of both nitrate reduction and *denovo* amino acid biosynthesis were decreasing. Another key parameter in regulation of water economy can be added to stomatal control is obviously the efficiency of the root system, as Zhang, Shan & Deng (2002) stressed for wheat, in regard to evolution of wheat from 2n to 6n.

Zhang et al. (2002) considered the physiological basis of raising crop water use efficiency (WUE), and cleverly designed their field experiments to investigate the change of wheat WUE at whole plant level, covering root system growth in evolution by using 10 wheat evolution genotypes with different ploidy chromosomes sets. They reported the results which were showing that evolution from diploid (2n), to allohexaploid (6n) increased WUE at whole plant level; but root system growth in terms of root weight, total length and root/shoot ratio decreased with the increase of ploidy under dry and irrigated conditions. The negative correlation of WUE with root weight and root/shoot ratio of wheat in evolution was found at significant level. Root system growth has an adverse redundancy for WUE in wheat evolution, and the root redundancy reduced with the increase of ploidy chromosomes, which resulted in the increase of wheat WUE at whole plant level.

Considering the results of the studies by Zhang at al and by Feller et al mentioned above, which were showing the increase in protective proteins like dehydrins, chaperones, antioxidant and proline biosynthetic enzymes in leaves and the effects on the effects on long-distance translocation of solutes via xylem and phloem, and also leaf senescence development, it can be concluded that all of those factors were relevant for the overall performance of crops under drought and heat stress. Thus, they should be considered for genotype selection and breeding programs, as the susceptibility to abiotic stresses might differ considerably among species or varieties of a crop, which was particularly important for the annual crops. The literature referred by them were showing the significance of stress period for the crop productivity, which was not ruling the fact out that subsequent recovery stages were equally crucial for a proper evaluation of the overall performance.

Feller et al. added that progression and duration of stress, plant developmental stage and other biotic and abiotic factors might be influencing the stress response. Certain species that were affected at early developmental stage, and could recover, survive; others could cope with the conditions at the beginning and remain quite productive, but their surviving potential could be exhausted and irreversibly damaged. Considering the need for a comprehensive evaluation of plant stress response including the overall characterization of plant physiological behavior and survival, they summarized some of the major physiological parameters characterizing stress response reactions which could be implemented as tools for evaluation of stress effects. They added that the impact of drought and heat on physiological status and productivity of agronomically important plants would become even more relevant during the following decades of global warming era. Assimilatory processes, long-distance translocation of solutes via xylem and phloem, changes in protein patterns and free amino acids, as well as the physiological phenomena associated with induced leaf senescence were addressed in their article.

The comments of Feller et al. on the relations of developmental stage and stress response, flower abortion and premature fruit abscission can be added to the effects they mentioned, as Chandra, Roychoudhury (2020) did so in their chapter titled "Penconazole, Paclobutrazol, and Triacontanol substances in Overcoming Environmental Stress in Plants"which was the 26th chapter of in the very comprehensive and excellent book on "Protective Chemical Agents in the Amelioration of Plant Abiotic Stress" edited by Roychoudhury & Tripathi (2020).In their chapter Chandra et al stressed the importance of the recent achievement of increasing yield by use of chemicals in agriculture. They focussed on triazolic fungicides, Penconazole (PCZ), paclobutrazol (PBZ) and triacontanol (TCN) natural plant growth hormone and regulator (PGR), adding that those chemicals had been widely exploited in agriculture to manipulate crop production and evading abiotic stress, as the agents directly stimulating growth hormones, capable of promoting growth also in adverse environmental conditions.

Chandra et al added that PCZ had been reported for its role in reducing undesirable effects of drought by reducing membrane damage and overcoming salt stress, decreasing also the level of ROSs, enhancing antioxidant potential, and promoting root growth. Likewise, exogenous application of TCN was stimulating production of free amino acids, enzyme activities, and ratio of L (+) and D (−) adenosine, which were known as the factors improving quality and quantity of agricultural crops. Despite the presence of numerous reports showing that application of PBZ was regulating vegetative growth and increasing fruiting, flowering and the yield in many crops, its antagonistic effect on gibberellin biosynthesis and many physiological changes such as rising photosynthetic pigments, nutrient assimilation, delaying aging process, increasing flowering, they said, only few articles were available on the molecular and biochemical aspects of its efficiency. Their comment on the weak interest in some aspects of beneficial effects of some findings and applications is another example supporting the idea expressed in the title of the present series of articles, and described in the previous ones (Duygu, 2020 &2021).

Zaid, Asgher, Wani et al. (2020) reviewed the literature in their brilliant article on role of TCN (Tria, TRIA) hormone in overcoming environmental stresses in the same book edited by Roychoudhury et al. (2020). The book covered chapters on the roles of many chemicals, metabolites, growth regulators and phytohormones: Ca, K, S, Fe, Zn, Cu, Se, Mn, thiourea, H_2O_2, NO, H_2S, proline and glycine, etaine; melatonin, glutathione, sodium nitroprusside, sugars, sugar polyols, ascorbate, tocopherols, oxylipins and strobilurins, isoprenoids, abscisic acid (ABA), polyamines, brassinosteroids, jasmonic acid (JA) and jasmonates, strigolactones, salicylic acid (SA), γ-aminobutyric acid and nanoparticles.

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Zaid, et al. (2020) listed some environmental stresses such as metal/metalloid toxicity, salt, ultraviolet-B, temperature, water and anthropogenic stresses such as machine-induced transplantation shock as the most extreme limiting factors to sustainable and productive agricultural practices. They considered them as intricate factors, occuring in individually and/or combination, which were inducing various detrimental impacts on physiological/biochemical and molecular processes of plants, and eventually causing abnormalities in growth, development, and overall yield.

After stressing the role of phytohormones in regulating growth and sustainable amelioration of abiotic stress-induced undesirable effects in plants, Zaid et al. focussed on the role of Tria hormone in improving abiotic stress tolerance in plants through regulation of main metabolic processes. They added that the fundamental mechanisms of Tria-mediated tolerance to major environmental stresses remained less explored in plants. After briefly highlighting the literature on historical background of Tria in plants, they focussed on the role of the hormone during major environmental stresses in plants, and discussed potentiality of foliar and priming applications in imparting abiotic stress tolerance in plants. The mechanisms of this signaling molecule in boosting growth in agriculture and allied sectors by behaving as an alleviation agent under various environmental pressures were also covered. In accordance with their approach to the hormone, there were only two chemical factors mentioned twice in the titles of the chapters of the book by Roychoudhury &, Tripathi (2020), as the chemicals involved in increasing crop abiotic stress tolerance: sugars and TRIA hormone.

Since Ries & Wert reported in 1977, the application of this 30-carbon primary alcohol to rice (*Oryza sativa* L.) seedlings in nutrient culture solutions at 2.3 ×10(-8) M (10 μg/l) level caused an increase in fresh and dry weight in addition to leaf area of the whole plants as early as 3rd h of treatment even at relatively low light intensities or in the dark, where control plants lost dry weight, the hormone attracted attention of scientists. The dry weight gain in the dark unless CO_2 was removed from the atmosphere, and 30% increment in Kjeldahl-N per plant over controls after keeping them in the dark for 6 h. were the results deserving attention. Ries, Wert, Sweeley et al. (1977) also reported that alfalfa meal and its chloroform extracts increased the growth and yield of several plant species; they also succeeded to isolate a crystalline substance from the active fraction of the meal, which increased the dry weight and water uptake of rice seedlings when sprayed on the foliage or applied in nutrient culture. The substance was identified as Tria by mass spectrometry by them, and the effects of its sprays were also experimentally shown to increase the growth of corn, barley and tomatoes grown in soil, and rice grown in nutrient cultures over a wide range of concentrations.

Similar results for 4-day-old hydroponically grown leaf lettuce (*Lactuca sativa* L.) seedlings in a controlled environment by Knight & Mitchell (1987): leaf fresh and dry weight increased 13% to 20%, root fresh and dry weight increased 13% to 24% 6 days after $10^{(-7)}$ M application of relative to plants sprayed with water. Interesting to note here that, there was no benefit of repeating application on leaf dry weight. In their excellent paper on the total nitrogen increases and changes in its fractions in rice and corn plants following applications of TRIA, Knowles & Ries (1981) reported that the hormone increased total reducible nitrogen (total N) of rice seedlings within 40 minutes besides the increases in fresh and dry weight values. They added that increases in total N in the supernatants from homogenates of corn (*Zea mays* L.) and rice leaves treated with TRIA only for one minute before grinding had occurred within 30 and 80 minutes, respectively. Their further investigation of the source of the increase by using ^{15}N isotope enrichment and depletion studies showed that it was the result of utilization of atmospheric substitution. They observed that the increase in total N in the seedlings was independent of the method of N analysis and the present level of nitrate in them; TRIA was not altering the nitrate uptake or its endogenous levels in corn and rice seedlings studied, but increased the soluble N pools, specifically the free amino acid and soluble protein fractions, that might be stimulating an effective change in the chemical composition of the seedlings.

