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A review on enhancing the fertilizers use efficiency to minimize environmental impacts

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Abstract
Considering the increasing societal demand for food, fiber and fuel, intense global financial stress, and growing concerns over impacts on water and air quality, simultaneous improvement of productivity and resource use efficiency, including nutrient use efficiency (NUE), is an essential goal for agriculture. Any fertilizer, whether in the natural, inorganic, or organic form, can harm the environment if misused. Recently, fertilizer use has been labeled by environmentalists as one source of polluting soil, water and air environments. The main environmental impacts associated with fertilizer use have been linked to nitrate leaching into ground water, emission of greenhouse gases (nitrous oxides), soils polluted with toxic heavy metals, and surface runoff of N and P nutrients causing aquatic eutrophication. To ensure that proper use of fertilizer is beneficial to both crop production and the environment, researchers and fertilizer producers have tried to find ways to achieve the newly defined goal of fertilizer use, that is, improving fertilizer nutrient use efficiency and minimizing environmental impacts.

Keywords: fertilizers use efficiency, environmental impacts, Ideal fertilizer, and enhanced-efficiency fertilization

1. Introduction

For many years, the main goal of applying fertilizers was to provide nutrients to plants to increase or sustain optimal crop yield. Thus, improving fertilizer use efficiency in terms of nutrient uptake and crop yield is important to fertilizer producers and users. However, any fertilizer, whether in the natural, inorganic, or organic form, can harm the environment if misused. The main environmental impacts associated with fertilizer use have been linked to nitrate leaching into ground water, emission of greenhouse gases (nitrous oxides), soils polluted with toxic heavy metals, and surface runoff of N and P nutrients causing aquatic eutrophication. To ensure that proper use of fertilizer is beneficial to both crop production and the environment, researchers and fertilizer producers have tried to find ways to achieve the newly defined goal of fertilizer use, that is, improving fertilizer nutrient use efficiency and minimizing environmental impacts.

Inefficient fertilizer use is a key factor pushing the cost of cultivation and pulling down the profitability in farming and total factor productivity (TFP) is used as an important measure to evaluate the performance of a production system and its declining trend is a serious issue in Indian context.

The fertilizer industry faces a continuing challenge to improve its products to increase the efficiency of their use, particularly of nitrogenous fertilizers and to minimize any possible adverse environmental impact. This is done either through improvement of fertilizers already in use, or through development of new specific fertilizer types (Maene, 1995; Trenkel *et al.*, 1988) [5, 11].

2. Environmental problem associated with fertilizers and mitigation strategies

Fertilizer use efficiency in Indian agriculture is quite low even with good management practices. Efficiency of N fertilizer use seldom exceeds 40 %, in case of P and micronutrients the efficiency is only 20 % and 2 %, respectively and for K, the efficiency is about 50 %. The loss of nutrients, particularly N, from the agriculture system into the environment has several adverse effects, including eutrophication of surface water, pollution of groundwater due to nitrate leaching, global warming due to nitrous oxide emission, decreased plant species diversity in natural terrestrial ecosystems. And increased local air pollutant by ozone, for which NO_2 is a precursor (Table 1).

Table 1: Environmental problem associated with fertilizers and mitigation strategies

Environmental problems	Causative mechanisms	Mitigation strategies
Ground water contamination	Nitrate leaching	Judicious use of fertilizers, increasing efficiency, nitrification inhibitors, coated fertilizers
Eutrophications	Erosion and surface runoff	Reduce runoff, water harvesting, controlled irrigation,
Methaemoglobinemia	Consumption of high nitrates through drinking water and food	Reduce N leaching
Acid rain and ammonia redeposition	Nitric acid originating from reaction of N oxides with moisture in atmosphere, ammonia volatilization	Reduce ammonia volatilization loss, use the fertilizer formulations and inhibitors
Stratospheric ozone	Nitrous oxide emission from depletion and global warming	Use nitrification and urease inhibitors and increase N use efficiency

3. Concept of ideal fertilizer

Based on Figure 1, the ideal fertilizer should release nutrients in a sigmoidal pattern for optimal plant nutrition and reduction in nutrient losses by processes that compete with the plant's nutrient requirements.

