Review Article

Indian Journal of Plant and Soil
Volume 8 Number 1, January - June 2021
DOI: http://dx.doi.org/10.21088/ijps.2348.9677.8121.1

Recent Advancement and Impact of Nanoparticles in Sustainable Farming Practices

Rittick Mondal[1], Debasis Mitra[2]

Authors Affiliation
[1]Ph.D Scholar, Department of Sericulture, [2]PhD Scholar, Department of Microbiology, Raiganj University, North Dinajpur 733134 West Bengal, India.

Corrosponding Affiliation
Rittick Mondal,PhD Scholar, Department of Sericulture, Raiganj University, North Dinajpur 733134 West Bengal, India.
Email: rittickm98@gmail.com

How to cite this article:
Rittick Mondal, Debasis Mitra/Recent Advancement and Impact of Nanoparticles in Sustainable Farming Practices;2021;8(1):11-15.

Abstract

In this era of rapid urbanization and increasing population traditional-farming activities are facing various unforeseen hurdles. Due to some major drawbacks, traditional farming activities are unable to meet global food demand, necessitating the use of advanced technology to achieve food security. In this aspect, nanoparticles mediated advanced technology is an alternative tool to boost up crop production in a feasible way. Nanotechnology has a pronounced perspective to boost the status of precision farming techniques by increasing the plant-nutrient absorption level, disease detection capability, pest and pathogen control, food storage and packing, etc. Nanotechnology offers varied types of new tools for agriculture like nano-fertilizer, nano-herbicides, nano-pesticides formulations, nano-based antimicrobial solutions, and nano-sensors. Nanoparticles are considered a good carrier platform for various nano-based agrochemical formulations. It can enrich the efficacy of the site-directed delivery of nano encapsulated active ingredients. Moreover, nanoencapsulation also provides the slow and sustained release of active ingredients. In this review content, we attempt to describe the modern advancement of nanotechnologies and their application in farming to meet the increasing food demand in an eco-friendly manner.

Keywords: Traditional farming activities; Nanoparticles; Nano-fertilizer; Nanoencapsulation.

Introduction

To meet the food requirements of a large population, food grain production must be increased. In recent years, significant technological advances and innovations in the field of agriculture have been made to address the increasing challenges of sustainable production and food security (Fróna et al., 2019; Shang et al., 2019). Nanotechnology in particular can deliver effective solutions to multiple problems in agriculture. Nanotechnology has the ability to improve farming and play a crucial role in increased agricultural production. Nanotechnology can revolutionize agriculture and play an important part in the production of food and crops (Shang et al., 2019). A nanoparticle is a tiny particle (1-100 nm diameter). Nanoparticles were different from their bulk counter-part in terms of their physical, chemical and biological properties. The interest regarding nanoparticles was developed due to their unique properties like greater surface to volume ratio, better biocompatibility, etc. which makes it a 'magic bullet' (Gumber K, 2019). There are different methods to synthesize the nanoparticles, such as chemical, physical and biological (green) methods (Fig.1).

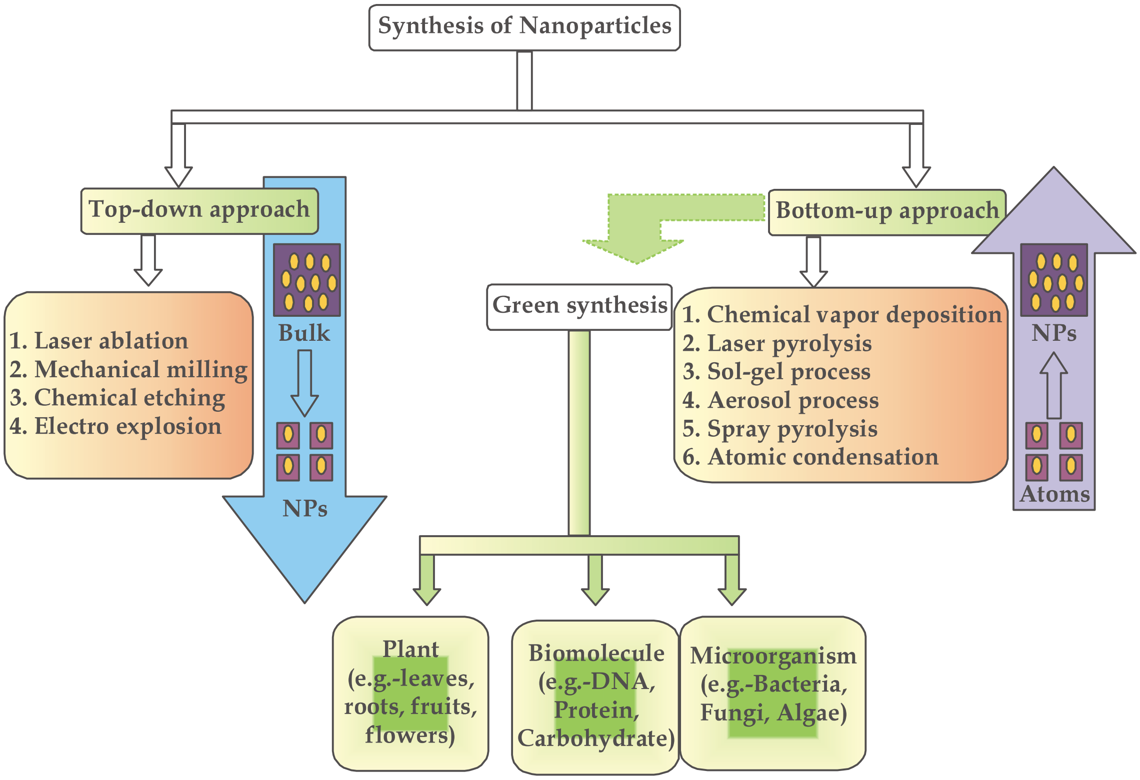

Fig.1. Different approach of the nanoparticles synthesis.

Among them, the biological synthesis is more eco-friendly and less toxic.

The synthesized nanoparticles are characterized by the help of different types of tools and techniques. The UV–Visible spectroscopy, used to determine the optical properties of nanoparticles. To know the presence of functional groups on the surface of nanoparticles, FTIR spectroscopy was used. XRD analysis was employed to know the nanoparticle crystal structure. The electron microscopy was performed to check the nanoparticle size, shape, structure, etc. (Mondal et al., 2021; Some et al., 2020).

