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Impact of agrochemicals on the environment and human health: The concerns and remedies

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Abstract

Chemical fertilizers and pesticides are essential aids in current agricultural practice to achieve the growing population's need worldwide. Excessive use of these agrochemicals often exerts toxic effects and imposes acute risks on human health and the surrounding environment. Importantly, they have negative impacts on the farmers during agricultural practice without proper safety measures. When a human comes in contact with these toxic chemicals due to leaching and drifting causes serious health hazards including diabetes, reproductive disorders, neurological dysfunction, cancer, and respiratory diseases. In this paper, we discussed the benefits and adverse effects of agrochemicals on humans and the ecology. Moreover, we also discussed some important remedial measures to reduce the toxic effects in farming. We have mentioned recent state-of-art nanotechnology techniques to improve agricultural research. This paper will give new insights into current farming strategies by which farmers will be able to decrease the application of chemical fertilizers and pesticides.

Keywords: Biomagnification, chemical fertilizer, environmental pollution, health hazards, pesticides, sustainable agriculture.

Introduction

Since, the advent of human civilization, agriculture has played a most vital role in food production for the growing population and put an immense contribution to the economy (Godfray and Garnett, 2014). In developing countries, the highly increasing population is often facing hardship to maintain food supply for consumption the expedited the process of imbalance between human needs and sustainable use of agricultural land. Interestingly, agricultural practice mainly depends on soil fertility which was created by the ecosystems (Kibblewhite et al., 2008). On the other hand, soil fertility is being destroyed when lands are used for agricultural purposes. In reality, ecosystems are threatened by agricultural expansion and nutrient release from chemical fertilizers (Figure 1). Though the use of chemical fertilizers and pesticides sufficiently increased the production of crops but consequently invited significant environmental and health problems (Aktar et al., 2009). Prolonged use of chemical fertilizers and pesticides has potential adverse effects on the soil quality, ecosystem networks, and the ultimate consumers. This paper comprehensively discusses the adverse effects of agrochemicals on the environment and human health to present insight for reducing the dependency on agrochemicals and achieving eco-friendly strategies in the agricultural system.

