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Enhancing Nutrient Use Efficiency through Next Generation Fertilizers in Field Crops

Ummed Singh, C S Praharaj
Narendra Kumar, Man Mohan Deo
Lalit Kumar

ICAR-Indian Institute of Pulses Research
Kanpur, Uttar Pradesh-208 024
Web site : http://www.iipr.res.in

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Ummed Singh

C S Praharaj

Narendra Kumar

Man Mohan Deo

Lalit Kumar

भाकृअनुप
ICAR

Division of Crop Production
ICAR- Indian Institute of Pulses Research
Kanpur, Uttar Pradesh- 208 024 India
(Web site : http://www.iipr.res.in)

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FOREWORD

ICAR-Indian Institute of Pulses Research is a premier institute in the Crop Science Division of Indian Council of Agricultural Research (ICAR). The institute is mandated with the basic, strategic and applied research on major pulse crops. With the key role in developing technologies and materials towards pulses improvement, production, and protection and giving its fruits to our clientele, *the farmers*, its activities also revolves round generating basic knowledge and information including human resource development by adequate training and education through tactical linkages and strategic coordination with the network on pulses research programs across the country and the globe.

The major challenges in 21st century are food security, nutritional security, environmental quality and soil health. In India, with increased crop production and productivity over the years, the nutrient removal has increased by over four times during the last four decades putting four-fold pressure on soil. A yearly gap of approximately 10 MT of nutrient (NPKS) still exists between nutrient removal and supply through fertilizers. The gap varies widely among different agro-climatic regions of the country and this gap, if not bridged timely, might pose major threat to agriculture sustainability.

Next generation fertilizers, superiority over straight or traditional fertilizers both in terms of higher nutrient use efficiency and cost effectiveness, have the potential to pace faster in future as sources of plant nutrients. Likely, specialty fertilizers are a fast growing and diverse group of fertilizer products containing one or more of the essential primary, secondary or micro-nutrients with different characteristics. Slow and controlled release and stabilized fertilizers are currently a relatively small part of the overall fertilizer market, but their production and usage are growing at very robust rates particularly in Asia. Due to higher nutrient use efficiency, lower cost of production, application charges and enrichment of grain quality characteristics of next generation fertilizers might attract the farmers and market in future. It is also having the capability to bridge the gap of imbalances caused in the soil.

It is in this context, the conduct of short course on '***Enhancing Nutrient Use Efficiency through Next Generation Fertilizers in Field Crops***' for 10 days organised to update the knowledge and scientific know how of the Indian agricultural scientists working in different ICAR institutes, state agricultural universities and central universities having agriculture faculties is quite noteworthy and timely. It will definitely help in building an understanding and awareness about the recent developments in efficient nutrient management, higher nutrient use efficiency and productivity in field crops aimed at sustainable food production in the country. I would like to congratulate the Division of Crop Production and their team of scientists for successful organisation of ICAR sponsored short course. I am confident that the compendium compiled out of lecture notes of short course will be very much useful for all stake holders including participants, policy makers and farmers'. I wish to compliment the team of scientists for bringing out this document well on time.

(N P Singh)
Director, ICAR-IIPR

Kanpur
Dated: 30-11-2017

PREFACE

Nutrients have been the key input in augmenting food production in India which has been confirmed right from the Era of Green Revolution in India. Despite our best and diverse efforts for sustainable crop production, the imbalance in the use of N, P and K still continue to haunt all of us. Besides this, deficiency of secondary nutrients (especially S) and micronutrients (mainly Zn, Fe and B) is becoming wide spread in the Indian soils, leading to micronutrient malnutrition or '*Hidden Hunger*' and the repercussion is low yield of field crops. Supplementing this, continuous addition of some of the straight fertilizers causes low nutrient use efficiency, reduced factor productivity and poor crop response which further results in economically unviability. It triggers for appropriate action or remedies for enhancing nutrient use efficiency, profitability, crop response and factor productivity.

In this account, one of the options available is to develop a suitable blend of fertilizers having all essential nutrients based on crop-need based release kinetics. Since straight fertilizers do provide one or two nutrients at one time to the plants which may not commensurate with crop demand and can lead to loss or imbalance in nutrient in the soil, complex or blending of fertilizer nutrients could be the right answer. Moreover, if these nutrients can be formulated to a fertilizer depending on crop requirement, it could be of immense useful for scaling nutrient use efficiency and crop productivity *per se*.

Keeping these in view, a short course entitled "***Enhancing Nutrient Use Efficiency Through Next Generation Fertilizers in Field Crops***" was organized at ICAR-Indian Institute of Pulses Research, Kanpur, Uttar Pradesh during November 21-30, 2017. The objectives of the 10 days short course was (a) to sensitize and orient the participants in understanding the present status and future perspectives of next generation fertilizers, (b) to enable the participants to acquire the knowledge on the latest techniques/strategies for enriching nutrient use efficiency in field crops through efficient fertilizer use, and (c) provide a suitable platform for interaction/discussion among the scientists and researchers working on scaling nutrient use efficiency through different means. The course content broadly covered the following topics: (i) Next Generation fertilizers-Introduction and Future Perspectives in Indian Context, (ii) Liquid, soluble fertilizers *vis-à-vis* solid fertilizers for higher fertilizer use efficiency, (iii) Micronutrient enrichment of staple food grains through ferti/ biofortification, (iv) Fortified, coated and slow realese fertilizers, (v) Heavy metals restraining NUE and correction measures , (vi) Nano-fertilizers: Approaches and scaling NUE, (vii) Multi-nutrient supplements or Combi products or Seaweed extract formulations for boosting crop growth and nutrient concentration, (viii) 4R nutrient stewardship in pulses, cereals and oilseeds, (ix) Marketing, policy and industry perspectives towards fertilizers, (x) Practical exercises on major and micronutrient analysis in plant, soil and fertilizers etc.

This training manual includes, lectures delivered by the resource persons, schedule of lectures/practicals, proceedings of different presentations, and list of participants. It is hoped that, this information will be useful in upgradation of the knowledge of all those associated with plant nutrition, fertilizer use efficiency and crop productivity including participants, policy makers and technocrats in the country ensuring *Quality Grain with Better Nutrition*.

Kanpur, Uttar Pradesh
Dated: 30-11-2017

Ummed Singh
C S Praharaj
Narendra Kumar

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Theme 1:

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Next generation fertilizers-Introduction, status and future perspectives in Indian context

Ummed Singh, C S Praharaj, Narendra Kumar, Lalit Kumar and Man Mohan Deo

ICAR-Indian Institute of Pulses Research, Kanpur, Uttar Pradesh-208024
E-mail: singhummed@yahoo.co.in

ABSTRACT

Next generation fertilizers, superiority over straight or traditional fertilizers both in terms of higher nutrient use efficiency and cost effectiveness, have the potential to pace faster in future as sources of plant nutrients. Likely, specialty fertilizers are a fast growing and diverse group of fertilizer products containing one or more of the essential primary, secondary or micro-nutrients with different characteristics. Slow and controlled release and stabilized fertilizers are currently a relatively small part of the overall fertilizer market, but their production and usage are growing at very robust rates particularly in Asia. Due to higher nutrient use efficiency, lower cost of production, application charges and enrichment of grain quality characteristics of next generation fertilizers will attract the farmers and market in future. It is also having the capability to bridge the gap of imbalances caused in the soil.

Keywords: Coated fertilizers, Customized fertilizers, Fortified fertilizers, Next generation fertilizers

1. Introduction

Fertilizers have been the key input in augmenting food production in India. The major roles of fertilizers were augmented in the Green Revolution Era. However, there is imbalance use of N, P and K in the soil. Deficiency of secondary nutrient 'Sulphur' and micronutrient 'zinc' and 'iron' is wide spread in the Indian soils, leading to micronutrient malnutrition or '*Hidden Hunger*' (Singh et al., 2016). Moreover, constant and injudicious application of straight fertilizers leads to lesser nutrient use efficiency, declining total factor productivity, reduced crop response and economic profitability. A serious thought needs to be given for enhancing nutrient use efficiency, profitability, crop response and factor productivity. Attempts are needed to develop blend of fertilizers having all essential nutrients in need based release kinetics. Contrary to this, straight fertilizers provide either single or two nutrients at a time to the plants. Farmers'using straight fertilizers irrespective of the crop or soil fertility status which not only causes imbalance nutrient status in the soil but also enhanced cost of production due to addition of transportation and application charges. The study will reveal the answers to: What is the present status of the straight fertilizers v/s blended fertilizers having slow release kinetics? What will be the advantages of such fertilizers over straight fertilizers? Will it Farmer's/crop friendly? What will be interaction effect between blend of fertilizer and water under limited supply? Keeping these above factors in mind the study is proposed.

Fertilizer is an essential key input for production and productivity of crops. Fertilizer alone contributes towards 55% of additional food production. Since there is no scope for extending the cultivable area, more productivity per unit area is the only option and fertilizer is the main cart puller. Custom mixed fertilizer is a mixed fertilizer formulated according to individual specifications furnished by the consumer before mixing. Some land needs much higher quantities of balanced fertilizer mixtures in granulated form, for soil application; water soluble form for drip irrigation, mini sprinkler and foliar spray systems. Customized fertilizer may also be defined as multi-nutrient carrier which contains macro and/ or micronutrient, whose sources are from inorganic or organic, which are manufactured through systemic process of granulation and satisfies crop's nutritional demand, specific to area, soil and growth stage of plant. Customized Fertilizers are enriched with both macro and micro nutrients and are manufactured through a systemic process of granulation with stringent quality checks.

2. Next Generation Fertilisers

2.1. Customised Fertilisers

"Customised Fertilisers (CF) are a multi-nutrient carrier designed to contain macro and / or micro nutrient forms, both from inorganic and / or organic sources; manufactured through a systematic process; satisfying the crop's nutritional needs, specific to its site, soil and stage; validated by a scientific crop model developed by an accredited fertiliser manufacturing / marketing company".

Customized Fertilizer is a concept around balanced plant nutrition. Such fertilizers are based on the sound scientific plant nutrition principle and research, Customized Fertilizer provides the best nutritional package for premium quality plant growth and yield. They are defined as package for premium quality plant growth and yield. They are defined as multi nutrient carrier designed to contain macro and /or micro nutrient forms., both from inorganic and/or organic sources, manufactured through a systematic process of granulation, satisfying the crop's nutritional needs, specific to its site, soil and stage, validated by a scientific crop model capability developed by an accredited fertilizer manufacturing/ marketing company. Such fertilizers also include water soluble specialty fertilizer as customized combination products. Prospective manufacturers or marketers are expected to use the software tools like. Decision Support System for Agro Technology Transfer (DSSAT). Crop Model etc. to determine the optimal grades of customized fertilizer.

Need incurred due to

- Declining total factor productivity
- Uneven growth of NPK, Secondary and Micronutrient consumption v/s food production
- Imbalanced and inadequate use of fertilisers
- Emerging multi-nutrient deficiencies
- Low fertiliser use efficiency (FUE)
- Inadequate fertiliser availability
- Declining crop response to fertilisers
- Unawareness of Integrated Nutrient Management (INM)

2.2. Slow Release (Coated fertilizers)

Some of the fertilizers which release nutrients slowly to the plants have been listed in the Table 4.1 below. Recently Government of India issued a notification on 25thMay 2015 making it mandatory for all the indigenous producers of urea to produce 100% of their total production of subsidized urea in the form of Neemcoated urea.

2.3. Neem coated urea

The indigenous manufacturers / producers of urea are allowed to produce Neem Coated urea which has been incorporated in Schedule I of the fertilizer Control Order, 1985, up to a maximum of 35% of their total production of respective subsidized fertilizers. The fertilizer companies will also be required to submit a certificate from the statutory auditors regarding total production of Neem Coated Urea as against the total production of subsidized fertilizer to indicate the adherence to the ceiling of 35% as indicated already. Further, it has been decided to restrict the extra 5% of MRP to be charged by the companies on Neem Coated urea for future to the extent of 5% of the existing MRP of urea only i.e. [1]†5360 per MT.

Table 1: Slow release fertilizers manufactured in selected countries

Chemical	Product trade name patented	Manufacturer
Sulphur coated urea	SCU	Nu-Gro, Canada, Inc., Canada
	SC compounds fertilizer	Mitsui Toatsu Fertiliser, Japan
Polymer coated urea	Osmocote^R Sierra^R Sierrablen^R, Agri. From Scottkote^R	The Scotts Co., USA
	POLYON^R	PursellTechnoloqies, Inc., USA
	Osmocote^R, Sierrablen^R Sierraform^R	Sierra Europe BV. The Netherlands
	Plantacote^R	AglukonSpezialDunger, GmbH, Germany
	Basacote^R	BASF Aktienges sells chaf, Germany
	Multicote^R	Haifa Chemicals, lsrael
	Nutricote^R	Asahi Chem. Ind., Japan
	Mcote	Mitsubishi Chemical Corp., Japan
Polymer/Sulphur	Trikote^R	Pursell technologies Inc., USA
	Poly-S^R	The Scotts Company
	Poly Plus	LESCO,Inc., USA
Neem Coated Urea (NCU)	Marketed in 2014-15 under Co's trade names	Brahmaputra Valley Fertilizer Corporation limited (BVFCL) Chambal Fertilisers& Chemicals Limited (CFLC) Gujarat Narmada Valley Fertilizers & Chemicals Limited IndoGulf Fertilisers (IGF) Indian Farmers Fertiliser Cooperative Ltd. (IFFCO) KrishakBharti Cooperative Ltd. (KRIBHCO) Madras Fertilizers Limited (MFL) National Fertilizer Ltd. (NFL) NagarjunaFertiliser and Chemicals Ltd. (NFCL) Rashtriya Chemicals and Fertilizer Ltd. (RCFL) Shriram Fertilisers& Chemicals (SFC) Tata Chemicals Limited (TCL) (All in India)

Source : Prasad (2012)

A list of major producers/manufacturers of neem coated urea along with production has been given in table 2.

2.4. *Fortified fertilizers*

It has been observed that the straight fertilizers are unable to fulfill complete nutrient needs of the crops. Therefore, fortified fertilizers may be a solution to complete the plant needs of nutrients. A list of major fortified fertilizers with composition has been given in the table 3 below.

2.5. *Water soluble fertilizers*

As we know that crop productivity and economics are influenced by several factors; efficient uptake of nutrients from soil and as result higher nutrient use efficiency being one of the most important among them. Being readily soluble in water, Water soluble fertilizers (WSF) achieve this by releasing essential plant nutrients at the root zone from where they are readily absorbed and used elsewhere in the plant system. Several advantages have been observed due to water soluble fertilizers

Table 2:Manufacturer-wise productionof neem coated urea (tonnes)

S . No.	Company	2011-12	2012-13	2013-14	2014-15
1.	Brahmaputra valley Fertilizer Corporation Limited, Namrup - III (Assam)	-	-	-	9033
2.	Chambal Fertilierse& Chemicals Limited, Gadepan I & II (Rajasthan)	751,099	732,103	673,062	861,428
3.	Gujarat Narmada Valley Fertilizers & Chemicals Limited, Bharuch (Gujarat)	-	100,076	222,915	372,781
4.	Indo Gulf Fertilisers, Jagdishpur (U.P)	406,996	385,015	362,138	454,601
5.	Indian Farmers Fertiliser Cooperative Ltd. [Phulpur- I (U.P.) + Kalol (Gujarat)]	1,060,685	1,272,427	1,223,637	1,718,011
6.	KrishakBharti Cooperative Ltd., Hazira (Gujarat)	-	100,628	769,457	955,772
7.	Madras Fertilizer Limited, manali (Chennal)	-	-	-	967
8.	National Fertilizer Ltd. (Bhatinda+Panipat+Vijaypur+Nangal)	639,568	1,083,119	1,263,702	1,365,304
9.	NagarjunaFertiliser and Chemicals Ltd. Kakinada (A.P.)	-	-	343,068	520,919
10.	Rashtriya Chemicals and Fertilisers Ltd. (Thal, Maharashtra + Trombay, Maharashtra)	83,985	480,523	599,143	1,363,335
11.	ShriramFertilisers& Chemicals, Kota	135,622	134,208	141,503	162,300
12.	Tata Chemicals Limited, Babrala (U.P.)	407,881	393,183	392,859	639,595
	Total	3,485,836	4,681,281	5,991,484	8,415,013

over non-soluble fertilizers. Some of the benefits are listed as under:

- 25-30% of recommended dose of fertilizer can be saved using WSF.
- Essential nutrients can be applied uniformly to each and every plant even on daily basis.
- Water soluble fertilizers cam be applied as foliar or fertigation. They are also suitable for soil application depending on requirement.
- Wide ranges of nutrient grades are available.
- Reduces accumulation of salts in soil

Water soluble fertilizers are available in various formulations which offer differing quantities of nitrogen, phosphorus, and potassium (NPK), but may also contain additional elements including micronutrients. Every formulation displays the NPK in a standardized format such as 19-19-19. The first number always refers to the percent nitrogen, the second expresses the percent phosphorous in the oxide form (P_2O_5), and the last number always represents the percentage of the oxide form of potassium (K_2O). Most WSFs have some effect on the pH of the growing mix after application. Each fertilizer is categorized by its acidity or basicity (it's acidic or basic properties). It is very important for growers to know and understand the affects acidic or basic fertilizers have on media pH and crop production. The specific acidity or basicity of each WSF is located on the product's bag and/or technical sheet. The measurement used (expressed as pounds of calcium carbonate per ton) represents the amount of calcium carbonate required to neutralize a ton of fertilizer.

Acidic fertilizers can be used to lower the media pH over time, while basic formulations gradually increase the media pH. The higher the potential

Table 3: Major fortified fertilizers and their composition

Nutrient	Zincated Urea	Zincated Phosphate (Suspension)	NPK Complex Fertiliser Fortified Zinc (12-32-16-0-0.5)	NPK Complex Fertiliser Fortified Zinc (10-26-26-0.5)	DAP Fortified Zinc (18-46-0-0.5)	SSP Fortified With Zinc	Bentonite Sulphur With Zinc	Boronated SSP (Powder & Granular)	NPK Complex Fertiliser Fortified with Boron (12-32-16-0.3)	NPK Complex Fertiliser Fortified Boron (10-26-26-0.3)	DAP with Boron (18-46-0-0.3)	Calcium Nitrate with Boron	NPK Complex Fertiliser Fortified With Boron (24-24-0-0.2B)	Nitrophosph Ate with Potash Fortified with Boron (15-15-15-B0.2)
Nitrogen (N)	43.3	-	12.0	10.0	18.0	-	-	-	12.0	10.0	18.0	14.6	24.0	15.0
Total P_2O_5	-	13.9	-	-	-	-	-	-	-	-	-	-	-	-
CS P_2O_5	-	2.8	32.0	26.0	46.0	16.0	-	16.0	32.0	26.0	46.0	-	24.0	15.0
WS P_2O_5	-	-	25.0	20.0	41.0	14.5	-	14.5	27.2	22.1	41.0	-	20.5	4.0
Zinc (Zn)	2.0	17.6	0.5	0.5	0.5	0.5	18.0	-	-	-	-	-	-	-
WS K_2O	-	-	16.0	26.0	-	-	-	-	16.0	26.0	-	-	-	15.0
Calcium (as S)	-	-	-	-	--	-	-	-	-	-	-	-	17.0	-
Sulphur (as S)	--	-	-	-	-	11.0	65.0	11.0	-	-	-	-	-	-
Boron (as S)	-	-	-	-	-	-	-	0.15-0.20	0.3	0.3	0.3	0.25	0.2	0.2

CS = Natural Ammonium Citrate Soluble ; WS = Water Soluble
Source: FAI,(2015); FCO (1985)

Table 4: Production status of water soluble fertilizers

S. No.	Company	Product	Grade	2011-12	2012-13	2013-14	2014-15
1.	Coromandel International Limited, Vizag (A.P.)	Other NPKs	-	1,422	1,518	1,729	-
2.	Coromandel SQM (India) Pvt. Limited, Kakinada (A.P.)	NPK	19-19-19	-	3,300	3,300	-
		NPK	13-40-13	-	500	225	-
		NPK	20-20-20	-	-	350	-
		Other NPKs	-	-	-	50	-
3.	Everest Fertilizer and Chemicals Pvt. Ltd., (Gujarat)	NPK	19-19-19	31	0	-	12
4.	Gujarat Narmada Valley Fertilizers &Chemicals Ltd., Bharuch (Gujarat)	NPK	19-19-19	-	-	17	70
5.	Gujarat State Fertilizers & Chemicals Ltd., Baroda (Gujarat)	Urea phosphate	17-44-0	-	118	109	198
		NPK	19-19-19	314	138	190	234
		Potassium Nitrate KNO3	13-0-45	53	73	100	96
		Mono Potassium Phosphate- MKP	0-52-34	15	65	86	73
		Mono Ammonium Phosphate - MAP	12-61-0	18	72	62	90
		Potassium Sulphate - SOP	0-0-50	40	70	127	105
6.	Indian Farmers Fertiliser Cooperative Ltd., Kandla (Gujarat)	Urea phosphate	17-44-0	5,900	8,556	2,783	2,585
		NPK	18-18-18	125	1,969	3,436	2,028
7.	Jajoo Fertilizer & Chemical Industries, Yavatmal (Maharashtra)	NPK	19-19-19	-	-	-	-
8.	Mangalore Chemicals & Fertilizers Limited Bangalore (Karnataka)	NPK	19-19-19	1,793	2,736	2,743	2,934
		NPK	13-40-13	29	49	205	322
		NPK	6-12-36	26	-	-	-
9.	Rashtriya Chemicals and Fertilizers Ltd., Trombay (Maharashtra)	NPK	19-19-19 (Foliar)	3,821	2,451	1,450	2,659
			19-19-19 (Drip)	-	862	2,410	3,366
		Potassium Nitrate- K NO_3	13-0-45 (Foliar)	260	5	-	-
			13-0-45 (Drip)	-	93	-	-
10.	Zuari Rotem Speciality Fertilisers Ltd., Baramati (Maharashtra)	NPK	19-19-19	6,095	5,093	2,294	5,599
		NPK	13-40-13	-	-	86	505
		NPK	20-20-20	-	-	131	181

Note : "-" denotes data nil / not available

Source: FAI (2015)

acidity value, the more of an effect it will have on lowering the media pH. Conversely, the lower the potential acidity value, the less affect a fertilizer will have on lowering the media pH. A similar relationship occurs with the potential basicity – the higher the basicity value the greater affect the fertilizer has at raising media pH.

A list of major water soluble fertilizers has been given in the table 4 along with manufacturers involved in the production of such fertilizers.

3. Research efforts

Balanced fertilizer i.e., use of fertilizer nutrients in right proportion and in adequate amount are considers as promising agro techniques to sustain yield, increase fertilizer use efficiency and to restore soil health (Yadav et al. 1998). Continuous heavy application of only one nutrient disturbs the nutrient balance and leads to depletion of other nutrients as well as to under-utilization of fertilizer N. the response of a crop to N not only depends on the status of N but also on the deficiency or sufficiency of other associated plant nutrients (Yadav et. al., 1998). Thus, balanced use of all nutrients is essential because no agronomic manipulation can produce high efficiency out of an unbalanced nutrient use.

Alva A.K. (1992) conducted an study on controlled-release fertilizers and the findings are presented here. Extremely sandy soils and poorly distributed high annual rainfall in the state of Florida contribute to significant leaching losses of nutrients from routine fertilization practices. A leaching column experiment was conducted to evaluate the leaching losses of nutrients when using currently available N, P, K blend fertilizers for young citrus tree fertilization. Fertilizer blends included NH_4NO_3, $Ca(NO_3)_2$, IBDU, IBDU plus Escote, Nutralene, Osmocote, and Meister. Following leaching of 1000 ml of water through soil columns, which simulates leaching conditions with 26 cm of rainfall, the amount of NO_3 and NH_4 recovered in the leachate from soil columns amended with an NH_4NO_3blend accounted for 37% and 88% of the respective nutrients contained in the quantity of blend per column. The corresponding values for soil columns amended with a $Ca(NO_3)_2$ blend were 48% and 100%. Leaching losses of both NO_3 (<3%) and NH_4 (<4%) were drastically decreased when using controlled-release fertilizers. The recoveries of P and K in 1000 ml of leachate were 1.3% and 8%, respectively, of the nutrients added as Osmocote, which contained coated P and K sources. In the case of the rest of fertilizer blends, the recoveries of P and K in 1000 ml of leachate were as high as 52%–100% and 28%–100%, respectively. Therefore, controlled-release technology offers an important capability for minimizing leaching losses of nutrients.

Kumar et al. (2012) while working on entrapped urea on rice find out the greater use efficiency. Field experiments were conducted to evaluate the effects of eco-friendly organic matrix entrapped urea (OMEU) on growth, productivity, and yield of rice (*Oryza sativa* L. cv. Basmati) and soil enrichment in the paddy field at Rohtak (Haryana) located near Delhi. The OMEU prepared in granular form contained cow dung, rice bran (grain cover of *Oryza sativa*), powder of neem leaves (*Azadirachta indica*), and clay soil (diameter of particles < 0.02 mm) in 1:1:1:1 ratios and saresh (plant gum of *Acacia* sp.) as binder along with half of the recommended dose of commercially available soluble urea (free urea; FU). Single basal application of OMEU showed an increase in plant growth in terms of fresh and dry weights, root length, root, leaf and tiller numbers, soluble protein, total N and ammonium in leaves, productivity in terms of grain and straw yield, and nutritional and microbial activities of field soil over free form of urea and no fertilizer application. Nutritional status of rice grains was also improved over the free urea and no fertilizer controls. Our data indicate that OMEU, which is low cost and based on bio-degradable, non-toxic, and locally available agro-waste, can be attempted to replace the conventional use of soluble urea in rice.

4. Conclusion

Deficiency of secondary (Sulphur) nutrient and micronutrient (Zn, Fe) is wide spread problem in the Indian soils, leading to micronutrient malnutrition or '*Hidden Hunger*'. Moreover, constant and injudicious application of straight fertilizers leads to lesser nutrient use efficiency, declining total factor productivity, reduced crop response and economic profitability. Contrary to this, specialty fertilizers including coated fertilizers, soluble fertilizers, liquid fertilizers, fortified fertilizers, customized fertilizers etc. led to balance use in soil while maintaining and improving soil health. Likewise, balanced fertilization i.e., use of fertilizer nutrients in right proportion and in adequate amount are considered as promising agro techniques to sustain yield, increase fertilizer use efficiency and to restore soil health. Thus, applying next generation fertilizers will be the future source of nutrients to the plants.

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Present status and future perspectives of coated and value added fertilizers in India and World

Shantanu Kar

Coromandel International Limited, Secunderabad, Telangana-500 003
E-mail: kars@coromandel.murugappa.com

ABSTRACT

Crop response to the applied nutrients is decreasing day by day. The gap between nutrients applied in soil and nutrients taken up by plant is quite wide. The challenge of fertiliser industry is to continuously improve their products keeping in mind the environmental concerns. The problem of soil fertilisers is the mismatch between the nutrient release and the time when the crop needs a particular nutrient. Worldwide, scientists are working on slow and controlled release fertilisers to improve the efficiency of plant nutrients, primarily NPK. By controlled release of nutrients and thereby, losses can be minimized and better availability to crop can be ensured. The longevity of these products can range from 20 days to 18 months *(Shoji and Gandeza, 1992)*. The term Enhanced Efficiency Fertilisers (EEFs) includes all slow and controlled release fertilisers as well as stabilized nitrogenous fertilizers.

Keywords: Controlled release fertilizers, Enhanced efficiency fertilizer, Stabilized nitrogenous fertilizer

1. Introduction

The fertilizer industry has a continuous challenge to improve the efficiency of its products keeping in mind the environmental concerns. To achieve this goal improvement in fertilisers are being done which are already in use or new type of specific fertilisers are being developed. (Maene,1995; Trenkel *et al.,* 1988). Due to prevailing mechanism of plant nutrition and possible technical difficulties it is not an easy task. Plants use their root system to take up nutrients from the soil or the soil solution. However, soil and plants are two opposite systems competing for the nutrients available in the soil or applied (Amberger, 1996). Whenever nutrients in the form of mineral fertilizers are applied to the soil to feed the plants, competition between plant and soil is the main problem. Due to this, only a proportion of nutrients is taken up and used by the plants and crops grown. Losses of nutrients take place through immobilization, de-nitrification/volatilization and leaching especially with nitrogenous fertilizers. Consequently, it has been the challenge of the fertilizer industry to develop special types of fertilizers avoiding or at least reducing such losses, in addition to the production of conventional nitrogen-containing fertilizer types (ammonium sulphate, ammonium nitrate, calcium ammonium nitrate, ammonium sulphate nitrate, urea, DAP, and NP and NPK fertilizers) (Joly, 1993). Another possible route of improving nutrient use efficiency is the use of mineral fertilizers, particularly nitrogen fertilizers, which release the nutrients contained according to the plants' requirements, so-called 'intelligent fertilizers', i.e. by application of slow and controlled-release, or by 'stabilized' nitrogen fertilizers, which preserve the nutrients until plants really require them. Worldwide, scientists are working on slow and controlled release fertilisers to improve the efficiency of plant nutrients, primarily NPK. By controlled release of nutrients and thereby, losses can be minimized and better availability to crop can be ensured. The longevity of these products can range from 20 days to 18 months *(Shoji and Gandeza, 1992)*. The term Enhanced Efficiency Fertilisers (EEFs) includes all slow and controlled release fertilisers as well as stabilized nitrogenous fertilisers.

These fertilisers work by affecting the following processes or activities in soil:

a) Microbial activities: Nitrification, denitrification, immobilization etc.

b) Chemical processes: Exchange of ions, fixation of nutrients, hydrolysis etc.

c) Physical activities: Leaching, run off, volatilization losses of nutrients.

2. Nitrogenous fertilizers

Urea is the predominantly used N-fertiliser globally. Among all the nutrients, N is readily released as well as lost from the rhizosphere. The following routes have been tried to control or slow down the rate of release of N.

A. Coated urea

- Due to the outer coating, urea comes into the soil solution through diffusion process.
- Urea may be coated with Organic-N low solubility compounds such as Urea-Formaldehyde (UF), Isobutylidenediurea (IBDU) etc.
- Neem coated urea: Apart from coating, neem cake contains alkaloids which inhibit the activities of nitrifying bacteria.
- Urea may be coated with inorganic materials such as sulphur, gypsum, mineral based coatings or organic polymer which act as physical barrier.
- **Sulphur coated urea**

a) Elemental sulphur coating is less soluble and gets oxidized by *Thiobacillus* activities.

b) Total N by weight (minimum) is 37% and Sulphur (as S) % by weight (minimum) should be 17% (as per FCO).

- **Zincated urea**

a) Zinc oxide which is sparingly soluble is mainly used as coating.

b) Total N by weight (minimum) is 43% (as per FCO)

c) Zn content is 0.5% by weight (minimum) (as per FCO)

B. Urea super granules/ Urea briquettes

N is slowly available due to smaller weight to volume ratio.

C. Other products

There are other products which either reduce the solubility o f N due to the chemical nature of the product or stabilising the release of N by reducing the activities of bacteria or enzymes.

- N-substances of low water solubility: Urea Form (UF), CrotonylideneDiurea (CDU)
- Nitrification inhibitors: These compounds inhibit nitrification process by reducing the activities of *Nitrosomonas sp.*e.g. Nitrapyrin, Dicyandiamide (DCD).
- Urease inhibitors: Inhibits the urease enzyme activity e.g. N-(n-Butyl) thiophosphorictriamide (NBPT), Phenylphosphorodiamidate (PPD/PPDA), Hydroquinone.

Though hundreds of compounds have been identified, these are of least practical relevance due to their cost, toxicity and impact on environment.

3. Development in Japan on controlled release N-fertilisers

In Japan, fertilisers have been developed which can release nutrient in linear or sigmoidal pattern. Farmers can obtain information on N release pattern and sigmoidal release formulations from the manufacturers, agricultural cooperatives and research institutes. Special softwarehave been developed to link nutrient release to soil temperature.

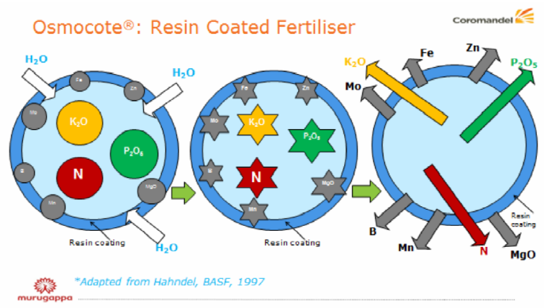
As for example, Meister®-7 (Urea), shows linear release pattern and requires 70 days to release 80% of its nutrient in water at 20^{O}C. Another variant, Meister®-S7 (Urea)* has a lag period of 35 days and needs 35 days to release 80% of its nutrient in water at 20^{O}C. So, farmers can choose the fertiliser according to the crop demand.

4. Phosphatic fertilizers

All straight P-fertilisers, NP and NPK grades will be considered as phosphatic fertilisers as phosphatic grades are majorly complex fertiliser grades.

A. Polymer coated/encapsulated controlled release fertilizers

Fertiliser granules are coated with polymer membrane which is semi-permeable or impermeable but has tiny pores on it. Depending on the desired nutrient release pattern, patented polymer coatings are applied. Polymer membrane is not significantly affected by soil properties such as pH, salinity, texture, microbial activity, redox-potential, ionic strength of the soil solution. It is mainly affected by soil temperature and moisture permeability of the coating. So, the nutrient release pattern of polymer coated fertilisers can be predicted more reliably (Fujita and Shoji,1999; Shaviv, 2005; Shoji and Gandeza, 1992).



*Adapted from Hahndel, BASF, 1997

Fig.1. Mode of action of polymer coated fertilizer

The micro-pores on polymer membrane allow the water to enter. By this process, osmotic pressure is increased which in turn, enlarge the pores. The nutrients are released into the soil solution through these pores over the course of time. The empty polymer shell later degrades biologically or photochemically.

5. Future scope of polymer coated fertilisers:

Cost of different polymer coatings make these fertilisers very costly. For this reason, application is limited to turfs and lawns and to some extent, high value crops. Combining encapsulated N/NP/NPK fertilisers with conventional fertiliser of the same grade may bring down the cost (in 1:1 or 1:3 ratio) for application in field crops. These kind offertilisers have been registered in countries like Germany and Japan.In Japan, CRFs such as polymer coated NPKs, blends of CRFs & conventional fertilisers, UF & CDU based N-fertilisers are used as 'one time fertiliser' in rice, particularly with rice transplanters.

6. Potassic fertilisers

6.1. K-fertilisers in India

Muriate of Potash (MOP) or Potassium chloride is the major source of K in India. 100% of K-fertilisers in India are imported. Because of its chlorine content, it is not suitable for chlorine sensitive crop. Chlorine decreases frying quality of potato and burning quality in tobacco. Farmers do not want to top dress K in broad leaved crops due to the problem of scorching of leaves. Sulphate of potash is being used in few niche segments.

Recently some natural marine evaporites are being used in some parts of the country. These are potassium schoenite and polyhalites/polysulphates.

6.2. Potassium schoenite

- Schoenite is a saline evaporite, consisting of potassium and magnesium sulphate.
- Contains 23% K_2O and 11% Mg as MgO

- Used in grapes, onion and few other crops, particularly in states like Maharashtra.
- Farmers apply it in small quantities at later stages of crop.

6.3. Polyhalites/Polysulphates

- Poly' means many and 'halite' means salts.
- It is a naturally occuring sedimentary marine evaporite mineral, a hydrated sulphate of K, Ca& Mg.
- Can be considered as a multi-nutrient fertiliser: K, Ca, Mg, S.
- It contains 14% K_2O, 17% CaO and 6% MgO.
- Major source is the rock layer below the North Sea off the North Yorkshire coast of UK.
- Sirius and ICL of UK are the major suppliers.

Coromandel International Ltd. has launched an alternative source of K which is produced by incineration of spent wash. It supplies 14% K_2O by weight.

7. Other avenues of increasing fertiliser use efficiency, Indian scenario

i) Fortified fertilizers

Fortified fertilisers are normal grade fertilisers which are already being used by the farmers, with the addition of other nutrients like S, B, Zn in the main grade. These grades have the built-in advantage of supplying necessary secondary/ micro nutrients along with N, P and K. Fortified fertilisers provide Initial insurance to a crop regarding a particular nutrient. This kind of fertilisers is aimed for larger masses who do not use secondary or micro nutrients.

Mostly Zn and B are considered for fortification in fertilisers. Zincated DAP, zincated SSP and boronated SSP are available in the Indian markets. As per FCO, Zn can be fortified at 0.5% in SSP, DAP, NPKs. In urea, Zn can be fortified up to 2%. B can be fortified at 0.2% in SSP and at 0.3% in NPKs. When Zn is fortified with urea, DAP or any NPKs, it helps in N distribution and accumulation in plants. Zn helps in the formation of Indole Acetic Acid, which is vital for plant growth. Experiment with zincated fertilisers has proved that agronomic bio-fortification of foodgrains is possible.

ii) Sulphur Enhanced Fertilizers (SEF)

Nowadays, sulphur is considered as the 4th major nutrient, after N, P and K. Sulphur is required by any crop for enhancing yield and quality. But, S has special roles in pulses for the formation of protein and oilseeds for oil production.

Two SEF grades were launched by Coromandel International limited by fortifying sulphur in urea ammonium phosphate. The grades are 20:20:0:13S and 24:24:0:8S. The uniqueness of these grades is that sulphur is available in two forms: 50% is in readily available sulphate form and 50% is in elemental form which will be available slowly. Thus it ensures availability of S for a longer period. In the same line, research is going on for sulphur enriched SSP for pulses and oilseeds.

iii) Customized fertilizers

Customized Fertilizers are a multi nutrient carrier designed to contain macro and /or micro nutrient forms, both from inorganic and / or organic sources, manufactured through a systematic process, satisfying the crop's nutritional needs, specific to its site, soil and stage and validated by a scientific crop model.