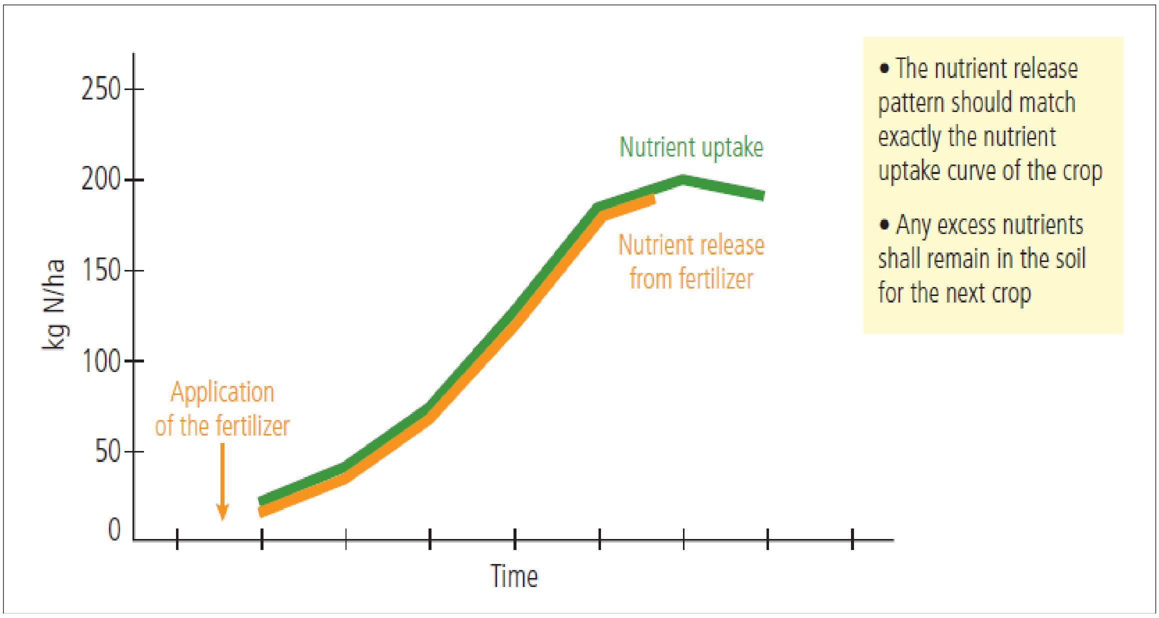


Fig 1: The ideal fertilizer: the nutrient release is synchronized with the crop's nutrient requirements

4. Enhanced-efficiency fertilization (EEF) concept

Plants demands for the mineral nutrients during specific times during which there is need to supply the required amount of nutrient. At this point of time split application of nutrient is really a tedious task because of the scarcity of labors and high cost of labour wages making the agriculture non remunerative. Because of that those reasons the concept of EEF came. In EEF concept fertilizer formulations are capable of minimizing the various losses and enhance the use efficiency of the nutrients by providing the continuous availability of the plant nutrients throughout the plant growth (Fig. 2 & 3).

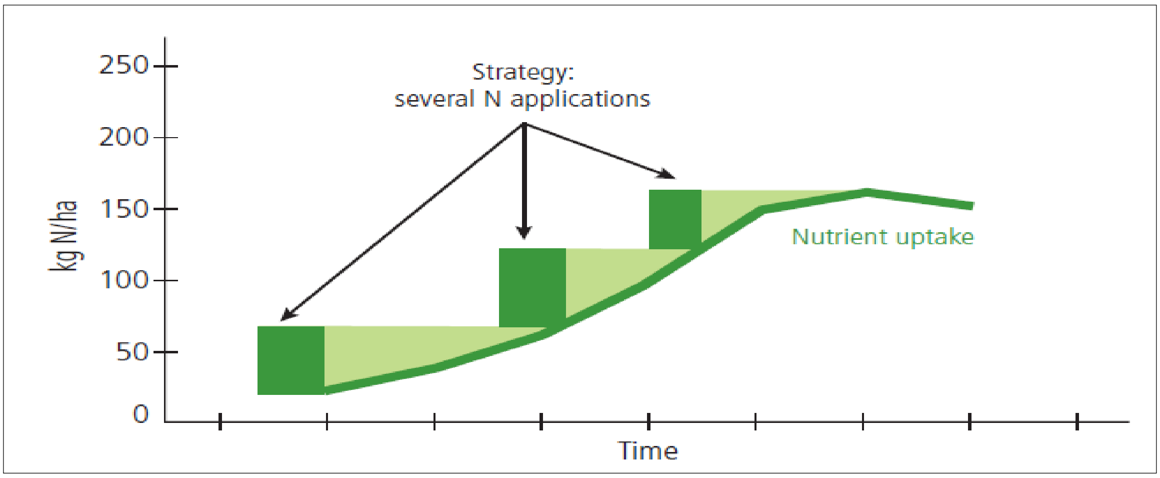


Fig 2: Enhanced-efficiency fertilization concept: fertilizer application in several N dressings