In agricultural practices, various types of nanoparticles are used like silver nanoparticles, silicon nanoparticles, gold nanoparticles, zinc nanoparticles, copper nanoparticles, carbon-based nanostructures, etc. in the form of nano-pesticides, nano fertilizers, nano-sensors (Paramo et al., 2020; Rastogi et al., 2019). Plants can uptake the different-sized nanoparticles through their different areas (like 4-100nm-sized nanoparticles can enter into the plant system through the cuticle, plant stomata can uptake the polymeric nanoparticles (diameter 43nm), <5nm-sized nanoparticles enter the cell through the cell wall, etc.) (Mittal et al., 2020; Larue et al., 2014; Eichert et al., 2008). Moreover, different types of NPs (e.g. silver nanoparticles, zinc nanoparticles, copper nanoparticles, gold nanoparticles, carbon nanotube etc.) were used in agriculture as nanoscale delivery systems. The main role of these types of delivery systems was to slow the release of the active ingredients (e.g. pesticides, plant growth regulators, fertilizers, herbicides etc.) on their target site (Fig.2). The value of nanoscale delivery systems in agriculture is because of their increased solubility and stability against deterioration in environmental factors. The nanoscale delivery vehicles improve efficacy by attaching strongly to the plant surface and lowers the number of agrochemicals by stopping runoff into the atmosphere (Wu et al., 2008).

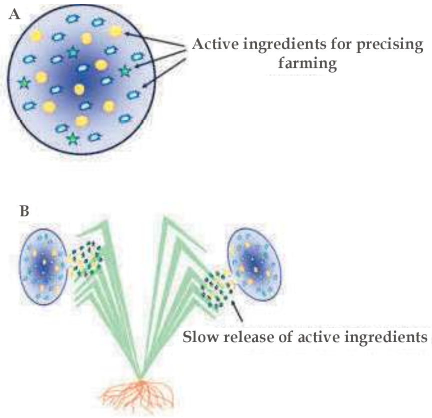

Fig. 2: (A) Nanoencapsulated active ingredients required for sustainable farming (B) Sustainable and controlled release of these Nanoencapsulated active ingredients.

Due to the unique properties of NPs, the interaction between plant and nanoparticles creates different types of alterations in plant physiological systems. The efficiency of nanoparticles depends on some factors like concentration, size, composition etc. Different types of nanoparticles show different types of plant growth-promoting attributes as well as performs their role as nano-fertilizer, nano-herbicides, nano-pesticides formulations, nano-based antimicrobial solutions, nano-sensors.

To combat nutrient deficiency in plants, scientists used nanotechnology to develop a smart transport platform that would release nutrients in a gradual and regulated manner to the target point. Nanofertilizers are considered as the nanomaterial encapsulated or covered plant nutrient, that helps to enhance plant growth and productivity (DeRosa et al., 2010). By regulating the number of vital nutrients to the plant, nanofertilizers boost crop productivity. Nanofertilizer has provided various benefits (like a) Production cost is low, maximum profit, b) Controlled and slow release of nutrients, c) Low toxicity than other chemical fertilizers, d) Optimum and sustainable production of plant yield) in agriculture. The nanofertilizers contain silver, gold, iron, silica, nano zinc, titanium dioxide, Mn/ZnSe QDs, gold nanorods, InP/ZnS core-shell QDs, ZnCdSe/ZnS core-shell QDs, core-shell QDs, etc.Silver nanoparticles (AgNPs) are the utmostextensively used commercialized nanomaterials, used in farming (Gumber K, 2019). Fungal extract (*Aspergillus fumigatus and Trichoderma harzianum*) mediated biogenic synthesized AgNPs acts as a plant growth-promoting agent. Helps to increase the tomato plant height (cm), fresh and dry biomass (g), the number of shoots per plant, yield of tomato per plant (g), the weight of root (g) (Noshad et al., 2019). It is reported that biogenic AgNPs can also increase some growth parameters (e.g. root & shoot growth, seed biomass & length) as well as biochemical properties (enhance the level of carotenoid, chlorophyll) (Gupta et al., 2018). Green synthesized AgNPs & AuNPs both have an impact on onion, helps to increase the plant height, seed germination, leaf diameter & length (Acharya et al., 2019). In the phosphorous amended soil, the TiO_2 NPs helps to improve the wheat quality by altering shoot & root length, nutrient level, protein percentages (Ullah et al., 2020). Carbon nanotubes (CNTs) were vital nanoparticles due to their distinctive mechanical, electrical, properties. The nanocarbon-based multi-walled carbon nanotubes show some growth-promoting activities (like area of the leaf, plant height, chlorophyll level) on onion (Abdul-Ameer et al., 2019).

Along with this nanofertilizer, crop production has also improved dramatically as a result of the use of nanopesticides, bactericide, nanofungicide, nanoherbicides to regulate pests and weeds. The nanoherbicide formulations use a variety of nanoparticles, including inorganic nanoparticles and polymeric. Nanopesticides allow the application of active substances to plants, distribute them evenly, and keep them stable after application. Nanopesticides have provided various benefits like a) an increase in efficiency towards pests, pathogens, b) high solubility and site-directed controlled release, c) less hazardous. Silver nanoparticles were the most used antimicrobial agents, due to their less toxic effect, higher biocompatibility, strong inhibitory and antimicrobial activities. *Phyllanthus emblica* extract mediated green AgNPs has a strong antibacterial property against rice pathogenic organism viz. *Acidovorax oryzae* strain RS-2, that causes bacterial brown stripe (Masum et al., 2019). Fungal extract (*A. fumigatus* and *T.harzianum*) mediated biogenic synthesized AgNPs can also show antibacterial activity against *Clavibacter michiganensis subsp. michiganensis* (*cmm*), which causes bacterial canker disease in the tomato plant (Noshad et al., 2019).The copper oxide nanoparticles (CuO-NPs) have antifungal activity against a plant pathogen viz. *Colletotrichum gloeoesporioides* (Oussou-Azo et al., 2020). ZnO NPs show antifungal actions against foodborne pathogenic organisms *A.fumigatus*, which can causes diseases in horticultural crops (Patra and Goswami 2012).

Nanobiosensors have real-time signal control and are used to track pesticides, disease-causing microorganisms, pollutants, soil health, nutrient content, plant growth, etc. all are monitored through this technology. The nanobiosensors are exceptionally precise and sensitive. These instruments use a microprocessor to convert the biological responses to electrical responses. Silica nanoparticles (fluorescent nano-probes) based biosensor was used to detect the Solanaceous plant pathogen, known as Xanthomonas axonopdis that can cause bacterial spot disease. Baek and his team (2017) developed an AuNPs (detection probe) based detection tool, that can easily detect the insecticide (organophosphorus) and fungicide (triazole). As per Sharon and Sharon (2008), pesticide residues can easily detect by using a carbon nanoparticles-based sensor.

Some future policy is required for the use of nanotechnology to maintain sustainable farming practices like properly maintain the standard guidelines, safety protocols, proper documentation for the use of nanoparticle-based platforms in agriculture, skilled professionals are required to minimize the hazards that can evolve during the application of nanoparticles in agricultural land etc.

Conclusion

Traditional farming activities are experiencing a number of unexpected challenges in this period of rapid urbanization and population growth. Due to numerous major restrictions, traditional farming activities are insufficient to supply global food demand, necessitating the use of modern technology to achieve food security. In this regard, nanoparticle-mediated advanced technology is a viable alternative tool for increasing crop production. Nanotechnology could be used as sensors to monitor the soil quality in agricultural fields, ensuring the health of the plants. This review outlines the current difficulties of sustainability, food security, and climate change, as well as how technological progress nanotechnology is addressing these difficulties for a more sustainable environment in order to improve agriculture.