Ries& Wert (1988) applied TRIA to shoots or roots of rice (*Oryza sativa* L.) seedlings and measured increases in the dry weight, and analyzed alterations in the metabolism within 10 min of application in order to understand the physiological mechanism of the hormone. They observed the loss of metabolic activity by application of octacosanol, C28 primary fatty alcohol (OCTA) with TRIA on the roots or shoots, when OCTA was applied on the opposite part of the seedling at least 1 min before TRIA application. They decided that TRIA was rapidly eliciting second Messengers, which were translocated rapidly throughout the plant. The apparent result was stimulation of growth and water uptake. They named the second messengers as TRIM and OCTAM, and succeeded to extract water-soluble TRIM from the plants treated with TRIA, which was increasing the growth of rice seedlings about 50% more than the extracts obtained from untreated plants within 24 h of application. They showed that both OCTAM and OCTA were inhibiting the activity of TRIA but not of TRIM; the TRIA messenger was isolated from rice roots within 1 min of a foliar application of TRIA. The TRIM elicited by TRIA was passing through a 4-mm column of water connecting cut rice shoots with their roots and could also be recovered from the water in which cut stems of TRIA-treated plants had been immersed. The clever study of Ries et al. (1988) revealed that TRIA applications to oat (*Avena sativa* L.) or tomato (*Lycopersicon esculentum* Mill.) shoots, which were connected to rice roots by a 4-mm water column also had TRIM in rice roots.

Ries, S. (1991) attracted attention to the fact that TRIA, which was used to increase crop yields on millions of hectares, particularly in Asia to affect photosynthesis, nutrient uptake, and enzyme activities, its initial site of action was still needed to be elucidated. He added that the TRIA messenger TRIM was identified as 9-beta-l(+)-adenosine (9H-purin-6-amine, 9-beta-l-ribofuranosyl) enantiomer, which had not been reported as a natural compound previously, was making about 1% of the total adenosine pool up in roots from untreated rice seedlings. It took a decade to reveal the molecular genetical mechanism of the TRIA by isolating the genes of rice regulated by the hormone; Chen, Yuan, Chen, et al. (2002) succeeded to characterize them by using the cDNA library

Chen et al. (2002) also showed that while dry weight, protein and chlorophyll contents of rice seedlings were increasing after foliar application of TRIA, there was a very quick increase in the leaf net photosynthesis rate (Pn), and this increase was persistent at a given photon flux density (PFD, mean number of photons per leaf area). They also succeeded to isolate all of the TRIA-regulated genes from cDNA library by differential screening with probes generated from the forward-and reverse-suppression subtractive hybridization (SSH) populations, and confirmed their results by Northern blot. Their sequence analysis revealed that most of the up-regulated genes were involved in encoding the photosynthetic and photorespiratory proteins. Two down-regulated genes were encoding an Abscisic acid (ABA) inhibitor and also a stress, wounding related protein. They interpreted the results obtained as evidences of up-regulation of the photosynthesis and suppression of stresses in rice plants. Time-course profiles of expression of rbcS isogenes (Clone names of Tria-Regulated Genes in Rice) lead them to suggest that promotive effect of TRIA on regulation of photosynthesis was organized by some complex mechanisms. Sperotto, Ricachenevsky, Duarte et al. (2009), as a matter of fact, identified up-regulated genes in flag leaves during rice grain filling stage and characterized a new plant growth inhibitor named OsNAC5, which was an ABA dependent transcription factor.

Considering that the main sources of insufficient levels of micronutrients such as Fe and Zn were the flag leaves in rice seedlings, Sperotto, et al. (2009) studied on the molecular mechanisms regulating metal mobilization from leaves to developing seeds by analyzing suppression subtractive hybridization in flag leaves of two rice cv.s. They succeeded to isolate 78 up-regulated sequences in flag leaves at the grain filling stage, relative to the ones present at panicle exertion stage. They confirmed differential expression of selected genes, which were encoding seven transport proteins, the OsNAS3 enzyme and the OsNAC5 transcription factor by quantitative reverse transcription polymerase chain reaction (RT-PCR) technique, which could combine reverse transcription of RNA into complementary DNA (cDNA) for amplification of specific DNA targets using polymerase chain reaction. They also succeeded to show that OsNAC5 expression was up-regulated by natural aging and induced senescence processes by different factors, such as dark, ABA application, high salinity, cold and Fe-deficiency. They added that the expression was not affected in the presence of 6-benzylaminopurine (BAP) cytokinin senescence inhibitor under dark-induced senescence. Abolishment of salt induction of OsNAC5 expression by the ABA inhibitor nicotinamide and the presence of cis-acting elements in the promoter region of the OsNAC5 gene lead the researchers to conclude that regulation was controlled by ABA. By using four different rice cultivars, Sperotto, et al. also evidented that up-regulation of OsNAC5 was starting earlier and reaching to higher levels in flag leaves and panicles of IR75862 plants, which were containing higher Fe, Zn and protein concentrations in their seeds. They concluded that OsNAC5 was a novel senescence-associated ABA-dependent NAC transcription factor, which appeared to take part in remobilization of Fe, Zn and amino acids from green tissues to seeds. As known transcription factors are important switches of transcription networks, and NAC group are plant specific one taking part in some important processes, such as development, abiotic and biotic stresses.

Taking the important contribution of soil salinity as a major abiotic stresses to crop yield losses worldwide into consideration, Karam & Keramat (2017) studied the effect of exogenous foliar spray of TRIA on coriander (*Coriamdrum sativum* L.) under salt stress . After briefly reviewing the effects of abiotic stresses, such as induction of overproduction of ROS, damages of DNA, proteins, chlorophyll, and also cellular membranes by inducing lipid peroxidation in terms of malondialdehyde (MDA) content in leaves, they added that plant antioxidative system response was comprising several enzymes, such as superoxide dismutase (SOD), catalase (CAT), ascorbate peroxidase (APX), and peroxidase (POX) and non-enzymatic low molecular weight antioxidants, such as ascorbic acid (AsA), α-tocopherol, carotenoids and reduced glutathione (GSH), they presented their own findings. Karam et al. (2017) showed that salinity stress was causing a few morphological and physiological changes in coriander, including decrease in root and shoot dry weight, increased H_2O_2 content and lipid peroxidation. Foliar spray of 10µM TRIA was found effective in reducing the adverse effects of salt stress through modulating activities of antioxidant enzymes. They referred to the earlier studies evidenting that endogenous levels of phyto-hormones were undergoing considerable changes under salt stress, including the decreases in the levels of most of growth regulators in the plants exposed to salinity stress, they could, however, recover by the exogenous hormone applications. They also referred to the literature showing that various physiological and biochemical processes could be regulated by foliar application of TRIA under salinity stress. Growth and yield of various crop species could be increased at their various growth stages, by enhancing activities of some key enzymes, modulating photosynthesis, photorespiration, chlorophyll synthesis, cell division, and uptake of water and mineral nutrients.

Recently, Islam and Mohammed (2020) reviewed the literature on the role of TRIA as a dynamic PGR under diverse environmental conditions. Like Zaid, et al. (2020) did so, they referred to the studies showing the well defined roles of ABA, auxin, brassinosteroids, cytokinins, ethylene, gibberellins, jasmonates, NO, SA and strigolactones in plants very briefly, and attracted attention to numerous studies showing that the mode of the hormone actions were varying under stress conditions. After this short introduction they focussed on TRIA, which was first identified in the hay of alfalfa in 1997, and referred to studies reporting that it was found also in epicuticular waxes of diverse plant species, such as *Croton californicus*, *Copernica cerifera*, *Medicago sativa*, *Jatropha curcas*, *Oryza sativa*, *Vaccinium ashei,* and some others which have been reported by different researchers, such as green tea leaves, tea waste, rice bran economically [Sontakke, Nagavekar, Kumari et al (2018), Central Food Technological Research Institute] and also some of who are referrals in the present article.

As known very well, C and N metabolisms are interrelated, and Nitrate reductase (NR) is essential for nitrogen metabolism as the initiator of NO_3 assimilation (Foyer, Ferrario-Méry, & Noctor, 2001). On the role of foliar application of TRIA on NR activity Islam et al. concluded that an increase might be responsible for the enhancement of photosynthetic rate and increase in biomass and productivity. They referred to studies showing that 3 to 5 times foliar spray treatments of 1 µM or 10^{-6} M TRIA could increase NR activity against controls, within a range of 27.6 to 44.6% in various crops,. In accordance with the interrelated metabolitic activities affected by TRIA applications, Foyer et al. also reviewed the literature on the noticable effects on leaf nitrogen (N), phosphorus (P) and potassium (K) contents in most of the economically important crops, and referred to reports evidenting the significant increments in leaf N, P and K contents of various crops compared to control groups. As it would be expected, they added that TRIA was also improving the content and yield of most of the economically important harvests, and referred to a number of studies showing several times spray treatments of Vipul™ formulation containing 0.1% TRIA to the foliage of tomato, *Lycopersicum esculentum* Mill. increased yield attributes such as bud formation, number of fruits and their weight, diameter and total yields per plant of than control groups. Similar beneficial effects on yield and yield attributes, such as improved flowering, quality of flowers, fruit set and reduced flower drop and similar parameters of *Avena sativa* L., *Malus domistica* Borkh., *Medicago sativa* L., *Olea europaea* L., *Zingiber officinale* Rosc., *Cymbopogon flexuosus* L., *Curcuma longa* L., *Withania somniferum* L., and *Datura innoxi* Mill., *Lablab purpureus* L., and *Senna occidentalis* L., *Punica granatum* L. were also covered. It is worthmentioning the significant increases in *Solanum lycopersicum* L. attributes here as an example: in terms of weight, number and yield of fruits per plant over the controls were presented as 35.4%, 38.0%, and 57.6% respectively. In another referral study it was shown that application of 0.35 g a.i/ha (gr.s of active ingredient per ha.) TRIA enhanced seed yield and harvest index (wgt of grain per total wgt of above ground biomass) in *Medicago sativa* L. over the controls considerably.