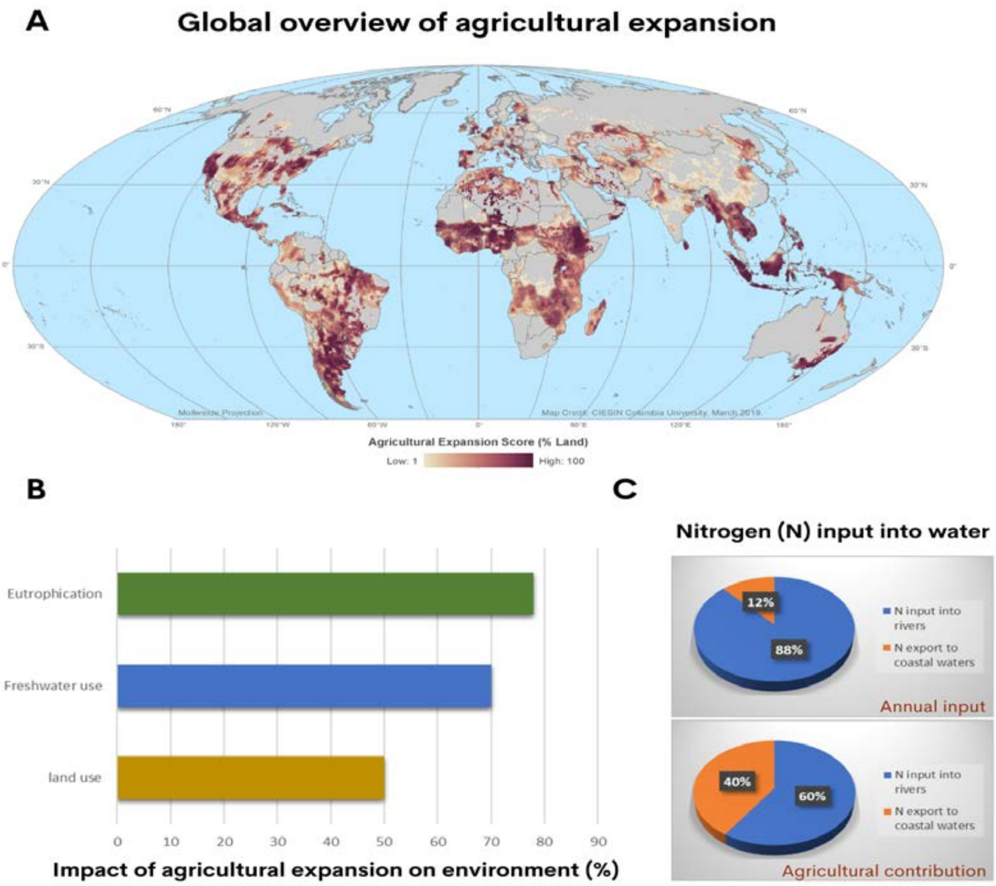

Figure 1. Effect of agricultural expansion and agrochemicals on the environment. (A) Diagram represents the global overview of agricultural expansion (Data Source: Oakleaf, J. R., C. M. Kennedy, S. Baruch-Mord o, P. C. West, J. S. Gerber, L. Jarvis, and J. Kiesecker. 2019. Development Threat Index. Palisade s, NY: NASA Socioeconomic Data and Applications Center (SEDAC). https://doi.org/10.7927/61jv-th84). Center for International Earth Science Information Network - CIESIN - Columbia University, International Food Policy Research Institute - IFPRI, The World Bank, and Centro Internacional de Agricultura Tropical - CIAT. 2011. Global Rural-Urban

Mapping Project, Version 1 (GRUMPv1): Urban Extents Grid (Africa). Palisades, NY: NASA Socioeconomic Data and Applications Center (SEDAC). http://sedac.ciesin.columbia.edu/data/set/grump-v1-urban-extents/maps. Accessed 25.11.2021. (B) Bar diagram shows the impact of agricultural expansion on rising eutrophication, freshwater pollutions, and land use in percentage. (C) Comparison of agricultural contribution vs annual input (%) of nitrogen release into rivers and seawater. The free and accessible data (under the Creative Commons BY license.) was used from the database of Our world in data (https://ourworldindata.org/). Citation: Max Roser (2019) - "Pesticides". Published online at *Our World In Data.org*. Retrieved from: 'https://ourworldindata.org/pesticides'.

The trend of using chemical fertilizers in agriculture

It was estimated that the world population has increased from 1 billion to 7 billion during the 20th century and scientists speculate about hitting around 9.2 billion by 2050 (Motesharezadeh et al., 2017). There is no doubt that global food security concern is the most important socio-economical issue in recent time. Of note, due to the rapid growth of the human population and the ever-increasing demand for food supply, there was an urgent need to apply different chemical fertilizers in the limited agricultural land. Therefore, fertilisers have become one of the most important inputs in agricultural practice and production.

Among the major constituents of fertilizers, nitrogen (N) is considered an essential element for the growth and development of plants. Especially, in arid and semi-arid areas where nitrogen is one of the most limiting elements due to its occurrence in low levels with considerably less organiccontent (White and Brown, 2010). On the other hand, excessive nitrogen use could be a major risk factor for ecosystem pollution and adversely affect the food chains of different ecosystem communities (Erisman et al., 2013). In addition, excessive use of phosphates(P) causes surface water eutrophication in freshwater lakes and streams (Carpenter, 2008). The estimated total nitrogen input (TN) of food production in 2000 shows 171 Tg N yr^{-1}. Moreover, the sum of 137 Tg N yr^{-1} was used for crop production (85 Tg N yr^{-1} for human food production, and 52 Tg N yr^{-1} for animal feed) and 34 Tg N yr^{-1} was attributed to produce grass for grazing animals. Of note, a big amount of the reactive N involved with this TN was found to be lost in soils, aquatic systems, and the atmosphere (Liu et al., 2016). Besides nitrogen, phosphorus is an important element for agricultural and natural ecosystems (Sharma et al., 2013). Researchers observed that worldwide demand for phosphate fertilizer showed an increased rate from 4.6 million tons in 1961 to approximately 21 million tons in 2015 and aided to the green revolution as well as food security.