Conflict of Interests

The authors have declared no conflict of interest.

References

1 Abdul-Ameer, M. A., &Almousawy, N. A. (2019). Growth and productivity of Onion (*Allium cepa* L.) as influenced by set size and spraying with Nanocarbon. In Journal of Physics: Conference Series, 1294(6), 062035.

2 Acharya, P., Jayaprakasha, G. K., Crosby, K. M., Jifon, J. L., &Patil, B. S. (2019). Green-synthesized nanoparticles enhanced seedling growth, yield, and quality of onion (*Allium cepa* L.). ACS Sustainable Chemistry & Engineering, 7(17), 14580-14590.

3 Baek, S. H., Lee, S. W., Kim, E. J., Shin, D. H., Lee, S. W., & Park, T. J. (2017). Portable agrichemical detection system for enhancing the safety of agricultural products using aggregation of gold nanoparticles. ACS omega, 2(3), 988-993.

4 Borase, H. P., Salunke, B. K., Salunkhe, R. B., Patil, C. D., Hallsworth, J. E., Kim, B. S., & Patil, S. V. (2014). Plant extract: a promising biomatrix for ecofriendly, controlled synthesis of silver nanoparticles. Applied biochemistry and biotechnology, 173(1), 1-29.

5 DeRosa, M. C., Monreal, C., Schnitzer, M., Walsh, R., & Sultan, Y. (2010). Nanotechnology in fertilizers. Nature nanotechnology, 5(2), 91-91.

6 Eichert, T., Kurtz, A., Steiner, U., & Goldbach, H. E. (2008). Size exclusion limits and lateral heterogeneity of the stomatal foliar uptake pathway for aqueous solutes and water-suspended nanoparticles. Physiologiaplantarum, 134(1), 151-160.

7 Fróna, D., Szenderák, J., & Harangi-Rákos, M. (2019). The challenge of feeding the world. Sustainability, 11(20), 5816.

8 Gumber, K. (2019). Silver nanoparticles: magic bullets of agriculture. Emergent Life Sciences Research, 5, 42-47.

9 Gupta, S. D., Agarwal, A., & Pradhan, S. (2018). Phytostimulatory effect of silver nanoparticles (AgNPs) on rice seedling growth: An insight from antioxidative enzyme activities and gene expression patterns. Ecotoxicology and environmental safety, 161, 624-633.

10 Larue, C., Castillo-Michel, H., Sobanska, S., Trcera, N., Sorieul, S., Cécillon, L.,Ouerdane, L., Legros, S., & Sarret, G. (2014). Fate of pristine TiO_2 nanoparticles and aged paint-containing TiO_2 nanoparticles in lettuce crop after foliar exposure. Journal of hazardous materials, 273, 17-26.

11 Masum, M., Islam, M., Siddiqa, M., Ali, K. A., Zhang, Y., Abdallah, Y., Ibrahim, E., Qiu, W., Yan, C., & Li, B. (2019). Biogenic synthesis of silver nanoparticles using *Phyllanthus emblica* fruit extract and its inhibitory action against the pathogen *Acidovorax oryzae* strain RS-2 of rice bacterial brown stripe. Frontiers in microbiology, 10, 820.

12 Mittal, D., Kaur, G., Singh, P., Yadav, K., & Ali, S. A. (2020). Nanoparticle-based sustainable agriculture and food science: recent advances and future outlook. Front. Nanotechnol, 2(10).

13 Mondal, R., Yilmaz, M. D., & Mandal, A. K. (2021). Green synthesis of carbon nanoparticles: characterization and their biocidal properties. In Handbook of Greener Synthesis of Nanomaterials and Compounds (pp. 277-306). Elsevier.

14 Noshad, A., Hetherington, C., & Iqbal, M. (2019). Impact of AgNPs on Seed Germination and Seedling Growth: A Focus Study on Its Antibacterial Potential against *Clavibacter michiganensis subsp.* michiganensis Infection in Solanum

lycopersicum. Journal of Nanomaterials, 2019.

15 Oussou-Azo, A. F., Nakama, T., Nakamura, M., Futagami, T., &Vestergaard, M. D. C. M. (2020). Antifungal potential of nanostructured crystalline copper and its oxide forms. Nanomaterials, 10(5), 1003.

16 Paramo, L. A., Feregrino-Pérez, A. A., Guevara, R., Mendoza, S., & Esquivel, K. (2020). Nanoparticles in Agroindustry: Applications, Toxicity, Challenges, and Trends. Nanomaterials, 10(9), 1654.

17 Patra, P., & Goswami, A. (2012). Zinc nitrate derived nanoZnO: fungicide for disease management of horticultural crops. Int J Innov Hort, 1, 79-84.

18 Rastogi, A., Tripathi, D. K., Yadav, S., Chauhan, D. K., Živcák, M., Ghorbanpour, M., El-Sheery, N. I., & Brestic, M. (2019). Application of silicon nanoparticles in agriculture. 3 Biotech, 9(3), 1-11.

19 Shang, Y., Hasan, M., Ahammed, G. J., Li, M., Yin, H., & Zhou, J. (2019). Applications of nanotechnology in plant growth and crop protection: a review. Molecules, 24(14), 2558.

20 Sharon, M., & Sharon, M. (2008). Carbon nanomaterials: applications in physico-chemical systems and biosystems. Defence Science Journal, 58(4), 460.

21 Some, S., Sarkar, B., Biswas, K., Jana, T. K., Bhattacharjya, D., Dam, P., Mondal, R., Kumar, A., Deb, A. K., Sadat, A., Saha, S., Kati, A., Ocsoy, I., Franco, O. L., Mandal, A., Mandal, S., Mandal, A. K., & Ince, I. A. (2020). Bio-molecule functionalized rapid one-pot green synthesis of silver nanoparticles and their efficacy toward the multidrug resistant (MDR) gut bacteria of silkworms (*Bombyx mori*). RSC Advances, 10(38), 22742-22757.

22 Ullah, S., Adeel, M., Zain, M., Rizwan, M., Irshad, M. K., Jilani, G., Hameed, A., Khan, A., Arshad, M., Raza, A., Baluch, M. A., & Rui, Y. (2020). Physiological and biochemical response of wheat (*Triticum aestivum*) to TiO_2 nanoparticles in phosphorous amended soil: A full life cycle study. Journal of Environmental Management, 263, 110365.

23 Wu, L., & Liu, M. (2008). Preparation and properties of chitosan-coated NPK compound fertilizer with controlled-release and water-retention. Carbohydrate polymers, 72(2), 240-247.