Customized fertilizers are prepared on the basis of rigorous studies on crops, soils, and water samples to suit the need of that particular area. This is a location specific and crop oriented approach and the grades may have to be changed after 3 years according to changing soil properties.

Approval has been given for a particular crop, particular area and particular time of application.

Table 1. Customized grades approved by FCO

Geography	Crop	Grade (NPKSZnB)	Time of application	Dosage (Kg/ac)
Telangana	Paddy	11-24-6-3-0.5-0	Basal	100
Telangana	Paddy	11-24-6-3-0.5-0	7 DAT	50-100
Telangana	Paddy	22-0-12	30-35 DAT	100
Telangana	Maize	14-27-10-4-0.5	Basal	100
Telangana	Maize	14-27-10-4-0.5	15 DAS	50-100
Telangana	Maize	18-0-14	55-60 DAS	100-150
Rayalseema	Paddy	18-33-7-0-0.5	Basal	100
Rayalseema	Paddy	18-33-7-0-0.5	15 DAT	50
Rayalseema	Maize	14-24-11-0-0.5	Basal	100
Rayalseema	Maize	14-24-11-0-0.5	15 DAS	50
Western UP	Sugarcane	7-20-18-6-0.5	Basal	200
Western UP	Paddy	10-18-25-3-0.5	Basal	200
Western UP	Maize	11-19-19-3-0.3-0.2	Basal	75
Western UP	Wheat	8-15-15-0.5-0.15	Basal	200
Western UP	Potato	8-16-24-3-0.5-0.15	Basal	200

Bentonite Sulphur: A Slow Release Fertiliser

The Sulphur Pastille (90% elemental S coated with 10% Bentonite clay) breaks into variable sized particles. The smaller ones get oxidized first and take care of immediate plant sulphur need whereas large particles take care of sulphate supply in the later period of plant growth

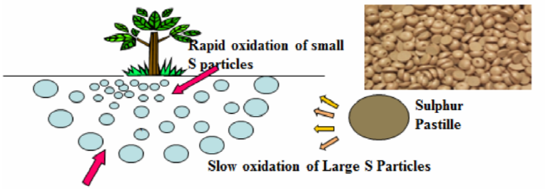


Fig.2. Mode of action of Bentonite sulphur

The customized grades may be reviewed after 3 years. Few customized grades approved by FCO are given below.

iv) Slow release fertilizers

Bentonite clay has been used to coat elemental sulphur pastilles/granules to develop Bentonite sulphur (90% elemental S). Elemental sulphur is not readily soluble and needs to be oxidized to sulphate to be available to plants. The pastilles swell 20 times by absorbing water in soils and break into particles of different sizes. The smaller particles get oxidized first by the activity of *Thiobacillus* bacteria. The larger particles again break into smaller particles and get oxidized at later stages.

Another proprietary fertiliser, Sulpho Zinc® has been produced by coating elemental sulphur and zinc oxide with Bentonite clay. It contains 65% S and 18% Zn I slow release form.

v) Water soluble fertilisers (WSF)

Water soluble fertilisers are gaining importance in India. When applied as foliar, it is complementary to soil application of fertilisers and nutrients can be applied in a customized way to match the requirement of crop. But it is essential in the case of drip irrigation where fertilization can be schedules through nutrigation. Blanket application of fertilisers does not help as nutrients falling in the wetting zone will be utilized by plants. Water soluble fertilisers comes with various combinations of NP, PK, NPK, KS and even with the added micronutrients. Moreover, WSF grades are free form harmful materials like chloride, fluoride etc. and therefore safe to crops. These fertilisers are 100% water soluble. Both water and fertiliser can be saved if WSFs are included in drip system.

8. Conclusion

- Resin coated fertilisers may be mixed with conventional fertilisers to bring down the cost and make it feasible for application in field crops.
- Zinc oxide-Neem oil coating (ZONO) may be

used to produce zincated urea.

- Fortified fertilisers may be included for bio-fortification of grains.
- Pulses are more micronutrient dense than cereals. So, Zn/Fe/Mo fortified fertilisers should be developed for pulses.
- SEFs may be recommended for pulses and oilseeds.
- Alternative sources of K to be recommended along with MOP.
- WSFs should be included in the nutrition package for better yield and quality.
- Developing new age fertilisers the nutrient release pattern of which will match the crop requirement at different stages.

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Customised fertilisers: Methodologies, guidelines and processes for manufacturing

Kanwar Singh[1], Subhendu Bhadraray[1] and Ummed Singh[2]

[1]Centre for Agri-solutions and Technology, Tata Chemicals Limited, Babrala, Uttar Pradesh
[2]ICAR-Indian Institute of Pulses Research, Kanpur, Uttar Pradesh
E-mail: ksingh@tatachemicals.com

ABSTRACT

The productivity of India increased with the increased use of high yielding varieties and it causes acceleration in the growth of fertiliser consumption but there exists a large gap between actual and potential level in fertiliser use. The usage of Nitrogen, phosphorus and potassium will remain the major one for higher and sustained productivity. Inadequate and imbalanced use of fertiliser nutrients, lack of integration with organic resources, non- availability of fertilisers/manures in time and outdated soil testing services are key issues related to nutrient management post green revolution in India and it causes Indian soils fatigued and put a question mark on the sustainable food production. As a result factor productivity for fertiliser nutrients is dwindling, fertiliser use efficiency is dismally poor, declining crop response and nutrient mining is prevalent in-spite of eight-fold increase in fertiliser use during last forty years. About 57% of our land is under some form of degradation and multi-nutrient deficiency. Soil Health Mission program of GOI is expected to provide National level base data to reveal severity of the problem and at the same time it would provide opportunity to test new and innovative approaches in nutrient management. Customised fertiliser is one the precision nutrient management step for providing multi-nutrient, site and crop specific fertiliser; developed with scientific principles to satisfy the crops nutritional demand.

Keywords: Crops, Customized fertilizers, Guidelines, Processes

1. Introduction

Indian Agriculture is currently staggering under the heavy load of second generation problems' of post green revolution era. Intensive cultivation in tropical and sub-tropical regions of our country has resulted in yield stagnation, particularly in the most productive belt. Declining factor productivity, deteriorating soil health, receding groundwater tables, decreasing diversity in production systems, and increase in cost of production are of primary concerns among these. Compound growth rates of production and productivity of all major crops are showing reverse trends during the last thirty years; in spite of considerable increase in fertiliser usage indicating a decrease in factor productivity India is having no likely prospect of increasing the cultivated area from 141 million ha to feed the highest increasing population of the world. But the pace of this agriculture growth is full of ups and downs as we know in this backdrop, achieving a food grain production target of 300 million tons by 2025 looks quite an uphill task. Increasing demand of land use for non-agricultural purpose and degrading soil health puts further pressure to it.

1.1. Role of fertilisers in food production:

Fertilisers play a critical role in ensuring food security, livelihood and overall growth of economy. Indian population increased from 361 million in 1947 to 1302 million, with 3.6 times growth in 2017 and is projected to reach to 1412 till 2025 and the fertiliser usage increased from 0.07 million tons in 1950-51 to

28 million tons in 2016-17 which helped in increasing the food production from 51 million tons to 273 million tons. Fertilisers contributed approximately 50 per cent towards increase in productivity during the post green revolution period (Kumar et al, 2004). The United Nations Millennium Task Force on hunger made soil health enhancement as one of the five recommendations for increasing agricultural productivity and to fight hunger in India (Saanchez and Swaminathan, 2005). Fertilisers contribute to increased crop production in several ways. First by replenishing nutrients it help in maintaining and enhancing soil fertility, second fertilisers help in increasing crop yield by providing proper nutrition required by high yielding varieties for giving high yields, third in nutrient poor soils fertilisers help in increasing crop yield and biomass, and this additional biomass can be used to augment the supply of organic matter required to improve moisture retention and nutrient use efficiency and help in increasing the crop yield.

1.2. Impact of Govt. policy on fertiliser scenario:

With the introduction of high yielding variety seeds, there was acceleration in the growth of fertiliser consumption and the annual uptake reached to 12.5 million tonnes in 1990-91 against 0.78 million tonnes in 1965-66. Since then, the growth in consumption of fertiliser was erratic and it reached to a maximum of 28.1 million tonnes in 2010-11 and again comes down to 26.7 million tonnes in 2015-16. The consumption of total nutrients per hectare of gross cropped area increased from 0.5kg/ha in 1950's to a maximum of 142.6 kg/ha in 2012 and it dropped to 125,9 kg/ha in 2014 and again increased to 137.6 in 2016. Introduction of nutrient based subsidy scheme with effect from 1st April 2010. Under the nutrient based subsidy scheme (NBS), Government has amended subsidy per kg of nutrients N, P, K and S contained in P & K fertilisers as well as per MT of fertilisers. Maximum retail prices (MRPs) of the decontrolled P&K fertilisers have been kept open and companies are free to announce their MRPs. This causes a significant increase in DAP and MOP prices and their usage decreased significantly against the consumption of Urea which was kept away from the decontrolled system. The $N:P_2O_5$: K_2O ratio had also favoured the increased consumption of Nitrogen in the form of Urea and this widens the ratio from 4.7:2.3:1.0in 2010-11 to 7.2:2.9:1.0 in 2015-16. The situation of some states like Haryana, Punjab and Uttar Pradesh is even worst as they become more skewed towards increased use of urea because of lower prices than phosphate and potassium fertilisers.

2. Content

2.1. Prime Nutrient Management Issues in Indian Agriculture

Table 1: Fertiliser Scenario in India

Year	Consumption of primary nutrients (Million tonnes)					
	N	P_2O5	K_2O	Total	kg/ha	N:P:K ratio
1950-51	0.055	0.009	0.006	0.07	0.5	9.2:1.5:1.0
1965-66	0.57	0.13	0.077	0.78	5.1	7.4:1.7:1.0
1990-91	8.0	3.2	1.3	12.5	67.6	6.2:2.5:1.0
2000-01	10.9	4.2	1.6	16.6	90.1	6.8:2,6:1.0
2010-11	16.6	8.1	3.5	28.1	142.3	4.7:2.3:1.0
2011-12	17.3	7.9	2.6	27.8	142.6	6.7:3.0:1.0
2012-13	16.8	6.6	2.1	25.5	131.4	8.2:3.2:1.0
2013-14	16.8	5.6	2.1	24.5	125.9	8.0:2.7:10
2014-15	16.9	6.1	2.5	25.6	131.6	6.7:2.4:1.0
2015-16	17.3	7.0	2.4	26.7	137.6	7.2:2,9:1.0

Source: FAI Statistics, 2015-16

Besides low factor productivity of fertilisers, the other major issues related to crop nutrient management are increasing fertiliser prices, increased nutrient mining primarily potassium, sulphur and some micronutrients, imbalance and inadequate use of nutrients as per need of high yielding varieties is an issue of both socio-political as well as technical in nature. A huge skew in usage towards N fertilizers is against the philosophy of balanced nutrient application. Farmers' choice regarding fertilizer input is primarily driven by crop response yielding net return. Soil health is often seen as a non-tangible entity and its role to obtain maximum attainable economic yield through balanced use of all deficient nutrients have been grossly ignored. Thus one of the prime reasons for decline/stagnation in agricultural productivity is possibly due to non-replenishment of secondary/ micro-nutrients; as confirmed through widespread sulphur, boron and zinc deficient areas in Western UP. This imbalanced nutrient management practice has resulted in of mining of yearly 8 million tonne of nutrients from our soils; primarily K, secondary and micronutrients.

Besides imbalanced nutrient application, lack of its integration with organic sources has also led to very poor fertilizer utilization efficiency. Our soils are poor in organic carbon, and possibility of its sequestration is remote due to prevailing high temperature in this sub-continent. Use efficiency of N and K fertilizers seldom exceeds 40 and 50 respectively, while that for P is hardly 20 per cent. However, most of the research results deal with the efficiency of individual nutrient in isolation, so have limitation of site specificity and reproducibility of similar response temporally and spatially. Interaction among the nutrients (both positive and negative) is often not considered in nutrient management planning. One wonders whether we will continue to stay complacent in such low-efficient system, which has both economical and environmental implications.

Being pro-active to correct the imbalance and to give back the nutrients removed by the cultivated crop needs a thorough revision of our conventional fertility ratings and recommendation charts used for ages in our Soil Testing Laboratories, which are neither crop specific nor yield-target oriented. The cultivars of 60s and 70s no way resemble current generation hybrids with relation to yield potential and nutrient demand. Neither the responses to nutrient application are similar. Multi-nutrient deficiencies increasingly observed in all major cropping sequence, and thus demands inclusion of all deficient nutrients and their interactions to be considered for our fertilizer recommendation. But there is no readily adoptable tool, neither any consensus among the scientific community on the road map to achieve this. In a nutshell, currently we are not ready to counter this new era of multi-nutrient deficiency.

2.2. Objective of Customised fertiliser

The main objective of customised fertiliser is to promote the site specific nutrient management so as to achieve the maximum fertiliser use efficiency of applied nutrients in a cost effective manner. Customised fertiliser may include the combination of macro and micro nutrients as per soil and crop specific need may be primary, secondary and micro-nutrients. It may include 100% water soluble fertilisers grade required in various usage of crop growth based on research findings.

2.3. What is customised fertiliser?

It is a multi-nutrient carrier designed to contain macro and/or micro nutrient forms, both from inorganic and/or organic sources, manufactured through a systematic process of granulation, satisfying the crop's nutritional needs, specific to its site, soil and stage, validated by a scientific crop model capability developed by an accredited fertiliser manufacturing/marketing company. It presents strategic opportunity for easy and innovative way to ensure balanced fertiliser use amongst farmers. Recognizing the importance of CF as well differentiating them from NPK granulated fertiliser;

the Government of India has included it in the Fertiliser Control Order as a separate category. Unlike NPK granulated fertilisers, CF is a concept around the plant nutrition backed by sound scientific plant nutrition principles and research

2.4. Methodology for development of Customised fertiliser

The research on customised fertiliser was started with an aim of developing, utilising and perfecting the scientific protocol to arrive at a crop and region specific grade. Scientific principles for nutrient prescription to crops are for point application. Hence, the challenge is to apply such principles to handle variability in soil nutrient availability values in as large areas as a few districts. The approach for development of crop specific grades (nutrient contents and ratio) is elucidated below:

A) Selecting target area and crop

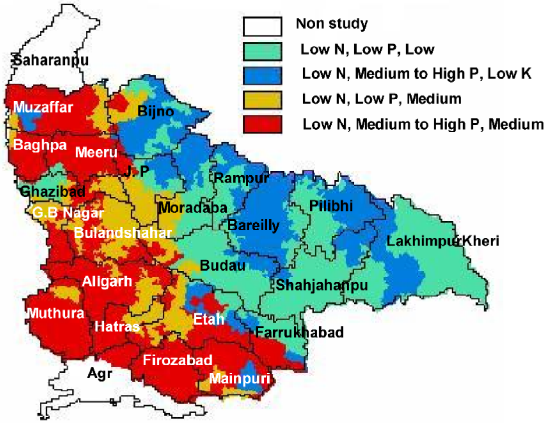
As customised fertiliser is both region and crop specific, one need is to first delineate the boundary conditions. Choice of crop was dependent on market research – which led us to choose potato, sugarcane paddy and wheat as the major crop in the western Uttar Pradesh for developing the customized fertiliser.

B) Building database

As the customized fertiliser is crop and region specific, a detailed database for both soil (fertility) and crop (yield, nutrient requirement) was found imperative. In order to ensure uniform and intensive data points, we digitized the geo-referenced map of target area, and placed cross-grids of 0.05' X 0.05'; which corresponded to 1 km x 1 km (approx.). Intersections of the grids formed the sampling points. Trained agronomists armed with GPS went to the specific locations and collected soil samples along with a questionnaire for collecting information on farmers' practices. For crop sample, a 1-m^2 area was chosen at cross-grid and collected to analyze economic yield as well as nutrient uptake. The analytical data were fed to GIS platform for further treatment.

C) Concept of Fertility Management Zones

Treatment of soil fertility data in GIS environment generated fertility-contours for each nutrient. Overlaying of such contours for N, P and K helped delineation of fertility management zones. Omission plot data were generated for NPK to quantify soil contribution.



The analysis of secondary and micronutrients in soil helped to identify crucial ones for possible inclusion in customized fertilisers. In case of our target area for paddy-wheat, bajra-potato and sugarcane-sugarcane rotation Zn, B and S were found to be most crucial for CF; Fe might be the next candidate.

Table 2. Nutrient requirement for target yield

Crop	Nutrients (kg/MT economic yield)				Target Yield
	N	P	K	S	MT/ha
Rice	23.3	5.2	21	2.85	5
Wheat	38.6	5.6	27.6	5.8	5
Sugarcane	2.05	0.24	2.4	0.5	100
Potato	4.6	0.44	4.53	0.3	27.5

D) Establishment of Nutrient Requirement

Crop analysis at grid samples established

Table 3. Customized fertilizer grades

Crop	Grade	Application Rate (kg/ha)
Paddy	10:26:17:1:0.3::N:P2O5:K2O:Zn:B	250
Wheat	10:18:25:4:0.5:0.2::N:P2O5:K2O:S:Zn:B	250
Sugarcane	7:20:18:6:0.5:0.2::N:P2O5:K2O:S:Zn:B	375-500
Potato	8:16:24:6:0.5:0.2::N:P2O5:K2O:S:Zn:B	625-750

nutrient requirements (see below), while yield data helped us to assume realistic targeted yield for each crop.

E) Grade fixation for Customized Fertiliser

Nutrient demand and soil fertility data were overlaid. Various approaches like STCR, QUEFTS, Nutrient Manager etc. were studied to arrive at possible grades. Prescription for secondary and micronutrients were primarily based on response curve along with reported critical limits. Various experimental grades were formed and were subjected to large scale agronomic response trials in all the soil fertility management zones.

2.5. Key guidelines released by GOI for manufacturing and sale of customised fertilisers

Keeping in view the focus on balance fertilisation GOI formulated guidelines for production and use of customised fertiliser under clause 20 B of FCO, 1985. The guidelines were issued on March 11, 2008 to enable interested companies to initiate the process of developing different grades of customised fertilisers.

As per the guidelines, permission for manufacture and sale of customised fertilisers shall be granted to the manufacturing companies whose annual turnover is 500 crore or above, having soil testing facility with annual capacity of 10,000 samples per annum and should have analysing capacity for NPK, secondary and micronutrients. The proposed grades shall be based on area and crop specific soil testing results. All subsidised products can be used by for manufacturing of customised fertilisers by the companies The Joint secretary (INM) Department of Agriculture & Cooperation, Ministry of Agriculture, Govt. of India will be the authority for granting permission on manufacturing and sale of scientifically developed customised fertiliser subject to fulfilling the eligibility criteria for a specific crop and area & its validity will be for a period of not exceeding three years. The companies interested in manufacture and sale of customised fertiliser in their vicinity should apply in the prescribed formats to ministry of Agriculture under intimation to the State Govt. Once the application for granting permission of specific customised grade will reach to competitive authority, he shall expedite the requisite for permission/ authorisation or otherwise after 45 days of putting the application the manufacturing company can start the production of the said grade for the specific area and crop. The approved grade production must start within six months after getting the approval from the competitive authority.

Quality checks on customised fertiliser are as per FCO. The tolerance limit prescribed under the FCO 1985 for NPK mixtures and NPK with micronutrient mixtures shall be applicable to customised fertiliser. However, such tolerance limit shall not exceed 3% for all nutrients particularly when secondary and micronutrients are also present with NPK. The customised fertiliser word shall be super scribed on the bags. The name of the crop and geographical area for which the customized fertiliser recommended shall also be indicated on the bag. The grades of customized fertiliser and nutrient quantities shall also be mentioned on the bag. The company shall fix reasonable MRP for its approved grade of customised fertilisers by taking all factors into consideration.

2.6. Revision or Renewal of customised fertiliser grade:

The customised fertiliser manufacturing company shall have to put an application for any amendment or renewal of their existing grades on completion of three years or earlier to the competitive authority. The manufacturing company shall have to declare through application even if here is no change in the existing grade to the competent authority. The competent authority shall thereon accord its approval with in 45 days from the date of receipt of such applications failing which the duly acknowledge copy of such application shall be treated as official approval.

2.7. Processes of manufacturing of Customised Fertiliser Grades:

Customised fertiliser can be manufactured by three ways and they are described below in the simplest way

2.7.1. Bulk blending process:

It is the process of mixing dry granule fertilisers in the ratio to obtain a multi nutrient formulation of NPK. It is the cheapest method which requires warehouse, weighing and mixing equipment Bulk blending provide the opportunity to prepare special blends with nutrient ratios to suit the particular farmer's need, appropriate to the soils and crops. This technique is most widely used in USA and now it is transferring to other European countries. During storage and application the raw materials of different sizes, forms and density segregate out with larger and heavier particles settle at the bottom of the sack. During application heavier particles dropped near and lighter particles travel further away which causes non uniform availability of the nutrients to the crop. In developed countries like USA the uniform size and shape raw materials are used for making bulk blending. In India NPK fertilisers are provided on subsidised rates and importing such raw materials for bulk blending with above physical specification will be unviable due to increased cost.

2.7.2. Steam granulation process:

Steam granulation is a wet granulation technique; water steam is used as binder instead of traditional liquid water as granulation liquid. In this method all raw materials are in solid form and there is no reaction of acids and ammonia. All raw materials are put in different surge hoppers and grinded together to a fine powder in pugmill. These fine particles are granulated by agglomeration process by using water steam and heat in the dryer. Steam, at its pure form is transparent gas, and provides a higher diffusion rate into the powder and a more favourable thermal balance during the drying step. After condensation of the steam, water forms a hot thin film on the powder particles, requiring only a small amount of extra energy for its elimination, and evaporates more easily. The advantages of this process include the higher ability of the steam to distribute uniformly and diffuse into the powder particles, production of spherical granules with larger surface area, and shorter processing time. However, this method requires high energy inputs for steam generation. At Tata Chemicals customised fertiliser plant this technique of steam granulation process is used for making all different grades of customised fertiliser.

2.7.3. Chemical granulation process:

This process is also called complex granulation or slurry granulation process. In this process the chemical reaction of ammonia and acids is made to form ammonium sulphate and ammonium nitrate salts and then granulated with the addition of discreet K2O either in solid or in liquid form. The granule is formed by accretion plus agglomeration method. Most of the NPK's available in Indian market like 12:32:16. 20:20:0:13 etc are results of chemical granulation process.

2.8. Customised fertiliser – key benefits:

Customised fertiliser is a step towards precision nutrient management to improve soil health with an objective of improving nutrient use efficiency through balance fertilisation, improving productivity and profitability in a cost effective manner. Customised fertilisers are developed for the local conditions after analysing soil, plant, water and the environmental conditions which help in minimising nutrient losses and improving their uptake Customised fertiliser provide all crucial nutrients together in the desired proportion and amount required by the crop. Customised fertiliser granules containing equal proportion of prescribed nutrients help in better mechanical placement. Customised fertiliser is a combination of primary, secondary and micronutrients based on nutrient requirement by the crop and soil capacity to supply nutrients based on GPS based soil sampling done for the particular geography and the nutrient combination is in the right proportion and farmers have no need to calculate the inputs by their own. Customised fertiliser is an assured quality fertilisers which can be utilised by the farmers based on the specific prescription made as per crop need.

Farmers will be benefitted by using customised fertiliser in many ways

- Customised fertiliser will help in improving the crop yield, quality and benefits
- It is an approach specific to crop and area based in soil fertility analysis
- The product is developed by using the scientific principles
- The use of customised fertiliser will help in improving soil health, and sustainable crop growth
- Farmers will have no need to calculate the individual nutrients as the product is available in the suitable nutrient proportion.
- The farmers can be benefitted with the assured product quality and it will reduce the use of spurious micronutrient fertilisers available in the market
- The product is available for the varied field conditions and ready to use form in a balanced way.

2.9. Research outcomes:

In order to validate the concept of customized fertilisers experiments were conducted on sugarcane, paddy, potato and wheat at various locations in the defined geography of western UP and the results have confirmed yield increase varying from 8 to 23% over farmer practice in different crops, marginal B:C ratio was 2 or more against benchmark against Farmer Practice (FP) and State Govt. Recommendation (SGR).Current commercial grades improved Partial factor productivity for all the major nutrients in most of the cases.

Tata Chemicals started sale of customized fertiliser in in the year 2010 and till March 2017 achieved a figure of 161197 tonnes in four different crops. The wheat grade sale was stopped because of lower return to farmers and was found to be a non-viable option to continue CF in wheat in-spite of more than 10 per cent yield increase. The sale of customised fertiliser had helped in adoption of balance fertilization approach in a large area which

Table 4. Sale (MT) and touch points of customized fertilizer

Grade	Customized Fertilisers sale (MT) & touch points				
	Total Sale of CF from 2010-2017 (Tonnes)	Rate of application (kg/ha)	Area under CF application (ha)	Average Land Holding of growers in UP (ha)	No. of farmers reached adopted CF or balance fertilisation
Paddy	28572	250	114289	1.5	76193
Potato	61247	625	97995	2	48998
Sugarcane	54561	500	109122	2	54561
Wheat	17537	250	70146	1.5	46764
Total	**161917**				**226515**

otherwise was very difficult to reach by the extension agencies through one to one contact and by promoting the application of fertilisers based on soil health reports. Customized fertilisers lead to improvisation of microbial population in soils of rice –wheat cropping system as reported by SK Singh et al (2016).

Research efforts carried out at IIPR, Kanpur substantially improved the LAI (leaf area index) and SCMR (SPAD Chlorophyll meter reading) of urdbean and soybean due to application of customized fertilizers over straight fertilizers. Application of customized fertilizer prepared as per nutrient need of maize (Locally prepared formulation; 6:5.4:10:6.0:1.0:0.6:0.2) substantially improved LAI and SCMR in intercropped urdbean (2.3 and 48.1) and soybean (2.6 and 43.5) indicated that urdbean and soybean plant adjusted their light harvesting efficiency under maize shading condition which might be the influence of balanced supply of majority of essential nutrients to the plants (Singh et al. 2015). In another study, application of straight fertilizers available in market (N:P:K:S:Zn:Fe:B:Mo::20:17:16:30:5:3:0.3:0.12) and customized fertilizer prepared locally (as per nutrient need based of chickpea corresponding to N:P:K:S:Zn:Fe:B:Mo:: 5.5:4.6:4.5:8.3:1.4:0.8:0.08:0.034) substantially improved NUE and partial factor productivity (PFP) in chickpea. The study showed that application of chickpea formula substantially enhanced both agronomic Zn and Fe use efficiency (110.4 and 184.1 kg grain/kg applied Zn and Fe, respectively) indicating the fact that both Zn and Fe were taken up by the plant more efficiently from customized fertilizer compared to straight fertilizers (58.3 and 97.2 kg grain/kg Zn and Fe applied, respectively). This further enhanced PFP (12.32 kg grain/kg NPK applied) in case of former over straight fertilizers (11.02 kg grain/kg NPK applied) which could explain the sustained release of nutrients from customized fertilizers as per the need of crop. Therefore, customized fertilizers are useful for enhanced NUE and minimizing nutrient loss in subtropics (Singh et al. 2016).

Similarly, customized fertilizers prepared locally as per nutrient need of the legume crop including chickpea (5.5:4.6:4.5:8.3:1.4:0.8:0.08:0.034 as NPKSZnFeBMo) enhances SPAD Chlorophyll meter reading (SCMR) and nodulation in chickpea at branching stage over straight fertilizers (include both macro- and micronutrients such as 20:17:16:30:5:3:0.3:0.12). The study clearly indicated that application of *chickpea formula* (a locally prepared customized fertilizer formulation) substantially improved SCMR and nodule number (45.6 and 28.3, respectively) over those in straight fertilizers (31.1 and 19.4, respectively). Therefore, enhanced chlorophyll content and nodule number due to application of customized fertilization in chickpea confirm the need for multi-nutrient sources for plant growth and development (Singh et al. 2016a).

3. Conclusion

Customized fertiliser is a site specific balance nutrition solution to achieve maximum nutrient use efficiency of the applied nutrients in a cost effective manner. Customised fertiliser includes the combination of primary, secondary and micronutrients as per crop need and soil analysis. It provides all-in-one easy-to-use solution for farmers, increases yield and improves farm income; decreases soil mining; and ensures uniform distribution of micronutrients. Govt. of India had made special provision in FCO by making revisions in the fertiliser policies to promote manufacturing and sale of customised fertiliser. Customized Fertilisers has a great potential to improve soil health and microbial population in longer term; specifically so if applied in integration with organic nutrient sources.

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Role of customized fertilizers for higher nutrient use efficiency

Ummed Singh, C S Praharaj, Lalit Kumar, P S Basu and G K Srivastava

ICAR-Indian Institute of Pulses Research, Kanpur, Uttar Pradesh-208024
E-mail: singhummed@yahoo.co.in

ABSTRACT

Fertilizer is an essential key input for production and productivity of crops. Fertilizer alone contributes towards 55% of additional food production. Since there is no scope for extending the cultivable area, more productivity per unit area is the only option and fertilizer is the main cart puller. Custom mixed fertilizer is a mixed fertilizer formulated according to individual specifications furnished by the consumer before mixing. Some land needs much higher quantities of balanced fertilizer mixtures in granulated form, for soil application; water soluble form for drip irrigation, mini sprinkler and foliar spray systems. Customized fertilizer may also be defined as multi-nutrient carrier which contains macro and/or micronutrient, whose sources are from inorganic or organic, which are manufactured through systemic process of granulation and satisfies crop's nutritional demand, specific to area, soil and growth stage of plant. Customized Fertilizers are enriched with both macro and micro nutrients and are manufactured through a systemic process of granulation with stringent quality checks.

Keywords: Crops, Customized fertilizers, Next generation fertilizers, Nutrient use efficiency

1. Introduction

Customized fertilizer will be the futuristic source of plant nutrients. The objective behind the customized fertilizer is to provide site specific nutrient management for achieving maximum fertilizer use efficiency for the applied nutrient in a cost effective manner. The customized fertilizer may be combination of nutrients, secondary nutrients and micronutrients. Customized Fertilizers are combination of micro nutrients like sulphur, zinc, boron added to the key items such as urea and diammonium phosphate (DAP) and potash, in a proportion that suits specific crops and soil patterns. A fertilizer formulated according to specifications that are furnished by/for a consumer prior to mixing, usually based on the results of soil tests. Customized fertilizers are dependent on soil, crop, water and specific nutrients. Customized fertilizer manufacture basically involves mixing and crushing of urea, DAP, MOP, ZnS, bentonite sulphur and boron granules for obtaining the desired proportion of N, P, K, S and micronutrients. The mixture is subjected to steam injection, drying, sieving and cooling, so as to get a uniform product with every grain having the same nutrient composition. The sharp rise in fertilizer prices emphasizes the need for more research to improve the efficiency of fertilizer use. Corporate social obligation to continue to help farmers in India, get higher yields with less fertilizer i.e. by Integrated Soil Fertility Management (ISFM) as a tool to improve the efficiency of fertilizer for increased profitability of small holder farmers of India. Although the production of fertilizer is energy intensive, the benefits of using energy to enhance food security through fertilizer manufacture and use are enormous. Every 1.0 million Btu of energy use in the fertilizers sector produces an additional 218 kg of grain – enough to provide the minimum calorific intake for one person for a year. Thus, converting energy into food security through fertilizer (customized fertilizer) & associated inputs is probably the worlds (more so for India) most cost effective & human alternative for use of energy resources. By 2020, energy used for fertilizer production & distributions is projected to increase to 8494 trillion Btu. But even then, energy consumed in the fertilizer sector will remain less than 2% of global energy consumption - far less than what people will use driving personal cars.

2. Content

2.1. Benefits of customized fertilizers

- Customized fertilizers is use of the Fertilizers Best Management Practices & are generally assumed to maximize crop yields while minimizing unwanted impacts on the environment & human health.
- Fertilizer Best Management Practices will make it "easier " in "future" for farmers, extension agents, crop advisers & researchers to exchange their experiences and also to restrict the unwanted nutrient impact on the ecosystem.
- Application of customized fertilizer is compatible with existing farmers system & hence it will be comfortably accepted by the farmers.
- Production of customized fertilizers will ensure improved 'Fertilizer Use Efficiency' & creating a new "Virtual" source of nutrients – implying from the existing quantity of DAP, MOP, Urea, SSP & A.S available & consumed in India, the agricultural produce output will increase, simultaneously the distribution & availability of fertilizer will be better. All this is achievable keeping the subsidy allocation constant.
- Customized fertilizer satisfies crop's nutritional demand, specific to area, soil, and growth stage of plant.
- As the micronutrients are also added with the granulated NPK fertilizer the plants can absorb the micronutrient along with macronutrient which prevents nutrient deficiency in plant.
- Mixed fertilizers with micronutrients provide recommended micronutrient rates for the agricultural field at the usual fertilizer application.
- The farmer need not buy micronutrient separately at extra cost, thus reducing the total cost. It is found that incorporation of micronutrient with granular fertilizer at the time of manufacturing results in uniform distribution of micronutrient throughout granular NPK fertilizer. This is because micronutrient source is in contact with the mixed fertilizer under the condition of high moisture and temperature. Micronutrient with the mixed fertilizer is one of the most convenient methods of fertilizer application and helps in more uniform distribution of nutrient with conventional application equipments. It is a very unique method developed in agriculture industry and has tremendous scope for future.

2.2. What is Customised Fertilisers?

"Customised Fertilisers (CF) are a multi-nutrient carrier designed to contain macro and / or micro nutrient forms, both from inorganic and / or organic sources; manufactured through a systematic process; satisfying the crop's nutritional needs, specific to its site, soil and stage; validated by a scientific crop model developed by an accredited fertiliser manufacturing / marketing company".

2.3. Why customized fertilizers needed?

- Declining total factor productivity
- Uneven growth of NPK, Secondary and Micronutrient consumption v/s food production
- Imbalanced and inadequate use of fertilisers
- Emerging multi-nutrient deficiencies
- Low fertiliser use efficiency (FUE)
- Inadequate fertiliser availability

- Declining crop response to fertilisers
- Unawareness of Integrated Nutrient Management (INM)

2.4. How to arrive at customised fertilisers?

Scientific principles were used as an ultimate guiding factor in deciding the grades of customised fertilisers. Following procedures were used to arrive at crop-soil specific customised fertiliser grades (CFG).

- Geo-referencing of chosen area
- Selecting sampling points on appropriate statistical procedure
- Actual sampling of the sites
- Analysing sampling of the sites
- Analysing soil, plant and water samples for nutrients and some soil characteristics
- Defining management zones
- Yield targeting in major management zones
- Computing crop removal of nutrients
- Calculating nutrient requirement (amount and ratio)
- Blending of nutrients based on the generated information

3. Solutions

ABFS has carried out the nutrient indexing in six main districts of Maharashtra namely Pune, Nasik, Ahmednagar, Aurangabad, Dhule and Jalgaon using Geographic Information System. The multi-micronutrient deficiencies assessed in these six districts on mainly Grape, Pomegranate, Banana and other potential fruits, vegetables and field crops required urgent attention. Initially four grades of Customised Fertilisers were created to provide a total nutrient package as basal application (Table 1).

