# Sustainable Nutrient Management

**Abdul Rehman, Aman Ullah, Faisal Nadeem, and Muhammad Farooq**

**Abstract** Agriculture production has substantially increased since green revolution due to introduction of modern cultivars and inputs. Organic fertilizers are key contributor to achieve high yield targets in sustainable way. From the last a few decades the uses of inorganic fertilizers have been increased to get higher yield. Low soil fertility is one of the major reasons for low crop production. However, under or over application of fertilizers and selection of wrong nutrient source causes nutrient imbalance in soil. Moreover, high application of inorganic fertilizers and unbalanced fertilization has reduced the nutrient use efficiencies (NUE) with high cost of production and environmental risks. Therefore, better NUE can reduce the fertilizer cost and environmental risks. This chapter discusses the challenges to sustainable nutrient management. Moreover, use of approaches for sustainable nutrient management including appropriate soil testing technique, fertilizer sources (organic, inorganic, biofertilziers and nanofertilizers) and application method in right combination using site specific nutrient management will reduce the fertilizer losses with high NUE and economic yield.

**Keywords** Organic · Fertilizer · Nutrient use efficiency · Biofertilizers and nanofertilizers

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# 1 Introduction

Nutrient management involves the practices linked to plant, edaphic and environmental factors with irrigation, water and soil conservation practices to attain optimal crop yield, crop quality, nutrient use efficiency and economic benefits while decreasing the nutrient losses (Delgado and Lemunyon 2006). It includes matching of edaphic and environmental factors to rate, time, source and place of nutrient application. The rising population and consumption, and reduction in available land and other productive units are placing unprecedented pressure on the current agriculture and natural resources to meet the increasing food demand. Achieving food security under sustainable systems poses a significant challenge in the developing world and is highly critical for alleviating poverty. To circumvent this challenge, crop producers tended to overuse certain inputs such as chemical fertilizers and pesticides which in turn have already started deteriorating environment.

Arable soil usually lacks plant nutrient in sufficient quantity to achieve higher and sustainable yield goals. Application of fertilizers and nutrient availability are closely associated with higher crop yield (Kaur et al. 2008) as plant nutrition is very crucial to maintain the productivity and quality of soil (Jaga and Patel 2012). Chemical fertilizers help to maintain soil productivity by ensuring supply of vital plant nutrients and thus help in economic crop production. In most of the countries demand of chemical fertilizer is increasing due to introduction of new high yield and intensive input requiring crop cultivars. For instance, the use of major fertilizers (nitrogen (N), phosphorus (P), potassium (K)) has increased up to sixfolds since green revolution (FAO 2014). The use of fertilizers is tremendously increasing as the annual demand of N, P and K is rising by 1.4%, 2.2% and 2.6% annually (FAO 2015). Fertilizer use has also increased in developing world as overall the growth in annual use of fertilizer is higher in Africa (3.6%) and Sub-Saharan Africa (4.7%) than developed countries. Most of the fertilizer demand/consumption is higher in Asia. For instance, N, P and K fertilizer consumption is highest in South Asia (24.5%, 31.3 and 19.3%) and East Asia (29.1%, 19%, and 35.8%) respectively than rest of the world (FAO 2015).

The manufacturing of fertilizers causes serious threat to environment as from mining to manufacturing; different harmful chemicals are released into the air, water and soil. For instance, emission of ammonia, fluorine, oxides of sulphur and nitrogen, acid mists, fertilizer dust and harmful radiations are emitted from the fertilizer manufacturing units causing major environment pollution (Li et al. 2013; Ju et al. 2014). This high use of fertilizers has also posed serious threats to environment. Maintaining agricultural production, while minimizing pollution to water and air, is a global problem. Direct emissions from agriculture comprises roughly 11% of global greenhouse gas emissions and these emissions are projected to rise by 20% by 2030 (US-EPA 2011). Including indirect emissions increases the total emissions from agriculture to 19–29% of the global total (Vermeulen et al. 2012).

Anthropogenic activities have profoundly altered the global nitrogen and phosphorus cycles and will continue to do so (Bouwman et al. 2009). Net anthropogenic nitrogen inputs in China, US and Northern Europe are estimated at between 2 and 3.5 t $ha^{-1}$ of which 15–30% is exported in rivers (Swaney et al. 2012). Indeed, studies across the globe have shown agriculture to be amongst the largest contributor of annual nitrate and phosphate loads to river waters (Liu et al. 2012).

Common field and farm management activities affecting diffuse pollution include the over-application of fertilizer (Withers et al. 2001), the inappropriate application of manure or slurry to land (Shepherd and Chambers 2007), or poor management of soil leading to erosion and surface runoff on both livestock and arable farms (Quinton et al. 2010). In this scenario, sustainable nutrient management approach will not only maintain the crop production but will also reduce the environmental pollution through over use of fertilizers. Sustainable nutrient management approach use the combination of well tested practices and principles of modern and traditional technologies in an integrated manner aimed at profitable crop production with better crop quality, nutrient use efficiencies and lower environmental pollution using crop management (crop rotation, intercropping), soil management (manures, green manures, organic fertilizers, nano fertilizers and crop residues), site specific nutrient application to fulfill the crop nutrient demand (Fig. 1). In this chapter, sustainable nutrient management approaches including soil management, crop management, fertilizer sources (organic, inorganic) and their application methods, site specific and integrated nutrient management practices and challenges to sustainable nutrient management are discussed.

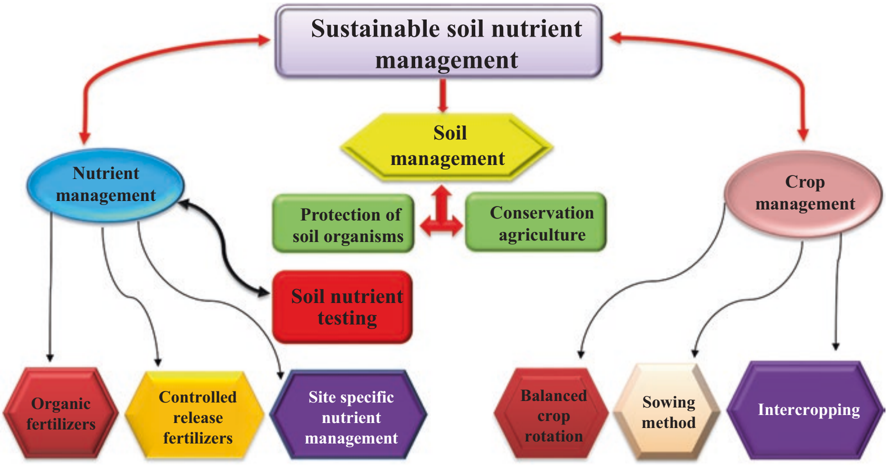

**Fig. 1** Pillars for sustainable nutrient management

## 2 Soil-Testing for Sustainable Nutrient Management

Optimal crop growth and yield depends upon the availability of essential and some non-essential (Si, Se, Co etc.) crop nutrients. Multiplicity in the crop nutrient demand, fertilizer combination using specific formulation of nutrients can increase crop yield from one to tenfolds, depending upon the crop and nutrient (Dimkpa et al. 2017). For better crop production a certain concentration of these nutrients should be present in soil that can be taken up by plants. However, soil physiochemical properties and moisture availability influence the availability of these nutrients (Marschner 2012). Moreover, microbes present in rhizosphere also influence the nutrient availability. Therefore, a comprehensive soil testing system is very crucial to determine soil nutrient status considering the biotic and abiotic factors that can influence nutrient dynamics.

The nutrient dynamics keep changing in the soil from fixation to dissolution in soil solution and uptake and translocation to shoot. Classical soil testing methods usually predict nutrient uptake to their presence in the soil solution. However, this is not true in all the cases. For instance, in Zn deficient soils fractions of Zn interacting with root surface are better indicator of Zn availability than Zn present in soil solution (Duffner et al. 2013). After estimation of soil physiochemical properties then next step is fertilizer recommendation based on these tests. However, soils having more than one nutrient deficiency, the fertilizer recommendation are not easy (Oliver and Gregory 2015; Voortman and Bindraban 2015) as identification of right balance between quantity and composition and their availability to plants pose serious challenge. Moreover, nutrient ratios in soil are very critical as excess of one nutrient can dilute the other nutrient. For example, urea is alkaline in nature and can affect the micronutrient (Zn) availability (Milani et al. 2015). Lime treatment to acidic soil based on soil testing my help to overcome the problem of low pH and release magnesium (Mg) and calcium (Ca) also. Similarly, use of acidic fertilizers ($HH_4SO_4$) can enhance the iron (Fe) and Zn supply in alkaline soils.

Soil testing methods may not solve the issue of fertilizer availability and suitability to specific soils completely; however, they serve as basis for fertilizers recommendation and can help in formulation of suitable fertilizer selection and nutrient blend for a specific soil. Conclusively, fertilizer recommendations based on harmonizing soil chemical properties with nutrient products for nutrient balance in a particular soil may or may not right all the time. However, rapid nutrient testing serves as the basis to maintain the soil fertility and crop nutrient demand.

## 3 Challenges in Sustainable Nutrient Management

Plant nutrition is the key factor that influences soil quality and productivity (Jaga and Patel 2012). Fertilizers maintain the productivity and fertility of soil by furnishing essential nutrients and ultimately result in economic crop production. However, the rise in fertilizer demand and over use of fertilizer also pose serious threats to sustainable nutrient management and environmental health. Fertilizer use efficiency is low for most of the agriculture soils, therefor, for sustainable nutrient management the nutrient use efficiencies should be improved (Fixen 2009). For instance, about half of the applied N is only used by plants while remaining N is bound in organic form (15–25%) in soil, volatilization (2–20%) and leaching (2–10%) into ground water (Sonmez et al. 2007; Chien et al. 2009). The nitrogen use efficiency (NUE) is even lower in some parts of the world. For instance, in China, two decades ago NUE for major cereal crops was 28–41% (Zhu 1992), which has declined to 26.1%, 28.2% and 28.3% in maize, wheat and rice respectively during last decade (Wang 2007). The NUE in some of the farmer field's in north China plain is reported to be 15% and 18% for summer maize and winter wheat (Cui et al. 2008). Furthermore, P recovery is also very low as only one-fourth of the applied P was recovered during crop growing season. It also precipitates with oxides of Al and Fe in acidic soils (Vance et al. 2003) and with Ca and Mg in calcareous soils (Rahmatullah et al. 1994) with further decline P use efficiency.