Future global demand assessments estimate 22–27 million tons P $year^{-1}$ by 2050 for cropland and an additional 4–12 million tons P $year^{-1}$ for grassland (Mogollon et al., 2018). Among the other inorganic elements, potassium (K) plays an important role in crop production by regulating the biosynthesis, conversion, and allocation of metabolites. Studies suggested that the K is directly or indirectly responsible for a higher yield of crops (Hasanuzzaman et al., 2018). Scientists also observed that K helps to increase the N uptake by the plant for increasing the yield of rice. For example, rice yield increased to 6.86 tons ha^{-1} $year^{-1}$with the proper application of K fertilizer, whereas without K supplement, the yield reduced to 5.19 t ha−1 year−1 (Islam and Muttaleb, 2016). The trend of excessive use of inorganic fertilizer combined with better irrigation and advanced plant genetics were the success factors to increase agricultural productivity in south Asian countries. In particular, cereal production in India increased from 82 million tons in 1960 to 284 million tons in 2019, meaning that India became self-sufficient in cereals production (Aryal et al., 2021). Consequently, the application of inorganic fertilizer has amplified intensely causing several environmental problems (Lin et al., 2019). Researchers identified the problems including, extensive nutrient leaching, groundwater pollution, eutrophication, biodiversity loss, and decline of essential soil microorganisms (Kidd et al., 2017). The scientific fact is that millions of tons of synthetic chemical nutrients which are loaded into the soil every year are not completely absorbed by plants, even up to 50% of N and 90% of P was reported to runoff from agricultural fields and released into the atmosphere, surrounding lands or water sources causing the greenhouse gas production, severe eutrophication, and reduction of soil quality (Bashir et al., 2020). Interestingly, several studies have confirmed that organic farming provides an alternative option to reduceissues and the farmers are getting sufficient production endowed with better nutritional properties (Liu et al., 2016).

Negative health consequences of chemical pesticide and fertiliser use

According to research, agrochemicals are known to cause serious health hazards in humans (Figure 2) and some pesticides are found to affect the human endocrine and immune system for promoting malignancy (Gangemi et al., 2016). Chemical fertilizers and pesticides which are used in agricultural fields, get transmitted directly or indirectly into the crops and vegetables and potentially affect human health after consumption. For example, nitrate-containing water can immobilize a fraction of hemoglobin in the blood. Phosphate pesticides show the symptoms of illness such as dizziness, headache, nausea, vomiting, skin rashes, eye irritations, and may even skin cancer (Jayaraj et al., 2016). Studies also reported that contamination of soil and water with toxic agrochemicals generally remains in small quantities, therefore cannot be examined at the right time as their detrimental effects do not manifest in humans for a long time but ultimately led to a severe pathogenic condition such as chronic kidney disease (Valcke et al., 2017).

From the time of the green revolution and as a part of the malaria prevention program in India, chemical pesticides were introduced for the betterment of agricultural practice (Kesavan and Swaminathan, 2008). In India, several pesticides are also used in vast quantities among Asian countries (Figure 3). Pesticides are mainly applied in farmland to protect plants from pests, weeds, or diseases. There are several pesticides categories, including insecticides, fungicides, herbicides, rodenticides, and plant growth regulators (Tudi et al., 2021). Of note, while pesticides turned beneficial for pest control and management, they were also responsible for human health problems. The toxic chemicals used in pesticides accumulate in the ecosystem's food chain and cause harm to human health upon consumption. Studies indicated that intake of pesticide-contaminated foods with the highest exposure causes several adverse health effects, mainly depending on the extent and duration of exposure (Damalas and

Eleftherohorinos, 2011). Although DDT (dichloro diphenyl trichloro ethane) as a pesticide is restricted nowadays, it still influences human health due to the accumulation through the food chain. DDT was found as an acute carcinogenic agent with the potential for causing insistent damage to the lung, nervous system, reproductive system, immune system, and endocrine system (Harada et al., 2016). The main reason for DDT toxicity has been identified is that farmers do not use proper protection by using face masks, gloves, and other protective measures during the application, causing the entry of pesticides in the bloodstream through inhalation and skin absorbance. Several studies demonstrated that the relationship between the degree of pesticide use and illnesses due to their long-term exposure in the farmers of Madhya Pradesh, India, showed acute symptoms of irritation of eyes, blurred vision, skin rash, excessive sweating, shortness of breath, sore throat, and burning of the nose (Kori et al., 2018).Therefore, awareness campaigns are needed for proper understanding of the health hazards of chemical fertilizers and pesticides while handling (Reeves et al., 2019).