Table 1. Grades of customized fertilizers

Grade 1 - N10 : P20 : K10 : S5 : Mg2 : Zn0.5 : B0.3 : Fe0.2

Grade 2 - N20 : P10 : K10 : S5 : Mg2 : Zn0.5 : B0.3 : Fe0.2

Grade 3 - N15 : P15 : K15 : S5 : Mg2 : Zn0.5:B0.0 : Fe0.2

Table 2. List of various grades of customized fertilizers

S.No.	Grade of Customized Fertilizer	Crop	Districts
	Nagarjuna Fertilizers Ltd.		
1.	15:32:8:0.5 (Zn)	Paddy	East and West Godavari of AP
2.	18:33:7:0.5 (Zn)	Paddy	Khammam, Krishna and Guntur of AP
3.	18:27:14:05 (Zn)	Maize	East Godavari, West Godavari and Vizag of A.P.
4.	18:24:11:0.5 (Zn)	Maize	Guntur, Krishna, Khammam
5.	12:24:0:0.5	Cotton	Krimnagar, Warangal, Nizamabad, Adilabad, Rangareddy, Medak, Khammam, Krishna, Guntur, Nalgonda and Prakasam
6.	24:0:16	Cotton	Krimnagar, Warangal, Nizamabad, Adilabad, Rangareddy, Medak, Khammam, Krishna, Guntur, Nalgonda and Prakasam
7.	16:16:10:1	Chilli	Krimnagar, Warangal, Khammam, Krishna, Guntur and Prakasam
8.	21:0:9	Chilli	Krimnagar, Warangal, Khammam, Krishna, Guntur and Prakasam

S.No.	Grade of Customized Fertilizer	Crop	Districts
9.	23:0:12	Paddy	East and West Godavari of AP
10.	27:0:10	Paddy	Guntur, Krishna, Khammam
11.	22:0:12	Paddy	Adilabad, Nizamabad, Krimnagar, Warangal, Medak, Rangareddy and Nalgonda
12.	18:0:14	Maize	-do-
13.	11:26:6:3:0.5 (NPK ZnS)	Paddy	-do-
14.	14:27:10:4:0.5 (NPKZnS)	Maize	-do-
	TATA CHEMICALS		
15.	8:16:24:6:0.5:0:1.5	Potato	Agra, Aligarh, Bulandshahar, Budaun, Bareilly, Baghpath, Bijanor, Hathras, Pilibhit, Muzaffarnagar, Mathura, Meerut, Moradabad, Etah, K.R. Nagar, Farukhabad, Ferozabad, G.B. Nagar, Ghaziabad, J.P. Nagar, Rampur, U.S. Nagar, Mainpuri, Shahjahanpur and LakhimpurKheri of Uttar Pradesh.
16.	7:20:18:6:0.5	Sugarcane	-do-
17.	10:18:25:3:0.5	Wheat	-do-
18.	8:15:15:0.5:0.15	Paddy	-do-
19.	10:13:12:6.2	Sweet Sorghum	Nanded district of Maharashtra
20.	11:32:13:0:0.9:0.24	Paddy	Agra, Aligarh, Bulandshahar, Budaun, Bareilly, Baghpath, Bijanor, Hathras, Pilibhit, Muzaffarnagar, Mathura, Meerut, Moradabad, Etah, K.R. Nagar, Farukhabad, Ferozabad, G.B. Nagar, Ghaziabad, J.P. Nagar, Rampur, U.S. Nagar, Mainpuri, Shahjahanpur and LakhimpurKheri of Uttar Pradesh.
21.	20:10:5:2:0.5:0.3:0.2	Grapes and Sugarcane	Pune, Nasik, Ahemdnagar and Aurangabad of Maharashtra
22.	10:20:0:5:2:0.5:0.3:0.2	Grapes, Pomegranate, paddy, tomato, leafy Veg.,Gourds Vegetables and sugarcane	Pune, Nasik, Jalgaon, Ahemdnagar and Aurangabad of Maharashtra
23.	15:15:15:5.:2:0.5:0.2	Graps, Cotton, Onion, Banana, Tomato, leafy Veg., Gourds and Vegetables	Pune, Nasik, Dhule, Jalgaon, Ahemdnagar and Aurangabad of Maharashtra
24.	10:20:20:3:2:0.5:0.3:0.0.2	Sugarcane, Citrus	-do-
	INDO GULF		
25.	12:26:18:0.5:5	Wheat & Paddy	Pratapgaarh, Barabanki, Jaunaaapuar, Raebareilli, Sultanpur, Faizabad, Ambedkarnagar, Lucknow

S.No.	Grade of Customized Fertilizer	Crop	Districts
26.	8:18:26:1.0:1.6 (NPKZnBS)	Potato	-do-
	COROMANDEL FERTLISERS Ltd.		
27.	16:22:14:4:1 (NPKZn)	Paddy	East and West Godavari, Krishna, Western delta of Guntur districts of A.P.
28.	14:20:15:4:0.6 (NPKSZn)	Maize	Karimngar, Warangal and Nizamabad districts of AP
29.	17:17:17:4:0.5:0.2 (NPKZnBS)	Groundnut	Anantpur, Chitoor, Kadapaaa, Kurnool, Mahaboobnagardistraicts of AP
30.	15:15:15:9:0.5:0.2 (NPKZnSB)	Groundnut	-do-
31.	20:0:15:0:0.2 (NPKZnSB)	Paddy and Maize	East and West Godavari, Krishna, Western delta of Guntur districts of A.P.

Source: FAI (2015); Nagarjuna 2017.

Grade 4 - N10 : P20 : K20 : S3 : Mg2 : Zn0.5 : B0.3 : Fe0.2

These customised fertiliser grades are subjected to change every three years as per the changing soil fertility and crop need. This is a pioneering effort made by ABFS in customised fertilisers.

4. Different Grades of Customized Fertilizer

Various grades of customized fertilizer which are manufactured in India. These grades are crop specific and location specific. The detailed list is mentioned below in the table 2.

In India, some of the manufacturers are involved in production of customized fertilizer grades as per the need of crop and locality. The manufacturer-wise production of customized fertilizers is being given in the table 3.

5. Guidelines for manufacturing and sale of Customized Fertilizer

The guidelines for manufacturing and sale of customized fertilizers are clearly given under the Clause 20'B' of Fertilizer (Control) Order.1985.

5.1. Reason Behind

The main objective of Customized Fertilizer is to promote site specific nutrient management so as to achieve the maximum fertilizer use efficiency of applied nutrient in a cost effective manner. The Customized Fertilizer may include the combination of nutrients based on soil testing & requirement of crop and the formulation may be of primary, secondary and micro-nutrients. It may include 100% water soluble fertilizers grades required in various stages of crop growth based on research findings.

5.2. Concept and Meaning

Customized Fertilizer is a concept around balanced plant nutrition. Such fertilizers are based on the sound scientific plant nutrition principle and research, Customized Fertilizer provides the best nutrition al package for premium quality plant growth and yield. They are defined as package for premium quality plant growth and yield. They are defined as multi nutrient carrier designed to contain macro and/ or micronutrient forms., both from inorganic and/or organic sources, manufactured through a systematic process of granulation, satisfying the crop's nutritional needs, specific to its site, soil and stage, validated by a scientific crop model capability developed by an accredited fertilizer manufacturing/ marketing company. Such fertilizers also include water soluble specialty fertilizer as customized combination products. Prospective manufacturers or marketers are expected to use the software tools like. Decision Support System for Agro Technology

Table 3. Production status of customized fertilizer in India (tonnes)

S. No.	Company	Grade	2011-12	2012-13	2013-14	2014-15
1.	Indo Gulf Fertilisers, Jagdishpur (U.P)	(12-26-18-5(S)-0.5 Zn)	651	3,559	2,775	10,397
		(8-18-26-6(S)-1 Zn-0.1 B)	-	600	900	702
		(12-22-18-6(S)-0.5 Zn)	-	254	767	2,570
		(8-18-10-6 (S)-0.5 Zn)	-	-	338	571
		(8-18-26-6(S)-0.5 Zn)	-	-	415	914
2.	Nagarjuna Fertilizers and Chemicals limited Kakinada (Hyderabad)	22-0-12	2,220	7,786*	24,422*	-
		15-32-08-0.5 Zn	1,641			
		18-24-11-0.5 Zn	730			
		23-0-12	920			
		18-33-07-0.5 Zn	1,368			
		18-27-14-0.5 Zn	541			
		27-0-10	758			
		11-24-6-3-0.5 Zn	4,057			
		14-27-10-4-0.5 Zn	659			
		18-0-14	148			
		12-24-0-1	73			
		16-16-10-1	1,789			
		21-0-9	1,438			
		24-0-16				
3.	Tata Chemicals Limited, Babrala (U.P)**	Wheat grade	15,897	2	-	-
		Sugarcane	14.978	1,105	5,031	13,401
		Paddy	11,564	2,732	3,437	4,121
		Potato	15,768	8,727	4,765	12,598
	Total (3 Companies)		75,394	24,765	42,850	45,273

*In the absence of production figures, Sales are assumed as production.

**Combined capacity of plant is 400 MTPD.

Note: "-" denotes data nil / not available.

Source: FAI (2016); Dass et al. 2017

Transfer (DSSAT). Crop Model etc. to determine the optimal grades of customized fertilizer.

5.3. Manufacture and sale of Customized Fertilizer

(i) Permission for manufacture and sale of Customized Fertilizer shall be granted to only such companies whose annual turnover is ¹ . 500 crores or above.

(ii) Such manufacturing companies should have soil testing facility with an annual analyzing capacity of 10,000 samples per annum and should have analyzing capacity for NPK, micronutrient and secondary nutrient. Such soil testing labs must process the requisite instruments.

(iii) The grade of customized fertilizer, which the company will manufacturer, must be based on scientific data obtained from area specific, soil specific and crop specific, soil testing results. These manufacturing companies, in association with concerned agricultural universities/KVKs concerned, should also conduct agronomy tests of the proposed grade to establish its agronomic efficacy.

(iv) Such manufacturing companies should generate multi-location trials (not on farm demonstration) on different crops for minimum one season.

5.4. Soil Sampling and Analysis

Such manufacturing companies must draw these soil samples from within its operational areas and should also ensure that minimum one sample is necessarily, drawn from each village. Scientific data on soil testing, results available with agricultural university /state Governments may also be used to prepare soil fertility map and for determination of required soil, area and crop specific grades for existing and potential marketing areas.

5.5. Grant of manufacturing permission

Subject to the fulfillment of eligibility criteria referred to in the preceding paragraphs, the permission for the manufacture and sale of Customized Fertiliser will be granted by Joint Secretary (INM). Department of Agriculture, Cooperation & Farmers Welfare, MOA, GOI. Such permission, for manufacture and sale of particular customized fertilizer grade shall be granted only for the specific area and for a period not exceeding three years. Such manufacturing companies must start their manufacturing and sales process with in a period of six months from the date of grant of such permission. For grant of permission to produce and to sell such customized fertilizers, the concerned manufacturing companies should necessarily apply for permission, to the office of the Joint Secretary(INM), Ministry of Agriculture under intimation to the State Government in the prescribed Performa as provided in annexure II. The competent authority shall expedite the requisite permission authorization of otherwise within 45 days of the receipt of such applications

5.6. Renewal/ Revision of customized fertilizer Grade

On completion of three years or earlier, manufacturing company of customized fertilizer shall submit a renewal/revision application for varied customized fertilizer manufactured by it. In case no change in the already approved composition of customized fertilizer is required, the same shall also be declared by the manufacturer. The competent authority, shall thereon, accord its approval; within .a period of 45 days from the date of receipt of such application, failing which the application duly acknowledged copy of such application shall be treated as official approval.

5.7. Customized Fertilizer Grades in India

The grades of customized fertilizer which the manufacturing company propose to manufacture and sell, shall be based on area specific and crop specific soil testing results. The manufacturer may be in association with Agricultural Universities/KVKs concerned, shall also conduct agronomy tests of the proposed grade to establish its agronomic efficacy. The manufacturing company, preferably in association with concerned agriculture universities/ KVKs may continue to conduct agronomy tests of the proposed grades on the farm, for at least one season. The minimum nutrient contents in a specific grade of customized fertilize, proposed to be manufactured, shall contain not less than 30 units of all nutrients, combined.

5.8. Manufacturing of area-specific grades of CF

For manufacture of area-specific subsequent grades of customized fertilizers, duly approved by the Joint Secretary(INM) MOA from time to time, the company shall intimate the competent authority within at least 45 days prior to its introduction of the said grades in the market. Since these grades will be based on the scientific data, no formal approval will be necessary.

5.8.1.Raw Material

(i) Use of subsidized fertilizers by Manufacturer of customized fertilizer

As per the existing policy, all subsidized fertilizers can be used for manufacturing of customized fertilizers. As such, domestic manufactures of all such subsidized fertilizers will have the choice to sell the requisite quantity to the manufacturing companies of customized fertilizers and the manufacturing company of such subsidized fertilizers shall be eligible to claim subsidy from DOF under relevant rules.

(ii) Captive use of subsidized fertilizers by the manufacturer of customized fertilizer

Domestic manufacturer of subsidized fertilizers will have the option to supply the required quantity of such fertilizers, as raw material, to its own manufacturing unit for production of customized fertilizers. All such supplies shall be eligible for subsidy as per the policy of DOF.

(iii) Import of subsidized fertilizers by the manufacturer of customized fertilizers

All manufacturers of customized fertilizers will have option to import subsidized fertilizers under the existing Policy guidelines of GOI for the manufacture of customized fertilizers not exceeding its realistic requirements. On the imported quality of such fertilizer to be used for manufacture of customized fertilizer, such manufacturers shall be eligible for subsidy from DOF, under relevant rules.

(iv) Allocation of subsidized fertilizer as raw material for manufacture of customized fertilizers

Specific allocations of subsidized fertilizers, to ensure adequate availability, in respect of States, may be made for use as raw material for manufacture of Customized Fertilizers, However, if required, permission for import of specific fertilizers as raw material (not included in schedule 1 of FCO, 1985) may also be granted to the manufacturers.

5.9. Quality of Customized Fertilizers

The Customized Fertilizers to be used for based application shall be granular in size with minimum 90% between 1-4 mm IS sieve and below 1mm should not exceed 5%. The moisture content should not exceed 1.5%. For foliar applications, however, the grades should be 100% water soluble. The specifications of the customized fertilizers provided by the company to manufacture of Customized Fertilizer, duly approved by the Ministry, shall be strictly adhered to.

5.10. Quality Check

(i) Procedure for drawl of sample of fertilizers:

(a) The method of drawing samples shall be provided in the FCO.

(b) Clause 4A (iii)- Weight of one sample should be 400g. as specified under Clause 4 A (iii) for Part A in Schedule 1 of the FCO,1985.

(ii) **Methods of analysis of fertilizer**

(a) The methods of analysis of fertilizers shall be as per the procedure prescribed in FCO.

(b) For preparation of sample for analysis in the laboratory (Clause 1-1) under part B in schedule II of FCO, 1985 the whole sample size of 400g should be powdered. The whole sample size of 400 gm shall be powdered.

(iii) Tolerance limit

The tolerance limits prescribed under the FCO, 1985 for NPK mixture and NPK with micronutrients, shall be applicable to the customized fertilizers. However such tolerance limit shall not exceed 3% for all nutrients particularly when secondary and micronutrients are also present with NPK.

5.11. Labeling

(i) The word Customized Fertilizer shall be super scribed on the bags.

(ii) The name of the crop and geographical area for which the Customized Fertilizer recommended shall also be indicated on the bags.

(iii) The grades of Customized Fertilizer and the nutrient contents shall be mentioned on the bags.

(iv) The manufacture should preferably have tampered proof bagging so as to check on adulteration.

5.12. Pricing of Customized Fertilizer

The Company shall fix reasonable MRP for its approved grade of customized fertilizers taking all factors into consideration.

5.13. Sale Authorization

The permission for manufacture of customized fertilizer shall be restricted to such manufacturing companies of fertilizers who have the certificate of manufacture and authorization letter for selling fertilizers in a particular State. All the provisions of Fertilizer(Control) Order, 1985 and Essential Commodities Act1955, shall be applicable for manufacture and sale of Customized Fertilizer.

5.14. List of equipments for setting up of new soil testing laboratories for creating NPK with micronutrient testing facilities

The following under listed equipments are necessarily required for setting up of new soil testing laboratory:

1. Atomic Absorption Spectrophotometer
2. Spectrophotometer
3. Flame Photometer
4. PH Meter
5. Conductivity Bridge
6. Colorimeter
7. Kjeldahl Distillation Set
8. Waster distillation Set (all glass)
9. Centrifuge
10. Deionizer
11. Balances
12. Grinders other instruments like Hotplate, gas Cylinders, heaters etc.
13. Stabilizers
14. Sample holding racks
15. Computer with printer
16. Software for preparation of recommendation and record of data.

5.15. Application for grant of permission for manufacture of customized fertilizer (CF)

The following information is required for grant of permission for manufacturing of CF:

1. Name of the Company and address
2. Location of the unit where the Customized grade of fertilizer proposed to bemanufactured.
3. Annual turnover of the company
4. Location/Particular of the Area where the Customized Fertilizer is to beintroduced
5. Soil Fertility Status of the Area.
6. Introduction Season
7. Cropping Pattern of the Area
8. Soil PH
9. Irrigated or un-irrigated land
10. Location of soil testing lab
11. Annual Analyzing Capacity of soil samples
12. Area Climate
13. Grades and other details relating to composition of CustomizedFertilizer
14. Raw Material (indicate whether the subsidized material to be used).
15. Quantity to be produced in each season
16. MRP
17. Whether the company possesses any

permission for manufacturing the grades of Customized fertilizer in any area

(i) Whether the company possesses the soil testing facility as prescribed in Annex II of guidelines.

(ii) Whether the proposed grades are based on the soil testing results and crop requirement.

(iii) Whether the multi location trials have conducted or not

(iv) Whether the agronomic test of the product in consultation with Agriculture Universities/ KVK have been conducted or not.

6. Conclusion

In the recent years Customized Fertilizer is a concept around balanced plant nutrition. Such fertilizers are based on the sound scientific plant nutrition principle and research. Customized Fertilizer provides the best nutritional package for premium quality plant growth and yield. These fertilizers are enriched with both macro and micro nutrients and are manufactured through a systemic process of granulation with stringent quality checks. Higher nutrient use efficiency and productivity are achieved through use of customized fertilizers. Such smart fertilizers could open up new avenues to the farmers in future.

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Technological interventions for higher water and nutrient use efficiencies in field crops

C S Praharaj, Ummed Singh and Man Mohan Deo

ICAR-Indian Institute of Pulses Research, Kanpur, Uttar Pradesh-208 024
E-mail: cspraharaj@hotmail.com

ABSTRACT

In India, efforts to adapt and promote Resource Conservation Technologies (RCT)for accelerating input use efficiency have been underway for nearly a decade but it is only in the past 4-5 years that the technologies are finding rapid acceptance by the farmers although these are more or less confined to irrigated agro-ecosystems. Water being the critical input for productivity enhancement, there is a need for its optimum and judicious use (through supplementary irrigation) for realizing higher input use efficiency through various technological options available. Similar is the case for nutrient and its use efficiencies. These should be in synchrony with the above basic principles of resource conservation. In this paper, an attempt is made for use of "Technological interventions" for higher water and nutrient use efficiencies in field crops especially in upland crops including pulses. Moreover, there is also a need to discuss the novel strategies for an effective input (water or fertilizer or others) management mediated through RCT. An implication of this is to bring together all the stake holders to share information/experiences and to encourage interaction for future research and development efforts in fulfilling our Sustainable Developmental Goals (SDG beyond 2015) for realizing production sustainability through conservation agriculture. The key technological interventions (KTIs) include some of the strategically important components of conservation agriculture which are discussed in this paper.

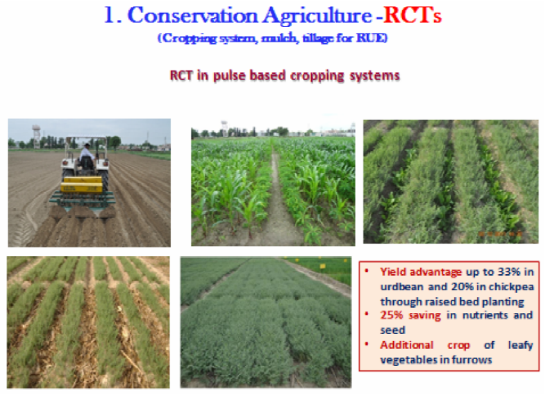
Keywords: Conservation agriculture, Resource Conservation Technologies, Technological interventions, Water and nutrient use efficiency

1. Introduction

Resource conserving technologies are the need of the hour as there is urgency in scaling productivity with reducing cost of cultivation and for accelerating nutrient use efficiency. Here is the role of key technological interventions (KTIs) which include some of the strategically important components of conservation agriculture. The details are discussed herein as under in subsequent heads.

2. KTIs for water and nutrient management

Need is arisen for evaluating existing conservation agricultural technologies '(RCT, Plate 1)' for developing the efficient water and nutrientmanagement strategies for their farm level impact in India. KTIs such as *precision land leveling, no-till systems, furrow irrigated raised bed (FIRB) planting systems, crop diversification and its residue management* have shown tremendous potential for efficient water and nutrientuse (NUE) and its use efficiency (WUE) for sustainable farming systems (Praharaj *et al.* 2011, Mishra et al. 2012a,b). Unevenness of the soil surface influences the farming operations, drudgery involved, energy use, aeration, crop stand and productivity mainly through nutrient-water interactions. The general practices of land levelling used by the farmers in India is either through use of plankers drawn by draft animals and small tractors or by iron scrappers/ levelling boards drawn by 4-wheel tractors (as in Indo-Gangatic Plains of India known as IGP) are not so perfect (less input use efficiencies and low yield at the cost of more water). Here laser land levelling is useful especially in intensively cultivated irrigated farming through achieving a better crop stand while saving irrigation water with improved input /nutrient use efficiencies. As a result, zero-till seed drill (Plate 2) performed better on a well levelled field compared to unlevelled or fairly levelled field due to better seed placement, germination and uniform distribution of irrigation water and plant nutrients (Sankaranarayanan *et al.* 2008). Zero tillage allows timely sowing of wheat, enables uniform drilling of seed, improves fertilizers use efficiency, saves water and increases yield up to 20 percent. Similarly, the importance of no till system in India is quite evident in terms of greenhouse gas emission and carbon sequestration (Venkatesh *et al.* 2013). It is estimated that for each litre of diesel fuel consumed, 2.6 kg of CO_2 is released to the atmosphere. Assuming that 150 litres of fuel is used per hectare per annum for use of tractor and irrigation in conventional system, it would amount to nearly 400 kg CO_2 being emitted per annum per hectare. Thus, the role of no tillage/conservation agriculture (CA) in economic growth can't be undermined as these are essentially conservation tools for a sustainable farming.



1. Conservation Agriculture -RCTs

(Cropping system, mulch, tillage for RUE)

RCT in pulse based cropping systems

- Yield advantage up to 33% in urdbean and 20% in chickpea through raised bed planting
- 25% saving in nutrients and seed
- Additional crop of leafy vegetables in furrows

In "*Furrow Irrigated Raised Bed (FIRB) planting systems*", the crop is sown on ridges or beds of 15-20 cm height and 40-70 cm width depending on the crops to enhance crop productivity (along with higher input use efficiency) and save the irrigation water (as in wheat growing area of NW Mexico). Potential agronomic advantages of beds include improved soil structure due to reduced compaction through controlled trafficking, and reduced water logging and timelier machinery operations due to better surface drainage. Typical irrigation savings range from 18% to 30-50% (Hobbs and Gupta 2003, Jat *et al.* 2005a,b). Trials by Farmer/ researcher in IGP suggest irrigation water savings of 12 to 60% was accrued for direct seeded (DSRB) and transplanted (TRB) rice on beds, with similar or lower yields for TRB compared with puddled flooded transplanted (PTR) rice (Balasubramanian *et al.* 2003). Similarly, raised bed planting out yielded flat planting by 18.8% and also enhanced both water and nutrient use and WUE in chickpea (Masood Ali 2009).

2. Zero till drill (mungbean, chickpea, lentil)

Labour Requirement, Man-h/ha	40
Field Capacity, h/ha	20
Cost of operation, Rs/ha	845
Energy Consumption, MJ ha^{-1}	78.4

Manual zero till drill

In the case of crop residue management, drop in soil organic matter (SOM) due to limited/reduced return of organic biomass has been identified as one of the key factors for unsustainability of the system (Singh *et al.* 2011). This is required for a larger replenishment of especially micronutrients removed by intensive cropping systems and of course enabling higher SOC. Improper crop residues Management (e.g., burning) due to inadequate *in-situ* recycling (Jat *et al.* 2004) not only leads to loss of considerable amount of N, P, K and S but also contributes to the global NO_2 and CO_2 budget (Grace *et al*. 2002) and destruction of beneficial micro-flora of the soil as a substantial quantum (80.12 m t per annum) of crop residues is available (Pal *et al*. 2002) for recycling in rice-wheat system. Similarly, growing a *cover crop/crop diversification* improves the stability of CA system and agro- ecosystem biodiversity. Legume intercropping in cereals grown with wider row spacing reduces nitrate leaching. *This is why CA systems will be the most thrust of the future farming*.

In *micro-irrigation techniques,* precision technologies are used for efficient management of both water and nutrient precisely near the root zone of crop plant with proven advantages of enhanced conveyance and water use efficiency. In the era of supplementary irrigation, there is a greater need to apply both fertilizer and water through drip (Plate 3) especially at very critical stages to improve input productivity of crop, water & nutrient (Praharaj and Narendra 2012). Study also suggests that a single irrigation (20 mm in 5 splits) by drip- fertigation with half of N+K fertilizers at branching produced significantly higher (20%) seed yields and economic return over rainfed pigeonpea (Praharaj 2013, 2017). This is further reinforced by laser levelling as it is very useful especially in intensively cultivated irrigated farming through achieving a better crop stand while saving irrigation water with improved input use efficiencies (Plate 4). More cropping intensity involving summer pulses could also be the fruit of laser levelling (Plate 5).

4. Laser leveling for higher water productivity

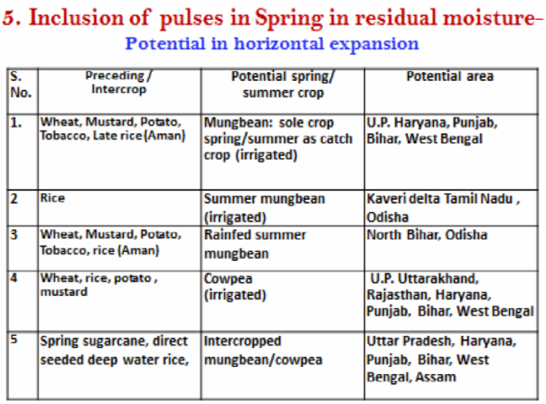
Advantages of Precision Tillage

Water Saving by 20-30%,
Saving of area 5% (under ditches & dikes)
Reduced risk of water logging , Increase distribution efficiency of irrigation
Uniform infiltration of water
Increase in yield by 15-20%

In pulses like chickpea, pre-plant irrigation + one irrigation at pre-podding stage increased seed yield by 77% over no irrigation. In addition, use of antitranspirant (HICO) gave significantly higher seed yield (33%) over control under rainfed conditions although no such improvement was recorded in irrigated condition (Masood Ali 2009). As conservation efforts often concentrate on maximizing the efficiency of the existing system, improved back up practices such as chiselling compacted soils, creating furrow dikes to prevent runoff, and using soil moisture and rainfall sensors to optimize irrigation schedules have their significant role to play.

3. Certain Constraints

Technological interventions have proved its worth on many counts viz., land configuration (bed planting, Plate 6) and other agro-techlogical needs including inter- and system based crops (Plate 7 & 8). These have made possible cultivation of pulses in rice fallows (Plate 9) using pond technology (Plate 10). Yet, conservation agriculture poses a challenge both for the scientific community and the farmers to overcome the *past mindset and explore the opportunities* that CA offers for natural resources improvement. Successful adoption of CA systems will call for greatly accelerated effort in developing, standardizing and promoting quality machinery aimed at a range of crop and cropping sequences, permanent bed and furrow planting systems, harvesting operations to manage crop residues, etc. Managing CA systems will be highly demanding in terms of knowledge base as it calls for enhanced capacity building and partnerships with concerned stakeholders. CA also determines the whole system performance. For example, surface maintained crop residues act as mulch and therefore, reduce soil water losses through evaporation and maintain a moderate soil temperature regime. However, at the same time crop residues offer an easily decomposable source of organic matter and could harbour undesirable pest populations or alter the system ecology in some other way. *Adaptive strategies for CA systems will also be highly site specific* yet learning across the sites will be a powerful way in understanding why certain technologies or practices are effective in a set of situation and not effective in another. For example, technologies can be more successful only these are amalgamated with machines for a drudgery free environment, higher economic benefits (BCR) and efficient on many angles (Plate 11). This will greatly accelerate our *learning process* for a sustainable resource management.

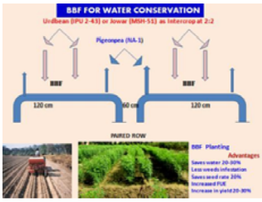


5. Inclusion of pulses in Spring in residual moisture–
Potential in horizontal expansion

S. No.	Preceding / Intercrop	Potential spring/ summer crop	Potential area
1.	Wheat, Mustard, Potato, Tobacco, Late rice (Aman)	Mungbean: sole crop spring/summer as catch crop (irrigated)	U.P. Haryana, Punjab, Bihar, West Bengal
2	Rice	Summer mungbean (irrigated)	Kaveri delta Tamil Nadu , Odisha
3	Wheat, Mustard, Potato, Tobacco, rice (Aman)	Rainfed summer mungbean	North Bihar, Odisha
4	Wheat, rice, potato , mustard	Cowpea (irrigated)	U.P. Uttarakhand, Rajasthan, Haryana, Punjab, Bihar, West Bengal
5	Spring sugarcane, direct seeded deep water rice,	Intercropped mungbean/cowpea	Uttar Pradesh, Haryana, Punjab, Bihar, West Bengal, Assam

6. RCT- Bed planting : A Water-Wise Technology

- ✣ 20-25% saving in irrigation water
- ✣ Opportunity for crop diversification
- ✣ Suitable for mechanical weeding & reduces herbicide use
- ✣ Ridge bed Sprinkler

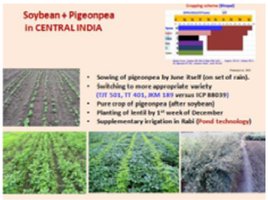


BBF FOR WATER CONSERVATION

Urdbean (IPU 2-43) or Jowar (MSH-51) as intercrop at 2:2

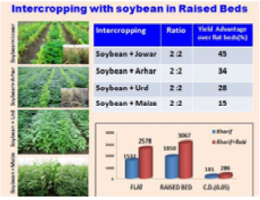
BBF Planting Advantages

Saves water 20-30%
Less weeds infestation
Saves seed rate 20%
Increased FUE
Increase in yield 20-30%



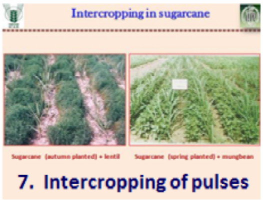
Soybean + Pigeonpea in CENTRAL INDIA

- Sowing of pigeonpea by June itself (on set of rain).
- Switching to more appropriate variety (TJT 501, TT 401, JKM 189 versus ICP 88039)
- Pure crop of pigeonpea (after soybean)
- Planting of lentil by 1st week of December
- Supplementary irrigation in Rabi (Pond technology)



Intercropping with soybean in Raised Beds

Intercropping	Ratio	Yield Advantage over flat beds(%)
Soybean + Jowar	2:2	45
Soybean + Arhar	2:2	34
Soybean + Urd	2:2	28
Soybean + Maize	2:2	15

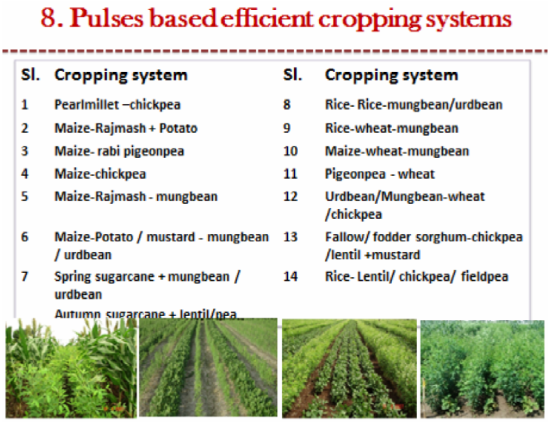


Intercropping in sugarcane

Sugarcane (autumn planted) + lentil

Sugarcane (spring planted) + mungbean

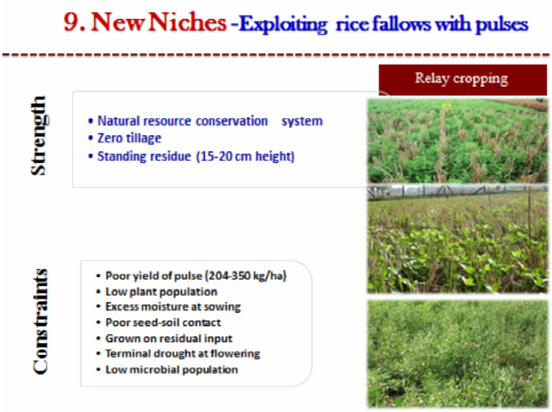
7. Intercropping of pulses



8. Pulses based efficient cropping systems

Sl.	Cropping system	Sl.	Cropping system
1	Pearlmillet –chickpea	8	Rice- Rice-mungbean/urdbean
2	Maize-Rajmash + Potato	9	Rice-wheat-mungbean
3	Maize- rabi pigeonpea	10	Maize-wheat-mungbean
4	Maize-chickpea	11	Pigeonpea - wheat
5	Maize-Rajmash - mungbean	12	Urdbean/Mungbean-wheat /chickpea
6	Maize-Potato / mustard - mungbean / urdbean	13	Fallow/ fodder sorghum-chickpea /lentil +mustard
7	Spring sugarcane + mungbean / urdbean Autumn sugarcane + lentil/pea	14	Rice- Lentil/ chickpea/ fieldpea

To conclude the above, conservation agriculture has emerged as a way for transition to the sustainability of intensive production systems over the past 2–3 decades globally. Since this permits

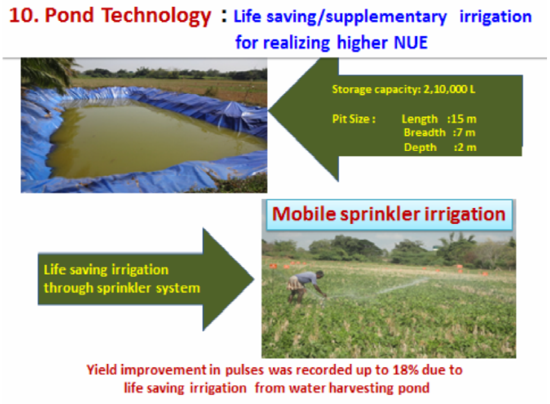


9. New Niches -Exploiting rice fallows with pulses

Relay cropping

Strength
- Natural resource conservation system
- Zero tillage
- Standing residue (15-20 cm height)

Constraints
- Poor yield of pulse (204-350 kg/ha)
- Low plant population
- Excess moisture at sowing
- Poor seed-soil contact
- Grown on residual input
- Terminal drought at flowering
- Low microbial population



10. Pond Technology : Life saving/supplementary irrigation for realizing higher NUE

Storage capacity: 2,10,000 L

Pit Size : Length :15 m
Breadth :7 m
Depth :2 m

Mobile sprinkler irrigation

Life saving irrigation through sprinkler system

Yield improvement in pulses was recorded up to 18% due to life saving irrigation from water harvesting pond

improved and efficient management of water and soils for agricultural production, it has assumed importance in view of the widespread natural resource degradation. This is attainable through effective and appropriate CA strategies aided RCT technologies.

11. Enabling Farm Mechanization for higher applied input and output efficiency

Moreover, attempts to promote CA globally are underway as reflected from developments worldwide where the objective of bringing together farmers, scientists, private sector stakeholders and decision makers to share information and experiences and to encourage interaction for future research and development efforts.

Therefore, some of the technological interventions with some novelty are summarized here as under:

4. Conclusion

Conservation agriculture (CA) has put forth management of water strategically so as to conserve and preserve our natural resources against soil deterioration and its environmental repercussions. Appropriate major technological interventions in today's agriculture are those which are strategically adopted so as to fit in the ecosystem or agricultural production system for its overall improvement over space and time. Here comes the role of resource conservation with appropriate conservation tillage that characterizes the development of new crop production technologies that are normally associated with some degree of tillage reductions, minimum mechanical operations, and more crop residue retention on the soil surface. Conserving natural resources, however removes the emphasis from the tillage component and addresses an enhanced concept of the complete agricultural system as conservation agriculture refers to the gamut of practice or technological interventions (RCT) with three basic principles of minimum disturbance of soil through practices like, zero or no tillage, keeping soil surfaces covered by leaving crop residues on it, and adopting diversified crop rotation measures, and growing crops that have a symbolic correlation to each other. Thus, conservation agriculture employed technological interventions with its roots in universal principles of providing permanent soil cover, minimum soil disturbance and crop rotations is now considered the *EXPRESS WAY* to sustainable agriculture.

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Enhancing nutrient use efficiency through differential formulations of fertilizers having slow release matrix

Lalit Kumar and Ummed Singh

ICAR-Indian Institute of Pulses Research, Kanpur, Uttar Pradesh-208024
E-mail: lalit1997@ymail.com

ABSTRACT

Nitrogen (N) and Phosphorus (P) are two important macronutrients responsible for the growth and yield of agricultural crops. Developing efficient fertilization practices has become more and more important due to the ever-increasing global demand for food products. About 40–70% of N and 80–90% of P applied as normal fertilizers are lost to the environment or chemically bound in the soil and are unavailable to plants. Recently, the use of slow release fertilizers (SRF) has been considered to be a promising strategy to improve the utilization of macronutrients. This article provides an overview of slow (SRF) and controlled release fertilizers (CRFs) as a cutting-edge and safe way to supply crops nutrients over the conventional ways. Essentially, CRFs entail fertilizer particles intercalated within recipients aiming at reducing the frequency of fertilizer application thereby abating potential adverse effects linked with conventional fertilizer use. The preparation and characterization of different type of controlled-release multi component (NPK) fertilizer formulations with the coating layer consisting of a biodegradable synthetic and natural copolymer is reported. The advantages of Slow-release fertilizers over conventional fertilizers, confirmed in different cultures, better matching of nutrient demand in crops and increased nutrient recovery is also explained.