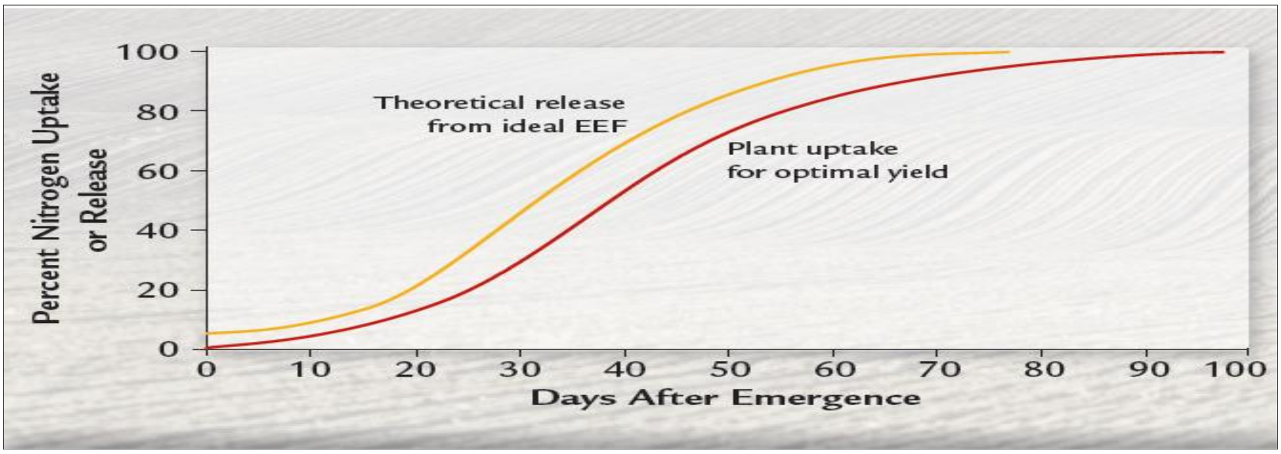
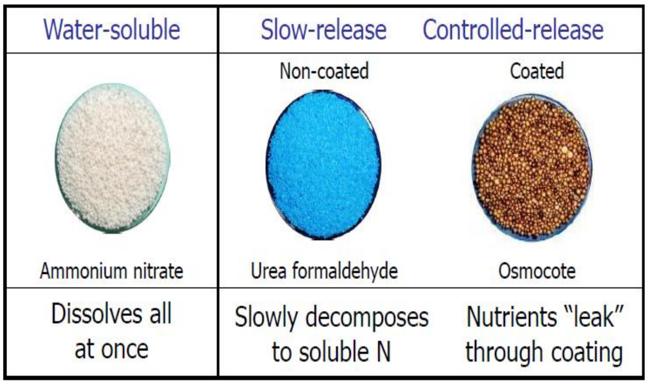


Fig 3: Theoretical plant uptake of nutrient using the growing season and matching release of nutrient from an EEF

Classification of Enhanced-efficiency fertilization (EEF)

Different fertilizers	
Nitrogen	**Phosphorous**
I. Slow release fertilizer ○ Urea super granules (USG's) ○ Urea formaldehyde (UF's) ○ Isobutylidene diurea (IBDU) ○ Crotonylidene diurea (CDU)	**I. Coating of WSP fertilizers with water-insoluble polymers** ○ DAP, MAP, TSP - DAP-Star by Hi Fert. **II. Urea super granules containing phosphorus and potassium**
II. Controlled-release fertilizers ○ S-coated urea ○ Polymer-coated urea	**III. Fluid versus granular water-soluble phosphorus fertilizers** ○ Ammonium polyphosphates ○ Fluid ammonium polyphosphates
III. Stabilized nitrogen fertilizers ↬ Treated with inhibitors ○ Nitrification ○ Urease	**IV. Phosphate rock for direct application** ○ Phosphate rock-acid soil