24 Yao, K. S., Li, S. J., Tzeng, K. C., Cheng, T. C., Chang, C. Y., Chiu, C. Y., Hsu, J.J., & Lin, Z. P. (2009). Fluorescence silica nanoprobe as a biomarker for rapid detection of plant pathogens. In Advanced materials research (Vol. 79, pp. 513-516). Trans Tech Publications Ltd.

Instructions to Authors

Submission to the journal must comply with the Guidelines for Authors.
Non-compliant submission will be returned to the author for correction.

To access the online submission system and for the most up-to-date version of the Guide for Authors please visit:

http://www.rfppl.co.in

Technical problems or general questions on publishing with **IJPS** are supported by Red Flower Publication Pvt. Ltd.'s Author Support team (http://rfppl.co.in/article_submission_system.php?mid=5#)

Alternatively, please contact the Journal's Editorial Office for further assistance.

Editorial Manager
Red Flower Publication Pvt. Ltd.
48/41-42, DSIDC, Pocket-II
Mayur Vihar Phase-I
Delhi - 110 091(India).
Mobile: 9821671871, Phone: 91-11-22754205, 79695648, 22756995
E-mail: author@rfppl.co.in

Review Article

Indian Journal of Plant and Soil
Volume 8 Number 1, January - June 2021
DOI: http://dx.doi.org/10.21088/ijps.2348.9677.8121.2

Nutrient Balance in Soil Ecosystem for Higher Productivity

Neeshu Joshi[1], Shourabh Joshi[2], Hanuman Prasad Parewa[3], Moola Ram[4]

Authors Affiliation
[1]Assistant Professor, Department of Agronomy, Agriculture Research Sub-Station, Sumerpur, Pali 306902, Rajasthan, India.
[2]Assistant Professor, Department of Plant Biotechnology, College of Agriculture, Nagaur 341001, Rajasthan, India.
[3]Assistant Professor, Department of Soil Science, College of Agriculture, Sumerpur, Pali 306902, Rajasthan, India.
[4]Assistant Professor, Department of Agronomy, Agriculture Research Station, Mandor, Jodhpur 342007, Rajasthan, India.

Corrosponding Affiliation
Neeshu Joshi, Assistant Professor, Department of Agronomy, Agriculture Research Sub-Station, Sumerpur, Pali 306902 Rajasthan, India.
Email: neeshu.joshi@gmail.com

How to cite this article:
Neeshu Joshi, Shourabh Joshi, Hanuman Prasad Parewa, et al./Nutrient Balance in Soil Ecosystem for Higher Productivity.2021;8(1):17-24.

Abstract

The rising population and reduction in the amount of land and some other resources have created tremendous pressure on current agricultural producers to meet the increasing food demands. To cope with this challenge, certain key inputs, such as fertilizers and other chemicals, are overused, which are worsening the surroundings. This intensive agricultural production without adherence to ecological sustainability has led to declining soil health, land degradation, and severe environmental problems. So, future efforts to feed the growing population should aim for greater agricultural production within sustainable environments. The present review suggests that a sustainable production system can be developed by combining the multifaceted efforts under soil and crop management strategies (SCMS) practices with short and long term preventive measures.

Keywords: Ecosystem; Nutrient cycling; Organic matter; Soil fertility; Micronutrients.

Introduction

Conventional agriculture, alternative agriculture, organic agriculture, chemical agriculture, industrial agriculture, eco-agriculture: Sharp distinctions are drawn among crop production systems attached to these labels. Differences in practices and philosophy are real, and can be a source of controversy and heated discussion, but there are important underlying similarities among farming systems of all types and labels.

Plants require three factors for growth and reproduction: light, water, and nutrients. The third of these factors, managing crops to provide an optimum nutrient supply, is where some of the major differences among farming systems occurs. These differences frequently are described as biological vs. chemical methods of maintaining soil fertility. This distinction is meaningful, but the categories are not mutually exclusive. It is important to understand both biological and chemical processes to effectively and efficiently provide plants with nutrients. Plant nutrients are chemical elements that are mostly absorbed by plant roots as inorganic chemicals dissolved in water. At the same time, plant nutrients are used by other forms of life and go through many biological transformations that determine when and how plants take them up. Biological materials like manure are major nutrient sources on many 'conventional' farms, as well as organic farms, while inorganic minerals (chemical materials) like rock phosphate and lime are acceptable fertility amendments for certified organic production (Anonymous, 1999).

Nutrient cycling

Sources of plant nutrients in the soil

Plants obtain mineral nutrients through root uptake from the soil solution. Sources of these soluble nutrients in soil include, decomposition of plant residues, animal remains, and soil microorganisms, weathering of soil minerals, fertilizer applications, manures, composts, bio-solids, seaweed and other organic amendments such as food processing byproducts, N-fixation by legumes, ground rock products including lime, rock phosphate, inorganic industrial byproducts, atmospheric deposition, deposition of nutrient-rich sediment etc.

Losses of plant nutrients from the soil

Mineral nutrients also can be lost from the soil system and become unavailable for plant uptake. Nutrient losses are not just costly and wasteful, they can be a source of environmental contamination when they reach lakes, rivers, and groundwater. Nutrient losses occur through, runoff - loss, erosion - loss of nutrients, leaching - loss of dissolved nutrients, gaseous losses to the atmosphere, crop removal etc.

Nutrient pools in the soil

In addition to the variety of inputs and outputs, plant nutrients exist in many different forms, or nutrient pools, within the soil. These pools range from soluble, readily available forms, to weakly bound forms that are in rapid equilibrium with soluble pools, to strongly bound or precipitated forms that are very insoluble and become available only over long time periods. Nutrients in solution can be taken up immediately by plant roots, but they also move with water and can easily leach below the plant root zone or be lost in runoff from farm fields. The 'ideal' fertile soil has high nutrient concentrations in the soil solution when crop growth rates are high and a large storage capacity to retain nutrients when crop needs are low or there is no growing crop. Exchangeable cations are a short-term storage pool that can rapidly replenish nutrient ions in the soil solution. Soil organic matter releases nutrients slowly as it decomposes, but is an important supply of N, P, S, B, and trace-metal micronutrients. Soil minerals vary from relatively soluble types (chlorides and sulfates) to insoluble forms (feldspars, apatite, mica) that release nutrients through weathering reactions with chemical and biochemical agents such as organic acids. Adsorbed anions, like phosphate and iron oxides bound to clay and organic matter surfaces, are held strongly and released very slowly, but can contribute to the long-term supply of plant-available nutrients.

Organic matter

Soil organic matter is a very important factor in soil fertility. It is a reservoir of plant nutrients, has a high CEC, buffers soil pH, and chelates micronutrients. Organic matter exists in different forms in soil, ranging from living soil organisms to fresh, readily decomposed plant residues to humus that is very stable and resistant to further degradation. Living soil organisms include bacteria, fungi, actinomycetes, nematodes, earthworms, mites, and insects. They make up the soil food web, which carries out biological nutrient cycling. Plant roots are a sometimes forgotten part of the living soil biomass. Readily decomposed or active organic matter is the form of organic matter through which nutrients are actively recycled. The cycling of plant nutrients through soil organic matter supplies a significant portion of a growing crop's nutrient needs. Another aspect of this cyclical process is that organic matter not only contributes to soil fertility, but fertile soils contribute to the production of organic matter. One of the best ways to add organic matter to the soil is to maintain fertility and grow healthy crops that add large amounts of plant residue (Anonymous, 1999).