It is worthmentioning here that TRIA has also been known as the natural constituent of insect waxes for some time [Irmak, Dunford, & Milligan (2006); Ma, Ma, Zhang, et al. (2018)] As mentioned by Irmak et al. policosanol (PC) was a mixture of high molecular weight aliphatic primary alcohols, and a number of commercial dietary supplements containing PC available in the USA were mostly prepared from beeswax or sugar cane extracts. They compared the PC contents and compositions of beeswax, sugar cane and wheat as the sources, and analyzed compositions of several commercial supplements. They found that wheat germ oil (WGO) contained the highest total PC (628 mg/kg) among the wheat extracts and milling products examined; total PC contents of wheat straw (164 mg/kg) and sugar cane peel (270 mg/kg) were of the same order of magnitude. The total PC contents of brown beeswax were about 20 and 45 times higher than those of the WGO-solids and sugar cane peel, respectively. The PC compositions of the samples analyzed found to vary significantly with the source, and wheat was chosen as the material which could be a viable PC source for further product developments.

Ma et al. (2018) focused on insect wax, considering its role in economic wax production in China and its value as a good source of PC, they took it as a candidate supplement in foodstuff and pharmaceuticals that had important physiological activities. They aimed to investigate a high-yield and rapid method for PC fabrication from insect wax, and reported their success in developing a method that increased the yield of PC to 83.20%, four times greater than that of other methods that were in use. Ma, et al added that hexacosanol, octacosanol and TRIA were the main policosanols of interest, due to their significant physiological activities, and presented their contents as 6% to 7%, 42% to 46%, 27% to 28%, and 5% to 6%, respectively. The point ought to be stressed here is the distribution of TRIA in a wide range of taxa. When it comes to the hormonal effects of its applications, an accelerating growth of scientific literature on the subject can be attributed to the outstanding beneficial performance as a GR on a wide range of living organisms. There are also studies showing its therapeutic uses and improving pharmacologically active chemical synthesis in medicinal plants [Khan, Bhardwaj, Naeem, et al. (2009); Naeem, Ansari, Alam, et al.(2019)], and also therapoetic uses (Wang, Yu, Wang et al. 2020), including its potential as an antitumor agent (Wang, Fan, Zhu, et al. 2014).

Islam et al (2020) referred to the vast literature on the positive effects of relatively low concentrations of exogenous TRIA applications to different crops, covering enhancement of plant biomass, photosynthetic pigments, gas exchange parameters, mineral nutrient acquisition, leaf carbonic anhydrase (CA), nitrate reductase (NR) activities, accumulation of osmolytes, modulation of antioxidant enzyme activities, yield and quality attributes, changes in stem and leaf anatomy including vascular tissue systems. They also covered the literature on suppression or enhancement of the stress responses by regulating the gene expression, its essential roles in responses to abiotic stresses such as acid mist, heat, chilling, drought, heavy metal and salt stress, amelioration of the toxic effects by increasing plant biomass, chlorophyll, gas exchange parameters, quantum efficiency, mineral nutrient acquisition, compatible solutes accumulation, enzymatic and non-enzymatic antioxidant defense system. Due to diverse roles of the hormone, they focussed on modulation of plant growth and development under normal and abiotic stress conditions, its relation with other phytohormones and its effects on L(+)-adenosine formation. They drew attention also to its indirect effects, such as activation of calmodulin protein and probably taking part in direct modulation of transcription factors via Calmodulin-binding transcription activators (CAMTAs). They added that its actuation of the activities of kinases and phosphatases was leading to expressions of photosynthetic and photosynthesis associated genes; TRIA might also regulate stress-mitigating genes, modulate antioxidant defense systems and increase osmolytes accumulation leading to growth and development enhancement at normal and stress conditions.

The beneficial effects of TRIA on various metabolic processes occurring at seed germination, seedling growth and development stages, stimulation of photosynthesis and enzyme activities, its pivotal role in inducing/establishing resistance against various abiotic stresses by regulating gene expression, and also triggering its secondary messengers have also been reviewed by Islam et al. in their outstanding article. They attracted attention to the presence of non-racemic adenosine in TRIA treated plants, which was stimulating the beneficial plant processes, whereas racemic form could not. As a matter of fact, the exogenous application of L(+)-adenosine was also stimulating plant physio-biochemical processes, affecting morpho-physiology and biochemistry of crop plants under normal conditions. They summarized the beneficial effects of the hormone in eleven roles from increasing root system length and fresh/dry mass, to Malondialdehyde (MDA)/H_2O_2 reduction, which was the sign of decreased damage by ROS, and finally to increased mineral nutrition, osmolyte accumulation, growth and yield.

The importance of high number of studies reporting the essential role of the hormone in regulating a broad spectrum of plant morphological responses in most of the harvests, such as *Solanum lycopersicum* L., *Zingiber officinale* Rosc. and *Curcuma longa* L. so forth, was emphasized by Islam et al. They referred to interesting results of some studies, such as the ones reporting enhancement of fresh and dry weight of shoot and root of *S. lycopersicum*, *P. somniferum* L. by twice foliar spray of TRIA up to 1 ppm concentration, a number of studies presenting similar results on a wide range of crops, enhancement of the physio-biochemical attributes of vegetables, oilseeds, medicinal, aromatic, ornamental and horticultural ones. The referral studies were the ones reporting beneficial increases in many parameters over the control groups: chlorophyll and carotenoids, net photosynthetic rate (P_N), internal CO_2 concentration (*Ci*), stomatal conductance (*gs*), size and number of the chloroplasts, carotenoids and total chlorophyll or chlorophyll *a*, *b*, $a+b$, ribulose-1,5-bisphosphate carboxylase/oxygenase (RuBisCO) and *rbc*S gene activities, and gas exchange attributes.

Islam et al dwelt on the second most abundant and key photosynthetic enzyme, Carbonic anhydrase (CA), which was known to have a role in carbon fixation, many carboxylation and decarboxylation reactions, photosynthetic electron transport system, maintaining chloroplast pH, respiration, and even protection of enzymes from denaturation. They referred to studies, such as the ones in which TRIA had been noted as the hormone enhancing leaf CA activity remarkably when its 1μM solution was sprayed three times to the foliage of *Mentha arvensis* L., and at 1.5-ppm level in artemisia leaves over the controls. They also mentioned some others presenting results on marked increases by TRIA sprays onto leaves of several other crops, and finally concluded that the PGR was stimulating CO_2 diffusion into the stomata by increasing stomatal conductance, and its assimilation by the increasing activities of CA and RuBisCO enzymes.

As known very well, C and N metabolisms are interrelated, and Nitrate reductase (NR) is essential for N metabolism as the initiator of nitrate assimilation (Foyer, Ferrario-Méry, & Noctor, 2001). On the role of foliar application of TRIA on NR activity, Islam et al concluded that an increase might be responsible for the enhancement of photosynthetic rate and ultimate increase in biomass and productivity. They referred to studies showing that 3 to 5 times foliar spray treatments of 1 μM or 10^{-6} M TRIA could increase NR activity by increasing within a range of 27.66 to 44.6% in various crops against the controls. In accordance with the interrelated metabolic activities affected by its applications. Islam et al. reviewed the literature on the noticable effects on leaf N, P and K contents in most of the economically important crops, and referred to reports evidenting the significant increments in N, P and K contents of the leaves of various crops compared to their control groups. They added that, as it could be expected, there were studies indicating the improvement of the content and yield of most of the economically important harvests, such as number of fruits, fruit weight, fruit diameter and total yields per plant of *Lycopersicum esculentum* Mill., yield and yield attributes of wide range of spp, such as *Avena sativa* L., *Malus domistica* Borkh., *Zingiber officinale* Rosc., and others at lower concentrations such as 10^{-6} M. They attracted attention to a report, which showed that four times application to foliage of *Solanum* *lycopersicum* L. could significantly enhance the yield attributes, such as weight, number and yield of fruits per plant by 35.4%, 38.0%, and 57.6% respectively over the controls.