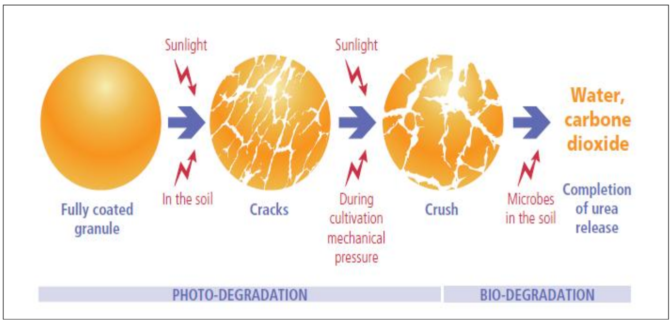
Brief pictorial classification of enhanced-efficiency fertilizers (EEF)



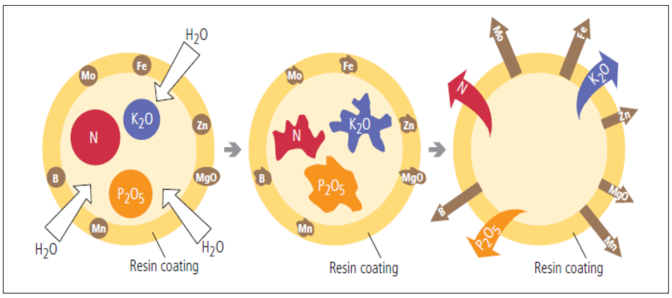
5. Slow-release fertilizers/ Controlled-release

Decomposition model of the coating polymer of controlled-release fertilizer

From the perusal of the bellow depicted model, when we kept the fully coated control released fertilizer in to the soil it will subjected to various kinds of destruction process in presence of sunlight, soil mechanical pressure and soil microorganism and finally external coat will go in to break and after that nutrient present inside the capsule will leak and release slowly.



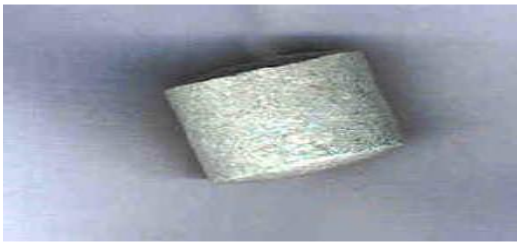
Decomposition model of the coating polymer of controlled-release fertilizer



Decomposition model of the coating polymer of controlled-release fertilizer

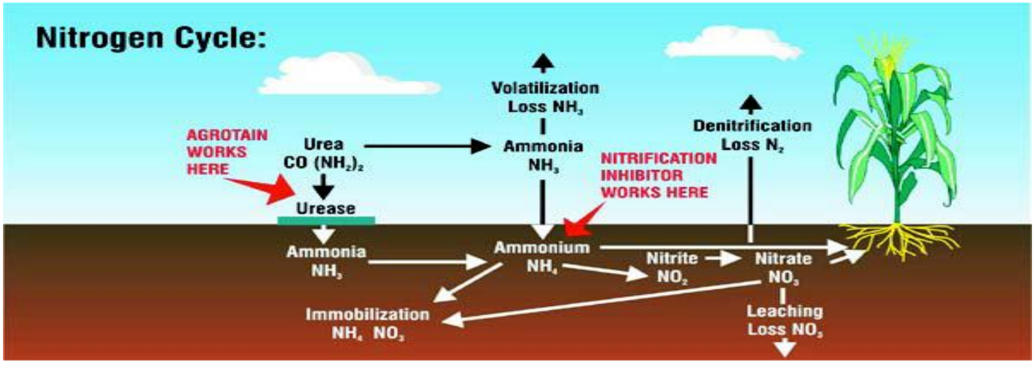
6. Fertilizer Tablets

These tablet formulations were compressed under many tons pressure so these tablets do not dissolve because of that reason nutrients are gradually released by the action of soil bacteria. Further, the risk of burning roots is negligible and tablets work in any kind of soil. Placed few inches away from the roots of the seedling and 6 inches down under the soil.



7. Stabilized fertilizer

These are the fertilizer formulations or products which are stabilized with the treatment of urease and nitrification inhibitors to avoid probable loss due to sudden hydrolysis of urea and oxidation of ammonia in to nitrous oxide. The act of these enzyme inhibitors must function at appropriate situation where it has been shown in nitrogen cycle here bellow.



Research findings on slow release nitrogenous fertilizers

Mishra *et al*. (1999) [6] reported that application of 76 kg N per hectare through urea super granules placed at 14 DAT recorded numerically higher agronomic and relative efficiencies, it might be due to prolonged supply of the nitrogen at critical stages increased the mid season vigor of the plants which ultimately reflected through the yield.