Mismanagement or over use of chemical fertilizers has resulted in low nutrient uptake and use efficiencies. For instance, N losses through leaching ($NO_3$), volatilization ($NH_3$), nitrification/de-nitrification ($N_2O/N_2$) and emission of NO causing serious environmental issues (Zhu and Chen 2002; Ju et al. 2009). Nevertheless, P is most lost through surface runoff or erosion while losses due to subsurface leaching are very low. Organic P have more subsurface leaching when it is in inorganic form as it is more soluble (Aziz et al. 2015). Potassium use efficiency is also low due to K losses through drainage water in acidic and sandy soils receiving high rainfall (Havlin et al. 1999).

Nutrient budget calculation has showed that overuse of fertilizers have resulted in accumulation of nutrient in soil. Nitrogen and phosphorus budget calculation in China showed that N and P which were deficient in 1950s are now surplus. However, the budget of K and micronutrient is mostly negative around the globe which causes nutrient imbalance and also reduce the chances of yield improvement due to better N and P use efficiencies. Moreover, overuse of macronutrient particular N and P is due to high yield targets by the farmers, and unavailability of suitable nutrient sources. Mostly fertilizers are applied manually which reduces the fertilizer use efficiencies as most of the farmers have small land holdings and they don't afford soil testing and modern nutrient application technologies.

Application of organic fertilizer only is also not effective as; higher application of organic fertilizers can change the nutrient dynamics in soil and their availability to plants. For instance, FYM increase the level of P, K, Ca and organic matter in surface soil wile nitrate, Ca and Mg level rises in subsurface soil (Edmeades 2003), which can lead to higher N losses (Goulding et al. 2008). Moreover, it is difficult to predict the mineralization of nutrient from different types of manures in different cropping systems which can result in under or over fertilization (Zhao et al. 2010). Therefore, use of appropriate combination of fertilizers (organic, inorganic) and their application at right time, right place and suitable rates can help in reducing the nutrient losses with higher use efficiencies.

# 4 Fertilizer Source

Along with soil and crop management; selection of fertilizer source is very critical for sustainable nutrient management for long term ecosystem sustainability and food security. The presence of widespread nutrients deficiency in the soils causes great economic losses to farmers and considerably decreases the quantity and nutritional quality of grains both for human beings and livestock. The application of fertilizers can enhance the crop productivity; however, the available nutrients present in the bulk chemical forms are not fully accessible to plants and their utilization is very low owing to their inversion to insoluble form in the soil (Solanki et al. 2015). The use of chemical fertilizers in large quantity to increase crop productivity in long run is not suitable option as in one direction these increase crop production but on the other direction disturb the soil mineral balance, soil fertility, soil structure, mineral cycles, soil fauna and flora and food chains across ecosystems leading to heritable mutations (Solanki et al. 2015). There is need to adopt a system which has smart delivery system, targeted application and in long run should be sustainable.

## *4.1 Chemical Fertilizers*

To increase and sustain food production the continuous fertilizer inputs are needed but there are problems with continued use of mineral fertilizers because of low nutrient uptake by crops in productive systems (Trenkel 1997). The high fertilizers application rates led to losses with negative impacts on atmospheric greenhouse gas concentration and water quality (Haygarth et al. 2013). Sustainable intensification with target to increase production on existing land area is a best option (Godfray et al. 2010). To keep the sustainability of agricultural and biogeochemical cycles there is need to develop nutrient efficient fertilizers which have high nutrient use efficiency. The nutrient efficient fertilizers include (i) controlled release fertilizers *vis* coated fertilizers, slow release fertilizers or uncoated fertilizers, (ii) nano fertilizers. These controlled release fertilizers have high efficiency owing to slow release of nutrients according to the crop demand and duration of the crop.

### 4.1.1 Coated Fertilizers

Excessive use of fertilizers causes problems especially with grown plants because roots are confined to small volumes, and the storage capacity of growth media for nutrients and water are limited. Frequent irrigation and fertilization are necessary to maintain the soil moisture and nutrient level, which may enhance leaching and runoff losses (Oertli 1980). Therefore, it is very important to select a proper fertilizer type, rate, and application technique to match the plant's nutrient and growth requirements as precisely as possible (Trenkel 2012). This can be achieved by using coated fertilizers compared to conventional fertilizers.

The population growth worldwide has increased the demand for food and to meet this demand a large area of fertile land is required to produce more food (Irfan et al. 2018). However, this fertile agricultural land is reduced owing to industrialization, urbanization and soil degradation (Chen et al. 2002; Brown et al. 2009; Gomiero 2016). To grow required food on diminished agricultural land a massive quantity of fertilizers are needed due to poor supply of nutrients (Irfan et al. 2018). The common solid fertilizers as uncoated or pristine granules have limitation as the release of nutrients from granules is fast and are vulnerable to losses in the form of leaching, volatilization and surface run-off (Bhat et al. 2011). Moreover, plants in their early/infancy stages cannot uptake all the supplied nutrients through fertilizers, so surplus nutrients are leached into the water table, causing problem for the aquatic life and cause economic losses (Vashishtha et al. 2010). To lessen these issues, one promising option is controlled-release fertilizers. There are two types of controlled-release fertilizers as (i) coated fertilizers (ii) uncoated fertilizers or slow-release fertilizers (Scherer 2005).

In coated fertilizers different types of impermeable coatings with small holes are used by which solubilized materials diffuse and semipermeable coatings through which water diffuses until the internal osmotic pressure raptures the coating (Scherer 2005). Coatings functions only as a physical barriers or a source of plant nutrient. The coating materials used in fertilizers are waxes, polymers, and sulfur. Osmocotes are covered with a plastic shell which allow the water to diffuse into the shell and tears the shell and nutrient diffuse into the soil. In sulfur-coated urea water vapor transfers through sulfur coating solubilizes the urea within the shell and builds sufficient osmotic pressure to disrupt the coating and urea is release (Scherer 2005).

The controlled release fertilizers are usually coated with organic polymers, modified biopolymers, natural macromolecule materials or nanocomposites. The coated film helps to achieve controlled, extended release rather than immediate release by providing the transport barrier to the fast dissolution of nutrients in the water when exposed without a coating (Salman 1989). The characteristics of coating materials are therefore important to get delayed or controlled release of nutrients (Table 1; Irfan et al. 2018).

The release process of coated fertilizers includes transport of water through coating, condensation of water molecules on the surface of nutrient core, dissolution of the active nutrient, development of osmotic pressure, swelling of controlled release fertilizers granule, and at the end the release of nutrient by transport through coating film via micro-pores (Irfan et al. 2018). The slow-release fertilizers (SRF) especially polymer-coated fertilizers improve the nutrient use efficiency and crop yield (Table 1; Shoji et al. 2001).

In a study, Tomaszewska and Jarosiewicz (2002) reported that the use of polysulfone as coating decrease the release rate of fertilizers and with the decrease of coating porosity the nutrient release rate further decrease. In case of coating with 38.5% porosity after 5 h 100% of $NH_4^+$ was released whereas in 11% porosity only 19% of $NH_4^+$ was released after 5 h.

**Table 1** Effect of slow release fertilizer on the nutrient release and use efficiency

| Nutrient | Compound name | Coating material | Formulation | Release time/ release amount | Increase in nutrient use efficiency (%) | Reference |
|---|---|---|---|---|---|---|
| Nitrogen | Sulfur-coated urea | Sulfur | – | – | – | Choi and Meisen (1997) |
| Nitrogen | Polyolefin-coated urea | Polyolefin | – | – | 79 | Shoji and Kanno (1994) |
| Nitrogen | Polyethylene- coated urea | Polyethylene | – | 1–4 months | – | Wei et al. (2017) |
| NPK | Polysulfone coated NPK-fertilizers | Polysulfone | NPK 06-20-30 with 18% polysulfone coating | After 5 h 19% $NH_4^+$, 8.7% $P_2O_5$, and 3.8% $K^+$ | – | Tomaszewska and Jarosiewicz (2002) |
| Nitrogen | Polymer coated urea fertilizers | DVB | N-DVB 20 g N and 0.38 mL DVB | 82.3% 45th day | – | Abraham and Rajasekharan Pillai (1996) |
| Nitrogen | Polymer coated urea fertilizers | NNMBA | N-NNMBA 20 g N and 0.23 g NNMBA | 85.6% 45th day | – | Abraham and Rajasekharan Pillai (1996) |
| Nitrogen | Polymer coated urea fertilizers | PETA | N-PETA 20 g N and 0.50 mL PETA | 88.9% 45th day | – | Abraham and Rajasekharan Pillai (1996) |
| Nitrogen | Polymer coated urea fertilizers | TTEGDA | N-TTEGDA 20 g N and 0.41 mL TTEGDA | 81.2% 45th day | – | Abraham and Rajasekharan Pillai (1996) |
| Nitrogen | Urea coated starch-g-PLLA fertilizers | Starch-g-PLLA | Urea 0.2 g and starch-g-PLLA 2.0 g | 100% at 26 h | – | Chen et al. (2008) |
| Nitrogen | Urea coated starch-g-poly(vinyl acetate) | Starch-g-poly(vinyl acetate) | Urea 0.2 and starch-g-poly(vinyl acetate) 2.0 g | 78% at 30 days | – | Niu and Li (2012) |

