Chapter

Excessive and Disproportionate Use of Chemicals Cause Soil Contamination and Nutritional Stress

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Abstract

Incredible achievements have been made in agricultural production worldwide, but many daunting challenges remain unresolved to ensure food security and environmental sustainability. Chemical fertilisers are used in excessive and disproportionate quantities to raise crop yields in order to combat certain circumstances. However, apart from being processed in crop plants, chemical fertilisers above the threshold level pollute the atmosphere. As the availability of nutrients becomes a constraint of plant growth and production, sustained crop productivity relies on constant renewal. To increase agriculture production and maintain soil fertility, the application of chemical fertilisers is indispensable. However, insufficient or unnecessary application of fertiliser does not guarantee consistently growing yields, which can result in low efficiency of nutrient usage. Today, the key goals are the study of the effective use of chemicals, the reduction of production costs and the efficient use of fertilisation.

Keywords: soil, chemicals, agriculture, toxicity, fertility

1. Introduction

Soil is a very important and sensitive resource of a nation. In order to meet increasing public needs and to promote crop products, the use of high inputs of chemicals in the soil in the form of fertilisers, pesticides, fungicides, insecticides, nematicides and weedicides, along with intensive irrigation practises, helped to achieve the target to a certain stage. However, the decrease in crop yield took place despite the application of fertiliser. The toxic chemicals influence the life of beneficial soil microorganisms, which are indeed responsible for maintaining soil fertility. Moreover, groundwater, air, and human and animal health have also been adversely affected by these chemicals directly and indirectly. Therefore, preserving the health of the soil is very essential. The avoidance of chemical fertilisers and the use of natural fertilisers such as biofertilizers, vermicompost, green manure and biopesticides, as well as the nourishing of the soil and the environment, can be a sustainable approach to crop productivity.

In order to boost crop quality and satisfy the global demand for food, chemical formulations being introduced as fertilisers and pesticides in appropriate amount are important for food management resources in agriculture. On the other hand, if used in excessive and disproportionate amount, there are harmful aspects of inorganic fertilisers and pesticides that can not be ignored. They persist for a long time in the soil and atmosphere and influence various biotic and abiotic factors. They negatively influence soil, microflora, other organisms, human health and the environment. The excessive quantities of agrochemicals, industrial chemicals, trace metals and urban waste enter the soil through atmospheric deposition, disposal of waste, industrial effluents and direct application¸ and pollute it [1–3]. Soil contamination is responsible for decreasing the soil biodiversity and fertility and hence, decrease soil health by obstructing the breakdown of soil organic matter and altering nutrient cycling. The contamination of soil, therefore reduces crop yield and affects food safety, especially when bioconcentrated pollutants enter organisms within food chains [4].

Through their roots, plants can also take up soil pollutants or absorb them through their leaves. The prolonged intake of infected foods, including human beings, can cause disease and lead to animal deaths [5]. In particular, urbanisation causes soil contamination in peri-urban areas, which have to deal with urban air pollution deposition and municipal solid waste disposal [1, 6]. Acid rain decreases soil aggregate stability, affects soil microorganisms and enzyme activities, increases soil erosion and mobility of nutrients, and in turn contribute to loss of nutrients [1, 7–9]. Soil pollution is also linked to the water quality used for irrigation purposes and to flooding events. Industrial and urban sewage is rapidly being adopted for irrigation to meet the rising demand for drinking water. This is particularly common in countries facing rapid urbanisation rates, such as China, where contaminated water and sewage have irrigated 3.62 million ha of agricultural land [1]. Due to atmospheric accumulation, industrial waste and the use of waste water for irrigation, soil contamination from trace metals is prevalent in peri-urban areas [1, 10, 11]. Trace metal supply is directly influenced by plant root exudates and by the activities of soil microorganisms. Owing to the high sensitivity of soil microorganisms to excessive trace metal concentrations, they are responsible for reducing soil biodiversity and fertility [12, 13]. Moreover, due to their close affinity with organic matter, trace metals accumulate in surface organic deposits, and passively taken up by plants by water flow [14]. Studies have documented the accumulation of trace metals in agricultural foods with high concentrations in stems and leaves rather than in fruits and seeds [15].