Grain yield of rice (4.60 t ha^{-1}), N uptake (74.2 kg ha^{-1}), N use efficiency (30 kg grain kg N applied^{-1}) and apparent N recovery (61 %) were significantly higher in the treatment where urea super granules were applied at the time of tillering compared to other sources of nutrient under test Nayak and Panda (2002) [8].

Savant and Stangel (1998) [9] have shown that N loss is significantly reduced, which results in a significant increase in rice grain yield under flooded conditions compared with split applied PU. For example, the average rice grain increase over control with USG was significantly greater than that with split-applied PU in 29 irrigated rice trials. Deep placement of USG essentially cuts off NH3 volatilization and also significantly reduces denitrification N loss compared to surface application of PU.

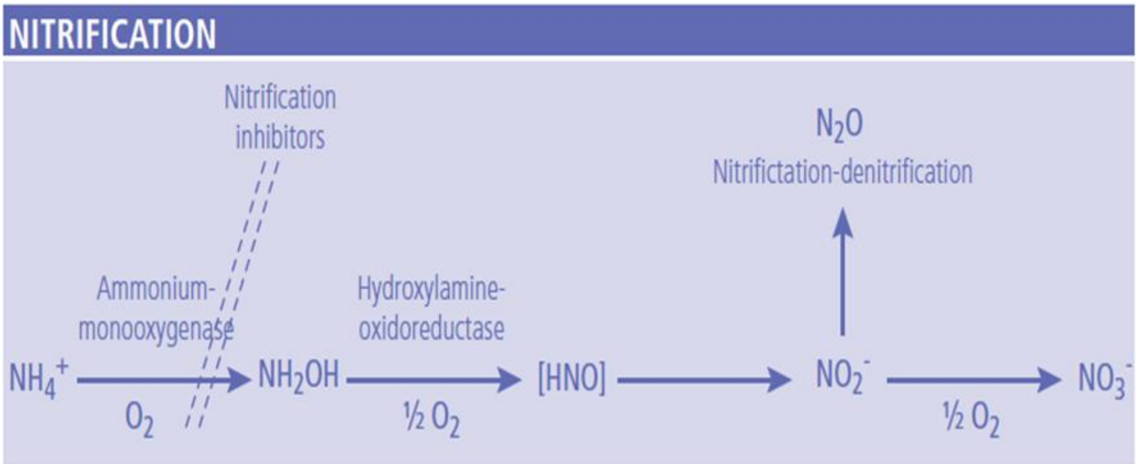
Different fertilizer treatments were organic matrix based slow release fertilizers, SRF-I (542.0 kg ha^{-1}); SRF-II (736.5 kg ha^{-1}) and chemical fertilizer combinations, boron (3 kg ha^{-1})+sulphur (15 kg ha^{-1})+nitrogen (80 kg ha^{-1}) and boron (3 kg ha^{-1}) + sulphur (15 kg ha^{-1}) + nitrogen (80 kg ha^{-1}) + phosphorus (15 kg ha^{-1}) + potassium (100 kg ha^{-1}). Organic matrix based SRF-II released ammonium up to 50-d in wet soil under laboratory conditions which showed maximum retention of the nutrients. A very significant increase in plant growth, nitrate assimilation and seed yield was recorded in organic matrix based SRF-II applied plants. The maximum percent increase in biomass production was observed with organic matrix based SRF-II (increase of 65.8% in root fresh weight, 38.0% in root dry weight, 45.9% in leaf fresh weight plant-1 and 27.5 % in leaf dry weight plant-1 in 60-d old plants). It also increased the acquisition and assimilation of nitrate from the plant's rhizosphere which was evident by 45.6% increase in nitrate, 27.5% in nitrite and 11.7% in nitrate reductase activity (NRA) in leaves of 45-d old plants over control. The organic matrix based SRF-II significantly increased the seed yield by 28% in Indian mustard Sharma and Singh (2011) [10].

Bangladesh Agricultural Research Institute USG applicator

Amany *et al.* (2006) [1] reported that application of 100 kg N fed^{-1} as SRF recorded significantly higher grain yield (4.23 t fed^{-1}), biological yield (7.98 t fed^{-1}) and N uptake (99.46 kg fed^{-1}) and which was significantly higher than 120 kg N fed^{-1} as urea.

8. Nitrification Inhibitor

Nitrification inhibitor is the substance that inhibits the biological oxidation of ammoniacal-N to nitrate-N.