Basic plant nutrient cycle

The basic plant nutrient cycle highlights the central role of soil organic matter. Cycling of many plant nutrients, especially N, P, S, and B, closely follows parts of the Carbon Cycle. Plant residues and manure from animals fed forage, grain, and other plant-derived foods are returned to the soil. This organic matter pool of carbon compounds becomes food for bacteria, fungi, and other decomposers. As organic matter is broken down to simpler compounds, plant nutrients are released in available forms for root uptake and the cycle begins again. Plant-available K, Ca, Mg, P, S, and some micronutrients are also released when soil minerals and precipitates dissolve.

We use models to depict relationships between location, form, and transfer of nutrient cycles. These models can be adapted to represent nutrient cycling at any scale, with varying degrees of detail. An ecosystem can be divided up into very few compartments, i.e., the simplest nutrient cycle might only distinguish between plant and soil compartments. As more compartments and pools are added, the cycling model becomes more complex. To address nutrient flows at the landscape level, individual fields or farms and adjacent waterways would be the designated compartments. A very simple depiction of N flows is shown in Fig. 1A.

Only three compartments are shown, with two biologically mediated processes that control the flux of N from soil organic matter (SOM) into the inorganic pool (Flux A, mainly controlled by microorganisms), and then from the inorganic N pool to plant biomass (Flux B, regulated by the plant). If mineralization and plant assimilation are equal (N moving in and out of the inorganic N pool is the same), and if these two processes are the dominant fluxes regulating this pool, then the size of the inorganic N pool will remain a constant, even though NO_3 2 is actually moving in and out.

This situation is called a steady state. You can see that if we collected monthly soil samples and extracted inorganic N under steady state conditions, the NO_3 2 pool will appear static since the concentration remains constant through time. We would miss the dynamics that are actually taking place, i.e., N is moving in and out of this pool. This is one of the difficulties in using static measurements of pool size as indicators of nutrient availability. The limitation of static measurements is particularly prominent when standing pools of inorganic N are very small. Small standing pools of NO_3 2 are usually interpreted as an indicator of low N fertility. However, if plant assimilation is keeping up with mineralization, you can have a very large flux in a very small inorganic N pool.

This is often the case in fields where organic residues have been used as nutrient sources for many years. We can close the cycle in this simple model by adding two more fluxes (Fig. 1B). These two new processes are the result of human management. In this model, harvest removes the N from our agroecosystem, and we do not consider the fate of the harvested N which could be going to animals, and/or humans, and the N remaining in crop residues is left in the field to become part of the SOM. In this case, harvest is considered to be an export, since the harvested N leaves our system while the other three fluxes are part of the internal N cycle.

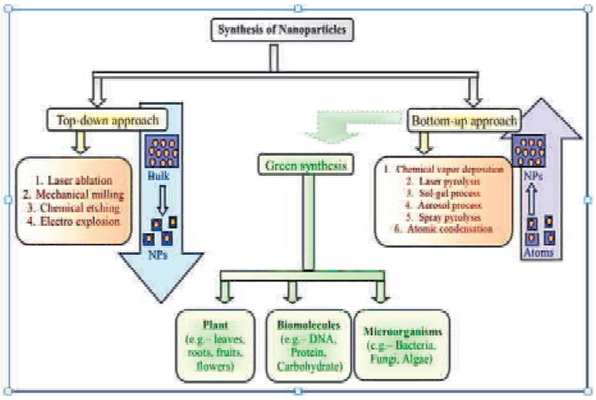

Fig. 1 A: Simple model demonstrating the use of compartments and fluxes to depict nutrient flows.

(A) Three compartments (a, b, and c) are shown with two biologically mediated fluxes. (B) The cycle is closed when plant residues are returned to the soil. Net export of N occurs through harvest.

A useful way to compare the dynamics of different compartments is mean residence time, or the average amount of time a nutrient spends in the compartment before being transferred out. Mean residence time is calculated as the pool size/flux, assuming the pool is close to steady state conditions (i.e., in _ out). For example, to estimate the mean residence time of nitrous oxide in the atmosphere on a global basis we calculate the total size of the pool and then divide by the estimated global rate of production:

[N_2O] 5300 ppb, Total N_2O = 2.3 X 1015 g

Rate of production: 20 X 1012 g/year

MRT = 2.3 X 1015 g/20 X 1012 g/year = 110 years.

Both turnover time and mean residence time require detailed knowledge of fluxes and pool size that can be difficult to accurately measure in soils without the use of expensive tracer experiments. However, the mean residence time for important soil nutrient pools varies widely. For example, mean residence time for NO_3 2 is about a day, while stabilized components of SOM have a mean residence time of hundreds to thousands of years (Tan, 2003). Given the huge difference in the temporal dynamics of these pools, it is not necessary to make measurements in your agroecosystems to apply these useful concepts. Estimates from the literature can be very helpful as a starting point.

Nitrogen cycle

The N cycle is the most complex nutrient cycle (the S cycle is equally complex). N exists in many forms, different physical states as well as both organic and inorganic compounds, so transformations between these forms make the N-cycle resemble a maze rather than a simple, circular cycle. Biochemical transformations of N, such as nitrification, denitrification, mineralization, immobilization (assimilation), and N-fixation, are performed by a variety of soil-inhabiting organisms. Physical transformations of N include several forms that are gases, which move freely between soil and atmosphere (Fig. 2). Although the N-cycle is very complex, it is probably the most important nutrient cycle to understand. Managing N is a critical part of soil fertility management. In agroecosystems, large quantities of N are added as inorganic fertilizer or organic residues from biological N fixation and various soil amendments, such as compost or animal manure, also playing a major role in driving the N cycle. The breakdown, or depolymerization, of the large, complex molecules that make up organic residues is facilitated by extracellular enzymes secreted mainly by soil fungi and prokaryotes (Schimel and Bennett, 2004). Plants also contribute to internal cycling via root exudation of a diverse array of organic compounds which are decomposed, but can serve as signals to soil organisms (Bais et al., 2006).