Intensive cultivation and mono-cropping have contributed to a large increase in the usage and reliance on agrochemicals. Fertiliser and pesticide soil contamination is due to inadequate management of nutrients in combination with pest and weed mismanagement, respectively [4]. In addition, because their behaviour in the environment and especially in the food chain is not comprehensively understood, the fate of pesticide metabolites is of concern [16]. The growth of the population raises the risk of pollution of the soil. Food protection is thus threatened by the presence of toxins and by the associated risks of bioaccumulation. Soil contamination is responsible for reducing crop yields and for turning productive agricultural land into unproductive areas by decreasing soil fertility and biodiversity. As a result, the food availability and stability dimensions of food security are affected by this. Food accessibility is challenged by the extent and spatial distribution of soil pollution, which, in particular in urban and peri-urban areas, restricts food access. Soil pollution is, therefore, a hazard to all dimensions of food safety.

2. Healthy soils: a prerequisite for sustainable food security

Soil health is defined as a living soil's ability to function within natural or regulated ecosystem boundaries, to preserve productivity of plants and animals, to conserve and enhance the quality of water and air, and to promote plant and animal health [17, 18]. Therefore, soil health is a multi-dimensional and holistically vital soil characteristic, and forms the basis for healthy food production, thereby contributing to local and global food security. By 2050, a 60 percent rise in global food production and related ecosystem services need to be accomplished. But, through soil erosion, nutrient loss, salinity, sealing and pollution, one-third of global soils are currently facing moderate to extreme degradation.To achieve sustainable soil management, evidence-based decisions and soil information are essential [19]. Soils impoverished by nutrients lead to systemic food and nutritional problems. Micronutrient deficiencies are significant cause of morbidity and mortality, and affect over two billion people [20–23]. Protein-energy malnutrition is due to food scarcity and ingestion of trace elements (i.e. iron, lithium, magnesium, zinc, copper, iodine) from crops with low tissue concentrations, which are directly attributable to nutrient-poor soils [24].

3. Impact of chemicals used in agriculture on environment

Since the chemical fertiliser increases the growth and vigour of the plant, it thus meets the world's food security, but the plants grown in this way do not develop good plant characteristics such as good root system, shoot system, nutritional characteristics and will not have time to grow and mature properly [25]. The deleterious effect of chemical fertilisers itself begins with the processing of chemicals whose products and by-products are certain harmful chemicals or gases that cause air pollution, such as NH_4, CO_2, CH_4, etc. And it will cause water pollution when the waste from industries is disposed of untreated in nearby water bodies. It also involves the most damaging impact of the accumulation of chemical waste in the bodies of water, i.e. water eutrophication. And its constant use, when applied to the soil, degrades the health and quality of the soil, thereby causing soil contamination. It is therefore high time to realise that our climate and biodiversity are depleted by this crop production input. Therefore, its continuous use without taking any remedial action to reduce or judicious use will one day deplete all natural resources and threaten the entire life of the earth. The adverse effects of these synthetic chemicals on human health and the environment can be reduced or eliminated by adopting new agricultural technological practises, including the use of organic inputs such as manure, biofertilizers, biopesticides, slow-release fertilisers and nanofertilizers, etc., and moving away from chemical intensive cultivation.