| | | | | | | |
|---|---|---|---|---|---|---|
| Phosphate | Monoamonium phosphate coated polyethylene/paraffin waxes fertilizers | Polyethylene/ paraffin waxes | Monoamonium phosphate 18 g and polyethylene/ paraffin waxes 2 g | 45 days paraffin wax,<br>52 days with polyethylene wax | – | Al-Zahrani (2000) |
| Phosphate | Diamonium phosphate coated polyethylene/paraffin waxes fertilizers | Polyethylene/ paraffin waxes | Diamonium phosphate 18 g and polyethylene/paraffin waxes 2 g | 48 days paraffin wax,<br>58 days with polyethylene wax | – | Al-Zahrani (2000) |
| Mixture of nitrogen and phosphate | Compound nitrogen and phosphate coated polyethylene/paraffin waxes fertilizers | Polyethylene/ paraffin waxes | Compound nitrogen and phosphate 18 g and polyethylene/paraffin waxes 2 g | 42 days paraffin wax,<br>48 days with polyethylene wax | – | Al-Zahrani (2000) |
| NPK | NPK coated polyethylene/ paraffin waxes fertilizers | Polyethylene/ paraffin waxes | NPK 18 g and polyethylene/ paraffin waxes 2 g | 50 days paraffin wax,<br>64 days with polyethylene wax | – | Al-Zahrani (2000) |
| Phosphate | Triple superphosphate coated polyethylene/paraffin waxes fertilizers | Polyethylene/ paraffin waxes | Triple superphosphate 18 g and polyethylene/paraffin waxes 2 g | 40 days paraffin wax,<br>48 days with polyethylene wax | – | Al-Zahrani (2000) |
| NPK | NPK-polymer coated fertilizers | Acrylate latex | NPK 80 kg and acrylate latex 16 kg | 9 days | 40 | Cong et al. (2010) |

*DVB* divinylbenzen, *NNMBA* N,~-methylenebisacrylamide, *PETA* pen-taerythritol triacrylate, *TTEGDA* tetraethyleneglycol diacrylate, *Starch-g-PLLA* starch-g-poly(L-lactide)

In conclusion, coated fertilizers are slow release fertilizers which provide the nutrients to the crop plants in a slow pattern; they slowly release with the passage of the time and fulfill the crop nutrients' demand with their growth pattern. Use of coated fertilizer can help in reducing the fertilizer application rates with higher NUE.

### 4.1.2 Slow/Controlled: Release Fertilizers

Controlled or slow release fertilizers are those fertilizers which contains plant nutrients in a form which either (i) delays the availability for plant uptake and use after its application (ii) or is available to the plant significantly longer than a "rapidly available nutrient fertilizers" (Table 1; AAPFCO 1995; Trenkel 1997).

Crops up take only 50–60% of the added N fertilizer to the soil in a growing season. This uptake of N fertilizer can be enhanced by controlling the rate of N fertilizer dissolution (Scherer 2005). On way to control the rate of N dissolution is controlled-release fertilizers and the aim of this slow release fertilizer is to provide the crops nutrients according to the demand (Scherer 2005). The slow-release fertilizers (SRF) release active nutrients in a controlled manner, extend the duration of release, and manipulate the rate of release so that they become compatible with the metabolic needs of plants (Irfan et al. 2018). The long term gradual release of nutrients from SRF is a solution to the current need of food (Trenkel 2010) and is necessary for the sustainability of the ecosystem. Un-coated urea fertilizers are readily soluble in water and quickly decomposed to release $NH^{+}{}_{4,}$ it forms several chemical reaction and products that are useful as slow-release N fertilizers (Scherer 2005).

Most of the studies (Yaseen et al. 2017; Trenkle 2010) have shown that by the application of P in the form of controlled-release fertilizers to citrus decrease potential losses and increase the fertilizer use efficiency compared with water soluble fertilizers (Zekri and Koo 1992). Conclusively, use of slow release fertilizers is effective approach for sustainable nutrient management as nutrients are available during the whole crop season. Moreover, it is also ecofriendly due to reduced nutrient losses through leaching and volatilization.

### 4.1.3 Nano Fertilizers

Nano-fertilizers are basically smart fertilizers which are designed to increase nutrient use efficiency and to reduce the adverse effects of conventional mineral fertilizers on the environment (Sharpley et al. 1992; Wurth 2007; Manjunatha et al. 2016). There are three types of nano-fertilizers as (i) nanoscale coating or host materials (nano-polymer), (ii) nanoscale additives and (iii) nanoscale fertilizers (synthesized nanoparticles) (Mastronardi et al. 2015). These nano fertilizers are most suitable alternatives to soluble fertilizers as they release nutrients at a slower rate during the crop growth so reduce nutrient losses (Table 2). In this regard, zeolites (natural clays) are best as they act as reservoir for nutrients that are slowly released (Manjunatha et al. 2016).

**Table 2** Effect of nano-fertilizers application on nutrient uptake and crop yield

| Nutrient | Compound name | Carrier | Grain nutrient contents | Technique | Crop | Release rate/time | Increase in yield (%) | Reference |
|---|---|---|---|---|---|---|---|---|
| Zinc | Zinc complexed chitosan nanoparticles (Zn-CNP) | Chitosan | 36% | – | Wheat | – | – | Dapkekar et al. (2018) |
| Iron | $Fe_2O_3$ NPs | – | 996 mg $kg^{-1}$ | ICP-MS | Rice | – | – | Gui et al. (2015) |
| Iron | Nano-iron chelate | – | 75 mg/g | – | Faba bean | – | – | Nadi et al. (2013) |
| Zinc | Zn-nano-zeolite | Zeolite | – | Atomic adsorption spectrophotometer | – | 1176 hurs | – | Yuvaraj and Subramanian (2018) |
| Phosphorus | P-nano hydroxyapatite | Hydroxyapatite | – | – | Soybean | – | 20 | Liu and Lal (2014) |
| Nitrogen | Urea hydroxyapatite nanoparticles | Wood | – | Kjeldhal method and vnadomolybdate method | – | 60 days | – | Kottegoda et al. (2011) |
| Zinc | MAP−nano-ZnO | Monoammonium phosphate | – | Inductively coupled plasma optical emission spectroscopy (ICP-OES) | – | 48 hurs | – | Milani et al. (2012) |
| Zinc | Nano-scale zinc oxide | – | 40 ppm | Transmission electron microscopy | Peanut | – | 29 | Prasad et al. (2012) |
| Zinc | Nano zinc | – | 23 mg/kg | – | Rice | – | – | Apoorva et al. (2017) |
| Nitrogen | Nanozeourea | Zeolite | 0.78 mg/kg | – | Maize | – | 8 | Manikandan and Subramanian (2016) |
| Iron and Zinc | Fe + Zn nano-fertilizers | – | – | – | Chickpea | – | 34% | Drostkar et al. (2016) |

The nano-fertilizers have high surface area, controlled release kinetics to targeted sites and sorption capacity called as smart delivery system (Fig. 2; Solanki et al. 2015). A nano-fertilizer is a product in nanometer regime that delivers nutrients to crops, for example encapsulation inside nanomaterials coated with a thin protective polymer film or in the form of particles or emulsions of nanoscale dimensions (DeRosa et al. 2010). The surface coatings of nanomaterials on fertilizer particle hold the material more strongly due to higher surface tension than conventional fertilizer surface and help in controlled release (Brady and Weil 1999). The nano-fertilizers have high solubility, effectiveness, stability, targeted activity, time-controlled release and less eco-toxicity, safe, easy mode of delivery and disposal (Tsuji 2000; Boehm et al. 2003; Green and Beestman 2007; Torney et al. 2007).

In a study, Corradini et al. (2010) evaluated the interaction and stability of chitosan nanoparticles suspensions containing N, P, and K fertilizers which can be useful for agricultural applications. In another study, Kottegoda et al. (2011) synthesized urea modified hydroxyapatite (HA) nanoparticles for gradual release of N to crop growth. These nano-fertilizers showed slow release of N up to 60 days of plant growth compared to commercial fertilizers which showed release only up to 30 days. The large surface area of HA facilitates the large amount of urea attachment on the HA surface. The strong interaction between HA and nanoparticles and urea contributes to slow and controlled release of urea. Few years back, Milani et al. (2012) compared the Zn solubility and dissolution kinetics of ZnO nanoparticles and bulk ZnO particles coated on macronutrient fertilizers (urea and monoammonium phosphate) and reported that coated monoammonium phosphate granules show faster dissolution rate.

Zeolite based nano-fertilizers are capable to release nutrient slowly to the crop plant which increase availability of nutrient to the crop throughout the growth period and prevent loss of nutrient from volatilization, leaching, denitrification and fixation in the soil especially $NO_3$-N and $NH_4$-N. The nutrient having particle size of below 100 nm nano-particles are used as efficient nutrient management which are more ecofriendly and reduce environmental pollution (Joseph and Morrisson 2006). The nano particles increased the NUE and minimized the costs of environmental protection (Naderi and Abedi 2012) and enhance plant growth by resisting the diseases and improving the stability of plants by deeper rooting and by anti-bending of crops (Fig. 2; Tarafdar et al. 2012).

In conclusion, nano fertilizers are ecofriendly can help in improving the agricultural productivity by improving the NUE with lower fertilizer requirement and better grain yield.