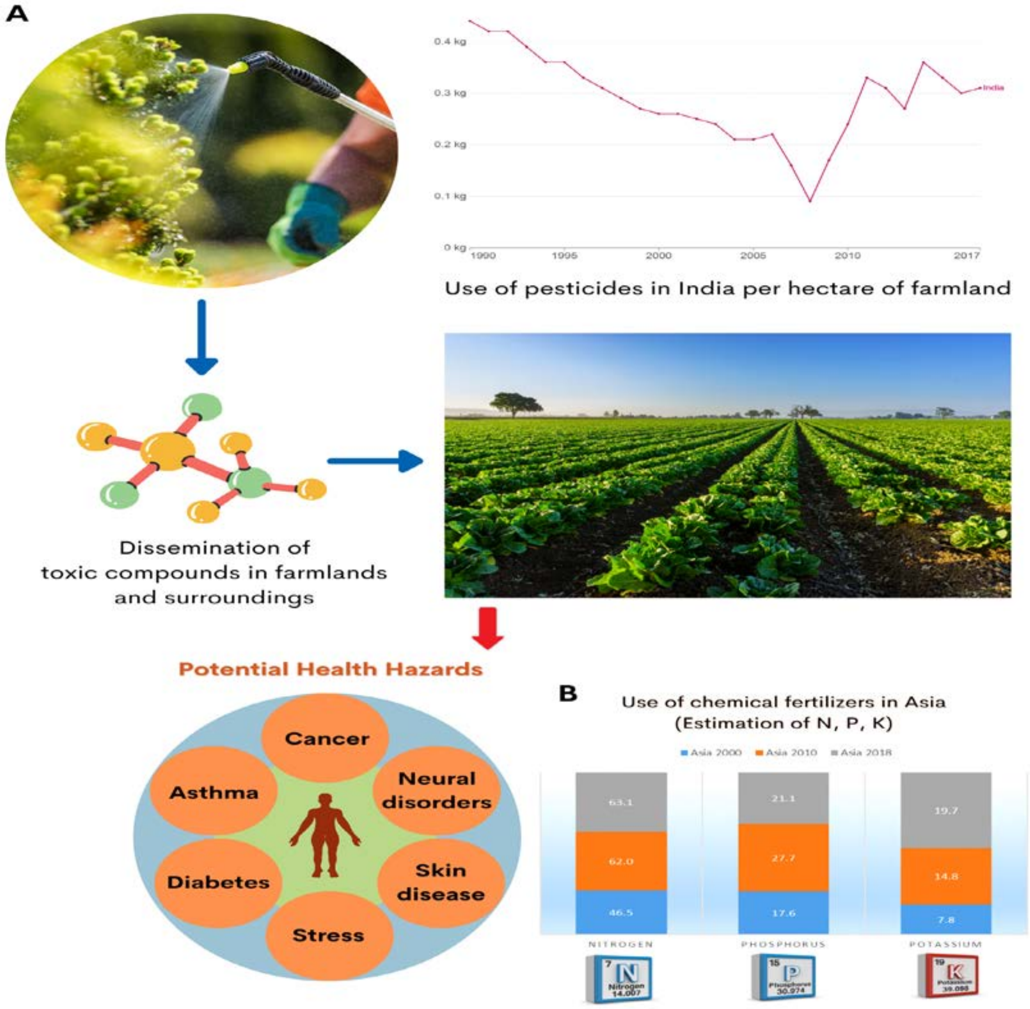

Figure 2. Effect of pesticides on human health. (A) The illustration demonstrates the routes of pesticide entry in the human body and the adverse effects on health. (B) The diagram represents the data of chemical fertilizers (N, P, and K) used in Asia (From 2000-2018).The free and accessible data (under the Creative Commons BY license.) was used from the database of Our

world in data (https://ourworldindata.org/). Citation: Hannah Ritchie and Max Roser (2013) - "Fertilizers". Published online at OurWorldInData.org. Retrieved from: 'https://ourworldindata.org/fertilizers'.