From the perusal of the Table 2 it was felt that among the different nitrification inhibitors Nitrapyrin having the ability to inhibit of nitrification process it was to the tune 82 per cent.

Table 2: Some patented nitrification inhibitors

Chemical name	Common name	Inhibition by days 14 (%)
2-chloro-6-(trichloromethyl-pyridine	Nitrapyrin	82
4-amino-1,2,4-6-triazole-HCL	ATC	78
2,4-diamino-6-trichloro-methytriazine	CL-1580	65
Dicyandiamide	DCD	53
Thiourea	TU	41
1-mercapto-1,2,4-triazole	MT	32
2-amino-4-chloro-6-methyl-pyramidine	AM	31

9. Urease Inhibitor

Urease inhibitors are the chemical substances that inhibit the hydrolytic action on urea by the enzyme Urease.

Dawar *et al.* (2011) [4] reported that application of urease inhibitor along with the recommended dose of urea with herbicide recorded significantly higher grain yield and biomass yield over other treatments (Table 3).

Table 3: Effect of urea with or without Urease inhibitor and herbicide on grain yield and biomass of maize crop

Treatments	Grain yield (kg ha-1)	% deference to urea only	Biomass yield (kg ha-1)	% deference to urea only
Control	4412a		709a	
Urea only	5339b		9562b	
Urea + herbicides	6003c	16	11160c	17
Urea + Agrotain	6359d	27	12440d	30
Urea + Agrotain +herbicides	6731e	38	14531e	52

Basten *et al.* (2005) [2] reported that application of NBPT along with the recomanded dose if nitrogen fertilizer significantly reduced the N loss from applied nitrogen compared with urea application alone (Fig. 4).

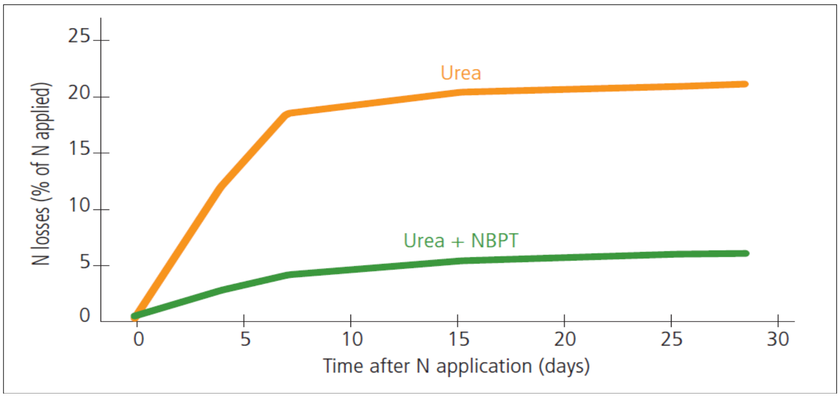


Fig 4: Reduction of N-volatilization through application of urease inhibiter

10. Phosphorus Fertilizers

Fate of phosphorus fertilizers in soil

When we apply the phosphorous containing fertilizers they are subjected in to several kinds of losses and fixation *viz.* absorption, adsorption, retention, fixation, precipitation and immobilization and applied fertilizers will not get available instantly.

Savant and Stangel (1998) [9] revealed that significantly higher grin yield of rice grain yield was obtained with application of deep placed urea super granules containing DAP and was significantly superior over split prilled urea + incorporated SSP and deep placed USG (Fig. 5).