Depending on the importance of the subject for the practitioners, availability of high number of studies gave Islam et al to review and present promising results held on different crops. In their comprehensive article, the literature related with the effects of TRIA on metabolism of active constituents and yield in the essential oil of aromatic and medicinal plants was also reviewed. They referred to studies presenting remarkable effects of the hormone applications on essential oils by increasing their content and yield, such as significant increase in morphine content in *Papaver somniferum* L. at its 10^{-6}M concentration. Considerable enhancement of curcumin and total alkaloid level in *Withania somnifera* Dunal L. and *Datura innoxia* Mill. and other examples lead them to reach a conclusion on the improvement in yield and content of essential oils might be the result of TRIA-mediated enhancement in growth and metabolism.

Considering the relation between oils with other low-energy CHO compounds, carbohydrates, Islam et al. also covered the positive effects of TRIA applications on the content and yield of essential oils and biofuel raw materials. They referred to studies evidenting the effects on the level of essential oils, such as a significant effect on morphine content in *Papaver somniferum* L., curcumin and total alkaloid content in *Withania somnifera* Dunal L. and many other crops. Their final conclusion was the reason of improvement in yield and content of essential oils up to 29.7 against controls might be the result of TRIA-mediated enhancement in growth and metabolism of plants.

The importance of the substances in carbohydrate group in biofuel production, lead Islam et al. to feature the topic in their review article, and focussed on microalgae as the most abundant photosynthetic microorganisms. As the most feasible sources for biofuel production with their outstanding capability of CO_2 assimilation shown by experimental studies, they added that microalgal oil was a good source for biodiesel production. They presented evidences showing that several phytohormones were increasing their growth and production of the key metabolites for biodiesel production, referred to studies evidenting TRIA application was also effective in enhancement of growth, chlorophyll, protein contents and biodiesel production in *Chlamydomonas reinhardtii* as some other PGRs. One of the referral study was a comprehensive one, reviewing the literature on the positive effects of auxins; gibberellins; cytokinins; ethylene and its precusors, ABA, TRIA and also some combinations on cell size, growth, biomass, pigments, proteins lipids, and others at numerious unicellular alg spp., including *Chlorella vulgaris, Dunaliella salina, Scenedesmus obliquus* etc. (Xingfeng, Z. H., Bartocci, P. et al., 2018). It was also noted by Islam et al. that 5 mg/L TRIA significantly promoted biodiesel production by increasing biomass and lipid productivity, and ultimately they concluded that the biological roles of phytohormones of microalgae and higher plants were similar; at certain dose ranges they were enhancing the adaptive ability of microalgae against biotic or abiotic stresses by working interactively in the regulation of cellular metabolism enabling them to accumulate biomass and bioproducts. Nevertheless, they said, the scalable and viable microalgal production still required investigations and studies and manipulation of phytohormones on microalgae, to exploit the great potential available for the "Green Revolution" for production of useful biochemicals and alleviation of climate and energy crises.

In accordance with their conclusion, some of the research focus groups in our laboratory studied on the positive effects of TRIA, SA and TRIA + SA on different growth, metabolic parameters of several cyanobacteria and microalgae spp, and also duckweed spp, *Lemna* spp. including their adaptation and resistance to different polluters, at different media and matrix conditions, and also their pollutant remediation capacities [Karacakaya, Kılıç, Duygu, et al. (2009); Kılıç, Karacakaya, Duygu et al. (2010); Aminfarzaneh, & Duygu (2010); Kılıç, Karatay, Duygu, et al. (2011); Taştan, Duygu, & Dönmez (2012), Taştan, Duygu, İlbaş et al. (2012); Taştan, Duygu, Atakol, et al.(2012); Taştan, Ertit, Duygu, et al. (2016).

Al-Maliki & AL-Masoudi (2018) studied on the adverse impacts of soil salinity on soil biological properties and growth of corn plants, which were majorly observed in arid and semi-arid lands. They conducted intelligently designed mesocosm experiments in order to obtain results representing controlled alterations of nutrient availability and food-web structure. They also aimed to eliminate open-system dynamics to be able to investigate the effects of several parameters on the toleration of the corn plants to salinity, and analyzed the effects of mycorrhizal fungi (M) (*Glomus mosseae*), tea wastes (T), algal dried biomass (A), and their combinations on soil respiration, total bacteria, total fungi, soil mean weight diameter (MWD), and corn yield (*Zea mays* L.).parameters under saline and non-saline soils. Results showed them that M, T, and A treatments increased significantly CO_2 release compared to the controls; whereas, M significantly decreased CO_2 release compared to T and A treatments. In non-saline soil, M increased greatly MWD, bacterial and fungal counts, and infection rate. The opposite was true in the saline soil; neither M nor T improved bacterial communities and MWD.; in the saline soil, however M + T was highly efficient in improving MWD, SOC, bacterial and fungal counts, infection rate, and corn grain yield. They concluded that the inoculation of M with T in saline soils could be considered as an important strategy that could increase the toleration of the corn plant to salinity by improving soil microbial activity, MWD, SOC, infection rate, and total grain yield.

Al-Maliki et al. (2018) referred to some studies which evidenced that one of the vital ways to increase the plant toleration to salinity stress was to incorporate the *Arbuscular mycorrhizal* fungi (AM fungi) in soils, which were capable of increasing the endurance of plants to salt stress by enhancing plant nutrient uptake and ion balance and also protecting soil enzymes and soil organic matter, and concurrently facilitating the uptake of water. They added that the combination of AM fungi with T was significantly more effective in increasing the bacterial population than the single addition of the T treatment; due to the the small C:N ratio T might had been rapidly decomposed by microbes and be supporting microbial community for a short period. Their explanation was mixation of AM fungi with the T, the exudates of AM fungi and a presence of protein and amino acids from the T might be stimulating the bacterial growth. They also referred to their previous paper reporting that the addition of T improved the biological properties of soil. In the saline soil, the highest significant increase in bacterial and fungal communities was found in M+T treatment, although it was not significantly different from A+T treatment, the main reason was given as the participation of organic acids and polyphenols in tea wastes in alternating the high pH of the saline soil, and stimulating intensive growth of AM fungi. Subsequent increase in mycorrhizal products could favor the growth of bacterial and fungal populations in saline soils. No effect of A and M treatment on bacterial community was explained by the high C:N ratio of algal dried biomass, which might had degraded rapidly and could not support the bacterial community. Secondly, they said, quantities of algal acids and mycorrhizal exudates were not sufficient to lower the high pH of the saline soil, which was restricting the bacterial population, even though presence of free and bound 1-triacontanol in tea leaves was analytically shown in tea leaves decades ago by a direct gas chromatographic method of identification and determination (Mandayam, Binayak, Dhanaraj, et al. 1988). They added that treatment of the tea leaves with CaO released a bound form in tea leaves. Although this article has been cited only three times until now, Tea Research Institute (UPASI) of Coimbatore city in the Indian state of Tamil Nadu isolated and obtained TRIA from active fraction of tea waste (UPASI, CFTRI-570 020).

In this report issued by UPASI it was noted that TRIA also was extracted from sugarcane press mud & rice bran waste and successful field trials performed to prove its efficacy for high yield in the case of a number of crops like barley, corn, paddy, maize lettuce, cucumber, etc. Tea Research Institute, UPASI, Coimbatore also included the results of successful field trials on tea cultivation, increases in yields to the extent of 20 to 30% and a reduction in dormant shoots (banji). It was added that some of the Agricultural Universities had tried the product on crops like paddy, tomato, brinjal, potato and obtained the results showing remarkable increases in the yields. It was added that number of tea planters in the country tried n-triacontanol and its formulations had shown excellent market potential. The three major raw materials that had been used to extract were tea waste – black tea waste including stiff sweeping, tea waste from instant tea processing, damaged tea, decaffeinated tea wax etc. Sugarcane press mud-obtained as waste product during the clarification of sugar cane juice in sugar factories and rice bran wax extracted from the co-product obtained from the rice milling/ solvent extraction industry. The tea waste was mostly available in tea processing centers, sugarcane pressmud from sugar industries, rice bran wax was available from the solvent extraction units handling rice bran. Comparative yields of n-triacontanol from various waxes were given in terms of Yield % & Purity %: sugarcane pressmud wax 20 & 20, tea waste 30 & 40, and rice bran wax 30 & 25. A feasibility report for the production facility was also presented.

Mori, Tanaka, Nakagawa et al.(2020) investigated chemical uses of Moso bamboo (*Phyllostachys pubescens*) shoot skin, and identified the main component of non-polar solvent extracts as 1-TRIA; GC-MS analyses showed that its concentrations were 13.3 and 41.7 ppm in fresh and boiled skins, respectively. They added that in boiled skins, the concentrations reached to a maximum of 71.3 ppm after 2 weeks of composting, gradually decreased to 19.7 ppm after compost maturation for 6 months. In a further experiment, when seeds of Welsh onion were sown on absorbent cotton impregnated with authentic 1-triacontanol solutions, significant increase in hypocotyl length was observed. They concluded that due to the presence ofthe hormone, Moso bamboo shoot skin had potential as functional compost that could serve as a biostimulant for agricultural uses. Randrianasolo, Krebs, Rakotoarimanga, et al. (2015) isolated 1-triacontanol and 1-icos-17-en-1-ol, 1-octacosanol, umbelliferone and skimmin from the aerial parts, leaves of *Phellolophium madagascariensis* (Apiaceae), an endemic species of Madagascar, which was used as an infusion to treat several health problems ranging from indigestion to skin diseases and nervous disorders.