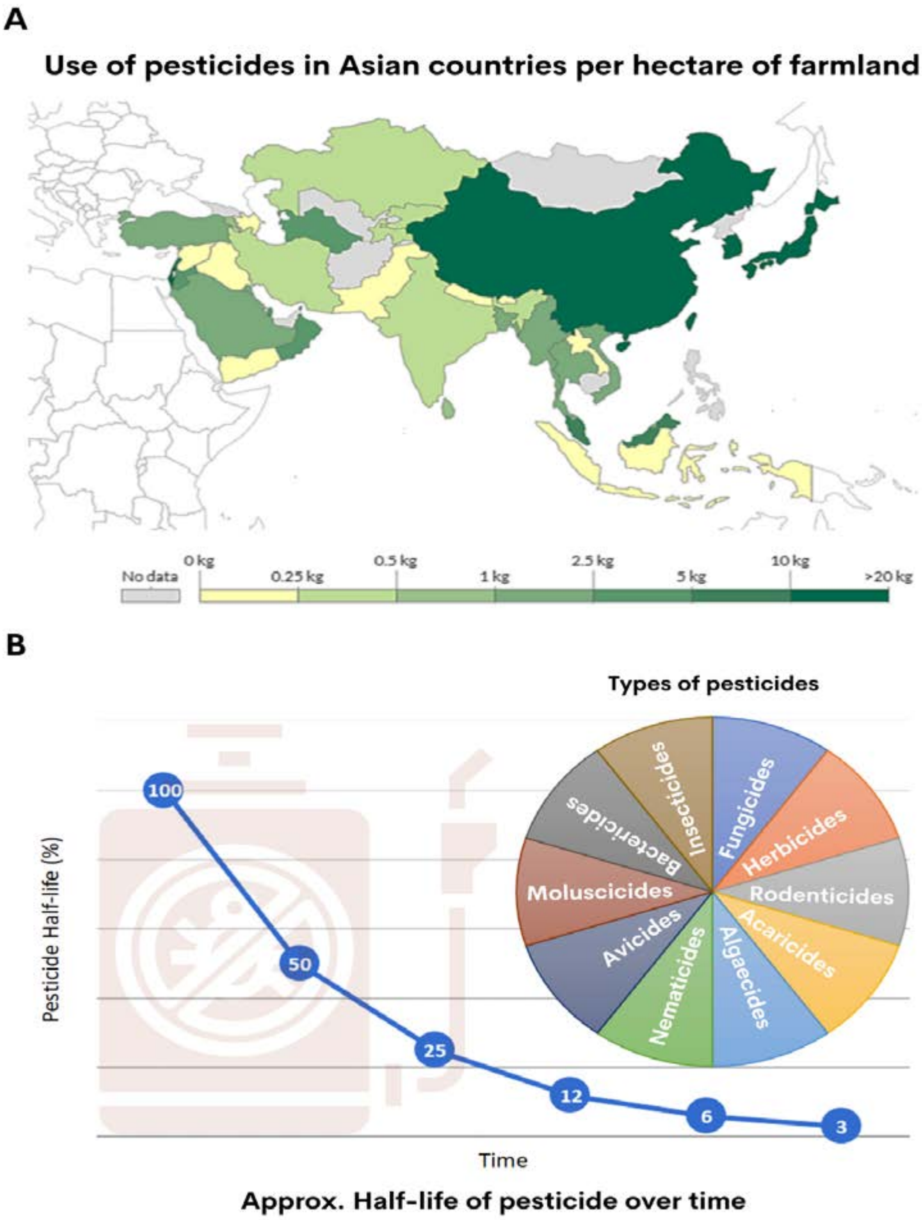

Figure 3. Usage of pesticides and their half-life. (A)Figure represents the use of pesticides in Asian countries (per hectare).The free and accessible data (under the Creative Commons BY license.) was used from the database of Our world in data (https://ourworldindata.org/). Citation: Max Roser (2019) - "Pesticides". Published online at Our World In Data.org. Retrieved from: 'https://ourworldindata.org/pesticides'. (B) Data shows the types of pesticides and their half-life. Data source: Hanson, B.; Bond, C.; Buhl, K.; Stone, D. 2015. Pesticide Half-life Fact Sheet; National Pesticide Information Center, Oregon State University Extension Services. http://npic.orst.edu/factsheets/half-life.html.