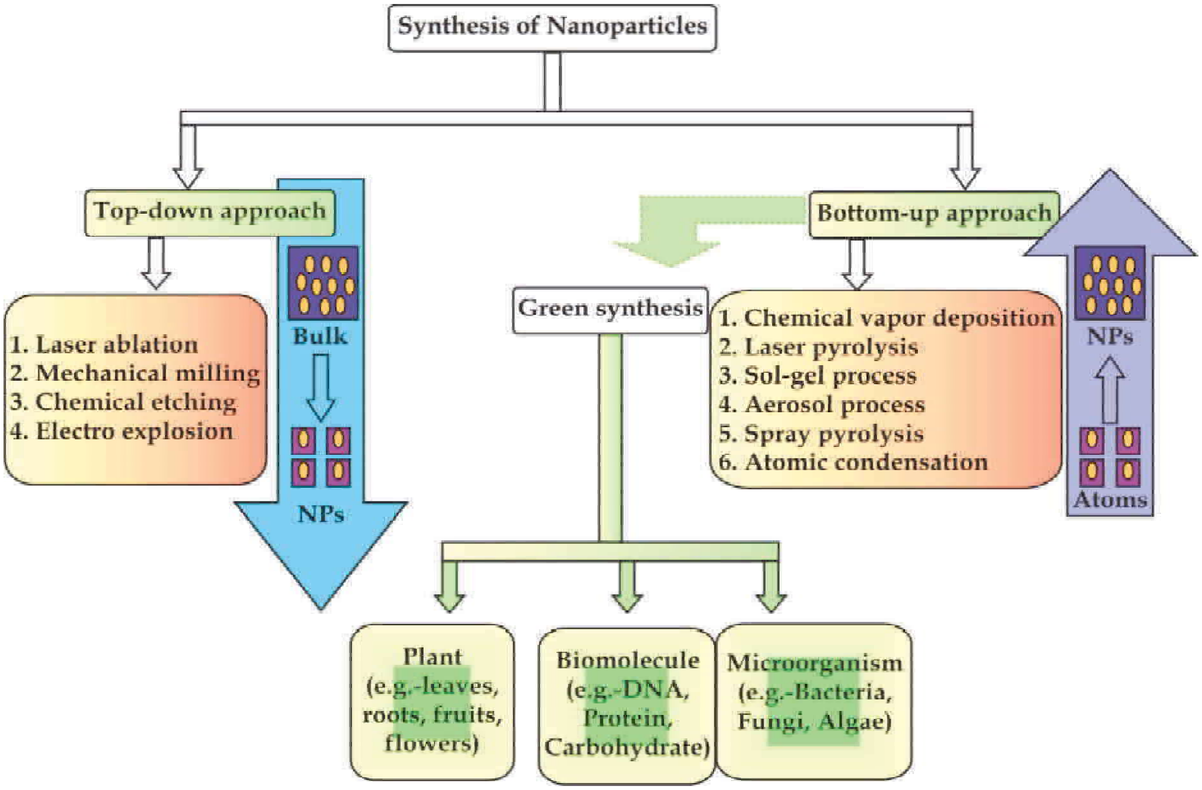

Fig. 2: Nitrogen cycling in agroecosystems.

See text for full discussion of cycling processes. New N is added through biological N fixation, synthetic fertilizers or organic amendments such as manure or compost (gray arrows). The main pathways of removal are through harvested exports, leaching, and denitrification (thick black arrows). Some gaseous losses also result from nitrification during the conversion of ammonium to nitrate (thick black arrows). Internal cycling processes occur through human management of residues, plant assimilation, and microbially-mediated transformations (thin black arrows).

Phosphorus cycling: The critical importance of soil P transformations.

Phosphorus (P) is important in plant cell division and growth. It is a difficult nutrient to manage because, although abundant in the soil, it is often in a form unavailable to plants. In acidic soils (pH below 5) the phosphorus gets tied up with iron and aluminum, and in alkaline soils (pH above 7) it gets tied up with calcium. Even with a favorable pH, phosphorus readily becomes immobilized by other soil minerals. Phosphorus anions may also be physically trapped in the clay-humus complex. Phosphorus is lost from soils through soil erosion, often at a greater rate than it can be replaced from the underlying subsoils. It accumulates in lakes and slow-flowing rivers, causing eutrophication (Cross and Schlesinger, 1995). The elimination of soil erosion is the first step in phosphorus conservation.

The addition of powdered rock phosphate or colloidal phosphate is a precautionary measure which, used in conjunction with the biological measures described below, can avoid phosphorus deficiency. The release of P to plants depends on soil biological activity, particularly that of certain bacteria and mycorrhizal fungi. Soil acids, produced by these micro-organisms and by OM decomposition, release phosphates. Phosphorus availability is therefore dependent on the maintenance of high levels of biological activity and stable humus in the soil. Under these conditions, phosphorus is continually recycled through the processes of OM decay (Fig. 3). Some plants produce acidity around their roots which assists in the uptake of P; examples of these are legumes actively fixing nitrogen, rapeseed, oil-radish and buckwheat (Gershuny and Smillie, 1986).

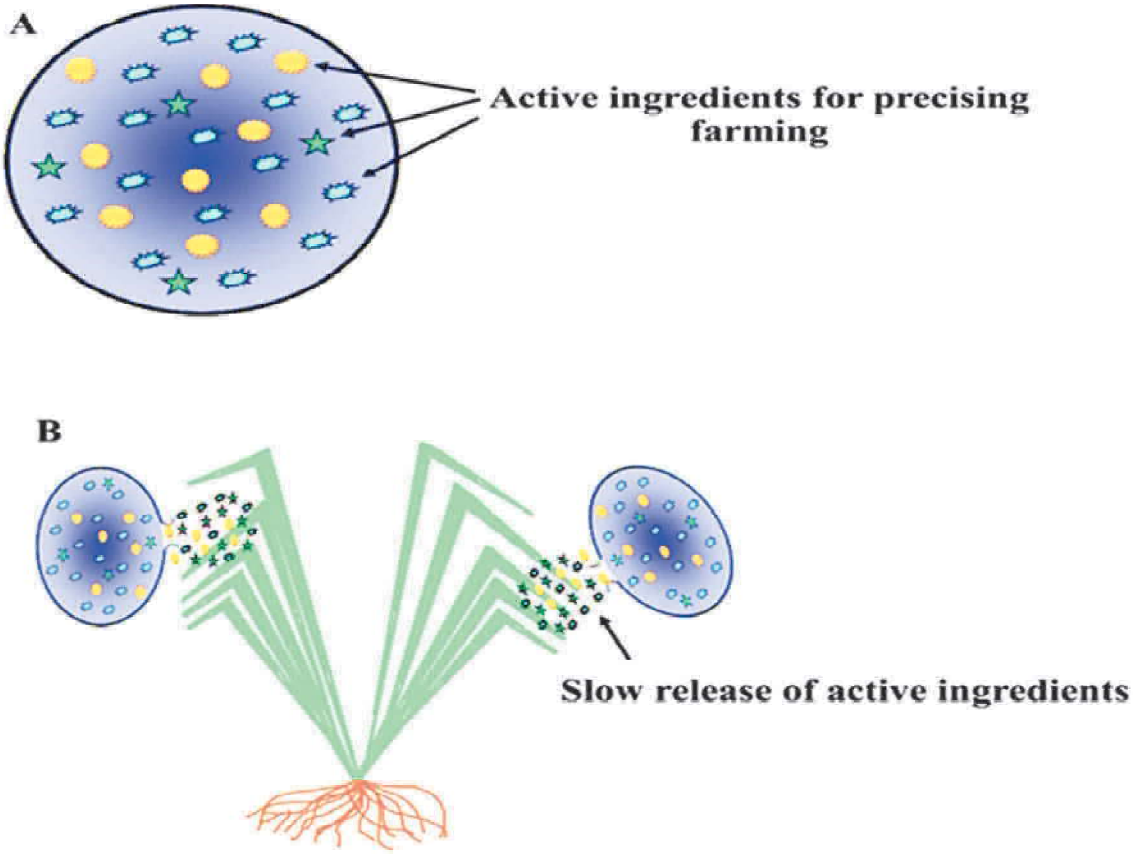

Fig. 3: The phosphorus cycle consists of biological and geochemical subcycles.