Ali, & Perveen (2020) studied effect of foliar TRIA application on three cv.s of wheat (*Triticum aestivum* L.) grown on sand and irrigated by full Hoagland solution containing 0, 50 and 100 ppm As ($NaAsO_2$), and they investigated the effects of 1μM TRIA containing nutrient solution on the changes in growth, yield and photosynthetic characteristics. After 16 week of germination, they found that TRIA significantly increased growth and yield attributes, chlorophyll b, internal CO_2 concentration, stomatal conductance, rate of photosynthesis, flavonoids and anthocyanin contents in all wheat varieties. Moreover, the results also indicated that 1 lM TRIA proved to be effective in reducing the adverse effects of As stress on all cv.s. studied. AARI-2011 was more sensitive than Anaj-2017 cv., and TRIA application was more effective on the sensitive one.

Perveen, Shahbaz & Ashraf (2014) investigated the effect of exogenous application of TRIA on two 2 wheat cv.s, S-24 and MH-97 under salt stress in a greenhouse under natural climatic conditions. Both cv.s were grown in full strength nonsaline Hoagland's nutrient solution or 150 mM NaCl containing salty sand cultures. After 0, 10, and 20 μM TRIA foliar sprays at 3 growth stages, i.e. vegetative, boot, and vegetative + boot stages, their data analysis on 92 day-old plants showed that salinity stress adversely affected various growth, physiological, and biochemical attributes in both cv.s at all growth stages. SOD and POX activities decreased in cv. MH-97, catalase (CAT) and POX increased in cv. S-24. H_2O_2 , MDA, Na^+, and Cl^- increased in both cv.s at all growth stages. A foliar spray of 10 μM TRIA was found to be more effective in reducing the adverse effects of salt stress on growth, yield, and leaf water relations of wheat plants when applied at the vegetative or vegetative + boot growth stages.

The study of pre-flowering foliar spray of plant growth regulator on growth, yield and quality parameters in Sweet Pepper (*Capsicum annuum* L.) by Sahu, Aslam & Das (2017) was carried out under protected condition to compare the effects of nine treatments viz. 10 and 50 ppm Gibberellic acid 3, (GA3), 10 and 50 ppm Naphthalene acetic acid (NAA), 5 and 10 ppm cycocel (CCC) and 5 and 10 ppm TRIA in Completely Randomized Block Design with three replications. The researchers recorded the observed effects on the basis of five random competitive plants selected from each plot separately for morphological, growth analytical, phenological, and yield parameters, and evaluated them as per standard procedure and also estimated the economics. They found that foliar application of artifical auxin 10 and 50 ppm PGR NAA and 5 and 10 ppm TRIA significantly increased growth and yield attributes, and were presented as better alternatives for boosting, higher production of sweet pepper cv. Pusa Deepti under protected cultivation.

Another important issue regarding the selection of water conservation methods that may be integrated to ecological approaches to agriculture for higher productivity and quality is the mutual growth stimulation among bacteria, algae, fungi, parasitic weeds and non-parasitic plants, as described by Rice, E. L. (1986) in the chapter titled "Allelopathic growth stimulation", in the book titled "The Science of Allelopathy". Examples of plants stimulating growth of other plants including *Ambrosia psilostachya, Agrostemma githago* (agrostemmin), *Medicago sativa* mentioned as a source of triacontanol, rape and pollen of *Alnus* sp. as a source of brassinolides, *Centaurea repens* [*Acroptilon repens*], *C. Solstitialis* and *Glechoma hederacea,* which could inhibit and stimulate growth of different plant spp. It was added that interference of *G. hederacea* with lawn and garden plants was studied using *Bromus tectorum* and radishes as test plants, and found that decaying leaves decreased seed germination, especially in *B. tectorum,* but stimulated root and shoot growth in both test plants. Root exudates stimulated shoot and root growth of radishes but inhibited that of *B. tectorum.*

Cheng & Cheng (2015) reviewed the progress of the research on allelopathy, the common term of biological phenomenon related with the biochemicals produced by an organism influencing the survival, growth, development and reproduction of some other organisms. They covered physiological and ecological mechanisms involved and its use in agriculture in their comprehensive article, by referring to articles evidenting that it was a natural ecological phenomenon. They added that it was known and used in agriculture since ancient times, after the realization of the beneficial effects of allelochemicals on target organisms and easing some agricultural practices, such as weed control, crop protection or crop re-establishment. Allelochemical effects might also be harmful with their autotoxicity, causing soil sickness by creating abiotic and/or biotic stress conditions, such as building soil-borne nematodes, pathogens up or competing for water and nutrients, even invasion of the field. Thus, Cheng et al. (2015) attracted attention to the need of exploiting such cultivation systems in order to take advantage of the stimulatory/inhibitory influence of allelopathic organisms to regulate plant growth and development and to avoid allelopathic autotoxicity.

Focussing on description of management practices related to allelopathy and allelochemicals in agriculture, Cheng et al. (2015) discussed the progress regarding the mode of action of allelochemicals, cytological, histological and physiological mechanisms involved in allelopathic effects. They also evaluated the effects of ecological mechanisms exerted by allelopathy, a sub-discipline of chemical ecology on microorganisms and the ecological environment. They considered also the changes in interrelationships within the ecosystems through the effects of allelochemicals produced by plants or microorganisms on the growth, development and distribution of others in natural communities or agricultural systems. They added that studies on allelopathy started to increase in the 1970s, and the rate of this increase since the mid-1990s had made it a popular topic in botany, ecology, agronomy, soil science, horticulture. Other areas of inquiry in recent years was mentioned as a significant factor contributing to species distribution and abundance within plant communities and in the success of invasions by Cheng et al.. They also drew attention to the possible role of allelopathy in the indirect causes of continuous cropping obstacles in agriculture, and the importance of developing strategies for the management of agricultural production and ecological restoration involving allelopathtic applications including algae, fungi and various microorganisms. They added that after broadening the definition to cover any processes involving secondary metabolites produced by any organisms including viruses by International Allelopathy Society in 1996, the scientific interest in the subject increased considerably.

Cheng et al. defined allelochemicals as non-nutritive plant secondary metabolites or decomposition products of microbes consisting of various chemical families which were classified in 14 categories ranging from water-soluble organic acids to complex quinones, purines and nucleosides, PGRs, including SA, GA and ethylene. As the allelochemicals could stimulate or inhibit germination and growth, they could be used to obtain yields with low phytotoxic residues as suitable substitutes for synthetic herbicides, although the efficacy and specificity of many allelochemicals were limited. They attracted attention to number of the studies on the use of allelopathic crops in agriculture showing the beneficial effects that were being realized: using as components of crop rotations, for intercropping, as cover crops or as green manure. Such suitable applications of allelopathy could improve productivity through environmentally friendly control of weeds, insect pests, crop diseases, in addition to of nitrogen conservation, an additional interest, they mentioned, in allelochemicals research was the synthesis of novel agrochemicals based on allelochemicals.

Since competition was one of the main modes of interaction between cultivated crops and their neighbouring plants, arrangement of cropping systems, Cheng et al. said, allelopathy could be used to suppress weeds and alleviate allelopathic autotoxicity to reduce inhibitory influence among allelopathic crops, as several earlier reports had evidented. Exploiting this possibility would mean to improve land utilization rate, increase annual soil output by establishing reasonable crop rotation and intercropping systems. An experimental field study clearly showed them that relative abundance and population suppression of plant parasitic nematodes under *Chromolaena odorata* (L.) (Asteraceae) fallow.

Considering the common intercropping practice in developing countries for maximizing land resources and reducing the risks of single crop failure, Cheng et al. also referred to studies showing the efficiency of intercropping in weed control and biomass production. However, they said, allelopathy between different species might cause promontory or inhibitory effects; therefore, they said, the literature was showing the need to take the allelopathic nature of crops into consideration in crop rotation. Intercropping and stalk mulching to provide economical and sustainable weed management by using allelopathic plants as ground cover species could be an environmental friendly option, as experimentally shown by some studies. They drew attention to allelochemicals from decomposed straw could suppress weed growth and reduce the incidence of pests and diseases, straw mulch could also increase soil fertility by improving organic matter content; but it also might exert negatively by increasing the C/N ratio. The authors cited several impressive references evidenting inhibition of different weeds by the straws in the fields of different crops and reducing the need for herbicide applications, including one presented experimental data on the application of allelopathic plant materials at 1–2 tons ha^{-1} could reduce weed biomass by approximately 70%, and increased rice (*Oryza sativa* L.) yield by approximately 20% in paddy fields over respective controls.