Role of agrochemicals for increasing environmental pollution and eco-system damage

Fertilizers contain major plant macronutrients (phosphorus, nitrogen, potassium), secondary macronutrients (magnesium, calcium, sulphur), and micronutrients including iron, copper, manganese, zinc, molybdenum, and boron which are essential for plant growth (White and Brown, 2010). Categorically, fertilizers can be grouped as organic fertilizers and chemical fertilizers. Importantly, conventional farming mainly relies on chemical fertilizers that provide greater crop production yield. Besides, chemical fertilizers possess a wide range of harmful impacts ecosystem. For example, aquatic systems become heavily contaminated and enriched with minerals and nutrients due to runoff from agricultural land. As a downstream effect, 'eutrophication' happens. The process induces excessive growth of phytoplankton and algae (algal bloom) which can kill aquatic animals and encourage the overgrowth of cyanobacteria (blue-green algae). Cyanobacteria produce harmful toxic substances that accumulate in the food chain and, when consumed by different consumers, show health hazards (Plaas and Paerl, 2021). In addition, chemical fertilizers-mediated eutrophication causes oxygen depletion (Malone and Newton, 2020). According to Kumar et al., (2013), pesticides are often used as an easy and low-cost option for controlling weeds and insect pests in farmlands, but it causes extensive surface and groundwater pollution (Khanna and Gupta, 2018). The main problem with pesticide contamination is that it adversely affectsnon-target organisms, including beneficial soil microorganisms, insects, fish, plants, and birds (Iyaniwura, 1991).

Scientists observed that the long-term usage of pesticides and chemical fertilizers causes deterioration of soil properties and heavy metals accumulation (Lu et al., 2016). Importantly, heavy metals accumulations in the soil such as cadmium when crossing the threshold limit, it is almost impossible to run standard agricultural purposes (Jaishankar et al., 2014). Apart fromcadmium, fluoride, lead, arsenic, chromium, and nickel are also responsible for disruption of soil biology (Tchounwou et al., 2012). Another important aspect that needs to mention is that residues of chemical compounds in pesticides have been identified in the food web. Therefore, an in-depth research is necessary on pesticide migration and their bioconcentration in food sources. It is concerning that toxic chemicals in pesticides may also accumulate in aquatic organisms through direct uptake from water by gills or skin or via uptake in the form of suspended particles. In addition, terrestrial animals can be highly affected by pesticides via the consumption of contaminated food or water (Nicolopoulou-Stamati et al., 2016). The type of pesticides, the time and route of exposure, and the individual health status are crucial factors determining the possible health outcome. In general, pesticides may be metabolized, excreted, deposited, or bioaccumulated in the body of an individual during exposure (Damalas and Eleftherohorinos, 2011).

Use of bio-organic fertilizers: The pros and cons

The approach of biological fertilization is mainly based on the use of decaying remains of organic components from animals and plants, crops excess, domestic sewage, animal manure, and combined with microorganisms including fungi and bacteria

(Pirttilä et al., 2021). As a part of the green and sustainable agriculture system, biofertilizers are used to improve the fixation of nitrogen in the soil, stimulate growth for plants, improve soil quality and stability, accelerate the biodegradation of organic substances, facilitate nutrients recycles, and develop effective bioremediation processes. Moreover, the application of biological fertilizers benefits from an economic, social, and environmental point of view as proper implementation of biofertilizers is required to achieve sustainable agriculture (Mahanty et al., 2017). There are so many benefits of biofertilizers as they are cost-effective and farmers can apply them to reducethe consumption of chemical fertilizers. Biofertilizers contain nitrogen-fixing microbes which provide atmospheric nitrogen directly to legume plants (Bhattacharjee et al., 2008). Researchers also proved that biofertilizers are very useful for better synthesis and the availability of vitamins, plant hormones, and different growth-promoting substances which help to increase crop yield by 10–20% (Schütz et al., 2018). In addition, biofertilizers are eco-friendly and do not cause any environmental pollution (Bhardwaj et al., 2014). On the contrary, they have some limitations, too as biofertilizers are not considered as the substitute for chemical fertilizers. The reason behind it, although biofertilizers providean increase in crop production but are not as effective for increasing productivity as chemical fertilizer.

Another limitation is maintaining the aseptic environment while producing microbial fertilizer as contamination is common which often spoils the microbial preparations (Timmusk et al., 2017). Moreover, there are time constraints for the usage of microbial fertilizer and the need to maintain them carefully in dark, dry, and proper temperatures (Nosheen et al., 2021). Most importantly, biofertilizer's efficiency of biofertilizer smainly depends on soil quality, including moisture, pH, temperature, organic substances, and types of microorganisms present in them. It was observed that when these parameters are uncomplimentary, biofertilizers may not show their full effectiveness for increasing crop production (Herrmann and Lesueur, 2013). Therefore, farmers always need to understand the pros and cons of using biofertilizers before application.