See text for full discussion of cycling processes. New P is added through soluble synthetic fertilizers, sparingly soluble amendments, such as rock P, or organic amendments such as manure or compost (gray arrows). The main pathways of removal are through harvested exports, erosion, occlusion, precipitation, with small losses occurring through leaching in some systems (thick black arrows). Internal cycling processes occur through human management of residues, plant assimilation, microbially-mediated transformations, and geochemical processes (thin black arrows). Dotted arrows indicate processes with smaller fluxes.

Potassium cycle

Potassium (K) is important as an enzyme activator in plants. It is involved in facilitating membrane permeability and translocation of sugars. Potassium is also needed for photosynthesis, fruit formation, winter hardiness, disease resistance, and amino acid and protein formation. Potassium builds plant stalk strength. It does not, however, form a permanent part of plant tissues, but is translocated to the stems and roots during ripening. Thus, potassium is readily available in crop residues roots, straw and corn stalks. Very little potassium is removed with a grain crop at harvest if the straw is left on the field (Belanger, 1977). Repeated cutting for hay or silage without returning potash in the form of manure or crop residues will quickly induce K deficiency. Soil potassium is present in minerals that dissolve slowly, thereby limiting its availability. Potassium availability is regulated by cation exchange. Potassium leaching increases as the amounts of clay and humus decrease and therefore may be a problem in sandy soils. A deep rooting green manure will help prevent losses. Increased biological activity and colloidal humus formation will increase potassium availability by enhancing the CEC in the soil.

Carbon cycle

All biologically mediated cycling processes are dependent on C, either for energy or as the backbone of biomolecules that must be synthesized for life to exist. SOM is defined as all carbon containing soil constituents, and is therefore the major biologically relevant soil reservoir for N and P in most arable soils. Because SOM is the result of all life, the biochemistry of SOM constituents is complex, reflecting the diverse array of compounds produced by plants, microbes, and larger soil organisms. The chemical composition and the accessibility of SOM to decomposing organisms (i.e., the actual size of the SOM and whether or not it is protected by soil minerals through occlusion or surface interactions) regulate the rate of decomposition with the former, being more important in the early stages of decomposition, and the latter, exerting more influence later in the process (von Lutzow et al., 2006). For practical purposes, SOM is conceptualized as a series of pools with varying flux rates that reflect differences in chemical composition and the degree of physical accessibility to microorganisms (Fig. 4). Decomposition of SOM is mediated primarily by bacteria and fungi, who release the majority of the C as CO_2 via respiration while incorporating a small portion of the C into cellular structures through biosynthesis (growth and reproduction). Growth, reproduction, and death, combined with interactions among soil organisms as part of the soil food web such as grazing, predation, and parasitism, regulate the flow of C and accompanying nutrients such as N, P, and other elements present in living organisms (Schmidt et al., 2011).

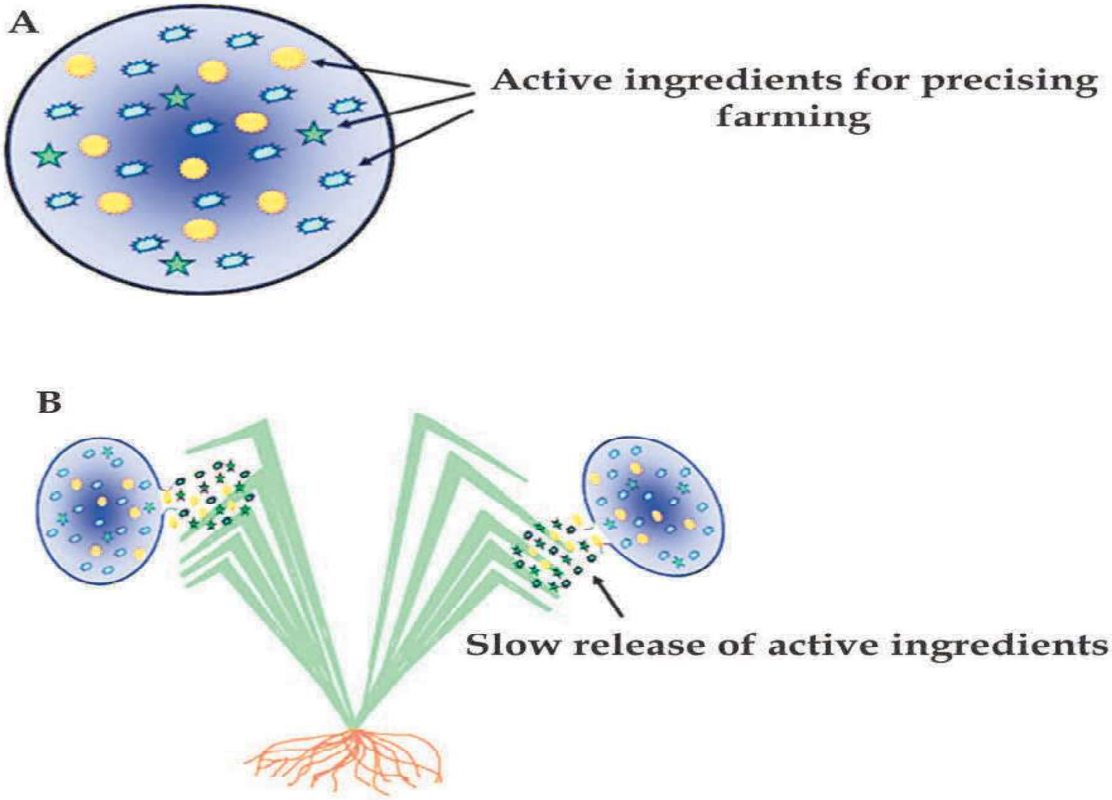

Fig. 4: Carbon cycling in agroecosystems.