4. Influence on soil compaction and degradation

Soil compaction is an important component of the syndrome of land degradation and is a major problem for advanced agriculture, affecting soil resources adversely [26]. As the soil is compacted, its composition changes by crushing aggregate units, decreasing the size of pore spaces between the soil particles, decreasing compaction due to the use of heavy equipment, reducing the use of organic fertiliser, repeated use of chemical fertilisers, and ploughing for several years at the same depth [27]. One of the principal causes of compaction is the usage of fertilisers more than the recommended amount for long periods and intensive cropping. Soil compaction causes problems such as excessive soil strength, root growth restriction, poor aeration, poor drainage, runoff, erosion and deterioration of the soil, etc. [28]. Such modifications lead to permeability, hydraulic conductivity and groundwater recharge reductions [29]. Excessive soil compaction impedes root growth and this decreases the capacity of plants to absorb nutrients and total porosity, leading to an increase in the density of soil bulk and resistance to penetration. It is reported that compaction decreases both root growth and yield by more than 80 percent [30]. Nitrification decreases by 50 percent as the density of soil bulk increases and plants consume less N, P and Zn from soil [31]. A great concern is the reduction of biological activities in soil due to compaction [32]. The most significant element in soil structure stability is organic matter. Soil that has high organic matter content and thrives with soil species is more compaction-resistant and can recover much better from mild damage to compaction [33, 34]. Over-use of fertilisers has led the development of continuous monoculture cropping, accumulation of fertiliser mineral salts in soil that forms compaction layers in soil, and cause long-term soil degradation.

5. Disproportionate usage of chemicals and soil nutrients

The soil is a home for soil organisms which are a mechanism for nutrient recovery, and offers many other environmental services. Chemical fertiliser overuse can contribute to soil acidification and soil crust, thereby reducing the content of organic matter, humus content, beneficial species, stunting plant growth, altering the pH of the soil, growing pests, and even leading to the release of greenhouse gases. The acidity of the soil reduces crop phosphate intake, raises the concentration of harmful ions in the soil and inhibits crop growth [35]. The soil's loss of humus decreases its capacity to store nutrients. The atmosphere is polluted by greenhouse emissions resulting from the excess use of nitrogen fertiliser. Over the time nitrogen fertilisers added in large quantities to fields kills the balance between the three macronutrients, N, P and K, resulting in decreased crop yields. Sandy soils are much more vulnerable to soil acidification than clay soils. Clay soils have the potential to buffer excess chemical fertilisation effects. Repeated chemical fertiliser applications may lead to a toxic build-up in the soil of heavy metals such as arsenic, cadmium, and uranium. Not only do these toxic heavy metals pollute the ground, but they also accumulate in food grains, fruits and vegetables. Fertilisers such as triple superphosphate, have trace elements such as cadmium and arsenic that accumulate in plants and enter humans via food chains that can cause health problems [36]. Application of fertilisers without the recommendation of soil testing can lead to implications such as soil degradation, nutrient imbalance, soil structure destruction, bulk density increase [37].

When crop plants are harvested, soil nutrient levels are reduced over time, and these nutrients are replenished either by natural decomposition or by adding fertilisers. Therefore, the basic component of modern agriculture thesedays is fertiliser. However, while chemical fertilisers are the main cause of adequate crop production for the world's population, their overuse presents serious challenges for present and future generations, such as contaminated air, water and soil, degraded land, soils and increased greenhouse gas emissions. Not only are these synthetic fertilisers being harmful to our climate, but also to humans, livestock, and microbial forms of life. It is high time that everyone realises the detrimental effects of using excess chemical fertilisers and take steps to minimise the usage of chemical fertilisers and pesticides by substituting other organic modifications such as organic manures that not only provide plants with essential nutrients, but also preserve soil quality for subsequent crops. There are so many other technologies that are being developed, such as slow or controlled released fertilisers, prilled or granulated fertilisers, inhibitors of nitrification, nano-fertilisers, etc., all of which are the promising alternatives that can be used to solve these serious challenges and save both our environment and the ecosystem [35].