Strategies to reduce chemical fertilizers and pesticides use in agriculture

Excessive use of agrochemicals in farming has caused severe food contamination with toxins, negatively impacting disease resistance and ecological integrity (Kaur and Kaur, 2018). Ultimately, they cause significant harm to human health. Most importantly, many pesticides and herbicides are known to have carcinogenic potential (Alavanja and Bonner, 2012). Therefore, we need to opt for new and advanced technologies for improving the production yield and quality of crops without risking human health. Scientists suggest some reliable alternatives such as ‘microbial inoculants’which can be used as biofertilizers, bioherbicides, biopesticides, etc (Chaudhary et al., 2020). As we know, microorganisms are capable of carrying out plant growth promotion, pest and weed control, nitrogen fixation. Studies suggested that microbial inoculants are effective for minimizing the negative impact of chemical fertilizers and thus increase crop production. Biofertilizer has been shown to have a significant role in the long-term preservation of human health. By enhancing antioxidant activity, total phenolic compounds, and chlorophyll content, biofertilizers help increase the nutritional characteristics of crops and vegetables (Khalid et al., 2017). The total phenolic content of spinach grown with various biofertilizers was found to be 58.72 and 51.43 percent greater than the un-inoculated control group (Alori and Babalola, 2018).

Recently, advanced nanotechnology techniques are being used in agricultural practices and are important for sustainable development by reducing the waste of agricultural inputs (Prasad et al., 2017). Of note, the delivery of agrochemicals (DNA or oligonucleotides inside the plant cells)is important for sustainable crop production and an integral part of precision farming (Shafi et al., 2019). In traditional agriculture, agrochemicals are directly applied to plants. As a result, agrochemicals reach their target sites in a very low quantity which is below the minimum effective threshold. The main causes for low quantity were identified as the leaching of chemical fertilizers, degradation by photolysis, hydrolysis, and soil microbes. Therefore, the application of nano-fertilizers can be a reliable option for safe and sustainable agriculture. To ensure eco-friendly agricultural practices, nano-technology-based slow or controlled release fertilizers, pesticides and herbicides have a good contribution to agriculture (Shang et al., 2019). The benefit of controlled delivery systems was observed as the release of the specific number of agrochemicals to gain full biological competency of the chemical with minimal loss and toxic effects (Basavegowda and Baek, 2021). In this revolutionary approach, nano-particles are incorporated into the specific agrochemicals through several techniques and trapped into the nano-matrix of active ingredients (Vega-Vásquez et al., 2020). Moreover, nano-fertilizers improve the stability of agrochemicals and protect them from degradation leaching into the groundwater, which is eventually eco-friendly and reduce the quantities of chemical fertilizers.

Mission and Vission of Neucrad Agri Farm Health LLP, East Burdwan, West Bengal

It is focused on reducing the application of chemical fertilizers and pesticides in agriculture to minimimising the health hazards and enrich the rural economy. There are so many obstacles (small areas of land owned by farmers ,education, markets, non-availability of quality biofertizers, lack of mindsets for cooperative farming, etc) that prevent the farmers from starting organic farming.

In collaboration with BioGuru Lifesciences PVT LTD and Radial Lab PVT LTD, Neucrad Agri Farm Health LLP, a new startup in West Bengal, is enriching the formulations of biofertizers, micronutrients, biopesticides and doing field trials at different districts (Burdwan, Hoogly, Bankura, South 24 Pargana, etc) for several crops including potato, rice, vegetables, etc. We are focused on enriching soil fertility stepwise using our BioKits in 2/3 years. We accepted the challenge not to hamper the yield of crop production. We are also training the local farmers about the proper application procedures of our BioKits.

In 2020, we conducted field trials on portato with 3 acres of agricultural land at Matchalandapur, Simlon, Kalna, East Burdwan, West Bengal (Figure 4, representative images). We used newly formulated BioguruBiokits that was designed for potato farming at West Bengal. It was a milestone development. We compared the length, branching of stems of the plants and the yield of potatoes per bigha land with other farmers who used only chemical fertilizers and pesticides measured as 100% chemical use. We reduced 20% chemical fertilizers and pesticides as the conventional measurement with our Biokits. It was evident from the study that the yields of the potato production per bigha (average 120 bags/ bigha; 1 bag contains 50 kg potato, 1 bigha = 40 sotok land) were similar when compared with 100% chemical use.