Another potential of allelochemicals that have been exploited was presented by Cheng et al. as the negative allelopathic effects were actually important components of plant defense mechanisms against weeds and herbivory. The technological approaches to modify allelochemicals for the production of environmentally friendly pesticides and PGR's were offering effective management of production by using considerably degradable allelochemicals. They referred to studies showing that formulation of sorgoleone, a hydrophobic compound found in *Sorghum bicolor* (L.) root exudates as a wettable powder. It was more effective in inhibiting weed growth, while crop species were tolerant to it, and some microorganisms were using it as a C source; which could also be mineralized via complete degradation to CO_2 in soil.

The mutually benefical relationship between plants and plant growth-promoting rhizobacteria (PGPR) was mentioned in the review as a mechanism eliciting induced systemic resistance (ISR) reducing susceptibility to pathogenic diseases. References were presented to conclude them that allelopathic bacteria could exhibit PGPR attributes and activity against allelopathic weeds. Cheng et al. added that there were some organic herbicides or plant growth inhibitors that had been manufactured from allelopathic plant materials to inhibit weed growth in fields, and they included a reference presenting the composition of a type of herbicide comprising a mixture of components extracted from several and herbaceous spp., as an example of practical application of plant allelopathy in paddy fields.

Reminding the severity of N leaching water pollution problem related with mineralization of soil organic N, especially nitrification of N fertilizer leading to enrichment of N in the soil, and the gradually increasing importance of biological nitrification inhibition (BNI), Cheng et al. referred to some recent studies evidenting the presence of nitrification-inhibiting substances (NIS) produced by plants, and BNIs were becoming the first choice in soil nitrification management. They also drew attention to the literature showing that BNIs were allelochemicals inhibiting soil nitrification, such as wheat allelochemicals, ferulic acid, p-hydroxybenzoic and hydroxamic acids, which could inhibit soil nitrification microorganisms and reduce N_2O emission. BNIs could also reduce pollution by improving utilization of N fertilizer, the allelopathic inhibition of soil N mineralization by *Plantago lanceolata* L. allelochemical activity on reduction of soil nitrogen leaching was a good example presented.

In the same article, Cheng et al. referred to numerious studies showing the potential of breeding new allelopathic cv.s in order to minimize the introduction of refractory chemicals and weed control. Successful cv.s would be the ones combining weed suppression, high yield potential, disease resistance, early maturity and quality traits. They stressed that presence of a high number of referral studies was proving that this combination was not a surrealistic one, and could be obtained even by conventional breeding. Physiological and biochemical processes and mechanisms underlying allelopathy, related changes in growth, shape, micro- and ultra-structure of plant cells, their walls, organelles and their mitotic activities that were related with the effects of allelochemicals. The imbalances in their antioxidant systems, changes in activities of ROS, redox balances and related enzyme activities, increases in cell membrane permeability as a result of higher membrane lipid peroxidation levels and membrane potential alteration and several other effects had been reported.

The allelopathic effects on the PGR system were also discussed by Cheng et al.; the results of a number of studies on the alterations in PGR contents, imbalances with respect to germination, growth and development, such as the effects of phenolic allelochemicals on IAA oxidase, POD activity on IAA, bound GA or IAA, changes of ABA levels, inhibition of ethylene synthesis by SA, and number of other interactions were presented. Similar changes in the functions and activities of numerous enzymes, such as the inhibition of λ-phosphorylase, the key enzyme involved in seed germination by chlorogenic acid, caffeic acid and catechol, POD, CAT, and cellulase suppression by tannic acid, phenylalanine ammonialyase (PAL) and β-glucosidase by tannic acid were also included in the review article. They also covered the effects of allelochemicals on photosynthesis, respiration, related changes in pigment and ATP metabolisms, water and nutrient uptake, inhibition of Na^+/K^+-ATPase activity which was involved in the absorption and transport of ions at the cell plasma membrane, and suppressing the cellular absorption of K^+, Na^+, or other ions. They referred to several articles on inhibition of ammonium and NO_3^-, Cl- uptake and K^+ loss by 250 μM ferulic acid by wheat, diminished NO_3^-, SO_4^{2-}, K^+, Ca^{2+}, Mg^{2+}, and Fe^{2+} uptake by cucumber seedlings under the effect of cinnamic acid. They also presented references showing that the effects of allelochemicals on ion uptake were closely related to their concentrations and classifications; at low concentration dibutyl phthalate, for instance, was increasing absorption of N, but decreasing that of P and K.

Cheng et al. also reviewed the effects of some alkaloids possessing allelopathic potential, and focussed on their influences on nucleic acid and protein metabolisms. They added that some could integrate with DNA, or prevent the transcription and translation of DNA by inhibiting DNA polymerase. Some of them could also interfere with protein synthesis, by inhibiting amino acid absorption and transport; subsequent effect was retardation of cell growth.

Phenolic acids could affect the integrity of nucleic acids. They referred to studies showing that the genes involved in reactions of allelochemicals could be categorized as the ones interacting with the environment, subcellular localization, proteins with a binding function or cofactor requirement, cell rescue, defense and virulence, or metabolism. The plant response to allelochemicals was similar to the response to biotic or abiotic stres. Allelochemicals might have relevant functions in the cross-talk between biotic and abiotic stress signaling, as they generate ROS. Cheng et al., in fact, referred to a comprehensive article reporting findings showing that the allelochemical receiving plants were reacting by inducing changes in gene expressions, leading to synthesis of enzymes involved in the biosynthesis of phenolic compounds.

Under the subtitle of "Effects of Allelochemicals on Microorganisms and the Ecological Environment" they discussed the literature that had evidented the presence of significant relationships between crop growth and soil microbiota; importance of indirect effects of allelopathy as a mediator of plant–plant interactions. They drew attention to chemical-specific changes in soil microbes, which could generate negative feedbacks in soil health and plant growth, while the members of microbiome rhizosphere were contributing to the allelopathic potential of plants through positive feedback. This contribution was helping to increase inhibition by activating a non-toxic form of an allelochemical, however, Cheng et al. said, bacteria could also help susceptible plants to tolerate biotic stress associated with weeds, and to decrease the allelopathic inhibition of weeds by causing alterations in the expression patterns of some genes. These genes might be responsible for different functions, but they ultimately lead to a self-defense process. Bacterial biofilms in rhizospheric regions could protect colonization sites from phytotoxic allelochemicals by degrading them. In conclusion, they referred to several studies supporting the idea that microorganisms were able to shape the vegetation composition and participate in the control of biodiversity by altering the components of allelochemicals present in the ecosystem. They also presented a schematic diagram showing the various roles of microbes in modulating the interactions of allelopathic donor-receiver species explaining how beneficial rhizobacteria could minimize the phytotoxicity of the allelopathic donor by using various rhizospheric processes. This observation was supported by presenting some references on the alteration of plant gene expression by changes in root-colonizing PGPR.

Finally Cheng et al. attracted attention to the complex nature of the allelopathy, covering environmental factors including both abiotic and biotic factors, changes in the composition of the allelochemicals released into the environment, their persistence andd affecting factors. Considering the results of the vast literature on allelopathy showing its application potential in agricultural production at small-scales, regional areas and the disadvantages associated with the methods, such as the evolution of herbicide resistant weeds, pollution, toxicological effects etc., they proposed to create diversity in weed control practices with the application of allelopathy.

Li, Meng, Chai et al (2019) took the greenhouse studies showing improvement of plant drought resistance by arbuscular mycorrhizal fungi (AMF) into consideration, and investigated the effects of AMF on drought resistance and productivity of grassland containing plants with different photosynthetic pathways in field conditions. They reported the results of the *in situ* rainfall exclusion experiment, which was conducted in a temperate meadow and showing that AMF significantly reduced the negative effects of drought on plant growth. On average, they said, AMF was enhancing plant biomass, photosynthetic rate (*A*), stomatal conductance (g_s), intrinsic water use efficiency (iWUE), and SOD activity of the C_3 species *Leymus chinensis* by 58, 63, 38, 15, and 45%, respectively, reduced levels of MDA by 32% under light and moderate drought condition exerted by excluding rainfall 30 and 50% of rainfall respectively. At 70% exclusion level, extreme drought condition, AMF elevated only aboveground biomass and CAT activities. Under light and moderate droughts AMF increased the aboveground biomass, *A*, and CAT activity of C_4 plant *Hemarthria altissima* by 37, 28, and 30%, respectively. As it could be expected the contribution to drought resistance was higher for the C_3 sp. under both light and moderate drought conditions. They concluded that photosynthetic type was important in the magnitude of AMF-associated enhancement in plant drought resistance, thus AMF should be taken as a determinant in plant community structure projections for future climate change scenarios affecting the drought resistance of different plant functional groups.