Keywords: Control release, Fertilizers, Formulations, Slow release

1. Introduction

Different fertilizers were developed to supplement major and micro plant nutrients as nutrient supplement to low fertility soils or poor soils. Use of mineral fertilization started about 1880, became a common practice in the 1920s and adopted on larger scale since 1950. Most commonly used commercial fertilizers are water soluble hence known as quick-release fertilizers (QRFs) therefore considered readily available source of plant nutrition. Quick-release fertilizers are ideal for pre-plant applications, side dressing, hydroponics, or fertigation for almost all crops. They are highly practical if nutrient leaching or immobilization of nutrients by soil particles is not a serious concern (Wolf 1999). The main drawback of most of the water soluble fertilizer is their losses by different mechanism such as denitrification, leaching, volatilization fixation with soil clay particles etc. Moreover QRF, if soil moisture is appropriate, release all readily available nutrients in a short period of time after their application to soil. Hence, their release curve is immediate and does not synchronize with or match with the dynamic needs of crop growth, which make timely side dressings necessary. In fact, crop nutrient requirements change as plants develop. Therefore; to avoid their losses, and match with the crop demand, recently enhanced efficiency and slow-release fertilizers have been developed. Enhanced efficiency fertilizers are defined as those containing nitrification and urease inhibitors, and slow-release fertilizers are defined as those which have a coating or a modification, which slows the rate of nutrient release. Nitrification inhibitors are compounds that delay bacterial oxidation of NH_4^+ by depressing the activities of nitrifier microorganisms in soil, whereas urease inhibitors are compounds that delay the hydrolysis of urea. Controlled release fertilizers (CRFs) are fertilizer granules intercalated within carrier molecules commonly known as excipients to control nutrients release thereby improving nutrient supply to crops and minimize environmental, ecological, and health hazards. In that sense, CRFs usage is an advanced way to supply crop's nutrients (cf. conventional ways) due to gradual pattern of nutrient release, which improves fertilizer use efficiency (FUE). In other words, depending on the thickness of the coatings within the formulation, CRFs enable nutrients to be released over an extended period leading to an increased control over the rate and pattern of release, consequently the excipients play a role in regulating nutrients release time and eliminate the need for constant fertilization and higher efficiency rate than conventional soluble fertilizers. Compared to natural organic fertilizers, most slow- and controlled-release kinds are more concentrated, easier to handle, and less expensive (on a cost per nutrient basis); and they are not dependent upon soil microbes and water to make their nutrients available. Broadly they can be divided in two categories: slow release and control release. Occasionally the terms controlled release fertilizers (CRFs) and slow release fertilizers (SRFs) have been used interchangeably, yet they are different. Typically, the endorsed differences between slow-release and controlled-release fertilizers are not clear.

2. Methods of slow release

There are several methods for formulated a product of sustained release kind properties. Mainly the nutrient source is embedded in a matrix of insoluble substance(s) so that the dissolving nutrient must find its way out through the holes in the matrix. The different methods used to obtain a sustained release product are as follows.

2.1. Diffusion systems

Diffusion systems rate release is dependent on the rate at which the nutrient source dissolves through a barrier which is usually a type of polymer. Diffusion systems can be broken into two subcategories, reservoir devices and matrix devices.

- Reservoir devices coat the nutrient source with insoluble polymers that allow the nutrient released through diffusion. The rate of reservoir devices can be altered by changing the polymer and is possible be made to have zero-order release.
- Matrix devices forms a matrix nutrient mixed with a gelling agent) where the nutrient is dissolved/dispersed. The nutrient is usually dispersed within a polymer and then released by undergoing diffusion.

2.2. Dissolution systems

Dissolution systems must have the system dissolved slowly in order for the nutrient to have sustained release properties which can be achieved by using appropriate salts and/or derivatives as well as coating the drug with a dissolving material. It is used for nutrient compounds with high solubility in water. Instead of diffusion, the drug release depends on the solubility and thickness of the coating. Because of this mechanism, the dissolution will be the rate limiting factor here for drug release. Dissolution systems can be broken down to subcategories called reservoir devices and matrix devices.

- The reservoir device coats the nutrient source with an appropriate material which will dissolve slowly. It can also be used to administer beads as a group with varying thickness, making the drug release in multiple times creating a SR.
- The matrix device has the drug in a matrix and the matrix is dissolved instead of a coating. It can come either as drug impregnated spheres or drug impregnated tablets.

2.3. Osmotic systems

Osmotic controlled-release have the form of a rigid tablet with a semi-permeable outer membrane and one or more small laser drilled holes in it. As the product applied to soil it absorbed water through the semipermeable membrane via osmosis, and the resulting osmotic pressure is used to push the active nutrient through the opening(s) in the tablet.

2.4. Ion-exchange resin

In the ion-exchange method, the resins are cross-linked water-insoluble polymers that contain ionisable functional groups that form a repeating pattern of polymers, creating a polymer chain. The nutrient is attached to the resin and is released when an appropriate interaction of ions and ion exchange groups occur. The area and length of the drug release and number of cross-link polymers dictate the rate of release.

2.5. Matrix systems

The matrix system is the mixture of materials with the drug, which will cause the drug to slow down. However, this system has several subcategories: hydrophobic matrices, lipid matrices, hydrophilic matrices, biodegradable matrices, and mineral matrices.

- A hydrophobic matrix is a drug mixed with a hydrophobic polymer. This causes SR because the drug, after being dissolved, will have to be released by going through channels made by the hydrophilic polymer.
- A hydrophilic matrix will go back to the matrix as discussed before where a matrix is a mixture of a drug or drugs with a gelling agent. This system is well liked because of its cost and broad regulatory acceptance. The polymers used can be broken down into categories: cellulose derivatives, non-cellulose natural, and polymers of acrylic acid.
- A lipid matrix uses wax or similar materials. Drug release happens through diffusion through, and erosion of, the wax and tends to be sensitive to digestive fluids.
- Biodegradable matrices are made with unstable, linked monomers that will erode by biological compounds such as enzymes and proteins.
- A mineral matrix which generally means the polymers used are obtained in seaweed.

3. Slow-Release Fertilizers

Nitrogen products decomposed by microbes are commonly referred as SRF fertilizers. Some SRFs such as N-SURE are made in factories. However, some such as manure are naturally originated and cannot be formulated to permit controlled release (Liu *et al.* 2011). The nutrient release pattern of SRFs is fully dependent on soil and climatic conditions. Slow-release fertilizer releases nutrients gradually with time, and it can be an inorganic or organic form. An SRF contains a plant nutrient in a form that makes it unavailable for plant uptake and use for some time after the fertilizer is applied. Such a fertilizer extends its bioavailability significantly longer than QRFs such as ammonium nitrate, urea, ammonium phosphate, or potassium chloride. Nitroform (also referred to as trinitromethane with a chemical formula $HC[NO_2]_3$) exemplifies inorganic SRF fertilizers (Loper and Shober 2012). Urea-formaldehyde (UF), urea-isobutyraldehyde/isobutylidene diurea (IBDU), and urea-alcetaldehyde/cyclo diurea (CDU typify organic SRF fertilizers (Trenkel 2010). Based on the source, there are two types of SRF fertilizers: natural and artificial (Table 1).

3.1. Natural SRFs

It includes plant manures, such as green manure or cover crops, all animal manures (chicken, cow, and poultry) and compost (Shukla *et al.* 2013). Because of their organic nature, these must be broken down by microbial activity before the nutrients can be released to crops. In general, organic fertilizers may take a long time to release nutrients, and these nutrients may not be available when the plant needs them. The duration of nutrient release of this type of organic fertilizers mainly depends on soil microbial activity that is driven by soil moisture and temperature. Organic SRFs contain both macro-nutrients (nitrogen, phosphorus, potassium, etc.) and micronutrients (iron, manganese, copper, etc). The nutrient concentrations of organic SRFs are relatively lower than those of synthetic SRF fertilizers. For example, Sup'r Green brand is a chicken manure fertilizer containing only 3-2-2 % N, P_2O_5, and K_2O, respectively.

3.2. Synthetic SRFs

They are sparingly water-soluble. The bioavailability of this type of fertilizers (typically in pellet or spike form) depends on soil moisture and temperature. Nutrients are released throughout a period of time that may range from 20 days to 18 months (Trenkel 2010). Therefore, fewer applications are needed with SRFs, but nutrients are released based upon the temperature and moisture conditions in the soil, which may not match the crop growth demand due to varying weather conditions (Trenkel 2010). Synthetic SRFs often contain a single nutrient at a much higher level than would occur in a natural SRF. For example, N-Sure® is a SRF that contains 28 percent nitrogen (28-0-0) (Clapp 1993; Liu and Williamson 2013).

4. Control release fertilizers (CRF)

It is generally applied to fertilizers in which the factors dominating the rate, pattern, and duration of release are well known and controllable during CRF preparation. Controlled-release fertilizers provide an attractive alternative to granular fertilizers. These are fertilizer 'cocktails' that slowly release nutrients to the substrate. The release depends on water availability or soil temperature. Controlled-release fertilizers are more expensive than the more common water soluble fertilizers, but they have several advantages:

- The danger of over-fertilizing is reduced as the release of fertilizers occurs gradually.
- Fertilizing is necessary only occasionally, sometimes only once in a season
- A balanced fertilizer mixture is provided at all times as the plants get what they need at different growth stages.
- Nutrients do not leach from the substrate so

Table 1. Relative insoluble synthetic materials used as slow-release fertilizers

Material	Trade name	N	P_2O_5	K_2O	Mg
Guanylurea	G. sulfate	37	-	-	-
Magnesium ammonium phosphate	Mag-Amp	8	40	0	14
Oxalic acid diamide	Oxamide	31.8	0	0	0
Potassium calcium phosphate	KCP	0	17–22	21–22	0
Potassium poly-phosphate	KPP	29–32	24–25	0	0
Urea aldehyde	IBDU	30	0	0	0
	CDU	32	0	0	0
	Crotadur	32	0	0	0
	Floranid	28	0	0	0
	Glyyccluril	39	0	0	0
	Ureaform	38	0	0	0
	Agriform	28	18	4.8	0
	Urea-Z	33–38	0	0	0

Source: Dinauer,1971, Halder (Eds.) 1979, and Wolf, B. 1999.

the plants receive all the nutrients applied.

5. Composition of CRF formulation

Basically most CRFs may contain among others the following components.

5.1. Polymer Solution

A number of polymers have been used in fertilizer coating; such polymers could be thermosetting, thermoplastic, or biodegradable ones. Some of the common thermoset polymers include urethane resin, epoxy resin, alkyd resin, unsaturated polyester resin, phenol resin, urea resin, melamine resin, phenol resin, and silicon resin. Among them, urethane resin urethane is very commonly used. Thermoplastic resins are not very commonly used in practice because they are either not soluble in a solvent or make a very viscous solution which is not suitable for spraying; however, polyolefin is used in the art for coating the fertilizer granules. Biodegradable polymers are naturally available and so they are known to be environment friendly because they decompose in bioactive environments and degrade by the enzymatic action of microorganisms such as bacteria, fungi, and algae and their polymer chains may also be broken down by nonenzymatic processes such as chemical hydrolysis. However, both synthetic and natural polymers containing hydrolytically or enzymatically labile bonds or groups are degradable. Some of the biodegradable natural polymers are: Hydroxy propyl methyl cellulose (HPMC), Chitosan, k-carrageenam, sodium alginate, xanthum gum, carageenam, pactin, tamarind seed polysaccharide (TSP), mimosa pudica seed mucilage, lucaena leucocaphala seed polysaccharide (LLSP), guar gum, terminalia catappa gum, gellan gum, grewia gum, mucunia gum, gum copal, gum acasia, nano clay etc.

5.1. Modified Clays

Nanoclay is the most common nanoparticle which has been used to produce CRFs. The layered clays like montmorillonite and kaolinite are made of high aspect ratio nanolayers. Large surface areas and reactivity of nanolayers are much greater than those of micrometre size materials. Also, their surfaces and interfaces provide an active substrate for physical, chemical, and biological reactions. Because of these features, nanolayers could be a suitable carrier or reservoir of fertilizers. Mechanisms which are involved in interaction between clay and organic materials depend on some factors like clay type, functional groups of organic material, and physical or chemical properties of organic material.

5.1. Other Components

Several other ingredients are known to compose CRFs formulations, namely, crosslinkers such as glutaraldehyde] and methylene-bisacrylamide (MBA)]; fertilizer nutrients such as urea and ammonium nitrate and initiators such as azobisisobutyronitrile (AIBN), ZnO], and ammonium persulphate (APS) have been used to create polymer before crosslinking. In addition to that, surfactants such as sodium octadecyl phosphate and sometimes a dispersion medium such as cyclohexane (which is normally used to disperse surfactant molecules) are also known in the release formulation practices. A list of polymer used in agro industry is given below in table-2.

Currently, there are three prominent kinds of controlled-release fertilizers marketed to home gardeners. Some of the developed product of this category is given below in table-3.

6. Major difference between Slow- and Controlled-Release Fertilizers

The terms “slow-release fertilizer,” or SRF, and “controlled-release fertilizer,” or CRF, do not mean the same thing.

- Controlled-release fertilizer is also known as controlled availability fertilizer, delayed-release fertilizer, metered release fertilizer, coated fertilizer (Oertli and Lunt 1962), or slow-acting fertilizer (Gregorich *et al.* 2001). According to

Table 2. Summary of polymers, carrier systems, and bioactive compounds with applications in agriculture

Carrier/polysaccharide	Active principle	Class	Reference
Alginate-chitosan spheres	Imidacloprid	Insecticide	Guan *et al.* (2008)
Starch-alginate spheres	Thiram	Fungicide	Singh *et al.* (2009a, b, c)
Alginate microspheres	Ecdysone	Hormone	Guan *et al.* (2011)
Starch-alginate microspheres	Chlorpyrifos	Insecticide	Roy *et al.* (2009)
Alginate-starch-clay spheres	Thiram	Fungicide	Singh *et al.* (2009a, b, c)
Agar/alginate beads	Thiram	Fungicide	Singh *et al.* (2009a, b, c)
Alginate particles	Carbofuran	Insecticide/nematicide	Fernández-Pérez *et al.* (2000)
Alginate granules	Chloridazon and metribuzin	Herbicides	Flores Céspedes *et al.* (2007)
Alginate spheres	Azadirachtin	Biopesticide	Kulkarni *et al.* (2000)
Alginate nanoemulsion	Azadirachtin	Biopesticide	Jerobin *et al.* (2012)
Alginate hydrogel	Clomazone	Herbicide	Wlodarczyk and Siwek (2013)
Alginate-chitosan nanoparticles	Paraquat)	Herbicide	dos Silva *et al.* (2011
Ethylcellulose microparticles	Norflurazon	Herbicide	Sopeña *et al.* (2011)
Ethylcellulose	Alachlor	Herbicide	Sopeña *et al.* (2007)
Ethylcellulose	Chlorsulfuron	Herbicide	Flores-Céspedes *et al.* (2009)
Chitosan nanoparticles and chitosan	Dichlorprop	Herbicide	Wen *et al.* (2011)
Chitosan	Dichlorprop	Herbicide	Wen *et al.* (2010)
Montmorillonite-chitosan bionanocomposites	Clopyralid	Herbicide	Celis *et al.* (2012)
Chitosan nanoparticles	Hexavalent	chromium Metal	Geng *et al.* (2009)
Chitosan	NPK	Fertilizer	Wu and Liu (2008)
Chitosan microspheres	Brassinosteroids	Hormones	Quiñones *et al.* (2010)
Chitosan	Rotenone)	Insecticide	Lao *et al.* (2010
Chitosan	1-Naphthylacetic acid	Hormone	Tao *et al.* (2012)
Cyclodextrins	Bendiocarb and promecarb	Insecticides	Pacioni and Veglia (2007)
Chitosan/ β-cyclodextrins Films	Carvacrol	Insecticides	Higueras *et al.* (2014)
Hydroxypropyl- β-cyclodextrin	Pyrimethanil	Fungicide	Fernandes *et al.* (2014)
β-Cyclodextrin	MCPA	Herbicide	Garrido *et al.* (2014)
β-Cyclodextrin	(2,4-D)	Herbicide	Pérez-Martínez *et al.* (1999)
β-Cyclodextrin	Chlorpropham	Herbicide	Ge *et al.* (2011)
Maize starch	Phosphate	Nutrient	Zhong *et al.* (2013)

Shaviv (2005), “The term controlled-release fertilizer became acceptable when applied to fertilizers in which the factors dominating the rate, pattern and duration of release are well known and controllable during CRF preparation.”

- Slow-release fertilizers involve a slower release rate of nutrients than conventional water-soluble fertilizers, but the rate, pattern, and duration of release are not controlled (Trenkel 2010) because they depend on microbial organisms whose effectiveness is dependent on soil temperature and moisture conditions.
- Because of their dependence on microbial digestion to enable nutrient availability, SRFs occasionally pose the risk of increased harmful

Table 3. Relative insoluble synthetic materials used as controlled-release fertilizers

Material	Trade name	N	P_2O_5	K_2O	Mg
Resin coated	Osmocote	14	14	14	0
		18	9	9	0
		18	6	12	0
		24	**4**	**8**	**0**
	Sierrablen	19	6	10	0
	Polyon	25	4	12	0
	Procote	20	3	10	0
	Nutricote	13	13	13	0
		18	**6**	**18**	**0**
		14	**14**	**14**	**0**
		16	**10**	**10**	**0**
		20	**7**	**10**	**0**
		18	**6**	**8**	**0**
	Woodlace	20	4	11	0
	SCU	37	0	0	0
	ESN	44	0	0	0
	Agrocote	39	0	0	0
		38	**0**	**0**	**0**

Source: Dinauer, 1971, and Wolf, 1999.

leaching events. This situation occurs when favorable conditions for microbial activity follow after the cropping cycle. Excess available nutrients can be pollutants irrespective of the source.

7. Coated fertilizers

Different types of coating are used: impermeable coatings with tiny holes, through which solubilized materials diffuse, and semi permeable coatings through which water diffuses until the internal osmotic pressure ruptures the coating or impermeable coatings that must be broken, for example, by biological actions. Further coatings may function only as physical barriers or be a source of plant nutrient. The most important coating materials, which are usually applied in intimate contact with the surface of the fertilizer particle, are waxes, polymers, and sulfur. Osmocotes are surrounded by a plastic shell, which allows water to diffuse into the shell, which tears as a result of the uptake of water and the nutrients diffuse into the soil. With sulfur-coated urea (SCU), water vapor transfers through the sulfur coating, solubilizes the urea within the shell, builds up sufficient osmotic pressure to disrupt the coating, and urea solution is released. The decomposition of the sulfur coat also depends on the oxidation of the sulfur, which is mainly brought about by soil microorganisms. Hence the availability of the sulfur-coated fertilizers depends on microbial activity.

Because the release of nutrients from the fertilizer depends on soil water content, and plant growth depends on soil moisture, nutrient release may also be adapted to plant growth.

8. Uncoated fertilizers

While urea is readily soluble in water and quickly decomposed to release NH4+, it forms several chemical reaction products that are useful as slow-release N fertilizers. Urea reacts with several aldehydes to form compounds that are sparingly soluble in water. Commercial products are ureaform (UF), crotonylidendiurea (CDU), and isobutylidenurea (IBDU). After application to the soil, these fertilizers are prone to hydrolysis and release urea. The rate of microbiological decomposition is controlled by the property of the aldehyde as well as by soil temperature.

9. Advantages of Using CRFs and SRFs

The major advantages for using SRFs or CRFs include: • Decreased nutrient losses and enhanced nutrient-use efficiency. The application of CRFs and SRFs can potentially decrease fertilizer use by 20 to 30 percent of the recommended rate of a conventional fertilizer while obtaining the same yield (Trenkel 2010).

- Minimization of fertilizer-associated risks such as leaf burning, water contamination, and eutrophication (a process where water bodies receive excess nutrients). The slow rates of nutrient release can keep available nutrient concentrations in soil solution at a lower level, reducing runoff and leaching losses.
- Reduced application and labor costs. For example, in current practices, commercial potato producers use 3 to 4 applications of nitrogen fertilizers for NE Florida and 2 applications for SW Florida (personal communication with local potato producers). Eliminating extra applications of fertilizer saves the farmer between $5 and $7/acre broadcasting expense (Liu et al. 2011). Additionally, avoidance of fertilizer application in late growth stage eliminates plant damages to crops.
- Better understanding of nutrient release rate and duration (CRFs only, because they are less sensitive to soil and climate conditions) (Shaviv 2005; Shoji 2005; Trenkel 2010). Knowing when to apply fertilizer and in what quantities saves money, reduces fertilizer-associated risks to crops and the environment, and improves nutrient management programs.
- Lowered soil pH in alkaline soils for better bioavailability of some nutrients. Applying sulfur-coated urea will probably increase soil acidity because both sulfur and urea contribute to increasing the acidity (lowering soil pH) of the soil. Consequently, phosphorus or iron may be more bioavailable and benefit some crops like blueberry, potato, and sweet potato (Liu and Hanlon 2012). In addition, sulfur is an essential nutrient for all crops.
- Reduced production costs if there is an abundant supply of SRF sources like manures nearby.

10. Disadvantages of Using CRFs and SRFs

Most coated or encapsulated CRFs and SRFs (Tables 1 & 2) cost considerably more to manufacture than conventional fertilizers. This extra cost increases growers' crop production costs. For example, the price was $650 per ton for environmentally smart nitrogen (ESN) (44% N) versus $481 per ton for urea (46 percent N) (Ruark 2012). Environmentally smart nitrogen was 35.1 percent more costly than urea. The price per unit of nitrogen was 41.3 percent greater for ESN than for conventional urea.

- Applying sulfur-coated urea almost always lowers soil pH as aforementioned. However, this acidification may cause nutrient disorders such as calcium deficiency or magnesium deficiency if there is not a proper nutrient management program.
- Nutrient deficiencies may occur if nutrients are not released as predicted because of low temperatures, flooded or droughty soil, or poor activity of soil microbes.
- Possible uncontrolled nutrient release of SRFs. Use efficiency of SRFs may be enhanced by planting shelter belts or nutrient trap crops where runoff is likely to occur.

11. How are CRFs or SRFs best used?

Crop nutrient requirements follow a dynamic pattern: they begin low in the early growth stage, increase sharply in the middle stage and decrease in the late stage. Conventional fertilizers (QRFs) are instantly available when they're applied, which makes them more vulnerable to loss from a variety of causes such as ammonia volatilization (ammonia emitting into the atmosphere), de-nitrification (nitrate is reduced to nitrogen), leaching, or runoff after being applied to the soil. Nitrogen and potash fertilizers are particularly easily lost. Assuming the same amount of fertilizer is applied, a one-time or seasonal application of conventional fertilizers has the potential to lose much more nitrogen than would be lost with multiple split-applications of fertilizer. Split applications of convention fertilizer are recommended (Hochmuth and Hanlon 2013). To match crop nutrient requirements, the ideal fertilizer should have this characteristic: the nutrient release matches the nutrient requirements of the crop throughout all of the plant growth stages. Obviously, QRFs do not have this characteristic, and they cannot meet such requirements without repeat applications. Fortunately, using deliberate applications of CRFs and SRFs in specific circumstances where they are appropriate can accommodate timely plant nutrient demand requirements, maximize nutrient use efficiency, and minimize environmental concerns. There is a close relationship between CRFs

12. Take-Home Message

- Quick-release fertilizers are water soluble and readily available for plants to take up when they are properly placed at the right time.
- Controlled-release fertilizers contain a plant nutrient in a form that delays its availability for plant uptake and use after application, or that extends its availability to the plant significantly longer than "rapidly available fertilizers" such as ammonium nitrate or urea, ammonium phosphate, and potassium chloride.
- Controlled-release fertilizers can dynamically release nutrients and meet the crop's changing nutrient demand throughout its growth cycle, maximize nutrient use efficiency, and minimize environmental concerns.
- Slow-release fertilizers generally have a slower release rate of the nutrient than conventional water-soluble fertilizers and CRFs. However, the rate, pattern and duration of release are not well controlled because they are dependent on microbial activity that is driven by soil moisture and temperature conditions. Slow-release fertilizers can occasionally be released very quickly when excessive moisture and high temperatures occur in the same period of time.
- Use of CRFs or SRFs can reduce nutrient losses, increase nutrient-use efficiency, and protect the environment. Thus, the application of CRFs or SRFs is considered to be a Best Management Practice (BMP) tool for crop production.

13. Conclusion

As we know that, most of the nitrogenous fertilizers being widely used in agricultural, owing to be of their high content of nitrogen (E"46%) with high solubility, are subjected to lose in a huge quantity by being production of ammonia through hydrolysis for example in case of urea by soil urease. In this course of action nearly 60% to 70% loss of the nitrogen was reported. It has also been reported that, due to surface runoff, leaching, and vaporization, the utilization efficiency or plant uptake of urea, for example, is generally below 50% which on turn escalated fertilization expenditure per season and reduced crop productivity. Such drawbacks related to the use of nitrogenous fertilizers or other water soluble fertilizers can be corrected by amending conventional nitrogenous fertilizers with manufacturing suitable excipients of CRFs kinds so that the fertilizer use efficiency by plants as well as losses could be minimize to a greater extent. The developed excipients of CRFs were not only found capable in reducing repeated fertilization expenditure per season but also proved beneficial in maximizing crop yields. Moreover, the use of CRFs reduce the demand for short-season manual labor obligatory during critical periods, reduce stress and specific toxicity (as a result of synchronizing nutrient release with plants' demands), increase availability of nutrients, supply of nutrient in such a form preferred by plants, and augment synergistic effects between nutrients and plant roots. Therefore by keeping in view of all the benefits of CRFs, it is worth to say that researchers should pay more attention to design nano-CRFs by using natural excipients materials. The developed fertilizer grades could not only be much efficient, effective, reliable, and cost-effective but also be useful in minimizing food crisis and other challenges facing crop production. At the last it is more essential to say that scientists should anticipate mending agronomic returns through scientific novelties; the motive behind this must be geared towards researching, innovations, and commercialization of the CRF products.

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Maximizing fertilizer use efficiency for sustainable agriculture

K N Tiwari

Ex. Director, International Plant Nutrition Institute, India Programme 5/1074 Viram Khand, Gomti Nagar, Lucknow 226010
E-mail: kashinathtiwari730@gmail.com

ABSTRACT

With increased crop production and productivity over the years, the nutrient removal has increased by over four times during the last four decades putting four-fold pressure on soil. A yearly gap of about 10 MT of nutrient (NPKS) still exists between nutrient removal and supply through fertilizers. The gap varies widely among different agro-climatic regions of the country and this gap, if not bridged timely, will pose major threat to agriculture sustainability. The responses to nutrient application have been decreasing for the country as a whole. Some of the factors related with nutrient management contributing to low responses are : suboptimal and unbalanced fertilizer use in large irrigated and assured rainfall areas, excessive and imbalanced use of N and P in potato, sugarcane and many vegetable crops grown for commercial purposes, inappropriate methods and time of application, deficiency of sulphur and micronutrients and lesser use of organics. Site specific nutrient management based on the principles of IPNS has now assumed great importance firstly, because of the present negative nutrient balance and secondly, neither the chemical fertilizers alone nor the organic sources exclusively can achieve the production sustainability of soils as well as crops under highly intensive cropping systems. Discussed here are the issues and strategies of maximizing fertilizer use efficiency in India.

Keywords: Fertilizer use efficiency, Nutrient, SSNM, Sustainable agriculture

1. Introduction

India witnessed a significant increase in productivity and cropping intensity till the 1980s; thereafter, new challenges caught up to slow down the growth rate. An agrarian country like India where population growth rate outstrips agricultural productivity, the need to produce more and more food compels the people to meet new challenges so as to maintain food security intact. Currently, Indian agriculture is facing a major challenge of declining factor productivity, which needs immediate remedial measures to ensure food security and maintain access to food for all. With the intensification of agriculture after mid-sixties without supporting adequate replenishment of nutrients from external sources, the number of nutrients becoming deficient in Indian soils has increased with time. Apparently, the growth in foodgrain production is showing a trend of stagnation after 1980s and the main culprit for this is inadequate and unbalanced nutrient use causing continuous depletion of the soil's nutrient reserve and increasing instances of multi-nutrient deficiencies in soils. The inadequacy and imbalance are so well ingrained in Indian farming that it is difficult to recognize which made the most damage to agriculture production system. The main reason for increasing instances of the nutrient deficiencies all over the country is the total disregard of the replenishment of these nutrients as per crop needs and existing deficiencies of these in soils and crops.

It has been estimated that fertilization accounts for nearly 50% of all crop yield in India. In other parts of the world, where farm land has been abused for centuries or where new land is brought into production and quickly mined of its nutrients, fertilization might contribute as much as 75% of total food production. Proper crop fertilization is essential to prevent massive global starvation. It is important to consider all the roles that soil plays in the production of food and fiber for feeding the people. Soil is the medium in which plants grow and the source of most plant nutrients. Soil, water and air bathe plant roots and help keep them and above-ground plant parts healthy and growing. The quality of soil in which plants grow is extremely important in determining factor productivity, crop yield as well as the agriculture sustainability. The key role of balanced use of fertilizers in maintaining soil fertility and enhancing fertilizer use efficiency (FUE) is well established. The paper deals with the issues and strategies to enhance FUE for agriculture sustainability in India.

2. Content

2.1. Changing Soil Health Scenario: A Big Issue

Nutrient removal by crops far exceeds nutrient additions through fertilizers. For the past 40 years, a gap (removals less additions) of 8 to 10 M t $N+P_2O_5+K_2O$ /year has been documented. This situation is akin to mining the soils of their nutrient capital. At the all-India level, soil deficiencies of N, P, K, S, Zn, and B are now of widespread importance. Nitrogen deficiency is common in the vast Indian plains. The magnitude is also quite large in respect of P (>75%) and K (>50%) deficiency. In fact, potassium fertility of soils in India is not only neglected, but also under severe stress with the ongoing scenario where K removals vastly exceed K input. Recent studies have shown that production is also constrained by S deficiencies which are now estimated to occur in close to 250 districts and about 40% of soil samples have been found to be S deficient. Based on several years of data and analysis of 250,000 soil samples under All India Coordinated Project on Micro and Secondary Nutrients and Soil Pollutants, 49% of soils were found to be deficient in Zn, 12% in Fe, and less than 5% for Cu and Mn. Boron deficiencies now need to be taken seriously in several areas with 33% out of 36,800 soil samples analyzed having been found to be B deficient. Apparently, Indian agriculture is faced with the problem of multi-nutrient deficiency on a quite large scale. Although it may be useful to examine physical, chemical and biological aspects of soil quality individually, soil should be viewed as an integrated system. For example, physical and chemical properties are shaped by biological activity, and biological activity is enhanced or limited by chemical and physical condition. A healthy soil is 'biologically active' containing a wide diversity of microorganisms. Relevant biological properties include soil organic matter content, microbial biomass, respiratory activity, nitrogen mineralization, soil enzymes, soil fauna and population of suppressive organisms.

2.2. Declining Fertilizer Use Efficiency (FUE): A Major Threat to Sustainable Agriculture

FUE refers to the proportion of applied nutrient recovered by the crop. It is commonly expressed as a percentage of fertilizer used by the crop or alternatively in terms of crop yield per unit of fertilizer (e.g. kg grain per kg of applied nutrient). FUEs vary widely rarely exceeding 50 to 60% or even as low as 20% for nitrogen (N), 10 to 30% for phosphorus (P), and 20 to 60% for potassium (K), hardly 50% for sulphur (S) and <10% for zinc (Zn). The efficiencies can be greater over the long-term because of the residual properties of the immobile nutrients like P, Zn (and other micronutrients) and to some extent of K and S also. The FUE trend at national level has been showing a consistent decrease mainly due to unbalanced use of fertilizers, mostly limited to N and P and poor land and water management. For example, the FUE which indicated 16 kg of increase in foodgrain by per kg NPK applied during 1970's has dwindled down to 6-7 kg of foodgrain per kg NPK applied at present. Apparently, the responses to nutrient application have been decreasing. Some of the factors related with nutrient management contributing to low responses are : suboptimal and unbalanced fertilizer use in large irrigated and assured rainfall areas, excessive and imbalanced use in some commercial and horticultural crops, inappropriate methods and time of application, deficiency of sulphur and micronutrients and lesser use of organics. Evidently, the magnitude of increase in foodgrain production could not keep pace with the increase in fertilizer consumption showing a clear cut fall in FUE, thus, the money spent by the farmers on fertilizers and also the money spent by the Government towards fertiliser subsidy has not yielded the desired result. The disturbing trend of yield stagnation/decline can be reversed by increasing FUE. The following constraints are generally being faced by the farmers:

- Lack of access to improved farm technology
- Lack of awareness about importance of optimum and efficient use of fertilizers
- Lack of access to soil testing service, that too is confined to NPK only
- Lack of awareness about depletion of soils nutrient reserves and deterioration in soil health.
- Inadequate and timely supply of agricultural inputs
- Reluctance towards preparation of organic manures/composts and use of biofertilisers
- Frequent distress sale of farm produce, thus reducing the potential gains from the adoption of improved technology.

2.3. Legumes and Nutrient Use Efficiency

2.3.1. N-Fixation

The ability of legumes to fix atmospheric nitrogen is perhaps the most notable aspect that sets them apart from other plants. In addition, legumes can provide a wide range of important soil quality benefits. Inoculated with the proper strain of *Rhizobia bacteria, legumes can supply* up to 90% of their own nitrogen (N). Soil microorganisms decompose the relatively nitrogen-rich organic material and release the nitrogen to the soil when they die. Legume plant and seed tissue is relatively high in protein. Generally speaking, the higher the protein content of a plant the more nitrogen it will return to the soil.

2.3.2. Soil Quality Benefits of Legumes

Soil quality benefits of legumes include:

(i) increasing soil organic matter,

(ii) improving soil porosity,

(iii) recycling nutrients,

(iv) improving soil structure,

(v) decreasing soil pH,

(vi) diversifying the microscopic life in the soil,

(vii) breaking disease build-up and weed problems

(i) Soil Organic Matter

Legumes are high in protein, and therefore, nitrogenrich. Because most crop residues contain much more carbon than nitrogen, and bacteria in the soil need both, the nitrogen supplied by legumes facilitates the decomposition of crop residues in the soil and their conversion to soil building organic matter.

(ii) Soil Porosity

Several legumes have aggressive taproots reaching 6 to 8 feet deep and a half inch in diameter that open pathways deep into the soil. Nitrogen-rich legume residues encourage earthworms and the burrows they create. The root channels and earthworm burrows increase soil porosity, promoting air movement and water percolation deep into the soil.

(iii) Recycle Nutrients

Because perennial and biennial legumes root deeply in the soil, they have the ability to recycle crop nutrients that are deep in the soil profile. This results in a more efficient use of applied fertilizer and prevents nutrients (particularly nitrate nitrogen) from being lost due to leaching below the root zone of shallower-rooted crops in the rotation.

(iv) Improve Soil Structure

Physical properties of the soils following legumes are improved. The improvements are attributed to increases in more stable soil aggregates. The protein, glomalin, symbiotically along the roots of legumes and other plants, serves as a"glue" that binds soil together into stable aggregates. This aggregate stability increases pore space and tilth, reducing both soil erodibility and crusting.

(v) Lower Soil pH

Because inoculated, nodulated legumes acquire their N from the air as diatomic N rather than from the soil as nitrate, their net effect is to lower the pH of the soil. Legumes could lower the pH and promote increased plant-soil-microbial activity on soils with a pH above the range for optimum crop growth and development.

(vi) Biological Diversity

Legumes contribute to an increased diversity of soil flora and fauna lending a greater stability to the total life of the soil. Legumes also foster production of a greater total biomass in the soil by providing additional N. Soil microbes use the increased N to break down carbon-rich residues of crops like wheat or maize.

(vii) Break Pest Cycles

Legumes provide an excellent break in a crop rotation that reduces the build-up of grassy weed problems, insects, and diseases. A three year interval between the same type (grassy, broadleaf, cool season, warm season) crop is usually sufficient to greatly reduce weed, insect, and disease pressure.

(viii) Multitude of Benefits of Legumes to Soil and Crop

Legumes can provide a multitude of benefits to both the soil and other crops grown in combination with them or following them in a rotation. Locally adapted legumes can be used in almost any conservation situation to improve soil quality. The yield increases to 'rotation effects' are attributed to improved soil physical properties, depression of phyto toxic substances, addition of growth promoting substances, and decreased disease pressure.

2.4. Measures to Enhance FUE

Crop's responsiveness to fertilizer or in other words fertilizer use efficiency (FUE) is maximized and environmental impact of fertilizer is reduced (and often eliminated) when crops are managed for improved nutrient efficiency through Best Management Practices (BMPs) which balance production inputs at the appropriate levels and utilize site-specific soil and water conservation techniques to maximize soil retention and minimize losses of plant nutrients to ground water. The BMPs are specific for individual farms, fields, soils, and climates. Past research, experience and knowledge of local soil and climatic conditions dictate the BMPs for a particular area. The BMPs help farmers achieve maximum economic yield (MEY) levels where costs per unit of production are lowered to the point of highest net return for existing soil and climatic conditions.The strategies for maximizing fertilizer use efficiency are given below.

2.4.1. Balanced Fertilization

The concept of balanced fertilization which endorses application of all required nutrients in a proportion and amount required by the crop, considering the nutrient supplying power of the soil as well as nutrient use efficiency and yield targets, was seldom suggested thus never practiced by the farmers. Most of the onus of such practice should go to the policy makers and scientists, who stuck to the 4:2:1 ratio as a synonym to balanced fertilization across the board. The total lack of site specificity in the nutrient prescriptions is the main reason for declining factor productivity and reduced growth in agricultural production in the country. Nutrient use on the principles of site-specific nutrient management can be the most vital weapon to reverse this negative trend.

Nutrient balance discussions are often confined to N, P and K because of their large scale deficiency and also larger demands by the crops. Unbalanced and inadequate use of major nutrients in general, and of P and K in particular, and utter negligence for secondary and micronutrients have created a situation where simply by increased use of N or N+P, the productivity of crops cannot be increased. The yields obtained by joint application of NPK are significantly higher in most of the cases. However, balanced nutrient management goes well beyond NPK. As the yield goals increase, the nutrients demand of the crops increases both in number and the quantity. Apparently, Indian agriculture is now in the era of multiple nutrient deficiencies. At least five nutrients (N, P, K, S, Zn) are of great importance from application view point. It would not be surprising if progressive farmers in several areas must apply 4-6 nutrients to sustain high yields of premium quality crops.