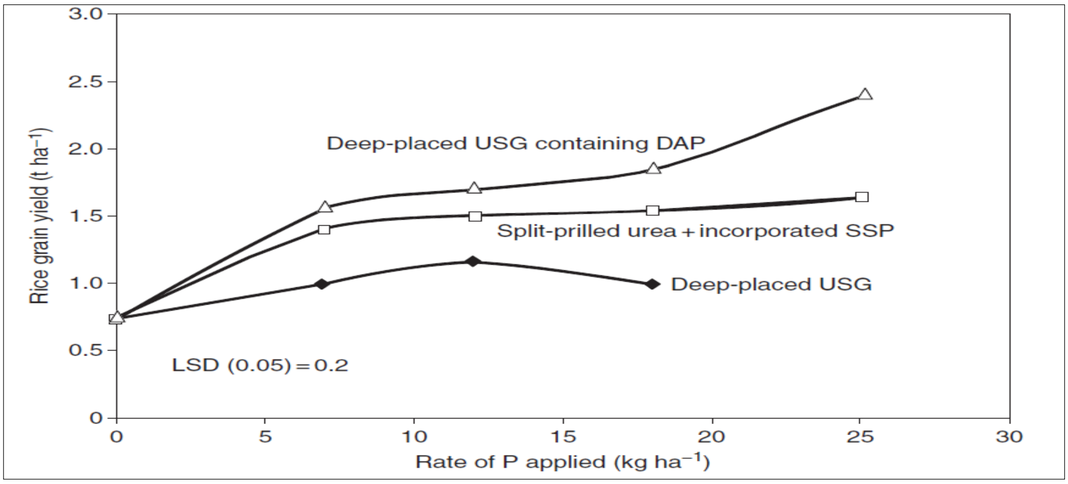


Fig 5: Grain yield of flooded rice obtained with different NP treatments

David and Stevens (2008) reported that application of triple super phosphate along with the polymers coating at all the rates of phosphorous given higher yield and significantly remunerative compared to the application of TSP alone at different rates.

Chien *et al.* (2009) [3] studied on method of placement of phosphorous fertilizer in the form of mono ammonium phosphate with and without polymer coating irrespective of method of placement MAP with polymer coating recorded significantly higher grain yield of maize.

11. Water Soluble Fertilizers

Fertigation leads to following advantages

1. Nutrient availability to the plant is improved
2. Nutrient uptake efficiency is increased
3. Fertilizer application rates & water requirements are reduced
4. Losses by leaching are minimized
5. Salt injuries & damages to root & foliage are prevented
6. Soil compaction is reduced due to less field operations
7. Weed population is decreased

Nanda (2010) [7] reported that fruit yield, water use efficiency and nutrient use efficiency of tomato was highest in the treatment where water soluble fertilizers were applied compared to normal fertilizers usage.

Different fertigation products (Drip Soluble Fertilizers)

NPK 19-19-19	
Composition	**Guaranteed (% w/w)**
Total Nitrogen (N)	19%
Nitrate - N (as NO3)	4.00%
Ammoniacal - N (as NH4)	4.50%
Ureic – N (as NH2)	10.50%
Water Soluble Phosphate (as P2O5)	19 % min
Water Soluble Potash (as K2O)	19 % min
Sodium (as NaCl)	0.5 % max
Matter Insoluble in water	0.5 % max
Moisture	0.5 % max

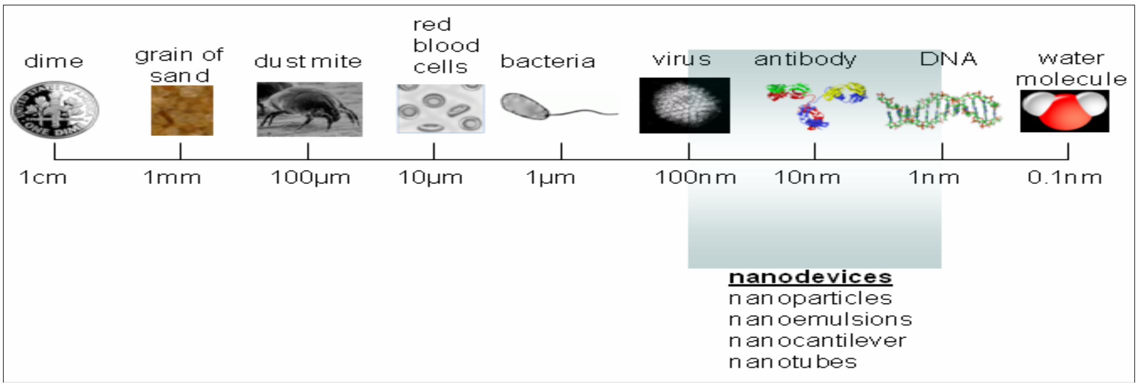
Mono Ammonium Phosphate (MAP) 12-61-00	
Composition	**Guaranteed (% w/w)**
Ammoniacal Nitrogen (as NH4)	12 % min
Water Soluble Phosphate (as P2O5)	61 % min
Sodium (as NaCl)	0. 5 % max
Matter Insoluble in water	0.5 % max
Moisture Content	0.5 % max

Mono Potassium Phosphate (MKP) 00-52-34	
Composition	**Guaranteed (% w/w)**
Water Soluble Phosphate (as P2O5)	52 % min
Water Soluble Potash (as K2O)	34 % min
Sodium (as NaCl – Dry Basis)	0.025 % max
Moisture Content	0. 5 % max
Potassium Nitrate (NOP) 13-00-45	
Composition	**Guaranteed (% w/w)**
Nitrate Nitrogen (as NO3)	13 % min
Water Soluble Potash (as K2O)	45 % min
Sodium (as Na) (Dry Basis)	1 % max
Total Chlorides (as Cl) (Dry Basis)	1.5 % max
Matter Insoluble in water	0.05 % max
Moisture Content	0.5 % max

12. Nano-Fertilizers

Nano fertilizer is a plant nutrient which is more than a fertilizer because of following characteristics.