In 2021, we are conducting field study at Burdwan, Hoogly, Bankura, and other districts of West Bengal. This year, we reduced 20% chemical fertilizers. Next year, we will reduce 40% chemical fertilizers in the same field. It will be a milestone if we can get similar potato yields compared to 100% chemical use.

We also focus on developing quality potato seed production and reducing dependence on Punjab. This year we are using foundation potato seeds (F3; Hemalini, Chandramukhi, Jyoti) from West Bengal Govt seed production unit, PashchimMedinapur (Figure 5, representative images). In the future, we are focused on developing a tissue culture laboratory and establishing the methodologies for quality foundation potato seed production.

Figure 4. Representative images about current activities at Neucrad Agri Farm Health LLP.
(A) Case study report of potato plants using Biokits with 20% reduced chemical fertizers and pesticides. Branched stems were found with average length 2 ft. (B) Case study report of potato plants using only conventional chemical fertizers and pesticides (normalized to 100% use). Predominately single Stem was found with average length 3 ft. (C & D) Tarun Ghosh, farmer, at Machalandapur, Simlon, Kal, East Burdwan used BioKits 9 with 20% reduced chemical use) in his potato fields and was able to get similar potato yields compared to fields with 100% chemical use.

Figure 5. Reprentative images for the current ongoing study using F3 seeds. Foundation seeds, details in the images, were used in the year 2021.

Discussion

Fast growth in the global human population comes with escalating crisis for food security as the cultivable land area is inadequate and consistently decreases over the timespan. Therefore, we need to enhance crop production but adopting this strategy will also bring substantial damage to soil quality due to the wide-ranging use of different agrochemicals. Intensive conventional agricultural practices are responsible for deteriorating ecological integrity and human health (Pingali, 2012). Henceforth, establishing an eco-friendly without along with the significant substitution of chemical fertilizers is one of the major aims of sustainable agricultural concepts. Biofertilizer and microbial inoculants are applied as eco-friendly alternatives to chemical fertilizers and pesticides to maintain sustainable agriculture. Such an innovative and useful approach protects the lithosphere, improves the biosphere by preventing environmental pollution and eutrophication (Bharti and Suryavanshi, 2021). Most importantly, biofertilizer enhances the yields of crops and keeps a significant contribution to the economy. In addition, the use of biofertilizers helps enrich the soil quality by adding macro- and micro-nutrients and releasing plant growth regulators in the soil (Itelima et al., 2018). Therefore, researchers of the developing countries may need urgent attention to develop target-specific formulations of biofertilizers which will increase the production of high-quality crops. In-depth agricultural research should also emphasize the molecular mechanism of actions of plant-microbe associations and how plants withstand extreme environmental conditions. In addition, scientists need to resolve certain issues, including improving the efficiency and availability of the bio-fertilizers to the plant cells and stabilising microbial inoculum in soil ecosystems. Advanced biotechnological strategies and initiatives could optimize the plant-microbe interactions with their best potentials. In this context, nanotechnological applications in the agricultural field appeared to be a promising and upgraded approach over conventional agricultural systems (Prasad et al., 2017). Research demonstrated thatnanotechnology is extremely helpful for the development of efficient and eco-friendly methodologies (Chand Mali et al., 2020). Thus, Nano-fertilizers could be a crucial approach for the protection of the ecosystemasthey are needed in smaller quantities in comparison with traditional fertilizers (Duhan et al., 2017). Consequently,they will reduce leaching, chemical runoff, and greenhouse gas emissions to the atmosphere (Mejias et al., 2021). Although, there are some uncertainty and limitations existregarding the applications of nano-fertilizers, although they are not costly compared to conventional chemical fertilizers their widespread applications depend on safety measures and marketing strategies (Seleiman et al., 2020). Further investigation is required to better understand whether nano-fertilizers are fully transformed into ionic forms inside the plant cells and eventually incorporated into cellular proteins and different metabolites or how much remains intact and enters into the food chains. Current agricultural biotechnology will immensely help us comprehend the physiological mechanisms of biofertilizers' actions towards sustainable agriculture.

Statement on conflict of interest

The authors declare that there is no conflict of interest.

Author's contribution

The manuscript was conceptualized, written, and edited by Shuvomoy Banerjee and Biswarup Ghose.

Statement of data availability

The required figures are made based on the scientific discussions of the paper. We used Canva software to make the necessary figures (https://www.canva.com/).

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