6. Microbial community structure

Soil microorganisms play an important role in the conservation of soil fertility and ecosystem work [38, 39]. The plant roots secrete carbon-containing organic material in the rhizosphere which is the source of carbon, nitrogen and energy needed for the growth and reproduction of soil microorganisms. A large number of microbes gather around plant roots, which results in a distinction between the state of soil nutrients and the composition of the soil microbial population [40]. The region with the greatest contact between plant roots, soil and microorganisms is the rhizosphere. Microbes of the rhizosphere play an important role in the cycling of soil material and the transfer of energy. Fertiliser application is an important management measure in agricultural production that not only promote crop growth and yield but negatively influence the soil microorganisms as well [41]. The widespread use of chemical fertilisers currently leads to a decline in soil fertility and a number of environmental problems, while bioorganic fertiliser not only improves soil fertility through the contribution of beneficial microorganisms and organic materials, but also eliminates many of the environmental problems caused by chemical fertilisers. Studies have shown that various fertilisation treatments have a significant effect on the structure of soil microbial biomass and the community. Different applications of fertilisers change the physical and chemical properties of the soil, which in turn affects the structure of the soil bacterial community. Previous studies have found that pH, nitrate, and available phosphate and potassium are significant soil factors that influence the structure of the microbial community [9, 42]. By direct effects on the quality of soil nutrients, fertilisation affects soil microbial diversity. In conjunction with other mineral fertilisers, the long-term application of nitrogen fertiliser influences the nitrogen cycle and associated bacterial populations. Repeated overuse of chemical fertiliser may have a detrimental impact on the quality of soil and the composition of the soil microbial population. Long-term use of chemical fertilisers can dramatically decrease soil pH, which is closely related to reduced bacterial diversity and major changes in the composition of the bacterial population [43].

7. Potential of biofertilizers to replace chemical fertilisers

As the land for agriculture is restricted and even diminished over time, the worldwide increase in the human population poses a major threat to the food security [44]. It is therefore important that agricultural productivity should be dramatically improved over the next few decades in order to meet the high demand for food from the emerging population. Furthermore, too much reliance for crop production on chemical fertilisers ultimately affects both environmental ecology and human health with great severity. A biofertilizer is a material that contains living microorganisms that colonise the rhizosphere or the interior of plants when applied to seeds, plants or soil and encourage plant growth by increasing the host plant's supply of nutrients [45]. The use of microbes as biofertilizers in the agricultural sector is considered an alternative to chemical fertilisers because of their wide potential to increase crop production and food safety [38]. Extensive work on biofertilizers has revealed their ability to supply the crop with the requisite nutrients in sufficient quantities to increase crop yield. Biofertilizers are widely used to accelerate certain microbial processes that increase the availability of nutrients that can be easily assimilated by plants. By fixing the atmospheric nitrogen and solubilising insoluble phosphates, biofertilizers increase soil fertility and produce plant growth-promoting substances in the soil [45].

The naturally accessible biological system of nutrient mobilisation, which greatly increases soil fertility and ultimately crop yield, has been encouraged by biofertilizers. Biofertilizers are expected to be a healthy alternative to chemical inputs and to a great extent mitigate ecological disruption. Biofertilizers are cost-effective in nature, eco-friendly, and their extended usage greatly increases soil fertility. It has been stated that the use of biofertilizers increase the protein content, essential amino acids, vitamins, and nitrogen fixation, thereby increases crop yield by about 10–40 percent [46]. The advantages of using biofertilizers include low-cost nutrient sources, excellent microchemical and micronutrient suppliers, organic matter suppliers, growth hormone secretion, and the counteraction of chemical fertiliser adverse effects. Microbes are important soil components and play a crucial role in the different biotic activities of the soil ecosystem that make the soil dynamic for the mobilisation of nutrients and sustainable for the production of crops [47].