### 4.2 *Organic Fertilizers*

Organic fertilizers supply nutrients in slowly soluble organic with belief that plants will get balance nutrition through the actions of soil microbes, roots and weathering of minerals (Kirchmann et al. 2009) and these organic forms of nutrients are

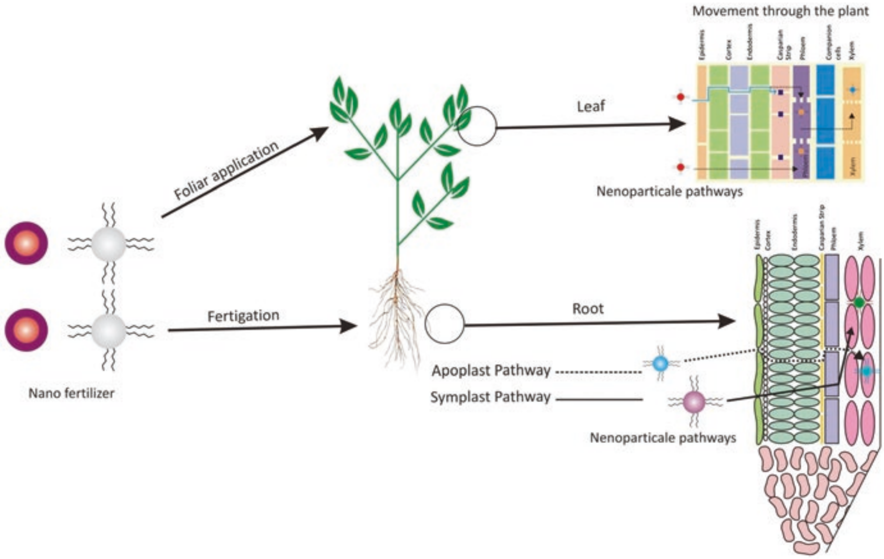

**Fig. 2** Mechanism of nano-fertilizer uptake through foliar and fertigation in plant

available to the crop plants with longer time period. In inorganic fertilizers application the plants are directly fed owing to complete and high solubility of inorganic fertilizers in water (Kirchmann et al. 2009) compared with organic sources which release nutrients slowly which are available according to the crop need and has less or negligible losses to the environment.

The application of organic manures enhances build-up of soil organic matter, support soil structure, increase the cation exchange capacity, helps to chelate micronutrients, increase soil moisture retention while inorganic fertilizers supply crops with nutrients at times when their demand is large (Kirchmann et al. 2009). Organic materials are added to the soils to protect the productivity and sustainability of the land. The natural wastes are mostly used as organic fertilizers to increase the efficiency of nutrients and nutritional value of soils (Demir and Gulser 2015). Green manure/green manuring, farm yard manure and Compost are most widely used organic fertilizers.

### 4.2.1 Green Manuring

Quantity of agricultural production, crop yield, soil nutrient, and the environment all are influenced by fertilizer use. The increased mineral fertilizers prices and decreased soil fertility made legumes a popular option as organic fertilizer to improve the soil fertility in long run (Talgre et al. 2012). In a study, Talgre et al. (2012) found that after incorporation of green manure crops into the soil was effective in releasing nutrients into the soil even in the 3rd year. The application of green manures can replace the entire N requirement for non-leguminous succeeding crops (Guldan et al. 1997).

The use of perennial legumes as green manure (such as alfalfa) import additional nutrients (P, K and Ca) due to their deeper root system (Teit 1990) to the soil which are accessible to the succeeding crops (Witter and Johansson 2001). When green manures are added into the soil, they add large amounts of N and other nutrients, but these nutrients are released at a slower rate also N from N-fixing bacteria becomes accessible over a long time span. These processes supply steady source of N for succeeding crops (Freyer 2003), in the long run maintains the sustainability of the system. In a study, Viil and Vosa (2005) found that the positive effects (16–18%) of green manure become visible in the 2nd year. Talgre et al. (2012) reported that the yield results of green manure application showed that N is slowly released from green manure which in result decrease the lodging and yield losses.

The slow release of N from decomposing green manure residues is better synchronized with plant uptake than inorganic N sources as it increases N-uptake efficiency and crop yield while reduces N leaching losses (Abdul-Baki et al. 1996; Agustin et al. 1999; Aulakh et al. 2000; Cline and Silvernail 2002). The green manuring also drives long-term increase of soil organic matter and microbial biomass (Goyal et al. 1992, 1999; Chander et al. 1997; Biederbeck et al. 1998) and further improves nutrient retention and N-uptake efficiency (Cherr et al. 2006). Green manuring also offers habitat or resources for beneficial organisms (Bugg et al. 1991; Nicholls and Altieri 2001). The application of green manures reduced soil bulk density, increased soil organic matter and N, P, K, Ca and Mg (Adekiya et al. 2017). In conclusion, the incorporation of green manures improves the soil fertility, nutrients and crop growth and yield.

### 4.2.2 Farm Yard Manure

Farm yard manure is a decomposed mixture of urine and dung of the farm animals along with litter and left over material from roughages or fodder fed to the cattle. The application of farm yard manure improves the soil chemical, physical and biological properties (Bayu et al. 2006). Oswal (1994) reported that the application of farm yard manure (FYM) increased the electrical conductivity, cation exchange capacity, organic carbon and soil moisture contents. Likewise, Aggarwal et al. (1997) found that FYM increases water storage, crop yield and soil nutrient availability. Application of poultry manure (5 t $ha^{-1}$), FYM (10 t $ha^{-1}$) and piggery manure (2.5 t $ha^{-1}$) were equivalently effective and added 11.2 kg Zn $ha^{-1}$ in maize-wheat cropping system (Nayyar et al. 1990). In another study, Alok and Yadav (1995) demonstrated that application of organic manure in rice wheat cropping system increased the Zn availability more than inorganic sources. Use of organic manures can meet the crop nutrient demand as they are rich in nutrients, improve physiochemical characteristics of soil and enhance nutrient uptake through formation of soluble nutrient complexes.

### 4.2.3 Compost

To satisfy the growing global food demand cereal production has increased (He et al. 2014) and this increase in production has in turn increased the amounts of harvested residues (straw, stubble) that can be a source of biomass feedstock or for animal feeding (Jiang et al. 2012; Habets et al. 2013). Unluckily, worst practice is removal of these residues by in situ burning with considerable environmental, human health and economic impacts (Singh et al. 2010; Gupta et al. 2016). These harvested residues can be a resource that can be utilized as organic raw material which improves the soil quality and productivity (Calabi-Floody et al. 2018).

One way to use these residues is their use as a composting agent (Roca-Perez et al. 2009; Medina et al. 2017). Compost is the final product which is obtained after composting and is rich and more stable than original material (feedstock) and can improve soil quality and productivity as well sustainability of the agricultural production (Farrell and Jones 2009; Barral et al. 2009). The application of compost slower the rate of mineralization (Bernal et al. 2009) and owing to this slow mineralization process the nutrients are available during the whole growing season and are more stable. With the application of compost soil structure is improved with the binding of soil organic matter and clay particles via cation bridges and through stimulation of microbial activity and root growth (Farrell and Jones 2009). In conclusion, the application of compost in the long run improves the soil structure, organic matter and fertility status of the soils.

## *4.3 Use of Soil Microbes*

In intensive agriculture system, use of chemical fertilizer is necessary for getting good crop yield, however, the utilization efficiency of these nutrients remain low due to losses through leaching, volatilization and denitrification and fixation (Ayala and Rao 2002). These chemical fertilizers also increase the cost of production and are not ecofriendly (Adesemoye and Kloepper 2009). In this scenario, bio-fertilizers offer a better alternative to synthetic chemicals as they improve crop quality, yield and also increase resistance to abiotic stresses (Kumar et al. 2006). Integration of PGPR with traditional inorganic fertilizers in the field proved to be effective means to increase the availability of nutrients to plants with simultaneous reduction in diseases incidence of oil seed crop has been reported (Kumar et al. 2009). Plant growth promoting rhizobacteria (PGPR) and arbuscular mycorrhizae fungi (AMF) have been reported to increase the availability and uptake of nutrients in the soil.

### 4.3.1 Mycorhiza

Mycorhiza colonization enhances the absorption and uptake of nutrients limited to diffusion from soil solution to plant roots (Fageria et al. 2011). The AMF increase the phosphorus uptake by plants by enhancing the root surface area for absorption and by mineralizing the organic phosphorus (Wang et al. 2014). Few years back, Yang et al. (2012) reported that rice colonized with AMF received 70% of acquired pi from symbiotic fungi. The AM fungi also increases the nitrogen uptake as $NH^{+4}$ transporters in AMF (GintAMT1, GintAMT2, GintAMT3) in *Rhizophagus irregularis* are involved in AM symbiosis (Lopez-Pedrosa et al. 2006; Perez-Tienda et al. 2011; Calabrese et al. 2016). These $NH^{+4}$ transporters genes express under low $NH^{+4}$ supply and enhance ammonium uptake from soil and surrounding media. Furthermore, AMF increase the availability of N to the plants by accelerating the decomposition of organic materials (Hodge et al. 2001; Leigh et al. 2009).

Mycorhizal colonization also increases micronutrient availability. For instance, soil inoculation with some *Penicillium sp. s*trains accelerates the uptake of Fe, Zn and Cu from soil and their accumulation in plants (Kucey 1988). Three decades ago, Meyer and Linderman (1986) established that co-inoculation of AMF and PGPR (*Pseudomonas putida*) enhanced the Al, Co, Cu, Fe and Ni uptake in shoots as *p. putida* release 2-ketogluconic acid which increase the micronutrient availability and uptake by plants through mycorrhizal colonization. However, plants grown on heavy metal polluted soils have low concentration of Cd, Cu, Mn and Zn with AMF inoculation than non-mycorrhizal association, indicating role of AMF in heavy metal stress tolerance (Weissenhorn et al. 1995; Guo et al. 1996). Furthermore, under enhanced Pd supply, AMF increase plant growth by accelerating the phosphorus uptake and protecting plants from Pd toxicity (Chen et al. 2005).

In conclusion, mycrorhizal associations improve the nutrient availability to plants under limited nutrient supply and can be used effectively as bio-fertilizers. Moreover, AMF regulate the metallic ions uptake thus protect plants from heavy metal toxicity.

### 4.3.2 Plant Growth Promoting Bacteria

Interaction of plants and soil bacteria play crucial role in maintaining the soil fertility. Plant growth promoting rhizobacteria improve the crop productivity when used in the form of biopesticides (Arora et al. 2008) and biofertilizer (Cakmakci et al. 2006). These PGPR improve the plant growth directly or indirectly through enhanced nutrient availability, root development and resistance against biotic and abiotic stresses (Glick 1995) by improving $N_2$ fixation, Fe sequestration, phosphate solublization, phytohormones synthesis, control on ethylene production and phytopathogens (Gamalero and Glick 2011). Plants can only utilize very small quantity of the applied phosphorus as >75% of applied P is precipitated with metallic cations and becomes fixed in the soil. In this scenario P solubilization and mineralization by phosphate solubilizing bacteria play key role in increasing phosphorus availability

(Jeffries et al. 2003). Phosphorus solubilizing bacterial synthesize organic acids like citric acid and gluconic acid which help in P solublization (Rodriguez et al. 2004).