See text for full discussion of cycling processes. The level of soil organic matter (OM) is determined by the balance between photosynthesis or new OM additions and decomposition. Decomposition encompasses two distinct processes that reflect the dual function of C: (1) respiration (energy), and (2) biosynthesis (growth and reproduction). Biosynthesis results in C from the various substrates actually being incorporated into microbial biomass, while respiration results in the release of CO_2 into the atmosphere. In this diagram we separate out OM pools based on their approximate rates of turnover. The stable OM pool is by far the largest, usually accounting for .80% of soil OM. The only route to stabilized OM that is directly under management control is through charcoal production. The vast majority of OM in the stabilized pool has undergone some form of microbial processing, and some of it has cycled through other trophic levels of the soil food web (i.e., grazers that feed on bacteria). In addition to the biological processes of respiration/biosynthesis, there are abiotic mechanisms which contribute to the stabilization of OM including adsorption, adventitious chemical reactions, and physiochemical interactions between clay particles and organic compounds that end up physically protecting these compounds making them inaccessible to decomposers or exoenzymes (von Lutzow et al., 2006; Schmidt et al., 2011). Thus, initially the rate of OM composition is controlled by the lability/recalcitrance of the compound. Some form of physical protection is required for OM to become stabilized in the soil for 100 years or more. Aggregate formation, which results in occluded OM, is mediated by both soil organisms and abiotic processes.

Micronutrients

About one hundred elements have been found in living plants. Carbon, hydrogen, and oxygen are the most abundant and are derived from water, oxygen and carbon dioxide. The nutrients N, P, K, calcium and magnesium have been discussed above. Of the other elements, we know that sulfur, iron, copper, manganese, zinc, molybdenum, boron and chlorine are required by plants in trace amounts. They are not constituents of the plant structure, but contribute to plant growth and development. Other elements, such as iodine, are essential to the animals that eat the plants. Deficiencies occur in soils that lack an inherent source of an element, or they can be caused by an imbalance in soil pH. Conversely, if certain micronutrients exceed trace levels, they can be toxic to plants. The range between deficiency and excess is very small. Therefore, micronutrients should not be applied unless a deficiency is shown by leaf analysis or by visible plant symptoms (Gershuny and Smillie, 1986). Micronutrients are best applied via compost, or by a foliar spray. Either of these methods is preferable to applying a trace mineral directly to the soil. In a biologically active soil with good CEC and balanced pH, micronutrient deficiencies are rare. Products based on seaweed (kelp) contain more than 80 elements, and organic farmers feed kelp meal as mineral supplement to their livestock, or incorporate small amounts of kelp products into compost as a precautionary measure against micronutrient deficiency.

Nutrient balance and nutrient budgets

Nutrient cycling is not 100% efficient. There are always some losses or "leaks" from the cycles, even for natural ecosystems. In farming systems, where products are bought and sold, the balance between nutrient inputs and outputs is easily shifted in one direction or the other. When the balance between inputs and outputs is quantified, a nutrient budget can be calculated. Nutrient budgets can be determined at different scales, from single fields to whole farms to landscapes and even broader regional areas. Strictly speaking, a cycle is a circular, closed-loop pattern. There are cycles within them, but they include other components and describe a larger picture where there is movement or flows of nutrients into and out of smaller systems such as farm fields. Nutrient balances or budgets look at these nutrient flows between different systems (Balfour, 1975).

Maintaining soil fertility

Management practices to maximize nutrient cycling & nutrient-use efficiency.

Nutrient management can be defined as 'balance use of all nutrient sources' and the primary challenges in sustaining soil fertility are to:

- Reduce nutrient losses
- Maintain or increase nutrient storage capacity
- Promote recycling of plant nutrients
- Apply additional nutrients in appropriate amounts

Summary

Goals of balance nutrient management are to provide adequate plant nutrients for optimum growth and high-quality harvested products, while at the same time restricting nutrient movement out of the plant-root zone and into the off-farm environment. Biological processes control nutrient cycling and influence many other aspects of soil fertility. Knowledge of these processes helps farmers make informed management decisions about their crop and livestock systems. Managing soil organic matter and biological nutrient flows is complex, because crop residues, manures, composts, and other organic nutrient sources are variable in composition, release nutrients in different ways, and their nutrient cycling is strongly affected by environmental conditions.

Management of inorganic nutrient sources is simpler than organic nutrient sources, because of their known and uniform composition and the predictability of their chemical reactions, but they are also more easily lost from farm fields. Use chemical fertilizers only after accounting for all organic nutrient sources to avoid overloading the system and losing soluble nutrients. For many farming systems, inorganic fertilizer will still be the largest nutrient input, but even then it is useful to think of chemical fertilizers as supplementary nutrients. When used to supplement biological nutrient sources, inorganic fertilizers can help make more efficient use of other available plant-growth resources, such as water and sunlight, by eliminating nutrient supply as the limiting factor in crop growth and yield. Chemical processes should be managed so they work together with biological processes for a productive agriculture and healthy environment.

References

1 Anonymous. 1999. Bulletin of the Ohio State University Piketon Research & Extension Center.

2 Balfour, E. 1975. The Living Soil and the Haughley Experiment, Faber and Faber, London, pp 382.

3 Belanger, J. 1977. Soil Fertility, Countryside Press, Waterloo,WN, pp 160.

4 Gershuny G. and Smillie J. 1986. The Soul of Soil, Gaia Services, Erle, Que., pp 109.

5 Schmidt, M.W.I., Torn, M.S., Abiven, S., Dittmar, T., Guggenberger, G., Janssens, I.A., et al.,

6 2011. Persistence of soil organic matter as an ecosystem property. Nature 478, 49_56.

7 Schimel, J.-P., Bennett, J., 2004. Nitrogen mineralization: challenges of a changing paradigm.

8 Ecology (Washington DC) 85, 591_602.

9 Cross, A.F., Schlesinger, W.H., 1995. A literature review and evaluation of the Hedley fractionation: applications to the biogeochemical cycle of soil phosphorus in natural ecosystems.

10 Geoderma 64, 197_214.

11 Tan, K.H., 2003. Humic Matter in Soil and the Environment: Principles and Controversies.

12 Marcel Dekker, New York, p. 386.

13 Bais, H.P., Weir, T.L., Perry, L.G., Gilroy, S., Vivanco, J.M., 2006. The role of root exudates in rhizosphere interations with plants and other organisms. Ann. Rev. Plant Biol. 57, 233_266.

Instructions to Authors

Submission to the journal must comply with the Guidelines for Authors.
Non-compliant submission will be returned to the author for correction.

To access the online submission system and for the most up-to-date version of the Guide for Authors please visit:

http://www.rfppl.co.in

Technical problems or general questions on publishing with **IJPS** are supported by Red Flower Publication Pvt. Ltd.'s Author Support team (http://rfppl.co.in/article_submission_system.php?mid=5#)

Alternatively, please contact the Journal's Editorial Office for further assistance.

Editorial Manager
Red Flower Publication Pvt. Ltd.
48/41-42, DSIDC, Pocket-II
Mayur Vihar Phase-I
Delhi - 110 091(India)
Mobile: 9821671871, Phone: 91-11-22754205, 79695648, 22756995
E-mail: author@rfppl.co.in