2.4.2. Balanced fertilization improves soil health

As science progressed, it was discovered that long-term sustainability of crop production was dependent on building and maintaining soil fertility, an important soil quality measurement. Later, it was demonstrated that organic matter levels could be maintained and even increased through balanced fertilization. One of the greatest benefits of crop fertilization, aside from increasing crop yields and improving farmer profit, is its effect on soil organic matter. Harvested crop yields increase as a result of crop fertilization, as does unharvested plant biomass left on the soil surface and crop residues (roots) remaining in the soil. Most of the unharvested surface biomass and underground residues become soil organic matter. It has long been known that organic matter positively influences structure, tilth, bulk density, water infiltration rates, water holding capacity, and water and air movement within the soil, thus improving soil quality. Organic matter helps to bind soil particles together, reduces soil crusting, increases the stability of soil aggregates, acts as a reservoir for plant nutrients, and reduces soil runoff and erosion losses.

Data from 12 long-term experiments (LTE) conducted in India under the Indian Council of Agricultural Research (ICAR) Coordinated Project on Cropping Systems were analyzed to evaluate the effect of different sources of organic matter (farmyard manure (FYM) and green manure (GM)) in combination with inorganic fertilizer, on the productivity of rice-wheat systems. The average rice yield with 100% NPK was still significantly higher than with FYM. In wheat, average yields and yield trends were not significantly different among the fertilizer treatments. The fertilizer treatments showed no significant effect on final yield, although the initial yield was significantly higher with 100% NPK than with FYM. Other long-term rotation studies in India have also demonstrated that moderate amounts of fertilizers increase soil organic matter quantity and quality. The positive benefits of fertilization have been directly attributed to the amount of crop residues returned to the soil. In addition to higher grain yields, fertilizer increased straw and root production, the precursors of soil organic matter. However, the realities surrounding short supplies of FYM because of burning of cow dung for fuel and the high labor and transportation costs continue to restrict its extensive and widespread application in agriculture. It is most likely that the most immediate solution to sustaining crop yields in the absence of adequate FYM supply will come from the regular use of site specific application of inorganic fertilizers.

2.4.3. Balanced fertilization ensures sustainable high yield

People and plants are alike in several ways. In particular, both need balanced nutrition for normal growth and good health. Unlike people (who require complex - mineral, protein, etc. - foods) plants need only 17 nutrients, 3 obtained from air and water and the rest from soil, to grow normally - if those nutrients are supplied in a proper balance. When crops have balanced nutrition, added bonuses include higher nutritive quality and increased environmental protection.

2.5. Site Specific Nutrient Management (SSNM)

Another development of considerable interest in directing the course of balanced and efficient nutrient management refers to site-specific nutrient management (SSNM). Nutrient management is a major component of a soil and crop management system. SSNM is a systematic agronomic approach which considers field-scale variability in soil fertility and crop responses to applied nutrients. In recognition of the potential applicability of SSNM, the IPNI-India Program in collaboration with Project Directorate for Cropping Systems Research (PDCSR-ICAR) has established collaborative SSNM research with the rice–wheat system and at 6 locations with the rice–rice system **(Table 1)**. In the SSNM experiments, 4 to 8 nutrients were applied in a pre-planned manner to evaluate responses to each of these at one or more levels (except N). Both crops received N, P, and K. Only *kharif* rice also received S and micronutrients implying that the *rabi* crop, whether rice or wheat, benefited from the residual effect of these nutrients.

Rice-wheat data averaged over 2 years show that annual grain yields of 15 to 17 t/ha were achievable. Average annual grain productivity of the system was 13.3 t/ha of which 60% was from rice and 40% from wheat. None of the SSNM locations had annual grain productivity less than 10 t/ha. Averaged over locations, SSNM caused a 3.4 t/ha annual advantage or 34% more yield than common farmers'

Table 1 : Experimental locations and the nutrients applied in the rice-wheat and rice-rice systems according to SSNM

Location	State	Rice	Wheat
	(A)	**Rice-Wheat System**	
Sabour	Bihar	NPK S	NPK
Palampur	Himachal Pradesh	NPK S B Zn	NPK
R. S Pura	Jammu & Kashmir	NPK S Mn Zn Cu	NPK
Ranchi	Jharkhand	NPK S B Zn	NPK
Ludhiana	Punjab	NPK S B Mn Zn Cu	NPK
Faizabad	Uttar Pradesh	NPK S B Mn Zn	NPK
Kanpur	Uttar Pradesh	NPK S Zn	NPK
Modipuram	Uttar Pradesh	NPK S B Mn Zn	NPK
Varanasi	Uttar Pradesh	NPK S B Mn Zn Cu	NPK
Pantnagar	Uttaranchal	NPK S B	NPK
		(B) Rice-Rice System	
Maruteru	Andhra Pradesh	NPK B	NPK
Jorhat	Assam	NPK S B Mn Zn Cu	NPK
Navsari	Gujarat	NPK S Fe Mn Zn	NPK
Karjat	Maharashtra	NPK B Fe Zn	NPK
Coimbatore	Tamil Nadu	NPK Fe	NPK
Thanjavur	Tamil Nadu	NPK S Mn	NPK

Source: Tiwari, K.N. (2006). Site Specific Nutrient Management for Increasing Crop Productivity in India. PDCSR (ICAR)–PPIC, India Programme, pp 92.

practices (FP). SSNM increased the expenditure on fertilisers by Rs.4,170/ha (US$104) compared to FP but generated additional produce valued at Rs.20,530 (US$513) – returning an extra net income per unit extra expenditure, or benefit-to-cost (BCR) ratio of 4.9. A frequency distribution of economic returns for the rice-wheat system (84 location x nutrient x rate combinations) found BCRs under 2 in 13% of cases, 2 to 5 in 17% of cases, 5 to 10 in 24% of cases, and above 10 in 46% of cases. The majority of cases with very high BCRs reflect very high grain yields achieved through high rates of response per unit applied nutrients.

Similarly, two years of rice-rice data revealed grain yields of 15 to 18 t/ha. Average annual grain productivity was 13.3 t/ha – the contribution of *Kharif* and *Rabi* rice being almost equal. The annual grain productivity under SSNM was more than 10 t/ha at all locations except one. Averaged over locations, SSNM brought a 2.5 t/ha advantage, or a 23% increase over FP. SSNM also increased fertilizer expenditure by Rs.4,540/ha over the FP but generated additional produce valued at Rs.11,900/ha – a BCR of 2.6. The application of several nutrients was profitable at most sites.

The major benefit of improved nutrient management strategy to the farmers is increased profitability. The SSNM avoids indiscriminate use of fertilizers by preventing excessive/inadequate rates of fertilization, and by avoiding fertilization when the crop does not require nutrient inputs. It also ensures that N, P and K are applied at proper rate and in proper ratio commensurate with crop's nutrient needs. The nutrient use on the principles of SSNM can accommodate a wide range of socio-economic variations, including those situations of labor shortage. Additional labor may be required, but labor costs for nutrient management are relatively small compared to those for land preparation, transplanting or harvesting. Efficient N management may also result in off-farm environmental benefits through a reduction of fertilizer N use without a reduction in yield especially in situations where N inputs are large compared to other nutrients, which may increase profitability.

Site-specific crop and soil management is really a "repackaging" of management concepts that have been developed and promoted for many years. It is basically a systematic approach to apply sound agronomic management to small areas of a field that can be identified as needing special treatment. The components of site-specific management may not be new, but now we have the capability with new technology to use them more effectively. Site-specific management includes practices that have been previously associated with MEY management, best management practices (BMPs), as well as general agronomic principles. The systematic implementation of these practices into site-specific systems is probably our best opportunity to develop a truly sustainable agriculture system.

The introduction of SSNM strategies should start with the priority areas facing one or more of such problems (1) Areas having inadequate or unbalanced use of fertilizer nutrients with low yield levels; (2) Areas with crops showing nutrient deficiency symptoms at large scale; (3) Areas with occurrence of pest problems linked to nutrient

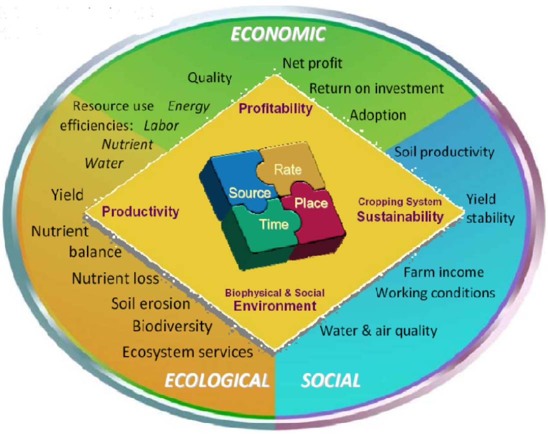

Fig.1. FBMPs for maximizing fertilizer use efficiency

imbalance or overuse of fertilizer N; (4) Areas with inefficient fertilizer N use at higher rates (no proper splitting and timings) with insufficient use of P and K; (5) Areas with the evidence of large mining of soil's P and K reserves; and (6) Areas having evidence of multi-nutrient deficiencies including secondary and micronutrients in soils and crops.

2.6. Fertilizer Best Management Practices (FBMPs)

To enhance FUE, all attempts should be made to practice "Fertilizer Best Management Practices" (FBMPs) on the principles of IPNS. The ideal model for fertilizer best management practices is exhibited in **Fig 1.**

When crops are managed for improved nutrient use efficiency through FBMPs on the principle of **"Four Rs"** ie. 1. Right Fertilizers, 2. Right Quantity, 3. Right Time and 4. Right Methods. FBMPs help improving FUE through increased nutrient uptake by crop plants and reduced nutrient losses from the soil. Thus, responsiveness of crops to applied fertilizers is maximized and the environmental impact of fertilizer is reduced. FBMPs help farmers achieve maximum economic yields (MEY) thus costs per unit of production are lowered to the point of highest net return. FBMPs, in fact, should ensure perfect adoption of all cultural practices from seed to grain or say from seeding to harvest. FBMPs are specific for individual farms, fields, soils and climates. The knowledge of local soil and climatic conditions, crops and cropping systems and resources available with the farmers often dictate FBMPs. Application of N in 2-3 splits and drilling/placement of entire quantities of P and K and a part of N as basal ie. at the time of sowing/transplanting depending on soil, crop, and availability of irrigation water, is ideal for improving FUE. Nitrogen use efficiency can further be increased through modified fertilizers like *neem* coated urea, urea super granules etc. particularly in paddy where the FUE is generally very poor due to many path ways to N losses (volatilization, leaching of nitrates, denitrification etc.). Adequate supply of other nutrients depending upon their deficiencies in soils enhances nitrogen use efficiency. Foliar application of urea under moisture stress condition can be of great help to increase N use efficiency. Increasing deficiency of S in soils is constraining crop productivity. Deficiencies of micronutrients are on increase. If the deficiencies of S and Zn have already been confirmed through soil tests or through visual symptoms in the previous crops, then basal application of 30-40 kg S/ha and 20-25 kg zinc sulphate should invariably be done. In case of boron deficiency, borax can be applied @ 5-10 kg/ha. In

Box 1. The Key Features of Optimum Plant Nutrition

- Maximizing the adoption of optimum nutrient application rates (no deficiencies, no toxicities)
- Ensuring balanced nutrient application (to supply all deficient nutrients, not only NPK) in addition to their optimum rate of application. This can often be achieved as lower cost.
- Ensuring the most efficient and productive use of applied nutrients, for which balance itself is a pre-requisite
- Using soil analysis, plant analysis and production goals as guidelines so that the external nutrient applications are used to supplement supplies expected from soil reserves without undue depletion of the soil from medium-long term sustainability point of view.
- Technologies available for optimizing plant nutrition must not only be adopted at the farm level but researchers must fine tune these to match local conditions and resources (as for example through SSNM).

Box 2. Important Tools for Enhancing FUE

Soil related: Soil testing for available nutrient status, soil conservation, reclamation of problem soils.

Water related: Water resource development, rain water harvesting, its conservation and recycling, water management to enhance nutrient and WUE.

Crop related: Use of best available varieties (hybrids, other HYVs, stress-tolerant genotypes), intercropping, adoption of best management practices, diversification and intensification of agriculture with most suitable crop rotations as part of farming system development.

Nutrient supply related: On-farm production of organic manures, green manures, development of integrated nutrient supply system (IPNS), improvement in supply chain of required fertilizers containing major and micronutrient as also bio-fertilisers of genuine quality at correct price, at right time and right place in adequate quantity.

Transfer of technology: Promotion of best management practices through field programmes to enhance fertilizer use efficiency, on-farm demonstrations/trials, creating awareness about practices associated with deteriorating soil health through various programmes and media including help lines, promotion of fertiliser best management practices (FBMP/BMP) and correct/responsible nutrient use based on validated research findings in improve nutrient/fertilizer use efficiency (NUE/FUE).

standing crops, micronutrient deficiencies can be corrected successfully by foliar fertilization. Foliar application of iron and manganese has been found more efficient than soil application. Application of specialty fertilizers like water soluble fertilizers through drip/foliar can further improve FUE. Customized and fortified fertilizers can be great help towards enhancing FUE. The key features of optimum plant nutrition are elucidated in **Box 1** and important tools for enhancing FUE in **Box 2**.

2.7. Integrated Nutrient Management : A Basic Need

The unexpected price hike of both the fertilizers and the raw materials in the international markets has exorbitantly increased the subsidy bill which is now becoming unaffordable. This fact emphasizes the need for chalking out sound strategies and preparing a performing action plan to meet the goal of Second Green Revolution without increasing the fertilizer consumption. To fight with this problem, the best approach should be the adoption of integrated nutrient supply system (IPNS) ie. rational use of external input (fertilizers) supplemented by on-farm produced inputs to minimize the increasing demand of fertilisers. The major components of INM are fertilizers, organic manures, crop residues and biofertilisers. These must be appropriately integrated in a pre planned manner to meet the total nutrient needs of a cropping system. In most cases, the packages of improved practices prepared by various institutions include the application of organic manures, appropriate biofertilisers, green manures etc along with fertilisers. But they rarely provide truly integrated packages. Indian agriculture is operating at a negative nutrient balance of 10 million tones. This is the gap between nutrient removals by the crops and the nutrient additions through fertilizers which needs to be bridged through increased applications of organics and biofertilizers. Both Organic and inorganic sources of nutrients contribute to crop productivity though the contribution of each sources varies considerably from one cropping system and from one soil climatic region to another under irrigated conditions.Judicious use of fertilisers, organics, agro-industrial wastes/byproducts, biofertilizers (Rhizobium, Azotobacter, Azospirillum, Phosphate solubilizing microorganisms cultures, Blue green algae, Azolla etc.), and soil amendments (gypsum in sodic soils and lime in acid upland soils) can substantially augment soils nutrient supplying capacity and thus meet enhanced nutrient needs of sustainable high yield agriculture. This is very essential to maintain soil health for sustainability of Indian agriculture. Simultaneously, the IPNS would help not only cutting down the import of fertilizers significantly but also minimize the costs of crop production.

2.7.1. Organics: Among the organic manures, the most common is the compost / FYM. However, scientific technology either for the composting or in situ incorporation of residues has not been popularized amongst the farmers. The farmers do not make a serious efforts in preparation and conservation of organic manures and recycling of crop and animal residues because of competitive uses of organic materials such as dung cakes for domestic cooking fuel and sugarcane bagasse as fuel in sugar factories and villages. Organic materials are a scattered resource and have to be collected. The production of organic manures involves labour for collection of materials, their processing with appropriate technology to obtain good quality compost with minimum nutrient losses, transportation to field and incorporation into soil. The extension activities on the whole have been weak in this aspect. Standard method such as proper moisture (50-60%) and turning of organic mass during composting of FYM preparation (2-3 turnings) are not followed resulting in nutrient losses and poor quality organic manures. The compost prepared at the mechanical compost plants from city garbage are poor in plant nutrients. There are several factors which affect the proper adoption of the recommendations of different types of organic manures by the farmers.

2.7.2. Technologies for improvement of compost quality: In situations where the crop residues because of high C:N, C:P ratios cannot be directly applied to soil as a source of nutrient, can be composted and in turn nutrient contained are converted into plant usable forms. The preparation and use of compost is handicapped due to low nutrient content and large volume. Recently, the technology for preparation of enriched compost in India has been standardized. For producing 100 tonne phosphocompost, the materials required will be 80 tonne organic wastes, 10 tonne cattle dung, 10 tonne soil, 5 tonne FYM/compost and 26 tonne rock phosphate which is sprinkled with each 15 cm layer of these composting materials. The mixture is allowed to decompose for a period of three months with periodic turnings. The end product contains 6-8% P_2O_5. It has been observed that 50% of the insoluble P or rock phosphate is converted into citrate soluble form. However, this compost contains less N than the conventional compost. Fertilizers like urea, DAP can also be used to fortify conventional composts either during composting or by mixing with ready compost during its field application. On equivalent P basis agronomic efficiency of rock phosphate enriched compost was at par to same dose of P applied through water soluble P carriers.

2.7.3. Green manures: Green manuring with legumes has long been known to be beneficial for sustainable crop productivity. In several studies conducted in India green manure was able to replace 60 kg N/ha. A fertilized green manure crop would substitute more mineral fertilizer N than an unfertilized green manure crop. A wide variability in N substitution through green manuring to the order of 45-120 kg has been reported. Most commonly observed N additions through an array of green manures are in the range of 40-60 kg N/ha. Inspite of the many virtues of green manuring, its use at the practical level is rather unsatisfactory, particularly in intensive cropping systems, for agro-economic and operational reasons. An estimated 2.1 million ha was green manured in 2010-11 which is 1.5% of he net cultivated area. However, where practiced, green manures have a significant proven positive impact on soil health, not only chemical but also physical and biological.

2.7.4. Constraints to use green manuring*:* Green manuring has a special place in view of the limited availability of other organic manures. However, with intensification of agriculture and the advent of mineral fertilizers, farmers enthusiasm for this practice declined. With increased irrigation facilities, intensive agriculture is being adopted and as such farmers do not wish to set apart 6-8 weeks exclusively for growing green manure crop with no direct crop with no direct cash benefit. Green manure crop in rice-wheat cropping is taken as a catch crop after harvest of wheat during May-June and the intense heat constrains field operations. To overcome this problem, on the basis of experimental results it is being advocated to grow a pulse crop, pick up the pods just prior to full maturity and turn the biomass into the soil when still green thus the twin benefit of crop production and soil health improvement is obtained. Incorporation of straw of summer grown greengram in soil just before rice transplanting help improving rice yield equal to the application of 60 Kg N/ha.

2.7.5.Crop rotation as a key to sustainability*:* To overcome the ecological diseases of monoculture, the first solution that man found was the changing of crops from one to another or from one season to another. Even before the modern agriculture was established the farmer had discovered the restorative power of legumes. The legumes restore soil fertility and enhance crop productivity through increased utrient use efficiency in many ways. Some of them are: (1) Fix atmospheric N_2 and leave part of it in soil after their harvest (2) Deeper tap root system absorbs moisture and nutrients from deeper soil layers and some of the nutrients absorbed are left in the root mass in the surface soil (3) Improve soil permeability (4) Lesser disease and pest problem and (5) Better weed control

Legume in crop rotation can contribute upto 40-60 kg N/ha to the succeeding crops. Even when grown as a inter-crop, legumes may transfer significant amount of nitrogen to co-growing cereals. Quick growing leguminous shrubs grown as a part of the cropping system and incorporated into the soil at an appropriate stage as green manure, leguminous trees grown in hedge rows and their lopping used as mulch materials or incorporated into the soil of the cropped alleys between them and leguminous forage, pulses and oilseeds properly inoculated with Rhizobium grown in cropping systems providesignificant quantity of N to the succeeding crops and also increase availability of other nutrients along with nitrogen and improve soils physical and biological properties. Preceding leguminous pulse and oilseed crops also leave behind substantial amount of residual nitrogen (about 30 kg/ha). Inclusion of legumes and use of biofertilizers, should, therefore, find place in crop rotations and mixed/inter-cropping systems to improve FUE and in turn enhance soil health and crop productivity. Legumes in cropping systems provide the first link towards integrated plant nutrient system (IPNS).

2.7.6. Crop Residue*:* In India, the burning of non-conventional fuel and resultant emission of greenhouse gases is severe in northern states. Incorporation of crop residue improves soil productivity due to over all improvement in physical, chemical and biological properties of soils. Regular return of residues to soil contributes to the build up of soil nutrient pool over a period of time. Incorporation of crop residue is known to enrich soils with organic C, N and other nutrients.

2.7.7. Biogas Slurry and Press Mud: Biogas slurry is semi-solid residue to biogas plants. Its typical composition is 1.4-1.8% N, 1.1-1.7% P_2O_5 and 0.8-1.3% K_2O and is a useful manure as such or as an ingredient for composting. Press mud which is a “waste product” discharged by sugar factories about three tones of press mud or filter cake is generated for every 100 ton of cane crushed. Press mud can be used in many ways (i) mud produced from the carbonation process can be used as a liming material, (ii) sulphitation press mud as a source of plant nutrients, particularly S as it contains 2.3% S on dry basis and (iii) as a n ingredient for making compost.

2.7.8. Biofertilizers: Biofertilizers by rendering unavailable sources of elemental nitrogen, bound phosphates and decomposed plant residues into available forms help enhancing soil fertility and crops yields. In India, during recent years due emphasis is being laid on biofertilizers.

2.7.9. Rhizobium: Extensive studies in different parts of the country under the All India Coordinated Pulses, Oilseeds, Legumes and Soybean Improvement Research Programmes it has been very well established that the yields of pulses and oilseed crops can be stepped up substantially by the use of rhizobial cultures. Some of the results from rhizobium inoculation trials show percent increase to the order of 9-54 in chickpea, 23-85 in moong bean 13-20 in urdbean 14-30 in pigeonpea, 15 in lentil and 23 in cowpea over un-inoculated controls. Among various soil factors, the organic matter and P and K contents of the soil influences the growth and survival of the rhizobia in the rhizosphere of legumes. It is, however, felt that in the era of multi-nutrient deficiency, application of S, Zn and B are also needed. As legume inoculation sometimes proves unsuccessful in acid and alkaline soils, seed pelleting with lime in acid soil conditions and with gypsum in alkaline soils protect rhizobia from the effects of acidity/alkalinity. Other pelleting agents like rock phosphate, tale, bentonite clay, charcoal etc. have also been used.

2.7.10. Azospirillum / Azotobactor:Multi locational trials with pearl millet, sorghum, finger millet, barley and vegetables have shown significantly increased yields due to inoculation with Azospirillum and Azotobacter, the effects of inoculation being more conspicuous under low levels of added nitrogen. Apart from nitrogen-fixing ability, Azospirillum is known to produce auxins, like cytokinins and gibberellins.

2.7.11. Blue green algae: Extensive field trials conducted in many parts of India on the use of the blue-green algae in rice fields indicate that algae could contribute about 30 kg N/ha through the inoculation. Algae are known to provide the crop plant with many other useful organic substances like growth factors, vitamins etc. Normally continuous inoculation for 3-4 consecutive cropping seasons results in an appreciable population build up without any further inoculation, unless some unfavourable ecological conditions supervene.

2.7.12. Azolla: The increase in yield of rice due to Azolla inoculation has been reported to be varying from 18-47 percent depending on the cultivar of rice used. Further, field experiments have shown that consistent increase in yield of rice could be obtained by the use of Azolla as a green manure in conjunction with fertilizer N. It has been estimated that a saving of atleast 30 kg N/ha in rice could be obtained by the use of Azolla biofertilizer besides residual effect for the succeeding crop.

2.7.13. P-solubilizers: Bacteria such as *Pseudomonas* and *Bacillus* excrete acids into the growth medium and hence solubilize bound phosphates. These organisms are quite useful in the solubilization of rock phosphates. Field experiments conducted with P-solubilizers like *Aspergillus awamor*i, *P. striata* and *B. polymyxa* significantly increased the yield of various crops like wheat, rice, cowpea, etc. in the presence of rock phosphate and a saving of 30 kg P_2O_5/ha with the use of phosphate solublizing microorganisms has been reported. Reports dealing with the interaction of VAM fungi with N_2 fixers present in soil are also increasing.

2.7.14. Constraints to use biofertilizers: In spite of the aforesaid benefits, effective exploitation of biofertilizers in India is constrained mainly because of quality of the inoculants, lack of knowledge about inoculation technology for the extension personnel and the farmers, ineffective inoculant delivery system and formulation of the policy dictating the desire to exploit biological N fixation successfully. The National Project on Biofertilizers sponsored by the Ministry of Agriculture, Government of India and other agencies like NAFED and fertilizer industries GSFC, IFFCO, KRIBHCO etc. are producing biofertilizers. These are important developments to enhance FUE and economize fertilizer consumption.

2.8. Conservation Agriculture

India witnessed over exploitation of natural resources threatening agriculture sustainability due to soil and water stress, technology fatigue and stagnation in crop productivity during 90's. Introduction of Conservation Agriculture (Resource Conserving Technologies) is an important breakthrough for sustaining productivity, natural resource base and economic growth of the farmers. Adoption of Laser Land Leveling, retention of crop residues on soil surface in combination with no-tillage and crop diversification /intensification resulted in improvement in soil quality, overall resource enhancement, and savings in non-renewable energy use and carbon as well as methane emission and finally increase in farm income.

Attention to soil physical health is as essential as that to chemical and biological health for continuously increasing and sustaining high crop productivity level. This demands site specific technologies viz., optimum tillage practices and mulching, use of suitable cropping system, amendment of acid soils and salt affected soil and amelioration of soil physical constraints, efficient use of organic manures and fertilizers, which can improve the soil physical health. Rice-wheat is the dominant system of this region wherein conventional method of land preparation/sowing, not only disturbs the soil environment but also leads to atmospheric pollution. One of the most important principles of conservation agriculture (CA) is minimal soil disturbance. In no-till or zero till system, the seed is placed into the soil by a seed drill without prior land preparation. This technology has been tested and is presently being practiced over 2.0 million hectares of India and proves more relevant in the high yielding and more mechanized areas of north western India, where most land preparation is now done with four-wheel tractors. However, in order to extend the technology in Eastern parts of the IGP, drills for small tractors, 2-wheel hand tractors and bullocks have been modified and the drills are made available to the farmers. The benefits of zero-till system could be summarized as (1) water saving by 20-30% (2) energy saving by 80% because of less tillage and labour for crop establishment (3) increase in yield by 10-30% due to timely planting and increase in fertilizer use efficiency and (4) decreased pollution due to less consumption of diesel. Zero-till seedling performs better on a well leveled field compared to unleveled or fairly leveled field due to better seed placement, germination and uniform distribution of irrigation water and plant nutrients.

2.9. Managing Fertilizer Use in Cropping Systems

Farmers always grow the crop in different cropping sequences but fertilizer recommendations are done for individual crops and not for the cropping systems. Fertilizers applied in the preceding crop benefits the succeeding crops because of the residual effect of fertilizers and also due to favorable effect of leguminous pulses and oilseed crops. Precise quantification and phasing of nutrients in the light of preceding crops and fertilizers applied can improve the system productivity through increased FUE. Few examples are given below: Proper phasing of fertilizer application help improving FUE in the cropping systems as mentioned below:

(a) Adequate P fertilization in *Rabi* crops in rice-wheat, maize-wheat, pearl millet-wheat and sorghum-wheat systems is desirable. For example, in rice – wheat cropping system, 60 kg of P_2O_5 /ha is recommended to each rice and wheat. Experimental evidence show that need based allocation of total P quantity of 120 kg/ha for the system gives higher yield of the system due to enhanced FUE. Application of 30 to 45 kg P_2O_5/ha to rice and 75 to 90 kg/ha to wheat improves responses to applied P than its application @ 60 kg/ha to each crop. As *kharif* crops are grown in wet conditions, P availability is relatively higher due to increased moisture regime.

(b) In rice-wheat cropping system, rice crop becomes more vulnerable to Zn deficiency. In case of severe deficiency, application of Zn becomes the deciding factor for the success/ failure of the crop. Therefore, Zn should preferentially be applied to rice crop and the succeeding wheat or other *Rabi* crops will be benefitted with the residual zinc and as such no fresh Zn application is needed.

(c) Potassium should invariably be applied in all the crops along with N and P for sustainability. Split application of K in light textured soils help improving FUE. Crop residue recycling and organic manuring should be promoted to cut down the K demand.

(d) Oilseeds and pulse crops respond relatively more to sulphur fertilizers. Adequate S supply should be ensured in such systems.

(e) Applications of compost/FYM prove more effective in wet season (*kharif*) crops with residual benefits on succeeding crop. Cumulative effect improves soil health by enhancing soils organic matter capital and by improving soils physical and biological properties. The residual and cumulative effects of organic manures should be taken into account while preparing fertilizer schedules for cropping systems. Nutrient enriched compost like Phospho-Sulpho-Nitro-Compost (PSNC) can supply 30-40 kg P_2O_5/ha along with other nutrients.

(f) In rice-wheat cropping sequence, green manuring in rice by growing green manure crop (*dhaincha/*sunhemp) as a catch crop after harvest of wheat and before transplanting of paddy helps supplementing 60 – 80 kg N/ha through biological N fixation and also enhances availability of other nutrients through recycling of nutrients in the soil. As a thumb rule, with one ton production of green biomass, about 4 kg N is added. A good crop of green manure can supplement 60-80 kg N/ha. Deep rooted legumes utilize plant nutrients from the various depths of the soil in such a way that they maintain favorable balance among nutrients not only in the surface soil but in the sub-soil also and thus play a vital role in curing the increasing deficiencies of various nutrient elements in soils.

2.10. Technology Transfer and Development Priorities

Research and education can be seen as the two sides of the technology coin. However, in fertilizer use, the full picture is provided not by a 2-dimentional coin but by a 3-dimentional cube, the third side being commerce or supply-related. When technology is generated or is put together, its correct dissemination is extremely important. In arid and semi-arid regions, water conservation and management are crucial to efficient utilization of nutrients. Specific research objectives should aim: (i) developing alternative sources of nutrients, (ii) developing methods for efficient techniques of nutrient utilization, (iii) improving retention and recycling of nutrients, (iv) evaluating effects of organic matter content on soil fertility and physical properties, (v) improving soil structure to effectively control erosion and reduce soil degradation, and (vi) restoring productivity of degraded soils. Innovative cropping/farming systems, which must be highly productive and fit within the socio-economic, political and cultural frame work of the farming community, should be developed. Resource inventories will provide the much-needed information on soil, climate or eco-region-specific technologies for addressing specific production related constraints. These technologies, with farmer participation and support, are ready for transfer following on-farm validation and adaptation. The resource inventory also identifies knowledge gaps for research needs on farming systems, and biophysical or socioeconomic and cultural environments. Development priorities, in relation to institutional support and marketing or logistic support, also are identified on the basis of resource inventory. The problem of adequate supply of the deficient nutrients at right time and right place need to be resolved. *It must also be ensured that what is needed, is promoted and supplied through genuine quality products.* Under conditions of food shortage, the major goal of fertiliser use is a high crop yield giving lower priorities to food quality and possible negative influences on the environment. However, when production efforts have resulted in meeting the food demand or even in surplus, the quality aspect and the potential pollution effects on soil, water and air receive the same importance than the crop yield itself or even more. The department of agriculture and industry should address all these issues in a systematic manner. Use of information technology (IT) in fertiliser promotion and agricultural development should be fully tapped. At the same time, the glamour of IT should not be allowed to dominate over the need for sound technical content, user friendly access, and speedy updating of websites and portals. This will be possible when more and more rural areas have access to computers, internet and use-friendly software in local language.

Fertilizer retailers will have to be involved more intensively in promotion, input supply, after sale service and even customized fertilizer application. Dealer training after the initial phase should essentially be through informal briefings, trouble shooting sessions, question - answer drills supported by visits to service centers and demonstration plots. With increasing availability of IT related services, dealers can be networked into not only using these but also providing the much needed feedback from the field. Successful dealers and farmers should be invited as speakers in fertilizer seminars, training efforts and workshops. They will also need more efficient display materials and modern tools of communication. One would like to see dealers as regular visitors to technology dissemination centers to pick up and deliver the latest findings to the farming community. Farmers themselves can benefit from organizing themselves into groups, clubs or societies and hire even trained agricultural personnel to serve as farm advisors to the members. Such efforts can receive technical support from the directorates of extension from SAUs, soil testing laboratories and the KVKs.

3. Conclusion

To enhance FUE, “Site-Specific-Nutrient-Management” coupled with fertilizer best management practices should be adopted in letter and spirit purely on the principles of IPNS. As current soil testing service in India is confined to N, P and K testing in contrast to the fact that the problems of multi-nutrient deficiencies are very common all over the country, the national soil testing system needs to be readily energized and made more farmer-friendly, under the SSNM approach. To achieve the goal of enhancing FUE, timely supply of needed fertilizers, soil amendments, biofertilizers, seeds for green manuring and best seeds of high yielding varieties and hybrids of various crops in adequate quantities should be ensured. To harness full benefits from agri-inputs inputs, the needed knowledge must be provided to the farmers through specific training programs. In addition to N, P and K fertilizers, supply of specialty fertilizers and sulphur (S), zinc (Zn) and boron (B) containing fertilizers will have to be ensured for maximizing FUE. Supply of plant protection chemicals and availability of sprayers/dusters etc. both for sale and for custom services should be ensured at Farmers’ Service Centers. Micro-irrigation systems should be promoted to enhance fertilizer and water use efficiency. Modern agri. Implements, for example, laser leveler, rotavator, seed cum ferti – drill, paddy transplanter, potato/sugarcane planter etc. which can be of great help to timely operations, energy and labor saving and for enhancing FUE should be available on custom service basis. Conservation agriculture needs to be promoted in letter and spirit. Needed literature in local languages will be of great help. The fertilizer industry and the department of agriculture should refine and redesign the promotion programs on the principles of IPNS that should be soil, crop, cropping system and climate specific with due consideration of the resources available with the farmers in a particular area. There is no alternative to site- specific BMPs.

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Best fertilizer management practices in field crops of arid zone

Nav Raten Panwar

ICAR-Central Arid Zone Research Institute, Jodhpur, Rajasthan
E-mail: npanwar_soil@yahoo.com

ABSTRACT

In modern agriculture, fertilizers are key to supply nutrients to the plants and thereby enhance crop yield and quality of produce. On the other hand, nutrient removal by the crops needs to be replaced by fertilizers. To handle the nutrient replacement, fertilizer best management practices are the positive and economical approaches. As best fertilizer management practices (BMPs) focuses on site-specific recommendations, intensive management, improved efficiency and effectiveness, and environmentally sound use of crop production inputs. Moreover, BMPs are site-specific and specific to agro-ecology, farm practices etc. depending on current and historic soil, climate, crop, and management expertise. The soils of arid region have been mapped in Entisols, Aridisols and Alfisols soil orders. The Entisols cover maximum 17134.26 thousand hectares (54.21%), followed by Aridisols and Alfisols. Characteristically these soils are very low in organic matter/ humus and most of the nutrients reserve is present in un-weathered mineral forms. Moreover, these soils have also having low clay and silt, and therefore nutrient adsorption and retention by these soils are very low. Concerted efforts were made to evaluated nutrient use efficiency using metrics that reflect crop uptake of fertilizer added in the current growing season. The problem of low nutrient use efficiency is conventionally viewed as a consequence of temporal asynchrony and spatial separation between applied nutrients and the crop. Under such situations, incorporation of crop residues and natural vegetation in soil improve microbial activity during decomposition. Legume rotations are an important practice for restoring soil fertility on larger land holdings. The amount of N returned from legume rotations depends on whether the legume is harvested for seed, used for forage, or incorporated as a green manure.

Keywords: Arid zone, Fertilizer, Fertilizer Best Management, Field Crops

1. Introduction

Arid areas are extensive in the tropical and subtropical zones of the world and account for a significant proportion of world food production. Arid region in India is spread over in 38.7 million hectare area. Out of the total, 31.7 m ha lies in hot and remaining 7 m ha lies in cold region (Fig. 1). The hot arid region occupies major part of northwestern India (28.7 m ha) and remaining 3.13 m ha is in southern India. The northwestern arid region occurs between 22°30' and 32°05'N latitude and 68°05' to 75°45' E, covering western part of Rajasthan, northwestern Gujarat and south-western parts of Haryana and Punjab. In southern India it occupies parts of Andhra Pradesh, Karnataka and Maharashtra. About 62% area of arid region falls in western Rajasthan followed by 20% in Gujarat and 7% in Haryana and Punjab. Andhra Pradesh, Karnataka and Maharashtra together constitute about 11% area of arid region (Fig. 2).

Arid zone is characterized by a low and erratic rainfall (100-450 mm year^{-1}), extreme temperatures (-5.7°C to 50°C), high wind speed (27.2 kn hr^{-1}), high evapo-transpiration (1600 – 2000 mm year^{-1}), frequent drought (once in 2.5 years) (Ram and Joshi, 2010). Arid soils belong to different soil types, depending on parent material and climate, but they share many characteristics regarding their fertility. Arid soils

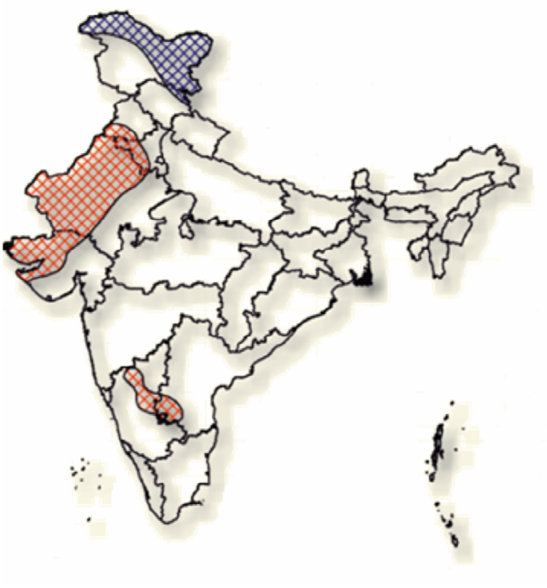

Fig.1. Arid zone in India

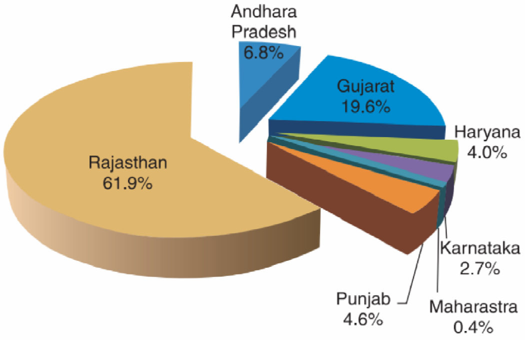

Fig.2. Distribution of hot arid zone in India

generally support sparse vegetation, because of a shortage of water. They are characterized by a neutral to slightly alkaline pH, have a good structure and are well supplied with K, Ca, Mg, S, B and Mo as a result of not being subjected to leaching. Clearly, their production potential is often considerable, provided sufficient amounts of water are available.