Biological nitrogen fixation (BNF) almost accounts for 2/3 of the total N used in agriculture and it will be crucial for crop production sustainability in future (Matiru and Dakora 2004). Key BNF biochemical reaction occurs between legume and nitrogen fixing microbes that convert $N_2$ into $NH_3$ (Shiferaw et al. 2004). Nitrogen fixed by *Rhizobia* in legume crops also benefits the associated cereals or non-legume intercrops (Snapp et al. 1998) or subsequent crop. For instance, in many grass land systems with limited inputs, grasses depend on legume fixed N to meet the N requirement which is needed for better fodder quality (Paynel et al. 2001; Hayat and Ali 2010). Moreover, use of plant growth promoting bacterial can improve the micronutrient availability. Recently, Rehman et al. (2018a, b) reported an increase in Zn uptake and its translocation in wheat with Zn solubilizing bacteria due enhanced production of organic acids from the root exudates of wheat. Iron availability is also enhanced by PGPR as they release siderophores which help in Fe chelation. Fluorescent pseudomonads bacteria increase the iron sequestration by releasing iron-chelation siderophores (Dwivedi and Johri 2003).

Soil bacteria fix the atmospheric nitrogen and increase the availability of other macro and micronutrients through nutrient solubilization mineralization, siderophore production and root development. These PGPR can be used as bio fertilizers as this will be cost effective, ecofriendly and sustainable approach for nutrient management in crop production systems.

## *4.4 Fertilizer Application Methods*

Fertilizer can be applied through several ways such as soil application, foliar application and through seed treatments (seed priming and seed coating). Each method of application has some limitations and advantages upon others.

### 4.4.1 Soil Application

Soil application of fertilizers is the most common approach to overcome the nutrient deficiencies. It can be done through broadcasting, band placement and fertigation. Mostly macronutrients are applied through soil application. For instance, soil incorporation/deep placement of urea minimizes the N losses with higher nitrogen use efficiency (Katyal et al. 1987). Nevertheless, soil incorporation of fertilizer depends on soil physiochemical properties but usually 5–10 cm depth is used for nutrient incorporation. Time of fertilizer application is very crucial for soil application as some fertilizers (phosphate fertilizers) are mostly applied at the time of sowing.

In a study, Rahim et al. (2012) found that band placement of P as basal application results in better phosphorus use efficiency than broadcasting of P. Contrary to this, Latif et al. (2001) reported that P application in splits as topdressing or fertigation was better than soil incorporation of P in wheat. In another study, Alam et al. (2005) established that application of N and P through fertigation enhanced the grain yield of wheat with better N and P uptake compared to topdressing. Furthermore, in wheat K is usually applied through broadcasting followed by incorporation in soil and drilling (Bijay-Singh et al. 2004).

Moreover, micronutrients are also supplied through soil fertilization. For instance, Zn fertilization through soil has increased the Zn uptake and bioavailability in wheat (Rehman et al. 2018a, b). In a recent study, Farooq et al. (2018) reported that Zn through soil application improved the grain Zn concentration in both conventional and conservation rice production systems. In another study, Zhao et al. (2018) demonstrated that band application of $ZnSO_4$ had little effect on grain Zn concentration but increase the loose organic matter bound Zn fraction in soil. Further, efficiency of Zn-EDTA and $ZnSO_4$ were higher when uniformly mixed rather than band application. However, both Zn sources have limited effect on grain Zn bioavailability due to higher fixation in calcareous soil.

Soil application of nutrient is very common approach to correct nutrient deficiencies and is most efficient method for macro nutrients (N, P and K) application. However, lack of soil plant nutrient status, higher rates of nutrient application, increased cost of production and unavailability of suitable nutrient sources are major bottleneck in this approach.

### 4.4.2 Foliar Application

Soil fertilization is mostly practiced for application of nutrients. However, higher plants also absorb nutrients through leaves when applied in suitable concentrations (Fageria et al. 2009). Foliar fertilization is mostly practiced for micronutrients as they are needed in small quantities. Otálora et al. (2018) conducted a study on foliar fertilization of urea and found that foliar applied urea enhances the N and other mineral uptake except Cu and Zn and enhanced the protein and amino acid accumulation. However, higher N rates reduced the sugar and phenolics accumulation in escarole (*Cichorium endivia* L. var. latifolium). Foliar fertilization has been found effective in improving the crop micronutrient demand. For instance Rehman et al. (2018a, b, c) reported that foliar Zn fertilization increases the grain Zn concentration in whole grain and endosperm with high Zn bioavailability. Likewise, a number of studies had reported increase in grain Zn and manganese (Mn) accumulation with foliar application (Zhao et al. 2014; Ullah et al. 2017a, b; Farooq et al. 2018; Rehman et al. 2018a, b).

Foliar application of $CaCl_2$ (1% solution) increased the Ca concentration of leaf while application of 2% $CaCl_2$ caused the leaf burn in pomegranate. Moreover, calcium fertilizer containing nanoparticles were not very effective in improving the leaf Ca concentration (Davarpanah et al. 2018). Likewise, application of B and Zn increased the both microelement concentrations in leaf of pomegranate (Davarpanah et al. 2016). Moreover, foliar fertilization of Fe at anthesis stage enhanced the grain Fe concentration and bioavailability. However, higher Fe accumulation was noticed for foliar application of Fe-EDTA (He et al. 2013). Foliar application of micronutrients along with endophytic bacteria improved the plant biomass, Fe and Zn concentration in wheat (Yaseen et al. 2018).

Foliar fertilization of macronutrients requires more number of sprays to fulfill crop nutrient demand. Moreover, there are chances of wash out by rain, leaf damage in case of higher solution concentration. Plant should also have sufficient leaf area for absorption of nutrient (Fageria et al. 2009). Despite these drawbacks in certain circumstances foliar fertilization is most effective method to overcome the nutrient deficiencies.

### 4.4.3 Seed Treatment

Nutrient application can be done through seed treatments. However, this practice mostly involves micronutrient application. Micronutrient delivery through seed treatment is economical and effective alternative to soil and foliar fertilization (Farooq et al. 2012, 2018). Seed treatments require very small amount of nutrient, hence are cost-effective and nutrients are available to the germinating seed (Singh et al. 2003).

#### 4.4.3.1 Seed Priming

In nutrient priming seeds are soaked in aerated nutrient solution to initiate the metabolic activities prior to germination without radical protrusion. Primed seeds have better, and synchronized seedling emergence compared to dry seeds (Farooq et al. 2009). For instance, Zn seed priming in maize improved the maize performance (Harris et al. 2007). Likewise, seed priming with Zn increased the grain yield (19%) and seed Zn concentration respectively (Harris et al. 2008). Moreover, seed priming with Zn and plant growth promoting rhizobacteria (PGPR) enhanced the grain yield, grain and endosperm Zn accumulation (Rehman et al. 2018a, b). In maize, seed priming with Zn enhanced the seed Zn content (600%) compared to untreated seed and also improved the crop growth and biomass under normal and salt stressed condition (Imran et al. 2018). Seed priming with Mn increased the grain Mn content and also enhanced the grain yield of wheat and rice in both conventional and conservation rice production systems (Ullah et al. 2017a, b). Likewise in another study, Farooq et al. (2018) reported that Zn seed priming increased the grain yield and grain Zn concentration in rice compared with untreated control.

Boron application through seed priming substantially improved the rice yield and seed B concentration (Rehman et al. 2012). Recently, Ali et al. (2018) found that seed priming with B, Mn and Zn alone and in combination improves the concentration of respective nutrient in grain and straw of wheat. However, in nutrient seed priming solution concentration and duration of seed priming is very critical as priming in high nutrient solution may prove toxic and inhibit seedling germination and growth (Rehman et al. 2015). Moreover, for certain nutrients seed priming is better than soil application. For instance, Mo application through seed treatment was more effective than soil application (Johansen et al. 2006) as Mo application through seed priming increased the yield by 20–25% compared to soil Mo application (Johansen et al. 2007).

Seed priming with micronutrients is an eco-friendly and economical approach for nutrient delivery. This technique is help full under diverse climatic conditions as it helps in early stand establishment. However, selection of appropriate nutrient source and concentration are very critical for nutrient delivery through seed priming.

#### 4.4.3.2 Seed Coating

In seed coating liquid or finely ground/suspended or dissolved solids are applied to the seed surface to cover the seed coat (Scott 1989). Seed coating mostly involve adhering of plant growth regulators, microorganisms, nutrients or other chemical on seed. Micronutrients are usually applied through seed coating as these are required in very small quantities. Seed coating of cowpea seeds substantially increased the grain yield. Moreover, seed coated with 250 mg $ZnSO_4$ $kg^{-1}$ seed performed better than all other coating treatment and increased the yield by 32.1% than uncoated seeds (Masuthi et al. 2009). Similarly, seed coating with 1.25 g Zn $kg^{-1}$ improved the stand establishment, grain yield, and grain Zn accumulation in wheat (Rehman et al. 2016). Application of Mn through seed coating improves the productivity and grain biofortification of rice (Ullah et al. 2017a). The application of Zn through seed coating improved the grain yield in direct seeded aerobic rice (Farooq et al. 2018).

Seed pelleting with boron i.e. 100 mg borax $kg^{-1}$ seed improved the yield related traits and grain yield of cowpea than non-pelleted control (Masuthi et al. 2009). Molybdenum application through seed coating (80 g Mo $ha^{-1}$) enhanced the chlorophyll index, yield related traits and grain yield of common beans (Biscaro et al. 2009). In another study, soybean seed coating with 0.25 g ammonium molybdate $((NH_4)6Mo_7O_24)$ and 0.5 g ferrous sulphate $kg^{-1}$ seed effectively improved the morphology, growth and dry matter production (Ramesh and Thirumurugan 2001).