Li et al(2019) drew attention to the literature reporting that AMF group was one of the most important groups of soil organisms, because they were functioning as mycorrhizal symbionts with the roots of approximately 72% of plants and could improve the growth of hosts by promoting nutrient and water uptake to alleviate the impacts of drought and other abiotic stresses. Since AM fungal hyphae were able to explore soil pores and access to water and nutrient sources that could not be reached by plants themselves, AM were improving plant performance, especially under drought stress. They also referred to some studies, which showed that AMF could also increase WUE by improving stomatal conductance (g_s) and reduce peroxidative damage by increasing antioxidant enzyme activities at greenhouse conditions. There were other experimental studies referred, which had evidented the upregulation of plant physiological performance to tolerate the impacts of drought, salinity, and cold stresses by upregulation of antioxidant enzyme activities and synthesis of jasmonate hormones. Although the knowledge on the biogenic emissions of volatile organic compounds from the higher plants started to accumulate a long time ago, and was reviewed by Fall (1999) in the book titled Reactive Hydrocarbons in the Atmosphere; as far as I see, this topic is still not very popular in evaluation of the effects of abiotic stresses related with global warming.

Fall covered ethylene hormone, but not methyl salicylic acid (MeSA) in his article, Liu, Kaurilind, Jiang et al. (2018), however, described the role of this volatile hormone in their article as a long-distance signal transduction chemical, that was playing an important role in plant responses to abiotic stress and also herbivore and pathogen attacks. They added that, it was unclear how photosynthesis and elicitation of plant volatile organic carbons (VOC) from different metabolic pathways respond to MeSA doses.

Liu et al (2018) applied different MeSA concentrations, within 0-50 mM range, to study alterations in VOC profiles of silver birch (*Betula pendula* Roth) leaves from application through 23 h recovery period. They showed that the application significantly reduced net assimilation rate in 10 mM and 20 mM MeSA-treated plants, without any significant effects on the stomatal conductance, elicited emissions of benzenoids (BZ), monoterpenes (MT) and fatty acid derived compounds (LOX products). While emission rates of benzenoids (BZ) were increasing, emission rates of monoterpenes (MT) were decreasing with the increase of MeSA concentrations; but total emission of LOX products was not influenced by changes in MeSA concentration. They reported that emission rate of MT was negatively correlated with BZ, and its share in the total emission blend decreased, the share of BZ, on the other hand, increased with increasing MeSA concentration. Overall, they said, the results demonstrated inverse responses of MT and BZ to different MeSA doses; lower doses induced plant defense mechanisms leading mainly to enhanced MT synthesis, whereas greater doses triggered BZ-related defense mechanisms. Liu et al. assessed the results as the evidences that would contribute to improving the understanding of induction of birch defenses upon regular herbivore attacks and pathogen infections in boreal forests.

As shown by Aminfarzaneh et al. (2010) TRIA and SA could support each other in increasing the growth and pollutant resistance of cyanobacteria; Baba, Ali, Kumar et al. (2017) found that, although the growth characters and yield of strawberry (*Fragaria* x *ananassa* Duch. cv. Camarosa) increased by 2 mM SA and 10 µM TRIA foliar sprays; but, their effects were not additive for all the studied parameters. This is another example of the need for organizing the research projects by selecting prospective parameters and combining efforts for finding efficient solutions to mitigate the harmful effects of global warming and climate change.

Agroforestry, for instance does not receive much attention from plant physiologists, although it is accepted as a practice for sustainable land use system, an alternative form of biological reclamation of soils apart from sustainable production, continuous income, regular employment along with food and nutrition security, as described by Behera, Nayak & Patel et al. (2015). The results of their study showed that trees grown with grain crops, horticultural crops or pastures resulted in improvement of physical and chemical properties of soil under various agroforestry systems. Improvement of water permeability and water holding capacity, infiltration rate and hydraulic conductivity, soil fertility enhancement and other features were the characteristics of soil as influenced by tree species, as well as through agroforestry practices.

The article on the contribution of agroforestry trees to nutrient requirements of intercropped plants published 25 years ago, which was mentioning that prunings of several tree species were containing sufficient nutrients to meet crop demand with the notable exception of P by Palm at 1995, and cited in 231 research papers. In spite of the of the academic interest, even the titles of some recently published articles on agroforestry show that it is still not a well understood and widely accepted in practice. “Building Agroforestry Policy Bottom-Up: Knowledge of Czech Farmers on Trees in Farmland” by Krcmarova, Kala, Brendzova (2021), “Changing the Agriculture Paradigm in the Brazilian Atlantic Forest: The Importance of Agroforestry” by Tubenchlak, Badari, Strauch et al. (2021) can be presented as good examples of this neglectance.

As a matter of fact, Miller, Ordoñez, Brown, et al. (2019) complained in the “2.4 Results and authors’ conclusions” section of their comprehensive article that, although their study had revealed rigorous evidence on the positive effects of agroforestry, the interventions on farmers’ land was remaining extremely limited. They found this result especially notable in the light of the present large volume of literature documenting the uptake of specific agroforestry practices, and also widespread promotion of agroforestry as a strategy to advance the Sustainable Development Goals (SDGs) 2030 by UN. They added that, it was also surprising to observe the general reluctance in spite of the given the relative prevalence of impact evaluations in the related fields of agriculture and forestry. The studies proved that a major benefit of agroforestry was the maintenance of soil fertility, this conclusion is based primarily on observations of higher crop yields near trees or where trees were previously grown. Recent objective analyses and controlled experiments have addressed this topic. This paper examines the issues of tree prunings containing sufficient nutrients to meet crop demands, as referred above.

The article by Carvalho de, Tavares, Cardoso et al. (2010), was one of the publications stressing the importance of beneficial biological interactions between micro-organisms and plant species, especially those formed by AMF and roots. After reminding the viability of AF systems as an alternative to the preservation of natural resources and contribution to food production, they added that the contribution of beneficial biological interactions were increasing the soil volume explored by the roots, nutrient absorption, protection of the roots against pathogens, toxic elements and certain heavy metals, helping the formation and maintenance of soil structure, increasing the input of soil C, and contributing to the maintenance of biodiversity. The potential of the AF systems to maximize the benefits associated with AMF could consecutively mitigate negative interactions between trees and annual crops, and this special symbiosis was deserving further studies. Although they noted the challenges in evaluation of impacts of complex AF systems, they stated that the presence of multiple benefits of AF contributing to a number of the SDGs simultaneously should be taken into consideration, and many more high-quality studies on the effects of AF interventions on agricultural productivity, ecosystem services, and human well being should be performed without losing time.

Rouffael & Colla (2020) also drew attention to the concomitant challenges of rising productivity in agriculture while reducing the environmental impacts. They reviewed the developments in the use of environmental-friendly natural plant biostimulants (PBs) that were shown to improve the tolerance against a wide range of abiotic stressors, in addition to flowering, plant growth, fruit set, crop productivity, and NUE. They added that the European Commission had assigned an *ad hoc* study on plant biostimulants to evaluate the substances and materials involved; referring to the related publication, they conveyed the definition as "Plant biostimulants are substances and materials, with the exception of nutrients and pesticides, which, when applied to plant, seeds or growing substrates in specific formulations, have the capacity to modify physiological processes of plants in a way that provides potential benefits to growth, development and/or stress responses". Rouffael & et al. (2020) specified PBs as very heterogeneous materials, such as humic substances, complex organic materials obtained from agro-industrial and urban waste products, sewage sludge extracts, composts, and manure, beneficial chemical elements, such as Al, Co, Na, Se, and Si, inorganic salts including phosphite, seaweed extracts obtained from brown, red, and green macroalgae, chitin and chitosan derivates, kaolin and polyacrylamide antitranspirants, free amino acids and peptides, polyamines, betaines, excluding microbial biostimulants. They referred to an updating report titled as "Biostimulants in Horticulture", which was supported by scientific evidence about the mode of action, nature and types of effects of PBs on agricultural and horticultural crops: "A plant biostimulant is any substance or microorganism applied to plants with the aim to enhance nutrition efficiency, abiotic stress tolerance and/or crop quality traits, regardless of its nutrient content", and stated that it could be completed by adding "By extension plant biostimulants also designate commercial products containing mixtures of such substances and/or microorganisms"to it.

Rouffael et al. (2020) referred to some articles published in 2015 on categorisation of PBs: chitosan, humic and fulvic acids, protein hydrolysates, phosphites, seaweed extracts, silicon, AMF, PGPR; and *Trichoderma* spp. They added that according to the new EU Regulation 2019/1009by, a plant BS should be an fertilising product stimulating NUE independently of the product's nutrient content by improving one or more characteristics of the plant or its rhizosphere, abiotic stress tolerance, quality traits, or availability of confined nutrients in the soil or rhizosphere. BSs have been classified accordingly on the basis of agricultural function claims of the diverse bioactive natural substances: humic and fulvic acids, animal and vegetal protein hydrolysates, macroalgae seaweeds extracts, silicon, and beneficial microorganisms including AMF and N-fixing strains of *Rhizobium*, *Azotobacter*, and *Azospirillum*. However, Rouffael et al. added, as the justification of agricultural claims had been considered in accepting PBs as sellable in EU market, the members of the European Biostimulant Industry Council had proposed general principles and guidelines for trials and assays to follow when justifying PBs claims.