8. Improving soil fertility

Physical fertility refers to the soil's physical properties, its composition, texture, water holding properties, the way water flows to the roots of plants, and how the soil is penetrated by those roots. Biological fertility refers to the species and their capacity to play important roles that live in the soil. A soil's composition, its acidity or alkalinity, and its ambient temperature are only a sample of the several variables that decide the degree to which plants have access to nutrients [9]. The relative value of these variables depends on the nutrients, the soil and the plant. Most notably, soil structure determines how well the soil holds nutrients and water. Organic matter-containing clays and soils retain nutrients and water much better than sandy soils. The microbial community of the soil would also be highly influenced by the soil structure. If the soil does not allow these species to survive, plants that rely on bacteria or fungal species for nutrient uptake will not grow. Until recently, the application of fertiliser was the most commonly used treatment for nutrient deficiency. As plant nutrient requirements vary over the plant life cycle, timing is also important. The effect of Liebig 's Law may obscure the identification of genuinely deficient nutrients, as the correct scarce nutrient may not be directly recognised by deficiency symptoms. Additional fertiliser would be of little to no assistance if the requisite structural and biological conditions are not present. The improved vitality of plants would rely on improving the structural and biological fertility of the soil. Inappropriate application of fertiliser is a waste of time and money, but it can also have dire environmental implications as well [19].

9. Conclusion

All living beings in some way are vulnerable to the widespread long-term use of chemicals in agriculture in any form such as fertilisers, pesticides, etc. Agricultural soil has been disrupted by the extensive and disproportionate use of chemicals and putting it back into order will take time and transition. While we cannot fully prevent the adverse effects of chemical fertilisers at an instant of time, we can definitely reduce the impact by minimising their use and promoting the use of biofertilizers. Biofertilizers will not reduce the use chemical fertilisers but they will improve the soil quality in various ways such as maintaining soil nutrient cycles, soil microbial communities, etc.

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References

[1] Chen, J. 2007. Rapid urbanization in China: a real challenge to soil protection and food security. Catena 69:1-15.

[2] Ashraf, M.A., Maah, M.J., Yusoff, I. 2014. Soil contamination, risk assessment and remediation. In: Hernandez-Soriano MC (ed) Environmental risk assessment of soil contamination. INTECH, Rijeka, 3-56.

[3] Masindi, V., Muedi, K. 2018. Environmental contamination by heavy metals, heavy metals. Hosam El-Din M. Saleh & Refaat F. Aglan, IntechOpen.

[4] Edwards, C.A. 2002. Assessing the effects of environmental pollutants on soil organisms, communities, processes.

[5] Liu, H., Probst, A., Liao, B. 2005. Metal contamination of soils and crops affected by the Chenzhou lead/zinc mine spill (Hunan, China). Sci Total Environ 339:153-166.

[6] Mclaughlin, M.J., Tiller, K.G., Naidu, R., Stevens, D.P. 1996. Review: the behaviour and environmental impact of contaminants in fertilizers. Aust J Soil Res 34:1-54.

[7] Calace, N., Fiorentini, F., Petronio, B.M., Pietroletti, M. 2001. Effects of acid rain on soil humic compounds. Talanta. 54:837-846

[8] Zhang, J.E., Ouyang, Y., Ling. D.J. 2007. Impacts of simulated acid rain on cation leaching from the Latosol in south China. Chemosphere. 67:2131-2137

[9] Neina, D. 2019. The Role of Soil pH in Plant Nutrition and Soil Remediation. *Appl. Environ. Soil Sci*. 5794869.

[10] Wang, Q.R., Cui, Y.S., Liu, X.M., Dong, Y.T., Christie, P. 2003. Soil contamination and plant uptake of heavy metals at polluted sites in China. J Environ Sci Health 38:823-838.

[11] Zhao, Y.F., Shi, X.Z., Huang, B., Yu, D.S., Wang, H.J., Sun, W.X., Öboern, I., Blombäck. K. 2007. Spatial distribution of heavy metals in agricultural soils of an industry-based peri-urban area in Wuxi, China. Pedosphere.17:44-51.