Seed coating is very cost-effective approach of micronutrient application; however, success of seed coating depends on type of nutrients, coating materials, soil fertility status, soil type and seed to nutrient ratio. Moreover, seed coating is effective technique for nutrient supply during early stages of crop growth.

## 5 Site Specific Nutrient Management

Site specific nutrient management (SSNM) approach emphasize on application of nutrient to crop when needed. It does not thrive to limit or increase the fertilizer use but it helps to supply nutrient at optimal time and rate to obtain higher yield with better NUE. For instance, in South Asian countries fields are small with high spatial variability in crop management practices. Moreover, there are differences in soil inherent nutrient buildup, crop residue management, organic and inorganic use of fertilizers, fertilizer rate, time and application method and resource available to farmers which disturb the nutrient balance within a small piece of land. Moreover, nutrients are supplied on extensive recommendation based on large areas having similar climate and soil conditions. These recommendations are usually good but imbalanced use of fertilizer due to variable soil fertility and other soil characteristic of a field lower the NUE as higher nutrient application beyond a limit will not enhance the yield but will reduce the NUE. Therefore, SSNM offers nutrient management of crop according to its requirement in a specific field and environment (Table 3; Jat et al. 2014). Furthermore, SSNM help farmer to adjust fertilizer application in an accurate and efficient manner to fill the gap between nutrient demand of crop and supply of nutrient from soil, crop residues, organic and inorganic nutrient sources.

Site specific nutrient management was developed as INM strategy and is based on the quantitative relationship of crop demand and nutrient supply of each field which special and temporal variations (Dobermann et al. 2002, 2003) in different crop production systems. There are two types of SSNM approaches i.e. soil based (involves fertilizer recommendation of a specific field based on soil analysis and inherent capacity of soil to supply nutrients) and plant based which involves relationship between crop nutrient requirement and crop yield and usually determined from nutrient concentration at crop maturity (Witt et al. 1999).

In plant based SSNM crop nutrient demand is predicted by attainable yield target. Crop nutrient demand is fulfilled by inherent nutrient supply from soil, residual effect of previous crop and crop residues. A decade ago, Singh et al. (2008) evaluated SSNM in rice wheat crop rotation and reported average increase of 1.3 t ha$^{-1}$ in rice yield than blanked recommendation. They further reported an increase of 0.39–1.92 t ha$^{-1}$ across different locations in rice wheat cropping system. Recently, Banayo et al. (2018) conducted a study and found that site specific nutrient management using rice crop manager (RCM) software reduced the fertilizer application of N and P with an average increase of 6% in grain yield and average profit of 154 US$ ha$^{-1}$.

In conclusion: SSNM includes quantitative relationship between crop demand and nutrient requirement and it varies from field to field. It is very effective approach for sustainable nutrient management. However, success of this approach depends on rigorous plant and soil sampling and development of decision support system softwares.

## 6 Fertilizer Prediction Models

Fertilizer application to site specific field condition need estimation and understanding of crop nutrient status and soil spatial variability and its relation to plant response. However, use high resolution geo remote and proximal sensed data to quantify the approximate variation between management zone (Song et al. 2009).

**Table 3** Effect of site specific nutrient management on crop yield and net economics returns

| Cropping system | Crop | Blank fertilizer recommendation kg/ha | SSNM | Increase in yield (%) | Net return (USD) over control | Reference |
|---|---|---|---|---|---|---|
| Rice wheat | Rice | 100 (N), 40 (P), 40 (K) | 150 (N), 30 (P), 100 (K), 40 (S) | 66 | 633 | Singh et al. (2008) |
| | Wheat | 120 (N), 60 (P), 40 (K) | 150 (N), 30 (P), 100(K) | 59 | 530 | Singh et al. (2008) |
| Rice wheat | Rice | 120 (N), 60 (P), 60 (K) | 120 (N), 60 (P), 120 (K), 40 (S), 25 (Zn), 5 (B), 20 (Mn) | 59 | 557 | Singh et al. (2008) |
| | Wheat | 120 (N), 60 (P), 60 (K) | 150 (N), 60 (P), 120 (K) | 65 | 475 | Singh et al. (2008) |
| Rice wheat | Rice | 150 (N), 75 (P), 75 (K), 2 (Zn) | 150 (N), 30 (P), 80 (K), 20 (S), 25 (Zn), 5 (B), 20 (Mn) | 45 | 678 | Singh et al. (2008) |
| | Wheat | 150 (N), 30 (P), 80 (K) | 120 (N), 60 (P), 40 (K) | 34 | 462 | Singh et al. (2008) |
| | Rice | 110 (N), 15 (P), 20 (K) | 75 (N), 10 (P), 20 (K) | 10 | 307 | Banayo et al. (2018) |
| | Rice | 75 (N), 8 (P), 18 (K) | 75 (N), 8 (P), 18 (K) | 11.2 | 275 | Banayo et al. (2018) |
| | Cotton | 312 (N), 312 (P), 180 (K) | 225 (N), 105 (P), 150 (K), 45 (Mn), 30 (Zn) | 19.8 | 561 | Jin and Jiang (2002) |
| Maize-wheat-mungbean | Maize | 150 (N), 60 (P), 60 (K) | 144–170 (N), 46–50 (P), 63–105 (K) | 5 | 68 | Jat et al. (2018) |
| | Maize | 150 (N), 60 (P), 60 (K) | 144–170 (N), 46–50 (P), 63–105 (K) | 7.4 | 130 | Jat et al. (2018) |
| | Wheat | 150 (N), 60 (P), 60 (K) | 125–140 (N), 37–68 (P), 60–101 (K) | 10.2 | 119 | Jat et al. (2018) |
| | Wheat | 150 (N), 60 (P), 60 (K) | 125–140 (N), 37–68 (P), 60–101 (K) | 12 | 184 | Jat et al. (2018) |

*SSNM* Site specific nutrient management, *N* nitrogen, *P* Phosphorus, *K* Potassium, *S* Sulphur, *B* Boron, *Mn* Manganese, *Zn* Zinc

These sensors generate and process large data set in real time to adopt precise management practices. For instance, site specific nutrient application using these sensors based on edaphic and soil condition increased the nitrogen use efficiency by 368% (Diacono et al. 2013).

Use of sensor and GPS technologies helped to monitor and identify plant and soil variability to specific inputs. Introduction of only GPS in farm machinery can improve the 5–10% efficiencies by decreasing overlaps and gaps during fertilizer application (Craighead and Yule 2001). Recently, Wang et al. (2014) studied the P losses from soil supplied with chemical fertilizers and cattle manures using SurPhos model. The model reliably predicted the losses of dissolved reactive P (DRP) from chemical fertilizer, liquid and solid cattle manure. Surphos also quantified the various sources of DRP loss and dynamics of labile P in soil which can help is adoption of appropriate P management practices to avoid P losses. Recently, Mahajan et al. (2014) used the hyperspectral remote sensing technique to predict wheat N, P, K and S requirement with very high accuracy. Efforts are going on to develop nutrient prediction models and technology for site specific nutrient management (Gregoret et al. 2011; Onoyama et al. 2015) however, there is still lot of work to be done on this aspect to achieve desired success.

## *6.1 Integrated Nutrient Management*

Integrated nutrient management (INM) is soil fertility and plant nutrition management system according to soil properties with balanced fertilization using all possible nutrient sources (organic and inorganic) and biological agents in judicious and integrated manner (Janssen 1993; Roy et al. 2006). Moreover, INM consider nutrient cycling of macro and micronutrients to synchronize nutrient requirement of crop and its release in the environment (Table 4). All the INM approaches are aimed at reducing the nutrient losses through runoff, leaching, immobilization, volatilization and emission, and to increase the NUE (Zhang et al. 2012). The INM also helps in restoration of soil fertility and physiochemical properties with better soil organic carbon (C) and thus sustain the system productivity (Table 4; Das et al. 2014). In a study conducted by Das et al. (2014) on integrated nutrient management in rice-wheat cropping system, they found that incorporation of organic material improves the aggregation and structural stability of soil with better C accumulation in macro aggregates showing higher C sequestration of soil. They further reported that use of FYM in wheat and green gram residue (GR) in rice effectively improved the C accumulation in macro aggregates. Further, residue incorporation was more beneficial than 100% inorganic N application or GR to rice.

The INM substantially enhance rice yield by reducing nutrient losses and managing nutrient supply which help in cost reduction, better resource use efficiency and increased resistance to biotic and environmental stresses (Prasad et al. 2002; Zhang et al. 2012). Chemical fertilizer especially N fertilizers are being excessively used in China and other developing world (Peng et al. 2002; Zhang et al. 2012), which cause saturation of chemical nutrients in agro-ecosystems, thus leading to nutrient loss through runoff, leaching, volatilization, fixation, emissions with low NUE (Vitousek et al. 2009). For instance, in northern plains of China in maize wheat system about 227 kg N and 53 kg P $ha^{-1}$ $year^{-1}$ surplus supply has been reported. Application of 120:26:37 kg NPK $ha^{-1}$ in combination with green manures improved the grain yield of rice. Similarly, highest groundnut production was obtained with residual effect of green manure and 30:26:33 kg NPK $ha^{-1}$ in combination with gypsum (Prasad et al. 2002).

Hossain et al. (2016) studied the INM in rice wheat cropping system by inoculation of legumes (mungbean, blackgram and dhaincha) and organic manures (poultry manure and cow dung). They reported that incorporation of legume residues enhanced the soil organic matter, N, extractable P and Zn, while all legume-based rotation with rice and wheat reduced the K and S concentration. Moreover, use of chemical fertilizer in combination with higher rates of organic manures increased the system productivity, showing that integrated approach is suitable option for balanced and sustainable nutrient management (Table 4). Likewise, maximum Zn concentration in grain and all seed fractions were recorded in wheat when chemical fertilizer was applied in through soil and foliar application in combination with Zn solubilizing microbial strain *Pseudomonas sp.* than sole application of chemical Zn fertilizer (Rehman et al. 2018a, b). Sharma et al. (2016) demonstrated that application of FYM along with recommended fertilizer dose substantially improved the physiochemical properties and biological activities of soil in finger-millet monocropping and groundnut finger millet crop rotation compared to sole inorganic fertilizer application.