2. Soils of Arid Region

The soils of arid region have been mapped in Entisols, Aridisols and Alfisols soil orders. The Entisols cover maximum 17134.26 thousand hectares (54.21%), followed by Aridisols and Alfisols. The area of latter two is 14254.32 and 213.10 thousand hectares, comprising 45.1 and 0.67% of hot arid India (Shyampura *et al.* 2002).

3. Nutrient Status of Arid Region Soils

Characteristically these soils are very low in organic matter/ humus and most of the nutrients reserve is present in un-weathered mineral forms. These soils have low clay and silt, and therefore nutrient adsorption and retention by these soils are very low. Soils are generally alkaline in nature and high in soluble salts and calcium contents.

4. Organic matter and Macro-nutrients: Arid zone soils are low in organic matter because of low vegetation cover, high temperature and coarse texture. Organic carbon content in soils below 300 mm rainfall zone ranges between 0.05-0.2% in coarse textured soils 0.2-0.3% in medium textured and 0.3-0.4% in fine textured soils. Nitrogen in soils is present as organic (95-98%) and inorganic but in arid region soils, the inorganic form constitutes about 5 to 18% of the total N.

Phosphorus present in soils as organic and inorganic forms but organic form constitutes hardly 10-20% of the total phosphorus. Total phosphorus content in soils ranges between 300-1500 µg g^{-1}. Soils are often medium to low in available P, response of P-fertilization in arid soils is generally observed only in good rainfall years. The arid soils are well provided with available potassium (70-890 kg ha^{-1}). The total K content in arid region soils ranged between 980-1890 mg 100 g^{-1} with an average value of 1489 mg 100 g^{-1} soil. Major proportion of total potassium in arid soil is present as mineral form followed by interlayer, non-exchangeable and water-soluble form. These forms beside related to each other are correlated with sand and silt fraction and K resistance to depletion (Praveen-Kumar *et al.,* 2009).

5. Nutrient Management in Arid Soils

Nutrient use efficiency is evaluated using metrics that reflect crop uptake of fertilizer added in the current growing season. The problem of low nutrient use efficiency is conventionally viewed as a consequence of temporal asynchrony and spatial separation between applied nutrients and the crop. As a result, efforts to improve nutrient utilization efficiencies have emphasized on improved delivery of nutrients to the root zone during the period of crop uptake through modifications such as banding, fertigation, split fertilizer applications, etc. To increase crop access to N fertilizer, a variety of additives have been developed that inhibit urease activity, nitrification and denitrification. These approaches have been extremely successful in terms of increasing nutrient use efficiency and maximizing yields; however, their utilization on mass scale has met with limited success.

Cereals crops respond well to N fertilizer; more than a thousand experiments in farmers' fields in India, i.e. show yield increases of between 5 and 20 kg grain per kg N applied. Response to N depends on total water available for crop growth (soil storage + precipitation) and a simple model is given relating N requirement with water supply. Ways of improving N fertilizer efficiency include splitting and application for cereals between seedbed (preferably drilled) and one or two top dressings, the use of sulphur coated area or urea supergranules in lowland rice production and the introduction of improved, N responsive crop varieties. Foliar application of part of the N fertilizer may be advantageous, i.e. for cotton or on saline sodic soils.

The use of P fertilizer is of increasing importance, particularly on soils of low available P status, but also because soil P status tends to fall with time, due to immobilization of this nutrient in the soil and to its removal in the harvested crop, the magnitude of which rises with crop yield. On many soils efficiency of P fertilizer use is much improved by band application. Response to K fertilizer is often lower than to N or P but its use becomes more necessary as soil K status and reserves are depleting by more intensive cropping. Deficiencies of secondary and trace elements, particularly sulphur and zinc, have been identified in many areas and their incidence varies with crop and soil properties. Their location and correction is essential to achieve potential crop yields.

Integrated nutrient management using bulky organic manures and green manuring improves soil fertility by increasing soil organic matter content and supplying plant nutrients; the N supplied by leguminous green manures is essentially important. The resulting improved soil physical and biological conditions usually increase fertilizer use efficiency. Legumes grown in sequence with other crops or as intercrops also improve crop yields. Many grain legumes benefit from biological N fixation by associated rhizobial bacteria and considerable advantage can be expected from the introduction of more efficient bacterial strains and innoculative procedures.

High fertilizer use efficiency and high yields depends on the adoption by farmers of improved crop production practices including correct sowing time, effective weed, pest and disease control and appropriate water conservation measures.

Despite more than 30 years of concentrated effort, mass balances indicate that annual N and P inputs consistently exceed harvested exports by 40 to >100% resulting in substantial losses of these nutrients to the environment. Thus, it is evident that global challenge of meeting increased food demand and protecting environmental quality will be won or lost in cropping systems (Cassman *et al.*, 2002). Major limitation of most of the approaches tried in past three decades is lack of their applicability on large scale on small farm holdings. Only two approaches hold promise for application on mass scale to increase nutrient use efficiency (1) application of optimum quantity and (2) internal nutrients circulation.

6. Application of optimum quantity

One of the first step necessary for achieving higher fertilizer use efficiency (FUE) is to apply the right amount of fertilizer. But the long term estimations of N requirement of crops under rain-fed conditions may be very difficult as the yield levels vary from zero to three times of average yield. Using average yields in arid regions is too conservative and may actually result in lowering average yields with time because of insufficient nutrient availability for the very favourable years and on contrary, use of relatively high yield goals results in excess N applications in most years and can greatly reduce profit. The current concern over the potential for excess N to degrade the environment also makes this alternative unacceptable. Tucker (1988) presented three ground rules to arrive at logical yield goals. These include choosing yield goals based upon: (1) highest yield within the past 5 years with good crop management (2) yield goal set a 1.5 times of long term average, and (3) yield goal based on soil capabilities as defined in Standard Soil Surveys, using yields of highest yield obtaining farmer's in the vicinity on the same kind of soil.

Uncertainties in soil nitrogen (N) supply in rainfed agriculture and crop N demand present a challenge to scientists in deciding on N fertilizer rates. Number of field studies have documented that the improvements in N use efficiency is possible with site-specific N management approaches. Lobell (2007) has presented a general model of N rate decision-making which computes the optimal N rate that maximizes expected profit given uncertainties in N supply and demand. The cost of uncertainty is measured as the difference in N rate when soil N supply and crop N demand are unknown versus known perfectly. Eliminating uncertainty in soil N supply (but not crop demand) reduces average N rates by 5–40% in different crops while perfect knowledge of potential crop N demand (but not soil supply) reduces rates by 3-10%. Simultaneous knowledge of both factors reduced N rates by significantly more than the sum of their individual effects. This approach is very different from most extension services in India which provide a single, standard fertilizer recommendation for an entire district or region. Farmers apparently have few guidelines for adjusting N-fertilizer amount to account for the large differences in the indigenous N supply, indicating the need for a 'field-specific' approach to N management. Field specific N management could lead to substantial reductions of N rates without yield loss in a wide range of cropping systems, thereby improving profitability and environmental quality.

7. Internal nutrient circulation

The approach comprises of various conventional practices like recycling of crop residues, either through direct application or as manure and cultivation of legumes often referred as integrated nutrient management in past. The practice of effective use of inorganic and organic sources of nutrients together in a proper proportion not only reduces the requirement of inorganic fertilizers, but also improves physical conditions of soil, enhances water retention capacity and its availability in the soil. Apart from this, the biological properties of soil are also improved considerably (Sharma *et al.*, 2005, 2009) and fertilizer use efficiency is also increased. The results of several studies have shown that the combined use of fertilizer and farm yard manure (FYM) is very much essential in rainfed areas for sustaining moderate to high yields and achieving higher nutrient use efficiencies. Besides, application of FYM and composted organic wastes and other organics improve yield stability in rainfed areas (Aggarwal and Venkateswarlu, 1989; Venkateswarlu and Hegde, 1992; Singh *et al.*, 2000).

Singh *et al.* (1981) observed that under arid conditions of Jodhpur continuous application of sheep manure in general gave substantially higher yields than the application urea alone. Rao and Singh

(1993) showed that substitution of 50% of fertilizer requirement by FYM resulted in yield levels nearly similar to those obtained with complete fertilization. Aggarwal and Praveen-Kumar (1996) on the basis of a seven year study on arid soils showed not only a beneficial effect of FYM application but also a synergistic effect of simultaneous application of FYM and inorganic fertilizers on crop yield. FYM application increases the utilization efficiency of fertilizer N, however, improvement in soil fertility after FYM application is a very slow process.

Nutrient content of pearl millet, sorghum stover is relatively low, stover can contribute to the productivity of the soil. Such residues must be managed carefully, however, because N can be immobilized at the time of peak maize N requirements, resulting in poor crop growth. In rainfed areas, cereal stover is often fed to livestock, and manure is applied in field. This way of recycling the residues is more beneficial for crop than their direct application in field. Losses of N from such systems are often high. Cattle manure is applied in a dried, aerobically decomposed form, often with a high sand content and N content that is frequently around 1% or less. Research shows that the most efficient use of manure is to combine it with some inorganic fertilizer. Ladd and Amato (1985) showed that the most promising route to improving inorganic fertilizer efficiency in cropping systems is by adding small amounts of high-quality organic matter (possessing a narrow C/N ratio and a low percentage of lignin) to soils. Soil microbes are valuable not only because they supply nutrients directly, but because they enhance the synchrony of plant nutrient demand with soil supply by reducing large pools of free nutrients (and consequent nutrient losses from the system). Thus, microbes maintain a buffered, actively cycled nutrient supply.

Incorporation of crop residues and natural vegetation in soil improve microbial activity during decomposition. Also adhesive action of decomposed products improves soil aggregation, hydraulic conductivity and moisture retention (Venkateswarlu, 1987, Gupta and Gupta, 1986). Leaving the crop residues in soil generally have a positive effect on grain yield (Aggarwal *et al.*, 1996). Crop residues are also efficient source of nutrient like other organics viz., cattle manure and compost. However, Aggarwal *et al.* (1996) did not find any significant change in the yield of succeeding crop of pearl millet after addition of crop residues with wide C:N ratio, whereas it was significant after incorporation of residues with narrow C:N ratio.

Legume rotations are an important practice for restoring soil fertility on larger land holdings. The amount of N returned from legume rotations depends on whether the legume is harvested for seed, used for forage, or incorporated as a green manure. Estimated net N return of 23-110 kg ha^{-1} from pigeon pea, 23-50 kg ha^{-1} from dolichos beans, and 25-60 kg ha^{-1} from groundnuts has been reported by Giri and De (1980).

Mishra (1971), Mann and Singh (1977) and Singh *et al.* (1985) also reported that in arid soils pearl millet-cluster bean rotation gave higher yield than of continuous cultivation of pearl millet due to improved soil fertility (Praveen-Kumar *et al.*, 1996). Singh *et al.* (1985) in a long-term study found an increase soil organic carbon by 12% and available soil P by 25% after legume cultivation. Singh and Singh (1977) on the basis of a long-term study reported that cultivation of green-gram in rotation with pearl millet supplied with 20 kg N ha^{-1} gave similar yield as with application of 40 kg fertilizer N ha^{-1}. Singh *et al.* (1985) observed that rotation of pearl millet with green gram or clusterbean was better than its rotation with moth bean.

Praveen-Kumar *et al.* (1996) reported that higher yield of pearl millet when it was preceded by clusterbean cultivation than green gram. Beneficial effect of legumes to pearl millet also depends on the number of seasons of their cultivation prior to pearl millet. The intercropping of pearl millet and legumes in arid soils has also shown promising results (Mishra, 1971; Singh *et al.*, 1978).

Major quantity of N i.e. upto 70% of total N uptake, can be taken up by the pearl millet within first 30 days of growth. Though it slows down thereafter, but continues gradually till the grain filling stage. This high N demand cannot be met from the soil and thus pearl millet respond favorably to the N addition (Aggarwal and Vekateswarlu, 1989), which ranged from 7.0 to 18.0 kg grain kg^{-1} N with higher values in good rainfall years. Singh *et al.* (1981) have reported that the yield of pearl millet doubled with the application of 40 kg N ha^{-1}. Similar results have also been reported by Singh *et al.* (1981). Aggarwal and Praveen-Kumar (1996) on the basis of a seven year long study reported significant response to application 80 kg N ha^{-1} only in the years of good rainfall. Comparison of different N fertilizers showed that, maximum yields were recorded with ammonium sulphate. But due to high cost of ammonium sulphate, urea has become the major source of N in arid regions even though utilization efficiency of N from urea by pearl millet is very low. Various studies in CAZRI Jodhpur have revealed that the mixing of elemental S with urea (Aggarwal *et al.*, 1987) or application of small quantity of ammonium sulphate before the application of urea (Praveen-Kumar and Aggarwal, 1988) increases its efficiency.

Venkateswarlu (1980) evaluated the difference in yield in rainfed conditions between farmers' fields using farmers' practices, farmers' field using improved cultivation practices and experimental stations in different parts of India. These data (Table 1) show that the achievable yields are three to five times those obtained by small farmers.

Table 1. Actual and potential yields (kg ha^{-1}) of some dryland crops in India

Crop	Farmers' fields			Research stations	
	No. of trials	Farmers' practices	Improved practices	No. of trials	Yield
Pearl millet	300	360	880 (244)	14	1900 (528)
Ground nut	117	430	870 (202)	5	1500 (349)
Chickpea	112	650	1520 (234)	8	2820 (434)
Rapeseed	40	550	1030 (187)	17	1700 (310)
Sorghum	101	610	1310 (214)	12	3000 (492)

Figures in parenthesis are percentage yield increases over farmers' practice

8. Crop response to nitrogen, phosphorous and potassium

Ways of increasing fertilizer use efficiency

Recovery of applied nitrogen by crops is generally low, seldom exceeding 50%, even under well managed conditions. Recovery of added nitrogen can be improved by using suitable crop cultivars and sowing dates, appropriate methods of fertilizer application, applying organic manures and adopting adequate soil and water conservation measures.

8.1. Crop cultivars

Improved, high yielding cultivars usually utilize N for grain production more effectively than unimproved cultivars.

8.2. Time of sowing

Optimum response to fertilizer as well as overall yield levels depends on timely sowing. For the post-monsoon season, time of sowing assumes greater relevance, especially for crops which are thermo-sensitive. The yield potential of cereal crops and their ability to utilize nutrients are both influenced by the meteorological conditions prevailing at seeding, during growth and at maturity.

8.3. Time of fertilizer application

Time of application of N fertilizer has

considerable influence on the yield of rainfed crops. Splitting the N application, half at sowing and half 25 to 45 days after sowing (depending on soil moisture availability) is generally recommended. Split application is a suitable practice for low and uncertain rainfall areas, where – as a contingency practice – the second application may be omitted if rainfall during the crop growth period is inadequate. Phosphorous and potassium fertilizer may be applied as basal application in bands for high use efficiency.

8.4. Methods of fertilizer application

8.4.1. Soil application

Split band application of urea is highly effective in sorghum and pearl millet in comparison to broadcast application. N data showed that the recovery of N in above ground biomass was highest with split application on Alfisol and Vertisol. Split application of N fertilizers is therefore, considered a risk avoiding strategy which results in the higher yield as compared to their one time application, increased utilization efficiency and lower risk. Praveen-Kumar and Aggarwal (1997, 1998) observed basal application of fertilizer N may be avoided if clusterbean has preceded the pearl millet.

Full doses of phosphorous and potassium fertilizer may be applied as basal application in soil which will give highest recovery. P fertilizer application to deficient soils stimulates initial vegetative growth and brings anthesis and seed maturity. This can be especially beneficial in enabling rainfed crops to complete their growth cycle within the period of moisture availability. Soluble P fertilizers react with and are rapidly converted to less available forms in soil, especially those soils with high P fixing capacity. The rate of immobilization can be reduced by minimizing the soil volume with which the fertilizer comes into contact, i.e. by band placement.

8.4.2. Foliar application

Foliar feeding, as a means of fertilizer application in situations where water is limiting, has received considerable attention in India. Early vegetative growth is not considered desirable for optimum yield of cotton in India. Little or no N therefore applied at sowing; mid-season application at square formation is recommended. Foliar application is of special relevance where the farmer has not been able to apply any fertilizer at sowing and subsequent soil application is impossible or operationally difficult. Also saline or alkaline soils may be more suitable for foliar feeding.

8.5. Integrated nutrient management

Most tropical soils are poor in organic matter, not only because of high temperatures but also because a high proportion of crop residues are used as cattle feed, fuel or thatching material and not returned to the soil. Increasing the soil organic matter content can improve soil physical properties as well as increasing soil nutrient status. Organic matter can be incorporated by keeping the post harvest crop residues after crop harvest which will improve the succeeding crop yield. Sometime termite may be a major problem in these areas. Another mean is by growing leguminous green manure crop in situ, with or without a non-legume and incorporating the biomass into the soil within 45 days of sowing. Organic matter can be incorporated through application of various organic manures/ compost/ enriched compost before harrowing the field @ 5-10 t ha^{-1}.

8.6. Legume in sequential cropping or in crop mixtures

In many arid environment a small grain cereals are alternated with short season annual legumes. In the fallow years the legume provides ground cover to reduce soil erosion and fix enough atmospheric nitrogen to benefit the subsequent grain crop.

Mixtures of legumes and non-legumes are widely grown in tropical countries and not only meet the dietary needs of small farmers but also act as an insurance against crop failures when rainfall is aberrant.

8.7. Moisture conservation

Moisture conservation is one of the cardinal principal of soil management in rainfed areas, with considerable potential for increased productivity. Profile water storage can be increased by suitable tillage practices or by fallowing. Use of organic mulches for the standing summer season crops can help to prolong the effectiveness of the profile water until grain maturity of the summer rainfed crops.

8.8. Secondary and trace elements

It deals with the application of secondary (S) and micronutrients (Zn and Fe) in deficient areas which is wide spread in tropical and sub-tropical regions. S deficiency occurs in many summer rainfall regions, its intensity depends on soil supply in which organic matter plays a very important role but the arid region is low in soil organic matter. S deficiency is controlled by soil application of gypsum, low grade pyrites, single super phosphate and other S-containing fertilizers. Zn deficiency is widespread in tropical regions. Wheat responds well to Zn in the arid and semi-arid regions. Crop cultivars differ in their need for applied Zn, those genotypes which took up more Zn showed a better response to Zn application. Zn is usually applied to the soil and Katyal (1985) found that foliar application was less effective except on horticultural crops. Fe deficiency is associated in particular with highly calcareous soils and foliar application was most effective in various cereals of arid zone. Foliar application of Fe is also helps plants against moisture stress.

8.9. Other management practices

Fertilizer application must be combined with other improved management practices if full yield benefits are to be obtained, particularly in rainfed crops. Unless other conditions of growth are optimum, limiting factors such as pests, diseases and weeds tend to have major depressive effects on growth and yield. Soil and water conservation measures prior to and during crop growth, optimum plant population and effective management of pests and weeds contribute substantially towards higher fertilizer use efficiency.

9. Recommendations

Productivity in arid zone areas can be improved by the choice of crops and cultivars which will mature within the period of adequate water balance, by rectifying nutrient deficiencies, controlling weeds, pest diseases, and taking appropriate soil and water conservation measures. Organic recycling and the use of legumes in sequential and intercropping systems are also very appropriate. Some general recommendations are as follows:

1) Half of the N application for non legumes should be applied before sowing and the rest applied after 30-35 days after sowing

2) All the P, K, S and soil-applied micronutrients should be drilled in band at sowing. Soil analysis should be used for deciding rates of nutrients.

3) Bulky organic manures should be applied before the onset of summer rains/monsoon, if possible at a rate of at least 5 t ha^{-1} once in 3 years or 2.5 t ha^{-1} annually.

4) Wherever possible green manuring with Crotolaria, Sesbania, cowpea or other succulent legumes which provide a useful source of organic matter and N. They should be turned into the soil just before they reach flowering stage and 5-7 days before sowing summer or post rainy season crop.

5) Intercropping cereals with legumes provides greater yield stability. Legumes for this purpose should preferably be of short duration and stature.

6) Areas subjected to runoff losses should be leveled and bunded, with ridge where appropriate. Cover cropping during the rainy

months is useful I checking soil erosion.

7) Where available, mulch materials applied between crop rows help to conserve soil moisture.

10. Conclusion

Fertilization with nitrogen (N) is almost always necessary; phosphorus (P) is often needed, especially in calcareous and sandy soils, and fertilization with potassium (K) is required in coarse-textured soils, especially for intensive cultivation and for K-loving crops. Due to the high light intensity in arid regions and limited zinc (Zn) availability, Zn deficiency becomes very common. Supply of iron (Fe) depends to a great extent on the soil pH and lime content. Micronutrients such as copper (Cu), manganese (Mn), boron (B) and molybdenum (Mo) are rarely needed for cropping in medium to heavy textured soils. Incorporation of legumes in cropping system or as intercropping is good for sustainable development. Proper management of pest and diseases and soil and water conservation is also important for better crop yield. Sandy soils in arid regions often require fertilization with most essential nutrients, especially in irrigated agriculture.

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Efficient resource conservation technologies for higher nutrient use efficiency in pulse systems

Narendra Kumar, C P Nath and K K Hazra

ICAR- Indian Institute of Pulses Research, Kanpur, Uttar Pradesh-208 024
E-mail: nkumar.icar@gmail.com

ABSTRACT

RCTs have emerged as alternative strategies to sustain agricultural production especially under rainfed/ dryland agriculture. RCTs is a concept for resource-saving agricultural crop production that strives to achieve acceptable profits together with high and sustained production levels while concurrently conserving the environment. Interventions such as mechanical soil tillage are reduced to an absolute minimum, and use of external inputs such as agrochemicals and nutrient of mineral or organic are applied at an optimum level that does not interfere with, or disrupt, the soil biological processes. The degradation of pulse crop residues add nutrients as well as made other fixed nutrients into plant available form. Organic acids released by pulse crop root in soil also mobilizing un-available soil nutrients like P and K.

Keywords: Cropping System, Pulses, Nutrient use efficiency, Resource conservation technologies

1. Introduction

Widespread adoption of green revolution technologies after 1960s led to increased productivity and elimination of acute foodgrains shortages in India. Foodgrains production enhanced mainly from increase in rice-wheat area as well as the system productivity due to development of high-yielding input responsive dwarf varieties of rice and wheat, increased use of chemical fertilizers and other agrochemicals, and increase in irrigation facilities. This was also accompanied by the other so called modern methods of cultivation, which included maximum tilling of land, virtually clean cultivation with complete removal of crop residues and other biomass from the field, fixed crop rotations mostly involving cereals, and elimination of fertility-restoring pulses and oilseed crops in the high productive north-western plain zone of the country. Continuous practice of the exhaustive rice-wheat production system over the last 60 years has aroused many problems which have restricted the ability of these resources to produce to the level matching future foodgrains requirement of the country. It is realized that soils are getting impoverished due to imbalanced use of fertilizers, discontinuation of traditional practices like mulching, intercropping and inclusion of legumes in cropping systems. Further, the use of organic manures, compost and growing of green manure crops has also decreased considerably due to various reasons. Similarly, water resources are under great stress due to their indiscriminate exploitation and also getting polluted due to various human interferences. Burning of fossil fuels, crop residues, excessive tillage including puddling for rice cultivation are leading to emission of greenhouse gases, which are responsible for climate change and global warming. The deteriorating production and sustainability of these systems are evident from either stagnation or decline in the yield and factor productivity of rice and wheat has led to undesirable decline in soil physical environment, excessive mining of essential plant nutrients from soil. The over exploitation of soil and water resources lead to reduction in use efficiency of inputs (e.g., fertilizer, irrigation, tillage). Thus, enhancing and sustaining the natural resource base is of paramount importance.

Pulses are next to cereals in terms of their economic and nutritional importance as human diet. It belonging to family Fabaceae, have considerable area under cultivation globally and these crops are important constituents of cereal-based vegetarian diets. Pulses are an important food crop for nutritional security, sustainable crop production and soil health. Consequently, they remained an internal component of cropping systems especially rainfed areas since time immemorial. Pulses are among the ancient food crops with evidence of their cultivation for over 8,000 years. Besides being a rich source and the cheapest source of dietary protein and it also play a key role in improving and sustaining soil productivity on account of inherent capacity to fix atmospheric nitrogen and addition of huge amount of organic matter through roots and leaves fall and thus increasing nutrient use efficiency. Pulses like lentil, chickpea, mungbean and urdbean may prove as ideal crops in agriculture. Continuous cultivation of cereal crops resulted in deterioration of soil, declining water tables, increasing insect pest and disease populations, and other environmental problems. Pulse crops with their unique ability of biological N_2 fixation, leaf litter fall and deep root system may be a suitable option for sustain soil health. A major advantage of pulses is that they can fix atmospheric nitrogen with the help of rhizobia bacteria, thus minimizing the requirement for additional fertilizer inclusive nitrogen supplements.

Pulses in India are grown on marginal and degraded land over the years under low or no inputs. The growth and productivity of pulses are affected by excess soil moisture during rainy season and moisture stress during winter season. Number of abiotic factors (water and soil related) limit pulse production in winter season especially under rice based systems. Dry spell during rainy season and mid/terminal season drought and terminal heat stress during reproductive stage adversely affects the pulses production in the country. In case of pulses grown after rice or in case of rice fallows, low moisture content in the soil after rice harvest, faster decline in water table with advancement of *rabi* season, and risk of soil moisture stress towards flowering and pod filling stages are some of the major constraints. Sometimes, frost and low temperature during night cause heavy damage to winter pulses. Due to anaerobic conditions in rice cultivation, many of the organisms including rhizobia would not be able to survive. Therefore, to overcome these problems resource conservation technologies may be very useful.

2. Resource conservation technology vs Conservation agriculture

The terms resource conservation technology (RCT) and conservation agriculture (CA) has a clear cut difference. Resource conservation technologies (RCTs) refer to those practices that enhance resource- or input-use efficiency such as new varieties that use nitrogen more efficiently, zero or reduced tillage practices that save fuel and improve water productivity, land levelling practices that help save water, etc may be considered as RCT. However, the term CA refers to the system of growing crops without tilling the soil while retaining crop residues on the soil surface. Land preparation through precision land levelling and bed and furrow configuration for planting crops further enables improved resource management. Essentially, conservation agriculture has three components, such as minimum level of soil movement, retention of crop residues on the soil surface, and sensible and profitable crop rotations.

RCTs have emerged as alternative strategies to sustain agricultural production especially under rainfed/dryland agriculture. RCT is a concept for resource-saving agricultural crop production that strives to achieve acceptable profits together with high and sustained production levels while concurrently conserving the environment (FAO, 2007). RCT is based on enhancing natural biological processes above and below the ground. Interventions such as mechanical soil tillage are reduced to an absolute minimum, and use of external inputs such as agrochemicals and nutrient of mineral or organic are applied at an optimum level that does not interfere with, or disrupt, the soil biological processes. Due to the efforts of the Rice-Wheat Consortium (RWC) and several institutions of the national agricultural research system, zero till technology has been popularized in India and neighboring countries and it is currently adopted by farmers in over 2 million ha largely in the Indo-Gangetic plains. World-wide, no-till farming or CA has spread mostly in the rainfed agriculture. However, in India its success is more in irrigated belt of the Indo-Gangetic plains. Considering the severe problems of land degradation due to runoff induced soil erosion, rainfed areas particularly in arid and semi-arid regions require the practice of RCT more than the irrigated areas in order to ensure a sustainable production.

3. RCTs for higher nutrient use efficiency

3.1. Crop diversification

3.1.1. Pulses in sequential cropping

Pulses are integral part of cropping systems under traditional practices since time immemorial. But, development of short duration and disease resistant varieties of different pulses led to the foundation of cropping system research in different agro-ecosystem. This also paved way for crop intensification in both irrigated as well as in rainfed conditions. Some of the examples are pigeonpea - wheat in NW plains, maize – pre-*rabi* pigeonpea/ frenchbean in NE plains, rice – wheat – mungbean, maize - potato/mustard - mungbean/urdbean in northern plains and rice - urdbean in coastal peninsula. Rice-wheat, major cropping system is highly nutrient exhaustive and therefore, its continuous use has depleted inherent soil fertility, causing deficiency of several nutrients. In rice-wheat and other cereal- cereal systems, major concern for sustainability is decline in soil physico-chemical and biological properties which led to decline in factor productivity. The process of decline in soil quality can be reversed by inclusion of pulses in the cereal based system. Pulses can act as soil fertility restorers in cropping system due to their ability to fix atmospheric N in symbiosis with *Rhizobium*. Pulses crops leave a substantial amount of residual N which may vary from 30-60 kg N/ha. This inclusion of pulses in intensive cropping system not only restores the soil fertility but also increases the farmer's profitability. In a LTFE study at Kanpur revealed improvement in bulk density, porosity, infiltration and other physical parameters were recorded under rice-lentil, pigeonpea-wheat and rice-wheat-mungbean. Inclusion of a single pulse crop like summer mungbean in rice-wheat and maize-wheat systems

Table 1. Effect of pulses based cropping system on soil available nutrients (after 8 crop cycles)

Cropping system	Available P (kg/ha)	Available K (kg/ha)	Available S (kg/ha)	DTPA –Zn (kg/ha)	B (kg/ha)
Rice-wheat	18.55	234.20	14.10	1.68	0.86
Rice-wheat-mungbean	18.37	271.58	16.71	1.60	0.89
Rice-wheat-rice-chickpea	21.20	247.94	17.54	1.69	0.92
Rice-chickpea	21.55	243.41	17.15	1.82	0.93
Maize-wheat	16.0	173.0	17.3	0.6	0.9
Maize-wheat-mungbean	17.2	186.0	19.4	1.1	0.9
Maize-wheat-maize-chickpea	18.0	185.9	18.5	0.8	1.0
Pigeonpea-wheat	16.8	183.2	19.1	0.8	1.0

Source: IIPR, 2012

improved the total soil organic carbon content, being greater in surface soil (0-0.2 m). Ali and Venkatesh (2009) also reported that pulses improve physical (soil aggregates, pore space, bulk density), chemical (OC, pH) and biological properties (soil biota population, efficiency and synergy, SMBC) of soil. Similarly, improvement in nutrients availability in soil was also observed with inclusion of pulses in cereal-cereal systems.

3.1.2. Pulses in intercropping

The major considerations for intercropping are the contrast in maturities, growth rhythm, height and rooting pattern and variable insect pest and disease associated with component crops so that these complement each other rather than compete for the resources and guard against weather adversities. Growing of crops in intercropping systems is found more productive particularly under rainfed conditions. Pulses can be easily intercropped with oilseeds, cereals, coarse grains and commercial crops. Among pulses, late duration pigeonpea is planted in wider rows and its initial growth is slow which provides an opportunity for intercropping with crops like mungbean, urdbean, sorghum etc. Being a deep-rooted crop it extracts nutrients and water from deeper soil layer and thereby minimizes the competition for these inputs with cereals. Pigeonpea intercropped with short duration pulses (mungbean and urdbean) is the most popular combination in Uttar Pradesh. The special feature of this system is that the productivity of the base crop i.e., pigeonpea remains unaffected and an additional 400-500 kg/ha of mungbean or urdbean or 6-8 q/ha of sorghum can be obtained without any additional inputs. Intercropping of winter pulses like chickpea and lentil with oilseeds is common in rainfed areas. Literatures reveal that high productivity and monetary returns can be obtained from chickpea + mustard, lentil + linseed and wheat + lentil intercropping systems (Kumar *et al*., 2008; Kumar *et al*., 2012). Intercropping of chickpea + mustard/linseed is commonly seen in Bundelkhand regions (Banda, Hamirpur, Chitrakoot Jhnasiand and Jaloun districts) of Uttar Pradesh. Some of new intercropping systems like spring sugarcane + mungbean/urdbean and rajmash + potato have been advocated in different parts of state.

Studies on genotypic compatibility in intercropping system were also carried out for most of the systems. Chickpea genotype 'KWR 108' was found more compatible than 'BG 256' and 'KPG 59' for intercropping with linseed cv. 'Neelam' and row ratio of 6:2, Similarly, lentil variety 'L 4076' was found more compatible than 'DPL 62' in lentil + linseed intercropping. Mungbean varieties 'PDM 11' and 'PDM 84-143' and urdbean variety 'DPU 88-31' were most compatible for intercropping with spring planted sugarcane (Ali, 1992 and IIPR, 2009). Recent released varieties of pulses can also fit well under intercropping. The erect growth behavior of pigeonpea variety 'IPA 203' is more suitable than 'Bahar' and 'Narendra Arhar 1'. Similarly, short duration variety of mungbean 'IPM 205-7' matured in 52-55 days is more suitable for intercrop than others. Similarly, genotypic interaction between 'VL Gehun 804' x 'VL Masoor 4' was found most compatible for intercropping of lentil+wheat in NW Himalaya (Kumar *et al.,* 2008).

3.2. Planting methods

3.2.1. Furrow irrigated raised bed system of planting

Furrow Irrigated Raised Bed (FIRB) system of planting is an agronomic intervention where crops are sown on raised beds of different size. Bed size depends on crop type, soil, objectives of making bed and machineries available for making bed. The concept of raised bed planting is very advantageous in both water logged and limited water area. The system of planting crops on raised bed alters crop geometry and land configuration, imposes effective control over irrigation and drainage. Water logged situation is common features of rainy season pulses in eastern and central Uttar Pradesh, however *rabi* pulses are normally grown under limited water condition or under rainfed such as in Bundelkhand region of Uttar Pradesh. Further, 40-50% reduction in incidence of complex *Phytophthora* wilt is observed in pigeonpea under heavy rains. Furrows can be used to drain out the excesses amount of water from water logged fields. In other hand, 40-50% saving in irrigation water was recorded when irrigation was applied through furrows. The problem of over irrigation or ponding at some parts in field can also be avoided. In a various studies at IIPR, Kanpur revealed that planting of 2 lines on raised bed size 75 cm enhances seed yield by 33.6% in urdbean, 15% in chickpea and 16% in lentil over conventional system of planting. In addition, 40-45% saving of irrigation water and 25% saving of fertilizers and seeds were also recorded under FIRB planting (Kumar *et al.,* 2015).

3.2.2. Effect of rice cultivation

Many parts of the country *rabi* pulses are grown after rice harvest. The cultural practices followed in rice crop have significant effect on *rabi* pulses. Rice crop commonly grown in eastern or NE regions are grown under puddle transplanted condition which harvested in month of November. Puddling disrupts the soil structure which affects pulses root development and nodulation. A study was conducted at IIPR Kanpur to establishing relative efficacy of different rice establishment systems in crop production and its water use under rice-chickpea rotation. It was observed that soil moisture remain available for longer period for chickpea crop under unpuddled transplanted and direct seeded rice than puddle transplanted. Thus, higher yield of chickpea was recorded in unpuddled transplanted and direct seeded rice than transplanted rice.

3.3. Conservation tillage

Excessive tillage of agricultural soils may result in short term increase in fertility, but will degrade soils in the medium and long term. Structural degradation, loss of organic matter, erosion and falling biodiversity are all to be expected. Soil erosion resulting from soil tillage has forced us to look for alternatives and to reverse the process of soil degradation. The logical approach to this has been to reduce tillage. This led finally to movements promoting conservation tillage, and especially zero-tillage, particularly in many part of the world. Over the last two decades the technologies have been improved and accepted by the farmers in our country, mostly in Indo-Gangetic plains. Conservation tillage involves the planting, growing and harvesting of crops with minimal disturbance to the soil surface. It is designed to reduce erosion and maintain or improve soil health properties, increases infiltration by reducing surface sealing and enhancing macropore connectivity and flow. The most commonly used definition is any tillage sequence, the object of which is to minimize or reduce loss of soil and water; operationally, a tillage or tillage and planting combination which leave a 30% or greater cover of crop residues on the surface. Conservation tillage has shown advantages over traditional tillage practices by means of improving productivity, nutrient use efficeincy and soil health in case of cereal/pulse crops in many parts of world. Study conducted by authors at Kanpur also shown improvement in soil health and pulse crop yield under conservation tillage.