By drawing attention to the publication of more than 700 scientific papers within 2009–2019 period on the topic, Rouffael et al. clearly demonstrated the capability of microbial and non-microbial PBs in inducing an array of morpho-anatomical, biochemical, physiological, and molecular plant responses, such as boosting crop productivity, NUE and increasing tolerance against abiotic stresses. On the implications for agronomic and physiological traits of crops, they referred to some studies relating the stimulation of germination, seedlings and plant growth, crop productivity to the action of signaling bioactive molecules in the primary and secondary metabolisms. They gave gelatin hydrolysate treatment as an example, which was shown to increase the expression of genes encoding for amino acid permeases, transporters of amino acids and nitrogen. These effects lead them to conclude that the hydrolysate was a biostimulant and sustained source of N. Rouffael et al. also presented a number of experimental research reports evidenting that some commercial PBs boosted shoot fresh weight, or stimulate the growth of epiphytic bacteria such as *Pseudomonas* and *Bacillus* spp. with Plant growth promoter (PGP) synergistically with organic compounds against pathogens, and so on. They added that use of bioactive natural substances and microbial inoculants were representing a valuable tool to enhance soil nutrient availability, increased NUE and nutrient assimilation, in particular N and P, which are known to be fundamental for economical and environmental reasons.

Under the subtitle "Implications of Biostimulants for Abiotic Stresses Tolerance" Rouffael et al. referred to an article stressing the importance of 70% of yield gap imposed by unfavorable environmental and soil conditions, which were dictated by global climatic changes. Another increase expected was the negative impact posing serious concerns on crop productivity and worldwide food security. They also made mention of another study suggesting the application of non-microbial and microbial PBs, in order to overcome this situation as one of the most promising and efficient drivers toward further yield stability. Presentation of several experimental studies supporting this conclusion, such as the metabolomic approach that had allowed the identification of the molecular mechanisms of improved drought tolerance following the BS treatment is definitely convincing. Improved tolerance to ROS-mediated modulation of phytohormones and lipids profiles, hormonal effects of an animal-based protein hydrolyzate (PH) containing L-α amino acids, free amino acids, organic-nitrogen, iron, and potassium on water-stressed tomato plants, the application of animal-based PH benefited an antioxidant protection and exerted a major hormonal effect in tomato water-stressed leaves by increasing the endogenous content of auxin, cytokinin, and jasmonic acid can be mentioned as few examples given by Rouffael et al. here.

They referred to a study reporting and evaluating physiological and molecular responses of tomato plants towards two AMF strains, which promoted their tolerance toward drought stress. One of the strains was found to be more effective on VOC production, the other exhibited the best performance traits by increasing WUE under severe drought stress, and was effective against combined abiotic and biotic stresses. In another referral study they presented, it was shown that mycorrhizal plants had higher water extraction rates per unit root length and higher biomass; substrate colonization by AMF that engaged in a functional symbiosis stabilized water retention and enhanced unsaturated hydraulic conductivity of the substrate. Theoretically, they said, enhanced hydraulic conductivity in AMF substrates constituted an effective enlargement of the water depletion zone around roots. Finally, the authors concluded that further studies should investigate how this would quantitatively contribute to water acquisition by plants and the variability of the effect across different soils.

Rouffael et al. also mentioned that several combinations of of several halotolerant PGPR isolates of *Bacillus* spp. isolated from the rhizosphere of durum wheat cultivated in hypersaline environments boosted plant growth traits of mungbean, and this finding lead them to conclude that such specific strains could be used as drought tolerant PGPR under open field conditions. Actually, they presented numerous examples of experimental studies proving that non-microbial and microbial PBs could also be considered a possible way to enhance tolerance to stress conditions, by affecting several biochemical and physiological mechanisms, such as decreased membrane lipid peroxidation, increased chlorophyll content, improved antioxidant activities, and a better efflux and compartmentation of intracellular ions. Another important point they stressed was the demonstration of mitigation of the negative effects of salinity on wheat seedlings grown under saline conditions by the polysaccharides derived from brown and red algae (*Pyropia yezoensis*). Experimental results of a referral study, for instance, lead them to conclude that the lower-molecular weight polysaccharides were effective in protection of wheat seedlings against salt stress damage by coordinating the efflux and compartmentation of NaCl and by enhancing antioxidant activities. The excellent review article by Rouffael et al. conclusively evidented that use of various BS products were offering a vast potiential to be exploited for several purposes; 5-aminolevulinic acid application, for instance, was shown to protect photosynthesis capacity, omeprazole (OMP) was protecting root system, affecting hormonal network by eliciting an increase in ABA, accompanied by a decrease in auxins and cytokinins, as well as a tendency in GA down accumulation.

Finally, Rouffael et al. discussed the value of current achievements and the challenges ahead, referred to the suggestion in a previous article recommending to the main players of PBs, covering scientists, industries, legislators, and stakeholders to focus on the development of a more sustainable and resilient second generation PBs with specific synergistic biostimulatory action through the application of both microbial and non-microbial ones.

Le Bayon, Bullinger, Schomburg et al. (2021) pointed the importance of increase in the recognition of the role of soil science by the engineers out in their review article. They focussed on the role of two parameters, plants and their root systems associated microorganisms and also earthworms. They explained the reason of their selection of these two parameters as 'ecosystem engineers', as they called them, on the grounds of numerous variables, such as texture, porosity, nutrient, and moisture dynamics controlling their activities in space and time, namely hotspots and hot moments. Then, they reviewed the roles of these engineers in three soil formation processes: rock and mineral weathering, soil formation, structure, stabilization and disintegration, finally bioturbation processes; they also covered the mechanisms involved at spatial scales, ranging from local to landscape.

It was added by Le Bayon et al. (2021) that tree uprooting was playing a key role in rock weathering and soil profile bioturbation, the living and dead roots had contribution to rock alteration and aggregation. Earthworms were mainly involved in the formation of aggregates and burrows through their bioturbation activities and also in weathering processes to some extend. They showed the contributions of the two main ecosystem engineers to provision and regulation of services through burrowing and soil aggregation, and also increasing plant productivity, water infiltration, and climate warming mitigation by acting as catalysts and providing, transforming and translocating organic matter and nutrients throughout the soil profile. They added that the concomitant contributions of their inter- and intraspecific interactions and/or symbiosis with microorganisms were increased soil fertility, decreased parasitic actions, and bioremediation of some pollutants. Considering these benefits, Le Bayon et al. noted that better understanding of the relationships between soil management, agricultural practices and soil biota was needed for relevant maintenance and durability of ecological services.

The President of the World Farmers' Organisation (WFO) since June 2017, De Jager, T. (2021) wrote in his article titled "Do You Want to Tackle Climate Change in Times of Pandemic? Roll Up Your Sleeves and Put Your Fingers in the Soil!" that Before COVID-19 outbreak protecting the Planet while ensuring Food Security was the priority number one in the international community. In the pandemic era, he said it was key to leverage to build back better and incorporate a reinvigorated approach to both mitigation and adaptation to ensure food security for a growing global population to enhancing biodiversity. As several referral researchers in the present article, he also mentioned a key ingredient of success was a coordinated, mutually beneficial and trustworthy engagement of the different stakeholders in different sectors of the whole food value chain at multiple levels. He reminded the foundation of "The Climakers"global farmers driven initiative in 2018 in World Farmers' Organisation, which took the Organisation into every corner of the globe. He added that, this initiative let them to discuss how to trade a little lighter across the pastures and to make a smaller footprint across the cultivated fields. The Climakers multistakeholder alliance, he said, was giving the farmers the chance to cooperate with all other actors in the value chain, research and civil society to promote better national commitments and ensure long-term sustainability on a healthier planet. He added that thinking on climate change in the perspective of food systems, there was only one entry point to all the challenges for every farmer: soil health.

As De Jager (2021) put it, a major C sink, health of soil was an entry point to multiple benefits, from addressing climate change mitigation through sequestration to strengthening resilience, enhancing biodiversity, improving food security and nutrition, as well as improving the livelihood of farmers and rural communities. He, finally said that, the dream of the possibility of having a global program to capture enough C and add to the soil as organic matter would be a significant contribution to combating global warming.

Congressional Research Service of U.S.A., in fact, calculated the efficiency of "Selected Carbon-Sequestering Management Practices in Use in U.S. Croplands"(Croft, 2020). After reminding the significant contribution of agricultural practices to net Greenhouse Gas (GHG) emissions, it was emphasized that certain practices could reduce them to certain extent. These practices were listed as follows: no-till or reduced-till land management and use of cover crops, compost, and manure, which were generally reducing soil exposure to air and increaing plant root growth. It was added that the combination of multiple practices might further increase C storage in soils. The adoption of C-sequestering practices would depend on factors requiring for certain equipment, labor and varied widely in the U. S. Management Practice Acres (millions) % of 396 million acres Total Cropland were presented as No-Till (includes Rotational Till) 105 (27%), Reduced-Till 98 (25%), Cover Crops 15 (4%).

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