In conclusion, INM approach is sustainable and ecofriendly approach as it reduces the chemical input by balanced fertilization and nutrient management using all possibly nutrient sources (crop rotation/intercropping, residue incorporation, organic manures and soil microbes) and minimize the greenhouse gas emissions.

## 7 Soil Management

The soil sustains all living organisms, being the ultimate source of their mineral nutrients. Good management of soils ensures that mineral elements do not become deficient or toxic to plants, and that appropriate mineral elements enter the food chain. Soil management is important, both directly and indirectly, to crop productivity, environmental sustainability, and human health. Because of the projected increase in world population and the consequent necessity for the intensification of food production, the management of soils will become increasingly important in the coming years. To achieve future food security, the management of soils in a sustainable manner will be the challenge, through proper nutrient management and appropriate soil conservation practices (White et al. 2012).

**Table 4** Influence of long-term integrated nutrients management on the soil nutrients concentration at different soil depth

| Nutrients combination | Study duration (years) | Soil depth (cm) | Increase in nutrients concentration (%) | | | | | Reference |
|---|---|---|---|---|---|---|---|---|
| | | | N | P | K | S | Zn | |
| N + FYM | 41 | 0–15 | 27 | – | – | – | – | Shahid et al. (2017) |
| N + FYM | 41 | 15–30 | 5 | – | – | – | – | |
| N + FYM | 41 | 30–45 | 25 | – | – | – | – | |
| NPK + FYM | 41 | 0–15 | 18 | – | – | – | – | |
| NPK + FYM | 41 | 15–30 | 14 | – | – | – | – | |
| NPK + FYM | 41 | 30–45 | 24 | – | – | – | – | |
| N fertilizers + cattle manure | 26 | 20 | 51 | | | – | | Zhengchao et al. (2013) |
| P fertilizers + cattle manure | 26 | 20 | 65 | – | – | – | – | |
| N + P fertilizers + cattle manure | 26 | 20 | 76 | – | – | – | – | |
| 25% RF + 75% RN (MOC) | 2 | – | 23 | 46 | 11 | – | | Mondal et al. (2016) |
| 100% RF + 25% RN (MOC) + 75% RF + 25% RN | 2 | – | 9 | 17 | 5 | – | | |
| (MOC) + Biofertilizer | 2 | – | 13 | 31 | 8 | – | | |
| 100% RF + 25% RN (MOC) + Biofertilizer | 2 | – | 15 | 39 | 11 | – | | |
| RF + Cow dung 5 t ha$^{-1}$ | 7 | 0–15 | 27 | 343 | 12 | 87 | 102 | Saha et al. (2007) |
| RF + Cow dung 5 t ha$^{-1}$ | 7 | 16–30 | 75 | 25 | – | 17 | 34 | |
| 50 + 50% N (FYM) | 23 | 0–15 | 46 | 566 | 63 | – | 201 | Walia et al. (2010) |
| 50 + 50% N (FYM) | 23 | 15–30 | 79 | 428 | 61 | – | | |
| 50 + 50% N (WCS) | 23 | 0–15 | 40 | 226 | 49 | – | 188 | |
| 50 + 50% N (WCS) | 23 | 15–30 | 73 | 214 | 47 | – | | |
| 50 + 50% N (GM) | 23 | 0–15 | 57 | 246 | 49 | – | 232 | |
| 50 + 50% N (GM) | 23 | 15–30 | 81 | 228 | 44 | – | – | |
| N + OM | 33 | – | 116 | – | – | – | – | Yang et al. (2015) |
| N + Straw | 33 | – | 17 | – | – | – | – | |
| N + green manure | 33 | – | 9 | – | – | – | – | |
| RF + VC at 2.5 t ha$^{-1}$ | 2 | – | 12 | 3 | 14 | – | | Kakraliya et al. (2017) |
| RF + FYM at 5 t ha$^{-1}$ | 2 | – | 12 | 21 | 15 | – | – | |
| RF + FYM at 10 t ha$^{-1}$ | 2 | – | 19 | 46 | 19 | – | – | |
| RF + VC at 2.5 t ha$^{-1}$ + Azotobacter | 2 | – | 14 | 17 | 14 | – | – | |
| RF+ FYM at 5 t ha$^{-1}$ + Azotobacter | 2 | – | 15 | 22 | 15 | – | – | |
| RF + VC at 2.5 t ha$^{-1}$ + FYM at 5 t ha$^{-1}$ + Azotobacter | 2 | – | 19 | 40 | 19 | – | – | |

(continued)

**Table 4** (continued)

| Nutrients combination | Study duration (years) | Soil depth (cm) | Increase in nutrients concentration (%) | | | | | Reference |
|---|---|---|---|---|---|---|---|---|
| | | | N | P | K | S | Zn | |
| RF + 200 kg N $ha^{-1}$ through FYM | 7 | 0–15 | – | 42 | – | – | – | Dhaliwal et al. (2014) |
| RF + 200 kg N $ha^{-1}$ through FYM | 7 | 15–30 | – | 62 | – | – | – | |
| RF + 200 kg N $ha^{-1}$ through FYM | 7 | 30–45 | – | 51 | – | – | – | |
| 400 kg N $ha^{-1}$ through VC | 7 | 0–15 | – | 76 | – | – | – | |
| 400 kg N $ha^{-1}$ through VC | 7 | 15–30 | – | 110 | – | – | – | |
| 400 kg N $ha^{-1}$ through VC | 7 | 30–45 | – | 103 | – | – | – | |
| 400 kg N $ha^{-1}$ through RSC | 7 | 0–15 | – | 64 | – | – | – | |
| 400 kg N $ha^{-1}$ through RSC | 7 | 15–30 | – | 100 | – | – | – | |
| 400 kg N $ha^{-1}$ through RSC | 7 | 30–45 | – | 136 | – | – | – | |
| 20 kg N (crop residue) + 20 kg N (urea $ha^{-1}$) | 20 | – | 13 | 32 | 14 | – | – | Maruthi Sankar et al. (2012) |
| 10 kg N (FYM) + 10 kg N (urea $ha^{-1}$) | 20 | – | 27 | 51 | 20 | – | – | |
| 40 kg N (urea) + 20 kg P + 25 kg $ZnSO_4$ $ha^{-1}$ | 20 | – | 21 | 42 | 16 | – | – | |
| 25 kg N (Leucaena) + 25 kg N (urea) + 25 kg P $ha^{-1}$ | 20 | – | 15 | 26 | 24 | – | – | |
| 50% RF + 50% FYM | 24 | – | 69 | 201 | 64 | 100 | 88 | Gawde et al. (2017) |
| 75% RF + 25% FYM | 24 | – | 61 | 230 | 71 | 62 | 85 | |
| 50% RF+50% GM | 24 | – | 77 | 188 | 57 | 63 | 70 | |
| N + FYM + P + K | 60 | – | 7 | – | 16 | 41 | 107 | Verma (2017) |
| Lime + N | 60 | – | 15 | – | – | – | 22 | |

*N* Nitrogen, *P* Phosphorus, *K* Potassium, *S* Sulphur, *Zn* Zinc, *RF* Recommended fertilizers application, *RN* Recommended N application, *FYM* Farmyard manure, *MOC* Mustard oil cake, *WCS* Wheat cut straw, *VC* Vermicompost, *RSC* Rice straw compost, *GM* Green manure

### *7.1 Mulching*

Mulching is an agricultural technique which is used to cover soil surface around the plants to create congenial condition for the growth. Mulching reduces the deterioration of soil by preventing the runoff, soil loss and helps in the control of temperature fluctuations, improves physical, chemical and biological properties of soil, as it adds nutrients to the soil and ultimately enhances the growth and yield of crops

(Kumar et al. 1990). It reduces both the overland flow generation rates and velocity by increasing roughness (Jordán et al. 2010), and it cuts the sediment and nutrient concentrations in runoff (Gholami et al. 2013). It also enhances the activity of some species of earthworms as well as crop performance (Thierfelder et al. 2013), interactions with nutrients (Campiglia et al. 2014), the soil structure and the organic matter content within the soil (Karami et al. 2012).

The increases in the soil organic matter content can be particularly significant when vegetative residues are used as mulches, as shown by Jordán et al. (2010). Mulching has also been shown to reduce the topsoil temperature for more optimal germination and root development (Dahiya et al. 2007) which helps in enhanced nutrient uptake. Moreover, mulches also decrease evaporation (Vanlauwe et al. 2015) thus reduce the nutrient losses (particularly N) through volatilization. In conclusion, application of crop residue mulches helps in moisture conservation, soil and nutrient loss through runoff and volatilization. Thus, use of mulches can be helpful in sustainable crop management.

## *7.2 Conservation Tillage and Residue Management*

Conservation tillage (CT), along with some complimentary practices such as soil cover and crop diversity (Corsi et al. 2012) has emerged as a viable option to ensure sustainable food production and maintain environmental integrity. Conservation tillage positively influence soil productivity and quality (Paul et al. 2013) by promoting the biological activities in top soil through maintaining soil organic matter (Dungait et al. 2012). Higher N, P and K concentration in soil was recorded for CT (Das et al. 2018) due to enhanced residue decomposition and nutrient mineralization. Increase in available soil P was observed in CT system (Das et al. 2018) as high soil organic carbon accelerate the conversion of immobile P into mobile form and also reduced losses due to erosion/runoff which maintained high applied P fertilizer on the soil (Falatah and Al-Derby 1993; Vincent et al. 2010).