[12] Giller, K.E., Witter, E., Mcgrath, S.P. 1998. Toxicity of heavy metals to microorganisms and microbial processes in agricultural soils: a review. Soil Biol Biochem. 30:1389-1414.

[13] Lenart-Boroń, A., and Boroń, P. 2014. The effect of industrial heavy metal pollution on microbial abundance and diversity in soils–a review. Actinomycetes, 1012, 107-108.

[14] Bradl, H.B. 2004. Adsorption of heavy metal ions on soils and soils constituents. J Colloid Interface Sci. 277(1), 1-18

[15] Mclaughlin, M.J., Tiller, K.G., Naidu, R., Stevens, D.P. 1996. Review: the behaviour and environmental impact of contaminants in fertilizers. Aust J Soil Res 34:1-54.

[16] Arias-Estévez, M., López-Periago, E., Martínez-Carballo, E., Simal-Gándara, J., Mejuto, J.C., García-Río, L. 2008. The mobility and degradation of pesticides in soils and the pollution of groundwater resources. Agric Ecosyst Environ 123:247-260.

[17] Doran, J.W. 2002. Soil health and global sustainability: translating science into practice. Agric Ecosyst Environ 88:119-127.

[18] Tahat, M., Alananbeh, K., Othman, Y., Leskovar, D. 2020. Soil Health and Sustainable Agriculture. Sustainability. 12, 4859.

[19] Rojas, R.V., Achouri, M., Maroulis, J. Caon, L. 2016. Healthy soils: a prerequisite for sustainable food security. Environ Earth Sci 75, 180.

[20] Black, R. 2003. Micronutrient deficiency—an underlying cause of morbidity and mortality. No. 81 (2) World Health Organization.

[21] Shetty, P. 2009. Incorporating nutritional considerations when addressing food insecurity. Food Security 1:431-440.

[22] Charles, H., Godfray, J., Beddington, J.R., Crute, I.R., Haddad, L. 2010. Food security: the challenge of feeding 9 billion people. Science 327:812-817.

[23] FAO, WHO (2014) Rome declaration on nutrition. second international conference on nutrition. Rome, Italy.

[24] Clair, S.B., Lynch, J.P. 2010. The opening of pandora's box: climate change impacts on soil fertility and crop nutrition in developing countries. Plant Soil 335:101-115.

[25] Li, D. P., and Wu, Z. J. 2008. Impact of chemical fertilizers application on soil ecological environment. Chinese Journal of Applied Ecology, 19, 1158-1165.

[26] Weisskopf, P., Reiser, R., Rek, J., Oberholzer, H.R. 2010. Effect on different compaction impacts and varying subsequent management practices on soil structure, air regime and microbiological parameters. Soil Till. Research111,65-74.

[27] Mari, G. R., Ji. Changying, Jun Zhou. 2008. Effects of soil compaction on soil physical properties and nitrogen, phosphorus, potassium uptake in wheat plants. J. Transactions of the CSAE, 24(1): 74-79

[28] Batey, T. 2009. Soil compaction and soil management -a review. Soil Use and Management. 25(4): 335-345

[29] Blanco, C. H., C. H. Gantzer, S. H. Anderson, E. E. Alberts, and F. Ghidey. 2002. Saturated hydraulic conductivity and its impact on simulated runoff for claypan soils. Soil Sci. Soc. Am. J. 66, 1596-1602.

[30] Rannik, K. 2009. Soil compaction effects on soil bulk density and penetration resistance and growth of spring barley (*Hordeum vulgare* L.). J. Acta Agriculturae Scandinavica. Plant Soil Science. 59 (3): 265-272

[31] Barzegar, A. R., Nadian, H., Heidari, F., Herbert, S. J., Hashemi, A. M. 2006. Interaction of soil compaction, phosphorus and zinc on clover growth and accumulation of phosphorus. Soil & Tillage Res. 87: 155-162

[32] Beylich, A., Oberholzer, H. R., Schrader, S., Hoper, H., Wilke. B. M. 2010. Evaluation of soil compaction effects on soil biota and soil biological processes in soils. Soil & Tillage Res. 109(2): 133-143.