3.4. Residue management

Crop residues are good sources of plant nutrients and are important components for the stability of agricultural ecosystems. Green revolution during 1960s not only drastically enhanced the food grain production but also crop residue production. In areas where mechanical harvesting is practiced, a large quantity of crop residues is left in the field, which can be recycled through proper residue mechanism for nutrient supply in the system. Apart from organic carbon and minerals, about 25% of nitrogen and phosphorus, 50% of sulphur, and 75% of potassium uptake by cereal crops are retained in crop residues making them valuable nutrient sources. Incorporation of urdbean and mungbean residue was found beneficial to the succeeding mustard crop in terms of higher yield (6-7%) in a study at Kanpur. In rice-chickpea sequence, yield of chickpea was significantly influenced by rice-residue incorporation and highest seed yield was obtained with incorporation of chopped straw + irrigation, while lowest yield was obtained in rice residue removal treatment. Incorporation of chopped residue of mungbean + irrigation resulted in maximum wheat yield which was significantly higher (38%) than control. In rice (upland) - lentil and rice-wheat – mungbean systems, incorporation of crop residues increased yield of all crops. Incorporation of both crop residues had shown an improvement of 17.6% in lentil yield over no residue in rice-lentil cropping system. Similarly, higher yields of all three crops in rice – wheat – mungbean were recorded due to incorporation of crop residues of either one crop or all crops in the system (Annual Report 2010-11; Kumar *et al.*, 2012).

Further, incorporation of urdbean and mungbean residue raised the organic carbon level by 35.48% over control. Residue incorporation also resulted in higher soil available N (24.6%), P (11.5%), and K (18.5%) over the initial fertility levels (Singh *et al.*, 2012). Soil physical parameters *viz.*, bulk density, particle density, per cent pore space and WHC also improved under residue incorporation plots over residue removal plots. In same set of study, periodic changes in soil microbial biomass carbon (SMBC) were also recorded. The results revealed that increase in SMBC up to 56 days after incorporation of urdbean and mungbean under chopping + incorporation + irrigation. Similar trend was also observed after harvest of wheat crop. The ratio of microbial carbon to soil organic carbon was also higher under chopping + incorporation + irrigation. Similarly, other studies at IIPR revealed that incorporation of all crop residues in rice (upland) - lentil and rice – wheat – mungbean systems enhanced yields of all crops in the system, besides, improvement in soil physico-chemical properties including infiltration rate, nodulation and earthworm population were also observed.

Table 2. Grain yield of rice and wheat as influenced by residue management in rice-wheat-mungbean system

Residue incorporation	Yield (Kg ha^{-1})		Sustainability Yield index
	Rice	Wheat	
Rice-Wheat-Mungbean	3507	5082	0.79
Rice - Wheat	3327	4902	0.74
Rice	3089	4855	0.74
No residue	2839	4434	0.67

Table 3. Leaf litter fall and nutrient contribution through leaf litter

Crop	Leaf litters (t ha^{-1})	N (kg ha^{-1})	P (kg ha^{-1})	K (kg ha^{-1})
Chickpea	1.1-1.7	7-14	3-5.5	8-20
Lentil	1.3-1.6	8-10	3.5-4.5	12.5-19
Pigeonpea	1.3-2.8	8-16	2.5-5	13.5-24

Pulses not only provide an excellent cover to soil surface due to their dense canopy but also leave substantial amount of easily decomposable crop residues. Incorporation of mungbean residue further improved yield of rice and wheat as well as sustainability index over and above rice + wheat residues (Table 2). The low harvest index in pulses eventually provides large amount of crop residues. A good crop of chickpea may provide 8-10 tonnes straw (crop residue). Winter pulses and pigeonpea shed a large number of their leaves at maturity (2-3 t ha^{-1} dry leaves) which provides a thin soil cover (Table 3).

3.5. Foliar nutrition

Deficit in soil moisture at flowering and pod development stages is most commonly observed in pulses under rice fallows that limit the flow of nutrients and water from soil to leaves and foods from source to sink. Under such a stress situation, foliar nutrition with 2% urea/DAP and micronutrients (Fe, Zn, Mo and B) may alleviate the soil moisture stress up to some extent. In urdbean, foliar application of micronutrients and urea (2%) could be beneficial in term of nodulation and BNF. Higher values of RLWC and SLW and chlorophyll content at flowering and pod development stages were also observed following foliar nutrition of 2% urea. Further studies, on foliar application of 2% urea combined with micronutrients at flowering and early pod development stage, had shown great promise. These nutrients have also shown to enhance micronutrient content seed (bio-fertification).

3.6. Micro-irrigation techniques

These techniques use precision technologies for efficient management of both water and nutrient precisely near the root zone of the crop plant. The major advantages in terms of water application include three factors that directly enhance both conveyance and water use efficiency, viz., i) water is applied directly to the root zone of plants, ii) water is applied in frequent intervals in precise quantities as per the crop water requirement and iii) Water is applied through a low-pressure pipe net work comprising Mains, Sub mains, Laterals and emitting devices. Thus, there are perceptible advantages through these techniques such as water is applied daily/alternate day at field capacity & near root zone. Here, saline water up to 8-10 m mhos/ cm can be used. Fertilizer can be combined with drip-water, thus, precision application of water results in lesser weeds & pests and greater pod retention. The likely benefits are substantial and these are:

- Uniform germination and optimum plant stand
- Reduced water use by 55% (may be maximum)
- Elimination of wide fluctuation of water
- Control of weeds and reduced weeding cost
- Increase in efficiency of fertilizers
- Early and uniform maturity
- For early planting - prerequisite for IPM

4. N-fixation and economy by pulses

The biological nitrogen fixation process is the most efficient way to supply the large amounts of nitrogen needed by pulses to produce protein rich high yield. For the fixation process to occur, plants must enter into a “symbiotic” or mutually beneficial partnership with certain bacteria called rhizobia. The intrinsic nitrogen fixing capacity of pulse crops enables them to meet large proportion of their nitrogen requirement and also helps in economizing nitrogen in succeeding non-pulse crops. Optimum rate of N-fixation of pulses is about 1.0 kg/ha/day within a cropping season, which generally referred as potential N-fixing ability of pulses in a given environment. Usually about two thirds of the nitrogen fixed by a pulse crop becomes available to next growing season. Pulses can fix 30-150 kg N/ha depending upon rhizobial population, host crop and varieties, soil properties, management level and environmental conditions. In sequential crop involving pulses, the preceding pulse may contribute 18-70 kg N/ha to soil and thereby considerable amount of N can be saved in succeeding crops. In rice-wheat rotation growing of short duration mungbean in summer may brings nitrogen economy up to 40-60 kg N/ha in succeeding rice crop. Similar effect of *kharif* and *rabi* pulses on productivity and N-economy of succeeding cereals are well established. The study at Kanpur revealed that soybean – wheat system was the most productive followed by pigeonpea – wheat among *kharif* pulse based cropping systems. The nitrogen economy due to preceding pigeonpea over sorghum was found to be 51 kg N equivalent/ha. Influence of *rabi* pulses on productivity and N economy in succeeding rice revealed that chickpea, rajmash and lentil exhibited most favourable effect in economizing nitrogen to the extent of 40 kg/ha. Rajmash – rice was the most productive system followed by chickpea – rice.

Further, an improvement in the N budget of soil measured by NO_3-N content left after harvest of *rabi* pulses was also recorded. Chickpea ranked first (20.4 kg/ha) followed by fieldpea and lentil in contribution of residual NO_3 in the soil profile. Among the genotypes, chickpea cv. BG 1003, lentil cv. DPL-62 and fieldpea cv. Rachana were highest in increasing the nitrate content in soil (IIPR 2009).

5. Recycling of nutrients in cropping systems

Pulse crops have deep root system in soil so they have ability to recycle crop nutrients that are deep in the soil profile. This results in a more efficient use of applied fertilizer and prevents nutrients (particularly nitrate nitrogen) from being lost due to leaching below the root zone of shallower rooted crops in the rotation. The pulses in rotation are not only responsible for biological nitrogen fixation, but they also improve nutrient availability. The association of pulse crops roots with VAM helps in increasing availability of nutrients and water to crop plants. The degradation of pulse crop residues add nutrients as well as made other fixed nutrients into plant available form. Organic acids released by pulse crop root in soil also mobilizing un-available soil nutrients like P and K. Chickpea is known to release citric acid and pigeonpea piscidic acid which react with Ca and Fe bind P and make available to plant (Table 4). Further, ability of pulses to fix atmospheric nitrogen plays a great role in N- recycling in agro-ecosystem.

Table 4. Organic acids released by different pulse crops

Crop	Organic acid	P fraction used
Pigeonpea	Piscidic acid	Fe-P
Chickpea	Citric acid	Ca-P
Lupin	Citric acid	Fe-P
Alfalafa	2-(3 S dihydroxy phenyl)-5,-6-dihydroxybenzofuran	Fe-P
Soybean	Citric, malonic acid	Ca-P

(Source: Ae *et al.* (1990 and 1993) and others)

Besides green manuring with pulse crops being a part of integrated nutrient management system, would enhance the efficiency of applied fertilizer and helps in raising the organic matter contents in the soil. It also favourably improves the availability of other plant nutrients. Many researchers have reported that pulses are potentially important to diversify cereal based mono cropping into cereal-pulses sequences which had nutrient cycling advantages.

6. Improve soil quality

Pulses have taproots that open pathways deep into the soil which improve soil physical condition. The improvements are mainly due to increase in stable soil aggregates. The protein, glomalin released by roots of pulses and other plants, serves as “glue” that binds soil together into stable aggregates. This aggregate stability increases pore space and tilth, reducing both soil erodibility and crusting. Similar, effects were recorded in two long-term trials at IIPR, Kanpur in rice-chickpea, rice-wheat-mungbean and maize-chickpea, pigeonpea-wheat and maize-wheat-mungbean system in comparison to rice-wheat and maize-wheat, respectively. A considerable residual impact of pulses on improvement in soil fertility could be brought by inclusion of pulses in crop sequence. It is also observed that pulses harboured higher microbial load except Azotobacter as compared to cereals or fallow. Pulses also contribute to an increased diversity of soil flora and fauna lending a greater stability to the total life of the soil. Pulses foster production of a greater total biomass in the soil by providing additional N. Soil microbes use the increased N to break down carbon rich residues of crops like wheat or corn. Yusuf *et al.* (2009) observed that soil microbial biomass C (MBC) and N (MBN) increased by about 30 and 200%, respectively, when maize (*Zea mays* L.) was rotated with cowpea compared to monoculture maize. Further, root exudates released by pulses and organic matter added to the soil make unavailable soil nutrients in plant available forms. Pulses acquire their N from the air as diatomic N rather than from the soil as nitrate, their net effect is to lower the pH of the soil. At favourable pH, both soil microbial activities and plant growth increase considerably.

7. Pulses in rice fallow

Growing rice is the predominant activity for farmers during the *kharif* season in most parts of south Asian countries. It is grown in both irrigated and rainfed conditions under various cropping systems. About 11.6 million hectares of land in India remains fallow after rice harvest during rabi/winter season due to number of biotic, abiotic and socio-economic constraints. Despite of ample opportunities, rice fallow systems did not get enough attention in the past. A number of abiotic factors related to soil and water lead to low productivity of grain legumes in rice fallows during past several years. Low moisture content in soil after rice harvest followed by fast decline in soil moisture with the advancement of *rabi* season results in mid- and -terminal drought at flowering and pod filling stages which adversely affects the productivity of grain legumes. Due to anaerobic conditions in rice cultivation, many of the organisms including rhizobia would not be able to survive. Besides the inherent constraints, rice fallows also affect seed germination, seedling emergence and crop establishment due to disruption of soil structure, soil water deficit, poor aeration and mechanical impedance of the seed zone. This hostile environment creates potential threat to microbial activity, nutrient availability, root growth (root is mostly confined in top soil layer) and water and nutrients uptake, thus sub-soil resources in rice fallows remain unutilized.

Pulses with properties like low input requirements, short duration, ability to establish even with surface broadcast in standing rice fields (para/utera cropping) and soil fertility restoration are ideal crops for rice fallow agro-ecosystem. They have ability to fix atmospheric nitrogen and thus improve/restore soil fertility of sick soils which developed due to continuous cultivation of rice crop. If this area is brought under cultivation it may benefit millions of poor and small farmers solely dependent on agriculture for their livelihood. Productivity and profitability from grain legumes in rice fallows can be improved with suitable crop management technique even by utilizing residual soil moisture. By adopting improved technologies like resource conservation, short duration disease resistance improved varieties, timely sowing, plant population, biofertilizers inoculation, fertilizer application, timely weed management practices, need based plant protection measures coupled with proper irrigation schedule (life saving) would definitely increased the yield of grain legumes in rice fallow agro-ecological situation (Kumar *et al.* 2016a). Further, resource conservation technologies which deal with soil moisture conservation, organic matter build-up, improvement in soil structure and microbial population could be an appropriate approach to address these problems in rice fallow. Therefore, if crop residues are retained on the soil surface in combination with suitable planting techniques (no-till planting or paira cropping), it may alleviate terminal drought/heat stress in pulses by conserving and regulating soil moisture (Kumar *et al.* 2013; Kumar *et al.* 2016b). Minimum soil traffic by adoption of suitable technology involving no-till and minimum soil disturbance and management of crop residues (conservation tillage) could lead to favourable effect on soil properties that further conserve the soil moisture to a longer period for plant use (Kumar *et al.* 2014). Conservation tillage with proper crop residue management is reported to reduce soil water evaporation, soil sealing and crusting (Kumar *et al.* 2016a). It is also evident that hydraulic conductivity under straw-retained in no-till drill is many times higher than that of conventional tillage. In fact higher yield of lentil after wet season (rainy season) rice with conservation tillage was also reported by Bandyapadhyay *et al.* (2016) under rainfed area of eastern India. This will also reduce cost of cultivation through savings in labour, time and farm power, and improve input-use efficiency. Traditionally, seeds of pulses (lentil, lathyrus, mungbean and urdbean) are broadcasted in standing rice (para/utera cropping) field without any tillage. Under such situation, 20-30 cm rice stubble needs to be maintained in the field to get advantage similar to conservation tillage. In areas where pulses are sown after harvest of rice with land preparation, zero-till seeding may be advocated as it facilitates advance planting by 7 to 10 days and saves energy and labour. Under soil moisture stress, movement of plant nutrients from soil is a limiting factor for plant growth and yield. Under such situation, foliar nutrition of 2 per cent urea and micro-nutrients may be used to mitigate the effect of soil moisture stress to certain extent.

8. Pulses effect on environment

Agriculture is one of the major sources of the greenhouse gas (GHG) emission, soil water pollution, and also the major consumer of fossil energy. The projected environmental change will certainly impact on productivity and sustainability of agricultural production systems in near future. A higher reliance on cereal-based rotations may lead to higher agronomic and ecological risks in the background of global climate change. According to the Newton *et al.* (2011), to improve the crop resilience to biotic and abiotic stress there is a need to increase the heterogeneity (both temporal and special) into the cropping system. Pulses in the cropping system can play a vital role in ecosystem services. Inclusion of pulses in intensive cereal-based crop rotations curtails the rate of N fertilizers, subsequently reduces the energy use, and GHG emission per unit cropping area. Likewise, pulses can minimize the use of fossil energy as well as reduce the N losses. Based on a comparative assessment of N-fixation by pulses and industrial fertilizer manufacturing, Crews and Peoples (2004) concluded that the ecological impact of pulses N fixation is positive. The low C: N ratio of legume residues increases the retention of soil C and N, and improves environmental quality. However, legumes cultivation sometimes favors higher N_2O emission. The main processes involved in the N_2O emission in legumes are rhizobial denitrification within nodule, nitrification/denitrification of biologically fixed N and decomposition of N-rich pulses. Added to this, the altered N dynamics with the symbiotic N fixation may cause N losses like NO_3^- leaching. Intercropping of grain legumes in cereals can reduce nitrate leaching. Sugarcane + urdbean and pigeonpea + maize resulted in low nitrate nitrogen leaching as compared to sole cropping of sugarcane and maize (Yadav 1982). In addition, inclusion of short duration summer grain legumes reduces fallow period between two crops (rice-wheat) and thus, reduces C-loss during hot summer and enhance C-sequestration of a system.

9. Conclusion

Adoption of Resource Conservation Techniques leads to sustainable improvement in soil health, nutrient and water use efficiency. RCTs reduce the pollution of environment from the less use of chemicals and pesticides. Thus, RCTs will play pro-active and decisive role in developing sustainable agriculture production system, where every person has the economic and physical access to supplement food for all times with environmental security. Conservation agriculture, which is mainly based on the three principles of minimum soil disturbance, permanent soil cover and crop rotation, has shown to improve, conserve and use natural resources in a more efficient way through integrated management of available soil, water and biological resources. It is now widely recognized as a viable concept for sustainable agriculture due to its comprehensive benefits in economic, environmental and social terms. Its ability to increase grain yields to provide better economic performance and reduce production risks and improve energy use efficiency has been well recognized.

10. References

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Heavy metals restraining nutrient use efficiency in cereals and pulses

M L Dotaniya

ICAR-Indian Institute of Soil Science, Nabibagh, Berasia Road, Bhopal 462 038, India
E-mail: mohan30682@gmail.com

ABSTRACT

Heavy metal pollution is an emerging with time and reduces the chances of healthy food production from natural resources. Heavy metals are toxic in nature and caused various types of malfunction in plant, animal and human bodies. Some heavy metals are essential for plant growth in lower level; but higher level showing toxic effects on plant growth. Heavy metals are also having carcinogenic, mutagenic, malfunctioning, teratogenic and mostly affected the neurological, liver and kidney function. Increasing population with higher pace needs food from the fixed cultivated land. It reduces the fertilizer use efficiency by affecting various plant metabolic process as well as nutrient supply from soil solution to plant parts. It is a great challenge for the researcher and policy maker that in one side mitigating the food crisis without contamination of natural resources. The waste generation per capita increased with tremendous rate and vice versa fresh water resources shrinking. Needs of management for waste water (WW) or metal contaminated soils are for the sustainable crop production. The various heavy metal remediation techniques are using for the removal of metals from environment. Among the techniques, bioremediation techniques are eco-friendly in nature, in situ, low cost and energy saving. Phytoremediation techniques are green techniques with a wider scope of contaminate removal. The climatic changes are also affecting the crop and soil production capacity; needs more research in abiotic stress.

Keywords: Geo-accumulation index; Heavy metals; Human health; Phytoremediation; Sustainable Crop Production

1. Introduction

Sustainable crop production is a demand of today agriculture. From the old age agricultural practices were having an immense natural resources and less pressure for the food grain production. As the growing human and animal population, the per capita pressure on natural resources, increasing with the pace of time. The fast industrialization, increasing burning of fossil fuels, poor management of natural resources and low awareness among the peoples towards environment promotes the pollution in natural resources. Indian population growing higher annual rate and needs 280 million tone food for fulfilling the hungry mouth of the country in 2020. If we consider at global level, it is much more than the potential capacity of natural resources. To mitigate the food crisis, we can follow: 1) use the poor quality natural resources 2) Use high potential genetic crop varieties 3) Sustainable management of natural resources. The use of poor quality water for crop production reduced the soil fertility potential of soil and ultimately produced poor crop. This is also toxic to human help, due to the presence of various heavy metals. Theses metals in trace amount affected the living systems, physiological function and in higher level caused the death also. In soil, the presence of heavy metals affected the plant nutrient transformation and enzymatic activities in soil (Dotaniya *et al.* 2016f). The restriction of nutrient transformation reduced the plant nutrient supplying capacity of soil, as a result poor crop production.

Heavy metals are metal and metalloids having higher density compared to water (Dotaniya *et al.,* 2016). A metal having specific gravity more than 5.0 or atomic number higher than 20 (calcium-Ca) is termed as heavy metal (Dotaniya *et al.* 2013e). It is the main group of inorganic contamination in a larger land, mostly due to application of sludge and sewage, municipal waste, through agricultural inputs, metallurgical industries and mining (Rajendiran *et al.* 2015; Lenka *et al.* 2016; Dotaniya and Saha 2017). These include metal and metalloids of chromium (Cr), cadmium (Cd), nickel (Ni), lead (Pb), mercury (Hg), arsenic (As), selenium (Se) and zinc (Zn). Apart from these, other heavy metals are also important, but these are having less account of human and plant health i.e., aluminum, cobalt, molybdenum. Among the heavy metals, few are necessary for the completion biochemical cycles in plant, animal and human systems (Ajay *et al.* 2012; Pingoliya *et al.* 2015). Heavy metals are also having the lowest level of concentration in soil, but it causes major effect of biotic life cycle (Dotaniya *et al.* 2014h). Heavy metals are carcinogenic in nature; therefore, its decontamination from a system is a necessary for the sustainable crop production or a healthy environment.

2. Heavy metals

On the basis of heavy metal originated and mode of dispersing into other systems are classified into the following groups. A list of heavy metal sources and its effect on human health are described in Table 1.

2.2. Geogenic

Such type of sources, includes the heavy metal toxicity from its origin of soils from rocks. The produced toxicity of heavy metals is in soil or in groundwater (Dotaniya *et al.* 2014h; Dotaniya *et al.* 2016c). With the help various soil and crop management practices; contaminated soil can be used for crop or forest plant cultivation. The as toxicity in Bangladesh and West Bengal of India is a good example of geogenic source of As metal. The weathering of natural rocks, erosion and volcanic eruptions are major sources of geogenic activities. Few pockets across the globe having geogenic sources of heavy metals and with the anthropogenic activities, it is dispersed in other natural ecosystems (Dotaniya *et al.* 2016d).

Table 1. Source and effect of heavy metals on human health (Singh *et al.* 2011)

Metals	Major source	Effect on human health
Arsenic	Pesticides, fungicides, metal smelters	Bronchitis, dermatitis, poisoning
Cadmium	Welding, electroplating, pesticides, fertilizers, Cd and Ni batteries, nuclear fission plant	Renal dysfunction, lung disease, lung cancer, bone defects, increase blood pressure, kidney damage, gastrointestinal disorder, cancer
Lead	Paint, pesticide, smoking, automobile emission, mining, burning of coal	Mental retardation of children, developmental delay, congenital paralysis, sensory neural deafness, acute and chronic damage of the nerve system, liver, kidney, gastrointestinal.
Mercury	Pesticides, batteries, paper industry	Tremors, gingivitis, minor psychological changes, spontaneous abortion, damage to nervous system, protoplasm poisoning.
Chromium	Mines, minerals, leather industry	Damage to the nervous system, fatigue, irritability
Zinc	Refineries, brass manufacture, metal plating, plumbing	Zinc fumes have a corrosive effect on the skin, cause damage to nervous membrane
Copper	Mining, pesticide production, chemical industry, metal piping	Liver and kidney damage, stomach and intestinal irritation.

2.3. Anthropogenic sources

Heavy metals are extracted from point sources or from geogenic sites for utilization in different activities. The contamination in the environment may be due to natural as well as anthropogenic activities. The activities of mining, smelting and electroplating and other industrial units are discharging significant amount of metals into natural systems. The leather industries are using chromium sulfate and discharging noteworthy amount of Cr into effluent. This effluent is used for the cultivation of crops and other agricultural purpose; mostly in water scarce areas. Dotaniya *et al.* (2014c) reported that long- term application of leather industrial effluent for crop production accumulated 25-30 % more Cr in soil than tube well irrigated fields. Similarly, other industries like Pb, Hg, Cr, Ni, Cd, Zn, As, Se are also contributing a meaning amount of metals into natural ecosystems. Apart from these, various heavy metals are used for preservation of wood and other household activities.

The use of sewage water or biosolids for the cultivation of vegetable in peri-urban areas of mega cities are also a source of heavy metal accumulation in soil (Dotaniya *et al.* 2013f; Dotaniya *et al.* 2016h). Due to progressive industrial developmental activities and increasing population growth, huge volume of domestic sewage water is being produced in mega cities. On an average approximately 90% of generating wastewater (WW) at the global level is left untreated, causing extensive water contamination, especially in developing countries. Here the WW means industrial effluent, household WW and sewage effluent (Meena *et al.* 2015). It is cheaper to dispose such effluent in this way and provides water and nutrients to crop. Therefore, Indian agriculture is encountering the problems of irrigation water scarcity and rising cost of fertilizers, domestic sewage water generated from cities is the better option to successfully use for irrigation. Peoples are using WW for crop production and getting good yield due to the presence of organic matter and trace amounts in micronutrients; but in negative side these WW channels are also contributing heavy metals into the soil and human body via food chain contamination (Meena *et al.* 2013a; Dotaniya *et al.* 2015a).

One of the major sources of heavy metal contamination in soil and water bodies is through agricultural crop production inputs. In recent years, there has been increasing concern towards the health hazards through heavy metal contamination via food chain contamination (Dotaniya *et al.* 2014g). Fertilizers contain heavy metals as impurities; in this respect rock phosphate being a highly potential source. The contaminated soil or contamination through fertilizers impurities came into human and animal body and caused various types of malfunctions (Dotaniya *et al.* 2012a). The application of rock phosphate or its products during crop production in soil always implies the addition of a significant amount of Pb and Cd into the soil. The analysis of Pb and Cd from phosphatic fertilizers suggested that low grade and straight fertilizers having more chance of contamination than high analysis and mixed fertilizers (Dotaniya *et al.* 2014; Singh 2002). During the application of phosphatic fertilizers for crop production accumulated heavy metal concentration on the surface of the soil and easily available to plants. The surface retention of heavy metals is more chances to contaminants the water bodies during rains and via soil erosion. In soils with coarser textures and acidic reaction, are having greater chances of heavy metal availability than finer texture (contain more amount of clay) and with the alkaline reaction medium. It is very interesting to note that less than six percent of annual deposition of Cd in the soil of the European Economic Community comes, due to the use of phosphate fertilizers; with a further two per cent from phosphoric acid manufacture. Whereas, two third is contributed from solid wastes and excrement, aerial deposition and use of pigments and stabilizers (Anonymous 1992).

3. Geo-accumulation index

The heavy metal contamination in soil due to wider sources and whether these soils are heavy metal contamination or not. In this index the metal concentration with respect to uncontaminated soil are used for the cultivation of toxicity. Geo-accumulation index (I_{geo}) is widely used for assessing heavy metal contamination in sediments (Ball and Izbicki 2004; Chabukdhara and Nema 2012), dust (Kong *et al.* 2011); and trace metal pollution in agricultural soils (Wei and Yang 2010). The geo-accumulation index was calculated using the following formula described by Muller (1969).

$$I_{geo} = \log_2 \frac{C_n}{1.5\,B_n}$$

Where, I_{geo} stands for the geo accumulation index; C_n is the soil trace metal concentration (mg kg^{-1}) and B_n geochemical baseline concentration (mg kg^{-1}) i.e. the mean trace metal concentration in the uncontaminated soils. The soil sample with $I_{geo} \leq 0$ indicates unpolluted and classified under class I. Similarly, I_{geo} values 0-1, 1-2, 2-3, 3-4, 4-5 and >5 indicates unpolluted to moderate polluted (class II), moderate polluted (class III), moderate to heavily polluted (class IV), heavily polluted (class V), heavily to extremely polluted (class VI) and extremely polluted (class VII), respectively.

4. Metal transfer factor

The contaminated soil or water using for the cultivation of food crops and the transfer of heavy metal soil to the human body via food chain contamination. To calculate the heavy metal toxic effect in the human body the metal transfer factor and hazard quotient (HQgv) are calculated for the safe utilization of metals through dilatory intake. The metal transfer factor showed the heavy metal concentration in edible part of leafy vegetables. It is a simple ration between metal concentrations in the plant part (on dry weight basis) from soil. The DTPA extractable concentration of heavy metals in soil is considered for computation of metal transfer factor. Risk assessment of heavy metal is calculated with the help of hazard quotient for the intake of leafy vegetables like palak, mustard, coriander; those are growing in effluent irrigated soil were computed with the help of Pierzynski *et al.* (2000).

$$HQ_{gv} = \frac{add}{RfD}$$

Where HQgv is the hazard quotient to a human from consumption of green vegetables, add: the average daily dose (mg metal per kg body weight per day) and RfD the reference dose. The values of RfD for Zn, Ni, Cd, Pb and Cr were used as 0.3, 0.02, 0.001, 0.0035 and 0.003 mg kg^{-1} body weight day^{-1}, respectively (IRIS 2015). For Cu, value of provisional maximum tolerable daily intake is 0.5 mg kg^{-1} body weight day^{-1} (WHO 1982) and the same is used as RFD (Alam *et al.* 2003). Daily intake of green vegetable was considered as 0.2 kg^{-1} person day^{-1}; which is recommended amount from a nutritional point of view (Hassan and Ahmed 2000). A factor of 0.085 was used to convert the fresh to dry weight of these green vegetables. Average body weight for an adult was considered as 70 kg (USEPA 1991). Average daily dose (add) was computed using following relationship:

$$add = \frac{mc \text{ X } cf \text{ X } di}{bw}$$

Where mc is the metal concentrations in plant (mg kg^{-1}) on dry weight basis, cf the fresh to dry weight conversion factor, di the daily intake of green vegetable (kg) and bw the body weight (kg). Assessment of risk as computed here is not complete since, metal accumulation to soil organisms, groundwater, surface water, direct uptake of soil by human and animal are some of the other risks which have not been considered here.

5. Effect of heavy metals on plant, human and animals

5.1. Lead

It leads to mental retardation of children, developmental delay, congenital paralysis, sensory neural deafness, acute and chronic damage of the nerve system, liver, kidney, gastrointestinal in human. In the present context, use of nanomaterial for the removal of Pb from water bodies is a major area of research at the top of the global issues. Use of titanium oxide and hematite nanoparticles is the foremost, for the 100% recovery of the Pb ions. This efficiency also affected by the pH and contact time; which is d" 6 and e"60 min, respectively, for the typical optimum conditions for Pb removal of water bodies. The recovery per cent also affected by adsorbent dose for the adequate surface area and number of adsorption sites (Bhatia *et al.* 2016).

5.2. Mercury

It is also a toxic metal is associated with kidney damage. Hair fall in early age a symptom of Hg toxicity. Apart from these, Tremors, gingivitis, minor psychological changes, spontaneous abortion, damage to the nervous system, protoplasm poisoning are also happing due to Hg toxicity. It is mostly in Hg industries WW utilization for fish and crop production.

5.3. Arsenic

This heavy metal problem aggravated mostly as chronically in Bangladesh, India, Chile, Mexico, Taiwan and part of West Bengal of India. These countries are suffering due to geogenic concentration of As and also use of As contaminated groundwater for consumptive use. The natural level of As in soil mostly range from 1 to 40 ppm, but use of pesticides or As contaminated waste, enhanced the level and caused toxicity (Tchounwou *et al.* 2004). Arsenic exposure much affected the mechanism of organs, including cardiovascular, renal, bronchitis, nervous and also respiratory disease in human(Tchounwou *et al.* 2003). Many cases are reported in affected due to higher intakes of As through drinking water or via food chain contamination. The higher level caused the cancer of kidney, gall bladder, liver in major affected areas. The severity of ill effect on health of plant, animal and human health is closely related to the chemical form of As and time and level of dose. In the harmful effect situation As (V) replaced the phosphate ions, which key to many biochemical pathways in different organ systems. The inorganic trivalent arsenite is 2 to 10 times more toxic than pentavalent arsenate for the human system. The binding of the thiol or sulfhydryl groups on protein; As (III) can inactive more than 200 enzymes (Hughes 2002).

5.4. Cadmium

In general, Cd is inhalation of cigarette smoke and also ingestion of Cd contaminated food materials. In other specific routes like peoples are working in metal industries, working at a Cd contaminated workplace and also eating or drinking with contaminated hand are the sources of Cd in the human body. The vegetables are growing in the Cd contaminated WW nearby peri-urban areas of major cities are having more chances of metal contamination. The Cd negatively affected the lung, bone and increased the blood pressure and higher dose can cause cancer and mortality. In plant system, Cd reduced transportation of food material from root to shoot, by damaging the root tissues. The blackish-brown root or necrotic root is a clear cut symptom of Cd toxicity in plants. The chronic inhalation exposure of Cd associate with the malfunction or decrease in the pulmonary and olfactory functions (Mascagni *et al.* 2003). The level of Cd in the body measured through the presence of Cd concentration in blood or urine. Both the blood and urine contaminated Cd is higher in highly cigarette smokers.

5.5. Chromium

It is a carcinogenic metal. Occupational exposure is a major concern for the Cr induced disease in industrial worker due to hexavalent Cr (Guertin 2005). Long-term exposure can cause kidney and liver damage, and damage to circulatory and nerve tissue. It is estimated that 33 tons of total Cr are released annually into the environment, which a matter of health concern. The US Occupational Safety and Health Administration (OSHA) fixed a safe level 5 µg m^{-3} for 8 hours working at the industrial work place. This level also may still pose a carcinogenic risk in the human body. In crop plants Cr reduced the germination rate, root and shoot growth in wheat (Dotaniya et al. 2014d) and pigeon pea (Dotaniya *et al.* 2014f).

6. Heavy metal chemistry in soil

6.1. Lead

It is a bluish gray, a constituent of the earth's crust ranged from 10 to 67 mg kg^{-1} and belonging to group IV and period 6 in the periodic table. It has atomic number 82 and density 11.4 g cm^{-3} with atomic mass 207.2. It is naturally occurring, but due to massive anthropogenic activities like burning of fossil fuels, metallic mining, industrial waste disposal spread the Pb concentration into the environment. The application of Pb in day to day life is more prominent mostly in industrial and domestic equipment. In nature, it is found in combination with other elements like sulfur (Pbs, $PbSO_4$); oxygen ($PbCO_3$) (USDHHS 1999). In nature, ionic form of Pb, Pb(II) and various types of oxide and hydroxide as well as lead metal oxyanion complexes are in the general form of Pb, which is mainly contributed in soil, surface and groundwater across the global length and width. The most common stable form of Pb is Pb(II); it is forming mononuclear and polynuclear oxides and hydroxides in major soil groups (GWRTAC 1997).

Lead ranked fifth place after Fe, Cu, Al and Zn in the list of industrial production of metal and metalloids. Major part of Pb used in batteries; apart from this solders and pipes, electric cable covers, bearing , tyre manufacturing, pigmentation, pulmbering, shield X-rays and caulking. Very high concentration of Pb in soil affected the soil process and is necessary to produce toxic response. It is fixed in soil by hydrolysis and polymerization mechanisms. Some of the metals are commonly alloyed with Pb are: 1) in storage batteries- antimony; 2) Ca and Sn in maintenance free storage electric batteries; 3) in solder and anode work silver metal is mostly used; 4) as anodes in electrowinning process with Sr and Sn; 5) tellurium during the process of pipe and sheet in chemical installation as well as nuclear shielding (Manahan 2003). The fraction of Pb from these metal industries is released into effluent and reached ultimately soil and water bodies. Soil factors such as high cation exchange capacity, alkaline pH, high organic matter, and P-content in the soil antagonizes Pb uptake by plants. The various types of soil also affected the availability of Pb metal for plant availability and also affected the soil critical limit for toxicity. It implies that if wastes rich in phosphorus (P) and organic matter (such as sewage water and sludge) are applied to the soil, very little hazards due to Pb are expected.

6.2. Chromium

Chromium is the 21st most abundant element in the earth's crust (Dotaniya *et al.* 2014h). It occurs in nature inbound forms that constitute 0.1–0.3 mg kg^{-1} of the earth's crust. It has several oxidation states ranging from Cr (-II) to Cr (+VI). It exists predominantly in the Cr^{+3} and Cr^{+6} oxidation states. The most stable oxidation state of Cr is Cr(III), and under most prevailing environmental conditions Cr (VI) is rapidly reduced to Cr (III). The intermediate states of +IV and +V are metastable and rarely encountered (Lokhande *et al.* 2011). The Cr(III) is strongly adsorbed on soil particles whereas, Cr(VI) is weakly adsorbed and is readily available to plant uptake or leaching to groundwater (James and Bartlett 1983). Plants don't accumulate a significant amount of Cr from soil in high concentrations. Thus, plants can tolerate higher amounts of Cr present in soil due to accumulate by long- term application of sewage or sludge. When the Cr was applied through hexavant for in soil; with the soil constituents, it rapidly converted into non -toxic form of Cr (III) as insoluble hydroxides or oxides. Suitable conditions for Cr (VI) reduction occur where organic matter is present and act as an electron donor, and Cr (VI) reduction is enhanced in acid rather than alkaline soils mentioned in Eq. 1 (Bartlett and Kimble 1976; Bolan *et al.* 2003).

$2Cr_2O_7 + 3C^o + 16H^+ \rightarrow 4Cr^{3+} + 3CO_2 + 8H_2O$…… Eq. 1

From the global research side many researchers find out the effect of organic matter or organic rich soil amendments for the reduction of Cr toxicity by transforming Cr(VI) to Cr(III) (Dotaniya *et al.* 2015b). Losi *et al.* (1994) reported that addition of cattle manure reduced the potential Cr toxicity from Cr(VI) to non toxic Cr (III) in soil. The presence of organic matter supply the C and protons and also stimulated the growth of soil microorganisms; which mediated and facilitate the Cr reduction process Cr(VI) to Cr(III) (Losi *et al.* 1994).

6.3. Cadmium

It is one of the toxic metals in nature located in transition element category. It is having atomic number 48 with density 8.65 g cm^{-3}. In nature exist as Cd (II) ion. It is having similarity with essential element of Zn, which is essentially required for plant and animal systems for potential growth. This may account some time, due to deficiency of Zn, plant takes up Cd as a substitution of Zn and affected the metabolism of plants (Campbell 2006). Cadmium is one of the most toxic elements not having any well known essential physiological functions in plant and human. At low concentration in soil, is toxic to a number of plants. Accumulation of Cd varies with plant species, varieties and plant part under consideration and soil properties. Cadmium has a tendency to accumulate more in a leafy part rather than in fruits and grain/seeds. Factors such as soil pH, applied fertilizers, presence of other heavy metals, temperature and soil organic matter expert a profound influence on Cd uptake by plants. Although incidence of *itai-itai* disease in the Jintsu valley of Japan occurred because of the high Cd content of rice, reducing soil conditions hinder the uptake of Cd by rice. Anaerobic conditions during the grain filling stage depress the Cd content of grains (Singh 2002). Most common use of Cd in Ni-Cd electric batteries for rechargeable or storage for secondary purpose; due to high output, durability, low wearing and tearing, and larger tolerance to physical and electrical fluctuations. Cadmium also utilizes for the better corrosive resistance coating most of the marine equipments i.e., vessels & vehicles.