Crop residue management also imparts significant impacts on crop productivity and soil fertility. Yield responses to crop residue retention are increased when the ratio of incorporation of inorganic N fertilizer at vegetative stage of crop plants are increased from 70% to 100% (Huang et al. 2013). Increases in soil productivity require balanced fertilization and residue retention (Whitbread et al. 2003). Residue management has significant effects on physical, chemical, and biological properties of soil. Biological nitrogen fixation by leguminous crops and the recycling of fixed nitrogen when leguminous crop residues are returned to the soil can prove to be a rich source of N to the soil organic N pool as well as for subsequent plant uptake (Mosier and Kroeze 1998).

Plant residue decomposition involves two processes: mineralization, humification of carbon compounds by microorganisms and the leaching downward in the soil in the form of soluble compounds (Couteaux et al. 1995). Moreover, incorporation of residues increases the soil microbial biomass carbon which accelerates the N mineralization from organic form (Das et al. 2014). Comparisons of N recoveries from crop residue N and inorganic N fertilizers have shown that, in general, N recoveries from leguminous and non-leguminous residues are about one-half and one-eighth, respectively, of that from various forms of N fertilizers. Also, more legume N than fertilizer N is retained in soil and enters the organic N pool, whereas losses of legume N and fertilizer N are generally similar. Thus, there is a need to minimize losses of N from both systems by devising proper management practices for all cropping systems so that N mineralization synchronizes with crop N demand (Kumar and Goh 1999).

In conclusion, conservation tillage practices and crop residue retention/incorporation improves the soil organic matter, microbial activity, moisture retention and nutrient availability. Therefore, CT and crop residue retention reduces the N fertilizer application through buildup in soil N pool.

## 7.3 Use of High Intrinsic Nutrient Seeds

Plant growth is not only affected by external factors, but maternal environmental condition and plant nutrient status influence the germination, seedling development and several other traits of crop plants (Aarssen and Burto 1990). For instance, seed vigor and biomass production during early vegetative growth are closely linked with intrinsic seed Zn (Rehman et al. 2018a). Seeds with low Zn concentration have reduced emergence and seedling growth in a Zn deficient soil (Yilmaz et al. 1998). Moreover, seed with high Zn concentration due to fertilization in maternal plants increased the dry matter production and grain yield (Rengel and Graham 1995; Yilmaz et al. 1998). Seed with lower Zn concentration may cause cellular damage, loss of food and nutrient reserves or disrupt vital biochemical process during germination and early seedling growth (Ozturk et al. 2006; Cakmak 2008).

Wulff and Bazzaz (1992) reported that *Abutilon theophrasti* seeds having high intrinsic nutrient concentration have resulted in higher leaf development, dry weight, seedling growth, cotyledon area and seed weight owing to enhanced maternal nutrient supply. However, in a study, addition of several nutrients applied to the maternal plants only increased one element in the progeny plants (Parrish and Bazzaz 1985). However, our knowledge on the effects of Zn biofortification on germination and crop performance of progeny is scarce. Nonetheless, under nutrient deficient condition high seed with high intrinsic nutrients can help in better crop stand and early plant growth.

In conclusion, initial seed nutrient concentration is crucial for germination and early seedling growth, especially in nutrient deficient condition. High initial nutrient reserve may help plant to cope with environmental stresses during early period of plant growth. Furthermore, nutrient dense seeds will increase agricultural productivity by enhancing the seed vigor, reduced fertilizer application and higher grain yield.

## 8 Crop Management

Crop management and soil cultivation practices can improve the nutrient availability in soil. Management practices which simultaneously improve soil properties and yield are mandatory to maintain high crop production and minimize deleterious impact on the environment. Retaining crop residues along with no-tillage improves soil properties and environment (Malhi et al. 2006). Selection of suitable planting technique, maintaining suitable plant population and crop rotation can influence the nutrient availability in soil.

### *8.1 Sowing Method and Planting Density*

Nutrient losses from arable system can be minimized by adopting appropriate planting technique as it helps in adoption of appropriate fertilizer application method. Apart from balanced fertilizer and timely fertilizer application crop sowing method, crop sequence, crop root system and crop residue incorporation are very critical. For instance, top dressing and strip placement in maize-soybean improves NUE (Yong et al. 2018). Recently, Verma et al. (2018) found a decrease in weed dry mass with higher grain yield and increased availability of N, P, K, S and Zn in soil with raised bed sowing followed by furrow and ridge sowing of maize and these sowing methods were superior to flatbed sown maize.

The optimum plant population is very crucial for yield maximization in most of the field crops (Hiltbrunner et al. 2007). For instance, N uptake in wheat increased with optimal plant density while higher or lower seeding rated did not improve the N uptake (Blankenau and Olfs 2001). In a study, Dai et al. (2013) reported increase in N uptake, nitrogen use efficiency (NUE) and nitrogen uptake efficiency (UPE) due to increase uptake of above ground N when seedling rate increased from 135 to 405 $m^{-2}$, while, seedling rate higher than 405 $m^{-2}$ did not improve the N uptake and use efficiency. Moreover, higher seedling rate is linked with reduce grain N concentration (Geleta et al. 2002), while no effect on grain N concentration of higher plant population has also been reported in wheat (Ozturk et al. 2006). Moreira et al. (2015) demonstrated that in soybean-wheat cropping system 50 cm spaced rows with no N application and 333,000 plants $ha^{-1}$ are adequate for soybean as crop N supply is fulfilled with biological N fixation (BNF), while wheat N can also be fulfilled with BNF of soybean and N supply from organic matter.

Conclusively, plant population play key role in nutrient uptake and use efficiency. High and low planting density did not improve nutrient uptake. However, optimal planting density results in better grain yield with higher nutrient uptake and use efficiencies.

## 8.2 Crop Rotation and Intercropping

Crop rotation refers to the phenomenon of growing alternate crops in same field in order to avoid mono-cropping at a specific cropping season. Long term soil management practices affect soil pH, organic matter, bulk density, and nutrient availability. Different tillage and crop rotation practices require distinctly different soil fertility management strategies (Edwards et al. 1992). Changes in agricultural management can potentially increase the accumulation rate of soil organic carbon, thereby sequestering $CO_2$ from the external atmosphere (West and Post 2002). Enhanced monoculture production of cash grain crops and greater reliance on the import of chemical fertilizers and pesticides to maintain crop growth have resulted in greatly increased grain yields and labor efficiency. However, these conventional management practices have led to the decline in soil organic matter (SOM), increased soil erosion, nutrient depletion and surface and groundwater contamination (Reganold et al. 1987).

Legume based crop rotations reduced N leaching by 50% compared to conventional cropping systems (Drinkwater et al. 1998). For instance, reduced N fertilizer is needed for soybean as it meets 50–60% of N demand through N fixation (Salvagiotti et al. 2008). Few years back, Soltani et al. (2014) reported higher grain Zn concentration in wheat when grown after sunflower, safflower, clover and sudan grass. Likewise, wheat-cotton rotation increased the Zn accumulation of wheat (Khoshgoftar and Chaney 2007). Inclusion of legume crops in rice wheat cropping system enhanced the crop productivity with buildup in soil organic matter, N, P and Zn concentration (Hossain et al. 2016).

Intercropping can also improve the availability of nutrients to plants by altering the soil physiochemical properties. For instance, chickpea and wheat intercropping resulted in higher grain Zn accumulation in both crops than mono-cropping (Gunes et al. 2007). Similarly, barley-pea intercropping increased the N and C accumulation in both crops than monoculture (Chapagain and Riseman 2014). Intercropping of cereals with dicots is sustainable and effective Zn biofortification approach as it increases the Zn uptake in both crops (Zuo and Zhang 2009). In number of studies it has been reported that legume and cereal intercropping is efficient as it enhances N fixation, biodiversity, nutrient use efficiency with sustainable and higher grain yield (Awal et al. 2006; Hauggaard-Nielsen et al. 2008; Gao et al. 2010; Ghanbari et al. 2010; Wang et al. 2017; Yang et al. 2017).

In South West China, many studies have highlighted that relay intercropping of maize and soybean enhances the NUE, light use efficiency with higher crop productivity and is major planting pattern. Recently, Rehman et al. (2018a, b, c) concluded that intercropping of wheat with legumes augments Zn uptake more than monocropping of wheat due to formation of soluble Zn complexes. Recently, Gitari et al. (2018) demonstrated that potato intercropping with legumes improve the NUE. They reported that potato intercropping with *Pisum sativum* L. *Phaseolus vulgaris* L. and *Lablab purpureus* L. increased the NUE by 9%, 19% and 30% respectively while an increase of 21%, 14% and 6% in phosphorus use efficiency (PUE) was recorded respectively.

Intercropping of cereals and legume reduce N fertilizer input through enhanced N fixation. However, sowing method and fertilizer application are very crucial for legume N fixation (Li et al. 2001; Ghosh et al. 2006; Salvagiotti et al. 2008; Hauggaard-Nielsen et al. 2009; Wu et al. 2014). In conclusion, sequential cropping results in nutrient deficiencies. Intercropping of cereals with legumes enhances nutrient acquisition through enhanced N fixation, Zn availability, nutrient use efficiency and changing in the soil physiochemical properties through forming soluble nutrient complexes than mono-cropping.

## 9 Conclusion

Sustainable nutrient management includes optimization of all possible nutrients sources their special and temporal synchronization with plant nutrient demand with aiming at reducing nutrient losses and improving crop yield and soil nutrient balance. Use of appropriate chemical nutrient source with appropriate application method can help in meeting the crop demand. Recently, slow release fertilizer has found effective in improving nutrient use efficiency with significant increase in crop yield. However, excessive use of chemical fertilizers is serious threat to environmental health, use of organic nutrient sources and soil microbes (AMF and PGPR) can help in reducing the crop demand for chemical nutrient sources. Adoption of soil and crop management practices like minimum or no tillage, residue retention/incorporation, optimal plant density, crop rotation and planting methods reduce the nutrient losses and increase the soil N pool with high organic matter and increased soil microbial activities. Use of all possible nutrient sources (chemical, organic and biological) in an integrated manner using site specific nutrient management will help in improving the soil nutrient balance with better crop production and reduced environmental impact.

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