[33] Dexter, A. R., Richard, G., Arrouays, D., Czyz, E. A., Jolivet, C., Duval, O. 2008. Complexed organic matter controls soil physical properties. Geoderma. 144, 620-627.

[34] Celik, I., Gunal, H., Budak, M., Akpinar, C. 2010. Effects of long-term organic and mineral fertilizers on bulk density and penetration resistance in semiarid Mediterranean soil conditions. Geoderma. 160(2): 236-243.

[35] Chandini, K. R., Kumar, R., Prakash, O. 2019. The impact of chemical fertilizers on our environment and ecosystem. Research trends in environmental Sciences, 2nd edition, pp 69-86

[36] Sonmez Kaplan, M., Sonmez, S. 2007. An investigation of seasonal changes in nitrate contents of soils and irrigation waters in greenhouses located

in Antalya-Demre region. Asian Journal of Chemistry. 19(7):5639

[37] Savci, S. 2012. Investigation of effect of chemical fertilizers on environment. *Apcbee Procedia*.1, 287-292

[38] Bisht, N., Tiwari, S., Singh, P.C., Niranjan, A., Chauhan, P.S., 2019. A multifaceted rhizobacterium Paenibacillus lentimorbus alleviates nutrient deficiency-induced stress in *Cicer arietinum* L. Microbiol. Res. 223-225, 110-119.

[39] Bisht, N. and Chauhan, P. S. 2020. Comparing the growth-promoting potential of Paenibacillus lentimorbus and *Bacillus amyloliquefaciens* in *Oryza sativa* L. var. Sarju-52 under suboptimal nutrient conditions. Plant Physiology and Biochemistry, 146, 187-197.

[40] Jacoby, R., Peukert, M., Succurro, A., Koprivova, A.,Kopriva, S. 2017. The role of soil microorganisms in plant mineral nutrition-current knowledge and future directions. Front. Plant Sci. 8:1617.

[41] Bargaz, A., Lyamlouli, K., Chtouki, M., Zeroual, Y., Dhiba, D. 2018. Soil microbial resources for improving fertilizers efficiency in an integrated plant nutrient management system. Front. Micribiol. 9:1606.

[42] Liang, R., Hou, R., Li, J., Lyu, Y., Hang, S., Gong, H., Ouyang, Z. 2020. Effects of Different Fertilizers on Rhizosphere Bacterial Communities of Winter Wheat in the North China Plain. Agronomy.10, 93.

[43] Wu, L., Jiang, Y., Zhao, F. He, X., Liu, H., Yu, K. 2020. Increased organic fertilizer application and reduced chemical fertilizer application affect the soil properties and bacterial communities of grape rhizosphere soil. Sci Rep 10, 9568.

[44] Bisht N., Chauhan P.S. 2020. Microorganisms in Maintaining Food and Energy Security in a World of Shifting Climatic Conditions. In: Singh P., Singh R., Srivastava V. (eds) Contemporary Environmental Issues and Challenges in Era of Climate Change. Springer, Singapore

[45] Ramasamy,M., Geetha, T., Yuvaraj, M. 2020. Role of Biofertilizers in Plant Growth and Soil Health, Nitrogen Fixation, Everlon Cid Rigobelo and Ademar Pereira Serra, IntechOpen, DOI: 10.5772/intechopen.87429.

[46] Bhardwaj, D., Ansari, M. W., Sahoo, R. K., Tuteja, N. 2014. Biofertilizers function as key player in sustainable agriculture by improving soil fertility, plant tolerance and crop productivity. Microb. Cell Fact. 13:66. doi: 10.1186/1475-2859-13-66

[47] Ahemad, M., Kibret, M. 2014. Mechanisms and applications of plant growth promoting rhizobacteria: current perspective. JKSUS 26, 1-20.