They are of nano size (1 nm – 100 nm), contains over 200 types of nano size micro-organisms to effectively penetrate into the plant body e.g. leaves, trunks & roots within a short time, contains over 100 types of enzymes of various specific functions and non toxic.



Particle size of nano fertilizers

13. Fluid fertilizers

Fluid is the state of a matter which is neither a liquid nor a gas is called fluid state, fertilizer formulation in this states are called fluid fertilizers.

14. Micronutrient chelating fertilizers

Though micronutrients are required by the crop in small quantity their role in production system is significant, during green revolution and early green revolution period micronutrient deficiency was not noticed but as a result of intensive agriculture system and excess mining of the nutrient from the soil resulted in to deficiency of micronutrient during post green revolution era, so in present day situation application of the micronutrient as a part of nutrient management. Application of micronutrient elements directly in their original form is not recommended because of toxicity excreted by the crops, therefore there is need to combine micronutrient with other compound to make their use safe that process called chelating Singh (2004)

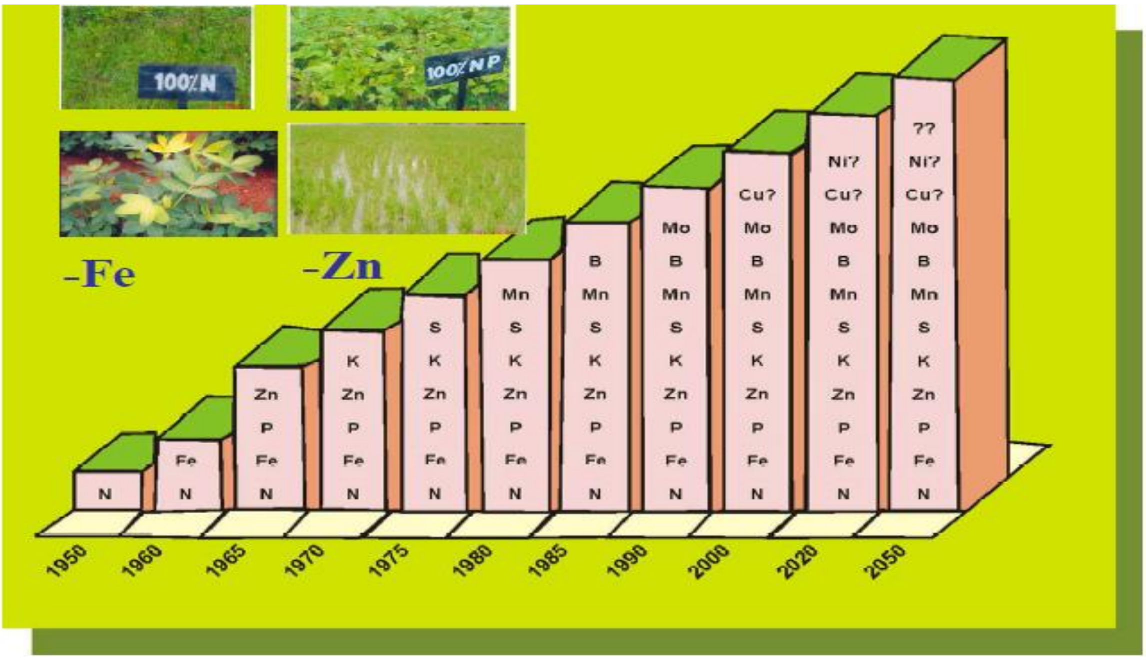


Fig. 6: Emerging deficiencies of multi- micronutrients in Indian

15. Conclusion

All Enhanced Efficiency Fertilizers (EEF) fertilizers are more efficient compared to conventional fertilizer formulations with respect to nutrient uptake by the crops and persistent behavior in the soil for a longer period. They are economically quite expensive but that can be compensated through higher efficiency and because of higher nutrient use efficiency environmental impacts due to fertilizers pollution can be effectively manage.

16. Acknowledgement

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