6.4. Nickel

It is a transitional metal having atomic number 28 and atomic weight 58.69. It is much affected by the soil- water pH. Most of the low pH regions, is found as nickelous ion, Ni(II); whereas in neutral to slightly higher pH soils precipitate as stable compound nickelous hydroxide, $Ni(OH)_2$. This stable compound readily soluble in acid environment and formed Ni(III) and in high alkaline conditions formed nickelite ion, $HNiO_2$, which is soluble in water. In the very oxidizing and the alkaline environment Ni found in the form of stable nickel-nickelic oxide, Ni_3O_4, is easily soluble in acid solvents. In highly acidic condition various types of Ni oxides i.e., nickelik oxide, nickel peroxide, Ni_2O_3 is converted into Ni^{2+} ions (Wuana and Okieimen 2011). Nickel content in the range of 50-100 mg g^{-1} (dry weight basis) is indicative of its toxicity to plants. Nickel behaves largely like essential plant nutrient Zn in the soil-plant system, but it forms stronger chelates with soil organic matter, thereby showing closeness to Cu. Possibility of Ni-toxicity to plants can’t be ruled out when industrial or municipal wastes with high Ni concentrations are applied to agricultural lands. Nevertheless, like Zn and Cu, phytotoxicity of Ni appears to provide an effective barrier against Ni toxicity to human population and animals.

6.5. Mercury

It is also one of the toxic metals in the human and animal systems. It belongs to the same group of Zn and Cd in the periodic table with atomic number 80 and mass 200.6. It is liquid in nature and mostly recovered during the ore processing (Smith *et al.* 1995). In environment major contribution through combustion of coal and release from manometers located at gas or oil pipelines. Mostly in the environment, is present in mercuric (Hg^{2+}), mercurous (Hg_2^{2+}), elemental (Hg^o); and also in alkylated form as methyl or ethyl mercury. Mercury is more toxic in alkylated form, because these are soluble in water and volatile in air (Smith *et al.* 1995). All most cases the form of Hg depends on the redox potential and pH of the existing environment. For example, under oxidizing condition Hg^{2+} and Hg_2^{2+} more stable; whereas under reducing conditions, organic or inorganic Hg may be converted to elemental Hg than again converted to alkylated forms by a biotic or abiotic process of nature. Mercury (II) formed strong complex with the organic and inorganic ligands present in the environment; which is easily soluble in oxidized aquatic systems (Bodek *et al.* 1988; Wuana and Okieimen 2011). In the uncontaminated environment, its concentration in plant part seldom exceeds 500 parts per billion (ppb). In naturally contaminated areas i.e., near Hg bearing deposits, its level can be as high as 3500 ppb. Many agricultural crop inputs are having significant amounts of Hg like fungicide Ceresan M. Mercury is strongly held by the soil particles at various adsorption sites for the element never approach saturation before another toxic element becomes hazardous. The Hg content in the aboveground part of plants is very low except Hg seed treatment or its addition to soil. Most of the cases, Hg toxicity was reported in aquatic food chains compared to intensive agriculture. For the removal of Hg from solution; sorption to soil, sediment and humic containing material is playing a valuable mechanism. Increasing the pH of the system, increasing the sorption mechanism. Removal of Hg from solution may be recovered by co-precipitation with sulphides and under low oxygen conditions anaerobic microorganisms specially sulfur-reducing bacteria converted organic and inorganic forms of Hg to alkylated form. In anaerobic conditions, elemental Hg also transformed into demethylation of methyl-Hg or by reduction of Hg(II). In high acidic condition $pH<4$ preferred the formation of methyl mercury; and higher pH range favor precipitation of HgS(s).

6.6. Arsenic

Arsenic is classified under the metallic group of VA and period 4 in the periodic table associated with other minerals the widely; mainly as As_2O_3. It has atomic number 33 and atomic mass 75 and exists in various forms of oxidation (i.e., -III, 0, III, V). Most of the aerobic environment, As(V) is the dominant species in the form of arsenate (AsO_4^{3-}) in the different protonation states like: H_3AsO_4, $H_2AsO_4^-$, $HAsO_4^{2-}$ and AsO_4^{3-}. It is recovering during the ore processing Cu, Pb, Zn, Ag and Au. Arsenic builds up in the natural soil environment through natural processes of weathering of As bearing bocks or As contaminated ground water used for crop production as a mean of irrigation. Apart from these, anthropogenic activities such as mining operations, burning of coal, smelting of base metal ores and application of As containing agricultural inputs. The concentration of As in world soils varied widely. In common, soils overlying sulphide ore deposits or derived from shales and granites and those surrounding geothermal activity, have high As contents. Arsenate and other anionic form of As act as a chelates and precipited with the presence of cations (Bodek *et al.* 1988). In West Bengal, water samples from about 55% tube wells have been found to contain As in a concentration greater than 10 µg L^{-1}; which is the maximum permissible limit of the World Health Organization (Chowdhury *et al.* 1999). The soils being irrigated with As-contaminated waters have already started showing the presence of 6-10 mg kg^{-1} of EDTA extractable As. Arsenic retention by soil is mainly performed by the adsorption mechanism rather than the precipitation of sparingly soluble As compounds.

The toxicity of As depends on soil environment by the oxidation states and its presence with organic and inorganic combinations. The oxidation states of As metal affected by pH and redox potential. The As mobility increases with increase in soil pH (Reed *et al.* 1995). The arsenates are very soluble, mobile and toxic than the arsenates. The biological availability and phytotoxicity of As in soil increases on reduction of the As (III) state, which is facilitated on the flooding of the soils. The As the uptake pattern is highly affected by crop, varieties, soil chemical environment and some extent by climatic factors. The lowland rice more susceptible to As toxicity than upland rice.

6.7. Zinc

It is an essential plant nutrient element and kept the place in the period 4, group IIB; having atomic number 30 and mass 65.4. It is also a transitional metal, occurring naturally in soil systems. Due to fast industrialization or other anthropogenic activities like mining, coal, waste combustion and use in steel processing activities enhance the Zn concentration in environment. The Zn availability varies with pH values. Increasing the soil pH, decreased the availability of Zn in soil and reduced the concentration in soil solution towards plant uptake. In higher pH condition, presence of carbonate and bicarbonates; is precipitate into unavailable forms and induced the Zn deficiency in soils (Dotaniya and Meena 2013).

7. Use of poor quality water in cereal and pulse production

The world 76 million hectare lands under cultivation of pulses with a 68 million tone production and average productivity is 800 kilogram per hectare. India contributing 33 per cent area with 22 per cent production and average productivity is below world level is 764 kg ha^{-1}. This production level is not sufficient to mitigate the increasing need of the empty stomach (Singh *et al.* 2016). Pulse production needs attention more now days. The year of 2016 celebrated as a 'year of pulses'. Increasing the pulse production from limited natural resources is a challenge (Singh and Pratap 2016) for researchers and policy makers. In one strategy, use of poor quality water for pulse production or cultivated degraded land with appropriate management practices in other side (Dotaniya *et al.* 2014g). The utilization of high salt containing for pulse cultivation injured plants due to salinity induced cationic and nutritional imbalance within the plants. Some examples are: excessive absorption of Na^+ ions can lead to a decrease in the absorption of Ca^{2+}, Mg^{2+} and K^+ ions; high concentration of bicarbonates in soil solution can induce iron chlorosis, and high pH in alkali soils might accentuate deficiencies of micronutrient cations. Increase in salinity and alkalinity in the soil can also adversely affect soil biology, mineralization of organic matter and transformation of plant nutrient dynamics, and also affected the nutrient chemistry of applied chemical fertilizers (Bajwa 2002). The use of WW also affected the biological nitrogen fixation (BNF) capacity of pulses. Al-Fredan (2006) reported that municipal mixed effluent was used in faba bean (*Vicia faba* L. cv. Hassawi) and found that it enhanced the BNF capacity of plant. Similarly,

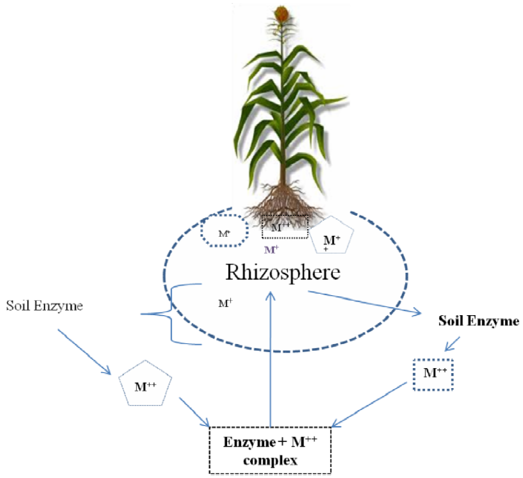

Fig. 1 Soil enzymatic activity process regarding metal uptake

another study was carried out by Chaudri *et al.* (2000) and observed that application of poor quality water or sludge reduced the N fixation capacity of faba bean. Heavy metal concentration reduce the microbial population and its process (biological N fixation) by *Rhizobia*; due to the toxic effect the symbiotic relationship break down and reduced N fixation in metal contaminated soil and effluent conditions (Vasseur *et al.* 1998; Barajas-Aceves and Dendooven 2001; Hernandez *et al.* 2003). The toxicity of heavy metals are also affected the soil enzymatic activities and reduce the availability of plant nutrient to plant. Soil enzymes play a crucial root in nutrient mineralization and enhanced the availability of nutrient especially micronutrient in deficiency conditions (Fig. 1). In this line poor quality water properly treated prior to application in pulse production. Pulse crops are more sensitive to heavy metals, salinity and other microbial attack compared to cereal crops. The saline water is predominant using in Rajasthan and Gujarat part of the India for the cultivation of pulse crops mainly gram. Such type of situation is more in developing countries like India, Pakistan, and Bangladesh etc. The fresh water aquifers are endangered due to excessive exploitation or contaminated with poor quality substances. Use of tannery industrial effluent in the Kanpur region for pulse crop or vegetable cultivation accumulated 25-30 times more Cr in soil as compared to freshwater irrigated fields (Dotaniya *et al.* 2014c). Few groundwater samples were also found contaminated with Cr. This situation reduced the pulse crop production in industrial contaminated water used for agricultural crop production. The various remediation methods are in practicing for remediation of accumulated heavy metals and other organic load by physical, chemical and biological methods (Saha *et al.* 2017l). Among the methods phytoremediation methods are eco-friendly, cheaper and required less skill (Dotaniya and Lata 2012, Dotaniya *et al.* 2012b).

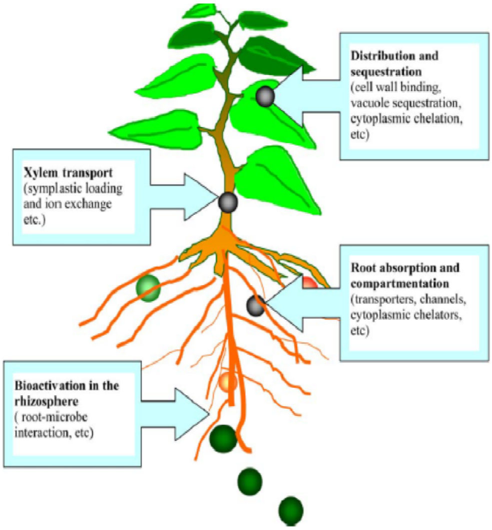

Fig. 2 Major process involved in heavy metal hyperaccumulation by plants (Yang *et al.* 2005)

8. Cellular mechanism for heavy metals

Most of the heavy metals are the toxic to plant systems except few. Largely heavy metals are low mobility in soils and having high adsorption with organic matter or silicate minerals. The plant uptake pattern is much affected by the presence of metal in soil and plant biochemical cycles. Hyperaccumulation in higher plant is a complex phenomenon and governed by various factors like 1) transported of heavy metals across the plasma membrane of root cells; xylem loading and translocation in various part of plants and; 3) heavy metal detoxification and sequestration at the plant and cellular level (Lombi *et al.* 2002).The first hyperaccumulators plants were identified by the family of Brassicaceae and Fabaceae; and the list of plants crossed more than 400 (Halim *et al.* 2003). These plants have a particular gene for the hyperaccumulation of metal or metals (Yang *et al.* 2005). Many of the plants accumulated a particular metal, and a few plants are having the capacity to accumulate more than one metal. Theses metal accumulator mechanisms are not fully understood; but the capacity of plants towards metal uptake is accounted. The intracellular mechanism of heavy metal uptake has also helped to understand the various metal uptake phenomenon's in soil plant dynamics. Some of the major processes influencing the accumulation rate in plants are defined in the Fig.2.

The hyper-accumulator plants showing the higher or extraordinary potential ability to absorb from the contaminated soil or aquatic systems and accumulated in various part of the plant (Ma *et al.* 2001; Yang *et al.* 2002). The metal uptake by a plant and total metal present in soil is not having a true correlation in the heavy metal dynamics. Knight *et al.* (1994) reported that no significant correction was observed between Zn accumulated by the *Thlaspi caerulescens* and total Zn metal in the soil. However, the close relation was also observed between metal concentration in plant shoot and metal concentration in soil solution. The bio-availability of metals are the part of total metal concentration and these fractions are truly represented of plant uptake. Plant roots and microbial population; and their interaction much determine the availability of a metal and also the form of metal in soil. The plants secreted the various types of low molecular organic acids through root exudates and act as a chelating agent or supply the food materials to soil microorganism (Dotaniya *et al.* 2013c,d). The interaction of microorganisms and plant roots can enhance the metal bioavailability in rhizosphere due to secretion of protons, amino acids, enzymes and phytochelatins. A part of proton extrusion of the roots is mediated by the plasma membrane H^+-ATPase and H^+ pump. The molecular

Table 2. Genes of transportation isolated from plants involved in heavy metal uptake

Genes	Plant	Elements	References
OsNramp1 OsNramp2	Rice	Mn	Belouchi *et al.* 1997
Cpx-type heavy metal ATPases	*Arabidopsis* rice	Cu, Zn, Cd, Pb	Tabata *et al.* 1997; Williams *et al.* 2000; Belouchi *et al.* 1997; Hirayama *et al.* 1999
Nramp	*Arabidopsis*	Cd, divalent metals	Belouchi *et al.* 1997; Alonso *et al.* 1999; Thomine *et al.* 2000
CDF family proteins	*Arabidopsis*	Cd, Co, Cd	Maser *et al.* 2001
ZIP family (ZAT1, ZAT2, ZAT3)	*Arabidopsis* *T. caerulescens*	Cd, Zn, Mn	Van der Zaal *et al.* 1999 Lombi *et al.* 2002; Pence *et al.* 2000; Assuncao *et al.* 2001

Table 3. Technologies for remediation of heavy metal contaminated soils (Wuana and Okieimen 2011)

Category	Remediation technologies
Isolation	i. Capping ii. Subsurface barriers
Immobilization	i. Solidification/stabilization ii. Vitrification
Toxicity and or/mobility reduction	i. Chemical treatment ii. Permeable treatment walls iii. Biological treatment bioaccumulation, phytoremediation (phytoextraction, phytostabilization, and rhizofiltration), bioleaching, biochemical processes.
Physical separation/extraction	i. Soil washing, pyrometallurgical extraction, in situ soil flushing, and electro-kinetic treatment

bases and various effects of these mechanisms are a matter of research regarding heavy metal removal by plant systems. The AtHMA4 is an *Arabidopsis thaliana* P-1B-ATPase is responsible for the transportation of Zn and Cd. Verret *et al.* (2004) described that AtHMA4 is located in the plasma membrane and expressed its effect on tissue surrounding the root vascular vessels. Yang *et al.* (2005) mentioned that the ectopic over expression of AtHMA4 positively influenced the root growth in the presence of toxic metals like Zn, Cd and Co. Whereas, a null mutant exhibited a lower translocation response in the plant root shoot system with regards to Zn and Cd metals. In plant nutrient deficient conditions, plant secreted the phytosiderophores can reduce the plant available metal form i.e., Fe^{3+}, Cu^{2+}, Cd^{2+} (Dotaniya *et al.* 2013c). The metal transportation from to contaminated sites to plant root membrane; and further in various plants part is mediated by a particular gene in a specific plant species. A broader understanding about the metal transportation process in plant is required for the better understanding for the formulating the effective strategies to develop genetically engineered plant species; that can accumulate higher amount of metal from toxicant. A range of gene is responsible for a particular metal or metals accumulation mentioned in Table 2.

9. Remediation techniques

The polluted environment can be remedied with the help of physical, chemical and biological techniques. Various types of remediation techniques are also categorized in various heads as per the mode of action listed in Table 3. In classical remediation of heavy metal from soil and water bodies with the help of chemical and physical technologies are available from ancient periods. With this techniques addition of chemical (chemical remediation's) which mobilize or immobilize the heavy metal contents from contaminated sites and in physical remediation excavations, capping, soil mixing, soil washing and solidification, mixing of contaminated soil with uncontaminated soil are included (Dotaniya *et al.* 2012b; Dotaniya and Lata 2012). In bioremediation techniques biological means are used for reducing the heavy metal toxicity. These techniques are having its on advantages and disadvantages as per the potential of remediation and cost.

9.1. Physical remediation

This type of techniques is applicable on particular form of metals. It consists of mechanical screening, floatation, electric and magnetic separation; and floation (Gunatilake 2015). The potential efficiency of these techniques are depends on soil properties, and type and extension of pollution. Some time contaminated soil is washed with good quality water. In highly metal polluted soils can be remediated by physical scrapper in which heavy metal contaminated upper layer of soils shifted to another place. Some time, uncontaminated soil mixed with contaminated soil to reduce the heavy metal concentration in lower side to grow the forage or crops. These methods are primarily important for check and balance mode for the soil and water pollution. It is almost necessary for before discharging polluted WW into soil or water bodies. In the heavy metal remediation point of view, is crucial for organic load containing metals or solid disposal in natural systems.

9.2. Chemical remediation

It is mostly used for the removal of heavy metal from a smaller area. In this heads consist of chemical precipitation, coagulation and flocculation, electrochemical treatments, ion exchange, membrane filtration and electrodialysis. The chemical precipitation method is one of the widely used methods; in which use of chemical formed insoluble precipitation with metals as hydroxide, carbonate, sulfide and phosphate ions. Fine particle coagulate into bigger particle and can be removed by physical methods. The coagulation and flocculation methods are based on zeta potential. Apart from these, electric field is also used for the remediation of pollutant

Table 4. Inorganic amendments for heavy metal immobilization (Guo *et al.* 2006)

Material	Source	Heavy metal immobilization
Lime (from)	lime factory	Cd, Cu, Ni, Pb, Zn
Phosphate salt	Fertilizer plant	Pb, Zn, Cu, Cd
Hydroxyapatite	Phosphorite	Zn, Pb, Cu, Cd
Fly ash	Thermal power plant	Cd, Pb, Cu, Zn, Cr
Slag	Thermal power plant	Cd, Pb, Zn, Cr
Ca-montmorillonite	Mineral	Zn, Pb
Portland cement	Cement plant	Cr, Cu, Zn, Pb
Bentonite	-	Pb

Table 5. Organic amendments for heavy metal immobilization (Guo *et al.* 2006)

Material	Heavy metal immobilization
Bark saw dust (from timber industry)	Cd,Pb, Hg, Cu
Xylogen (From paper mill wastewater)	Zn, Pb, Hg
Chitosan (from crab meat canning industry)	Cd, Cr, Hg
Bagasse (from sugarcane industry)	Pb
Poultry manure (from poultry farm)	Cu, Pb, Zn, Cd
Cattle manure (from cattle farm)	Cd
Rice hulls (from rice processing)	Cd,Cr, Pb
Sewage sludge	Cd
Leaves	Cr, Cd
Straw	Cd, Cr, Pb

from liquid medium. The opposite ions of metals are accumulated on the metal bearing cathode plate and insoluble anode. These methods are costly in nature required highly skilled persons.

In these techniques various substances comprised with organic and inorganic in nature are using (Dotaniya *et al.* 2016a). They are reacting with various heavy metals and converted into non -toxic or less available to plant and microbs. Some of the substances are responsible for the immobilization of a particular metal; whereas, few are using for more than one metals. The inorganic binder i.e., clay (bentonite or kaolinite), fly ash, basic slag, calcium carbonate and Fe/Mn oxides are described in Table 4; and organic stabilizers such as various type of manure, organic residues, composts and a combination of organic and inorganic substances listed in Table 5 may use for the immobilization of heavy metals. The use of organic residues for the plant nutrient mobilization (Dotaniya 2014; Dotaniya *et al.* 2015b) and also use for the reduction of heavy metal in soil. The organic residues decomposed with the help of soil microbial population and act as a biosorption (Dotaniya 2012; Dotaniya *et al.* 2012c). Low molecular organic acids released during the microbial decomposition of organic material by soil biota (Dotaniya and Datta 2014); bind the metal or decomposed the metal and ultimately reduced the metal toxicity. The other side of the decomposition it released the plant nutrients; which are also enhanced the crop plant immunity (Dotaniya *et al.* 2013b; Dotaniya *et al.* 2014a,b,e). The use of biochar reduced the metal toxicity particularly Cd in spinach crop (Coumar *et al.* 2016a, b). The efficiency of applied organic and inorganic substances is affected by climatic factors and soil parameters (Dotaniya 2013; Dotaniya *et al.* 2013a). The increasing the atmospheric temperature, enhanced the photosynthetic rate in low temperature regions and increased the root exudation in soil (Kushwah *et al.* 2014). Soil microbes take root exudates as a food material and increased the microbial population and diversity (Dotaniya and Kushwah 2013). It helps to reduce the metal toxicity towards plants. The carbon sequestration potential of soil enhanced the plant sustainability in abiotic stress condition (Kundu *et al.* 2013; Meena *et al.* 2016); due to more carbon help nutrient mobilization (Sharma *et al.* 2014a, b; Dotaniya 2015; Dotaniya *et al.* 2016e,g). The silicon fertilization in rice crop enhanced the abiotic stress and improved the crop yield (Meena *et al.* 2013b).

9.3 Bioremediation

It is a process of removal of heavy metal from polluted soil and WW with the help of biological techniques. The techniques are classified into 1) bioremediation by microorganism; 2) bioremediation by plants known as phytoremediation.

9.3.1 Bioremediation by microorganism

In this method, suitable micro-organism are used for the removal of heavy metals. In this method microorganism converted toxic metal to non- toxic or less toxic substances (Lata and Dotaniya 2013a). Technologies can be categorized into in situ or ex situ as per the place of treatment. In *in situ*, contaminated soil or water treated at polluted sites; in *ex situ* conditions, contaminants can displace from polluted sites and remediated. For the removal of heavy metals from activated sludge, microorganism treatment breaks down the organic material with aeration and agitation and finally allows solids to settle down in the bottom of the sewage treatment plants. A particular type of microorganisms is responsible for a specific type of metal removal (Lata and Dotaniya 2013b). Part of the metals taken by microorganism as food materials and is converted as non-toxic substances. These microorganisms are specific in nature and also sensitive to climatic factors. However, all the metals are not treated or remediate easily by microorganisms. For example, Cd and Pb are not readily absorbed by the microorganisms. The availability of food materials for soil biota enhanced the bioremediation rate in WW and contaminated soils (Pingoliya *et al.* 2014a,b; Singh *et al.* 2016). Increasing the N availability in contaminated soil may encourage the heavy metal biodegradation (Sims 2006). Microorganisms used for the metal remediation function are known as bioremediators. If fungi are used for the removal of heavy metals are known as mycoremediation. In this line, a lot of work going on to understand the different pathways and regulatory network to remediate from various contaminated systems. Calculate the C flux from different systems for the environmental aspect for a particular compound is-à-via microorganisms. The genetic engineered microorganisms may important in the process of bioremediation. The

Table 6. List of phytoremediation strategies (Yang *et al.* 2005; Dotaniya and Lata 2012)

Phytoremediation techniques	Action mechanism	Medium treated
Phytoextraction	Direct accumulation of contaminants into plant shoots with subsequent removal of the plant shoots	Soil
Rhizofiltration (Phytofiltration)	Absorb and adsorb pollutants in plant roots	Surface water and water pumped through roots
Phytostabilization	Root exudates cause metals to precipitate and biomass become less bioavailable	Groundwater, soil, mine tailings
Phytovolatilization	Plant evaporate certain metal ions and volatile organics	Soil, ground water
Phytodegradation (plant–assisted bioremediation)	Microbial degradation in the rhizosphere region	Groundwater within the rhizosphere and soil
Phytotransformation	Plant uptake of organic contaminants and degradation	Surface and groundwater
Removal of aerial contaminants	Uptake of various volatile organics by leaves	Air

Table 7. Heavy metal distribution in hyperaccumulators at tissue/cellular level

Tissue/organ	Element	Plant species	Reference
Trichone	Zn, Cd	*Arabidopsis halleri*	Kupper *et al.* 1999
	Cd	*Brassica juncea*	Salt *et al.* 1995
	Ni	*Alyssum lesbiacum*	Kramer *et al.* 1997
Epidermal	Zn	*T. caerulescens*	Kupper *et al.* 1999
	Zn	*T. caerulescens*	Vazquez *et al.* 1994
	Ni	*Alyssum*	Kramer *et al.* 1997
Mesophyll	Zn	*Arabidopsis halleri*	Kupper *et al.* 1999
	Cd	*Sedum alfredi H.*	Xiong *et al.* 2004
Cell wall	Ni	*T. goesingense*	Kramer *et al.* 2000
	Cu	*Elsholtzia splendens*	Yang 2002
	Zn	*Sedum alfredii H.*	Kramer *et al.* 2000
	Pb	*Sedum alfredii H.*	He *et al.* 2003
Vacuole	Zn	*T. caerulescens*	Kupper *et al.* 1999
	Zn	*T. caerulescens*	Vazquez *et al.* 1994
	Cd	*Sedum alfredii H.*	Xiong *et al.* 2004
	Zn	*Sedum alfredii H.*	Kramer *et al.* 2000

bacterium *Deinococcus radiodurans* modified with the help of genetic engineering for remediation of toluene and ionic mercury from the radioactive reactor WW and solids (Brim *et al.* 2000). These techniques are specific for a particular metal and microorganisms; needs specific tool and techniques for the remediation purpose (Dotaniya *et al.* 2016b). The higher cost for installation of modern equipments

Table 8. Genes introduced into plants and the effects of their expression on heavy metal tolerance, accumulation, or volatilization (Yang *et al.* 2005)

Gene	Product	Source	Target	Maximum observed effect[a]
merA	Hg(II) reductage	Gram-negative bacteria	*Liriodendron tulipifera*	50 µmol L^{-1} $HgCl_2$; 500 mg $HgCl_2$ kg^{-1}
			Nicotiana tabacum	V: Hg-votatilization rate increase 10 fold
merA	Hg (II) reductage	Gram-negative bacteria	*Arabidopsis thaliana*	T: 10 µmol L^{-1} CH_3HgCl (>40 fold)
merB	Organomercurial lyase	Gram-negative bacteria	*A. thaliana*	V: upto 59 pg Hg(0) mg^{-1} fresh biomass min^{-1}
APS1	ATP sulfurylase	*A. thaliana*	*B. juncea*	A: two fold increase in Se concentration
MT-I	MT	Mouse	*N. tabacum*	T: 200 µmol L^{-1} $CdCl_2$ (20 fold)
CUP1	MT	*Saccharomyces cerevisiae*	*B. oleracea*	T: 400 µmol L^{-1} $CdCl_2$ (Approximately 16 fold)
gsh2	GSH synthase	*E. coli*	*B. juncea*	A: Cd concentration 125%
gsh1	Γ-Glu-Cys synthase	*E. coli*	*B. juncea*	A: Cd concentration 190%
NtCBP4	Cation channel	*N. tabacum*	*N. tabacum*	T: 250 µmol L^{-1} $NiCl_2$ (2.5 fold), Pb sensitive A: Pb concentrations 200%
ZAT1	Zn transporter	*A. thaliana*	*A. thaliana*	T: Slight increase
TaPCS1	PC	Wheat	*Nicotina glauca R.*Graham	A: Pb concentrations 200%

[a]Relative values refer to control plants not expressing the transgene; A: accumulation in the shoot; GSH: glutathione; MT: metallothionein; T: tolerance; V: volatilization

and hygienic conditions are also needed of bioremediation with microorganisms.

9.4. Phytoremediation

Use of various types of plants for the remediation of metals from contaminated environment is known as phytoremediation. It can be used for the removal of organic pollutant, trace metals and radioactive materials from polluted soil and aquatic bodies. It is a cost effect, environmental and eco-friendly, and driven by the solar energy. It is used as *in situ* application and required less technical skill. The phytoremediation consist with two words: Greek *phyto* means plants and Latin *remediation* tends to correct or remove an evil. The green plants are having immense potential to remediate pollutant and also detoxification by various mechanisms. This concept (as phytoextraction) was suggested by Chaney (1983). The phytoremediation techniques include phytoexpraction, phytofiltration, phytovolatilization, phytostabilization, phytodegradation, phytotransformation and removal of aerial contaminants etc. A list of methods, action mechanism and medium treated are enlisted in Table 6.

9.4.1. Hyperaccumulator plants

These plants are having higher capacity of heavy metal adsorption in plant parts as compared to normal plants. These plants are not showing any adverse effect on plant growth. Such type of plants are having specific with a particular metal or a group of metals. Plants accumulated heavy metals in various parts listed in Table 7.

The hyperaccumulator plant should have higher capacity to produce plant biomass and suitable for a wide range of contamination. Hyperaccumular plants don't transfer the metal into edible parts. The capacity of phytoremediation can be enhanced with the inserting various foreign gene into plants through genetic engineering or biotechnological techniques (Table 8).

During the hyperaccumulation or the removal of metals from soil or water system can be calculated with various parameters, i.e. bioconcentration factors, translocation factor and translocation efficiency and crop removal with the help of below formulas.

Bioconcentration factor (BCF): It's defining the contamination removal capacity of the plant; was calculated by Zhuang et al. (2007).

$$\text{BCF} = \frac{\text{Cr}_{\text{harvested tissue}}}{\text{Cr}_{\text{soil/water}}}$$

Here, $\text{Cr}_{\text{harvested tissue}}$ is a concentration of Cr in harvested plant parts (root, shoot) and Cr_{soil} are total applied Cr levels of respective treatment.

Translocation factor (TF): Means transfer of Cr metal ions from root to shoot part and quantified by formula proposed by Adesodun et al. (2010).

$$\text{TF} = \frac{\text{Cr}_{\text{shoots}}}{\text{Cr}_{\text{roots}}}$$

Translocation efficiency (TE): TE was calculated with the help of formula described by Meers et al. (2004).

$$\text{TE (\%)} = \frac{\text{Cr}_{\text{content in shoots (mg/ kg)}}}{\text{Cr}_{\text{content in the whole plant}}} \times 100$$

The Cr removal (%): Percent Cr removal represented the Cr removal capacity of the crop with respect to contamination level; it was calculated as per given formula.

$$\text{Cr removal (x)} = \frac{\text{Total Cr uptake by plant}}{\text{Total Cr applied to the soil}}$$

$$\text{Cr removal (\%)} = \text{Value (x) X 100}$$

9.4.2. Phytoextraction

In this technique, plant uptake contaminants from soil and water through plant roots and accumulate in aboveground parts i.e., shoots. This is also known as phytoaccumulation, phytoabsorption or phytosequestration. This process stored metal in shoot is a crucial biochemical process; and researchers are focused more potential uptake as aboveground part, because the root biomass is generally not feasible (Tangahu *et al.* 2011). Phytoextraction may be classified into two types.

9.4.2.1. Natural phytoextraction

It is usually conducted through planting selected species in the contaminated soil. These plants are grown under normal farming conditions to reach the optimal size, harvested and disposed off appropriately. The plants (such as *Pteris vittata*) are highly specialized, occur naturally and can tolerate highly elevated concentrations of metals that would be toxic to other plants. Typically, these plants are small, have a shallow root system and grow relatively slowly.

9.4.2.2. Induced phytoextraction

In non hyperaccumulators plants such as *Thlaspi perfoliatum*, factors limiting their potential for phytoextraction include small root uptake and little root-shoot translocation of metals. Methods that use metal mobilizing agents have been proposed specifically to overcome these limitations. Following this approach, a high biomass crop is grown on the contaminated soil requiring remediation. Throughout the growth period, amendments are added to the soil to increase availability of metals to the plants. The most commonly used agents for induced phytoextraction are: ethylene diamine tetra acetic acid (EDTA), diethyl triamine penta acetic (DTPA), cyclohexylene dinitrilo tetra acetic acid (CDTA) and citric acid etc.

9.5. Phytofiltration

This technique also little bit similar to phytoextraction, but is concerned with the remediation of contaminated groundwater rather than the remediation of polluted soils. The contaminants are absorbed or adsorbed and thus their movement is less in underground water. This method also known as rhizofiltration (by roots), blastofiltration (by seedlings), caulofiltration (used plant shoots) (Mesjasz-Przybylowicz *et al.* 2004). Plants (such as *Helianthus annuus* used for rhizoliltration are not planted directly but are acclimated to the pollutant first. Plants are hydroponically grown in clean water rather than the soil until a large root system develops. Once a large root system is in place, the water supply is substituted for a polluted water supply to acclimatize the plant. Then they are planted in the polluted area where the roots uptake the polluted water and the contaminants along with it. As the roots become saturated they are harvested and disposed of safely.

9.6. Phytostabilization

Phytostabilisation is the process in which plants (*Festuca rubra* L, *Agrostis tenuis*) are used to immobilize soil and water contaminants. It mainly focuses on sequestering pollutants in soil near the roots rather than in the plant tissues itself. Pollutants become less bioavailable and livestock, wildlife, and human exposure are reduced. The contaminants are absorbed and accumulated by the roots, adsorbed onto the roots, or precipitated in the rhizosphere. This reduces or even prevents the contaminants migrating into the groundwater or air as well as the bioavailability of the contaminant which prevent its spread through the food chain. This technique can also be used to re-establish a plant community on sites that have been denuded due to the high levels of metal contamination. Once a community of tolerant species has been established, the potential for wind erosion (and thus spread of the pollutant) and the leaching of the soil contaminants is also reduced. Phytostabilisation involves three processes which include humification, lignifications and irreversible binding.

9.7. Phytovolatilisation

It refers to the process through which plants uptake water soluble contaminants and release them into the atmosphere as they transpire water. As the water travels along the plant's vascular system from the roots to the leaves, the contaminant may be modified whereby it evaporates or volatilizes into the air surrounding the plant. Phytovolatilisation is relevant in the remediation of soils rich in mercury, selenium and to some extent in arsenic. The mercury ion is transformed into less toxic elemental mercury and selenium is lost to the atmosphere in the form of dimethylselenide (DMSe). It is also applicable for the removal of organic contaminants. For example, poplar trees have been shown to volatiles 90 percent of the TCE they take up.

9.8. Phytodegradation

In this process plant secreted various types of enzymes, i.e., dehalogenase and oxygenase through root cells; which are breakdown the organic pollutants in soil (Vishnoi and Srivastava 2008; Dotaniya and Lata 2012). Some contaminants can be absorbed by the plants and broken down by their enzymes. These smaller pollutant molecules may then be used as metabolites by the plant as it grows, thus becoming incorporated into the plant tissues. Plant enzymes that breakdown ammunition wastes, chlorinated solvents such as trichloroethane (TCE) have been identified.

10. Conclusion

Heavy metal pollution is emerging with the time and the functional capacities of natural resources are shrinking towards production of food materials. The increasing crop production on limited land with poor quality resources are a challenge to researcher and policy maker across the global world. The use of poor quality soil and water after proper management is need of today and tomorrow. The poor quality water or industrial effluent are having trace metal; which are carcinogenic in nature and affecting the natural biochemical mechanism in living organisms. More focus on the safe utilization of poor quality water and contaminated soil after proper remediation or treatment. In present context, one industry is location at nearby the other industrial unit and the effluent merging at a common point and utilizing for various propose. The multi-metal toxicity should be identified and proper strategies should be made to reduce the metal inhale in human body. The effect of climate change on heavy metal uptake pattern in soil and in crop should be investigated. The extension of phytoremediation techniques in urban and contaminated areas are also needs attention. The uses of modern biotechnological with traditional techniques are in combination to combat the heavy metal toxicity. The public awareness is also a need of today regarding heavy metal toxicity with the help government agencies as well as non government agencies (NGOs) for sustainable crop production.

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Aqua-fertilization: An easy approach for higher water and nutrient productivity under arid and semi-arid region of India

D S Gurjar[1], Ummed Singh[2] and R K Shivran[3]

[1]Water Technology Centre, ICAR-Indian Agricultural Research Institute, New Delhi-110 012
[2]Division of Crop Production, ICAR-Indian Institute of Pulses Research, Kanpur-208 024
[3]Mechanized Agriculture Farm, Agriculture University, Ummedganj, Kota-324 001
E-mail: dsgurjar79@gmail.com

ABSTRACT

Water resources are of vital importance in arid and semi-arid regions of our country. More than 50 % of land area comprises arid and semi-arid regions in India. Low and erratic rainfall coupled with extreme temperatures and intense solar radiation makes these regions the most vulnerable regions in India. Water is scarce in these regions. The groundwater tables are low, rainfall is low and the water run-off is high. Arid and semi arid regions contribute 42% of the total food grain production of the country. Crop cultivation in these regions is a difficult task due to uncertainty of soil moisture during sowing time. There is problem in germination of seed and good establishment of crop due to moisture deficit condition in the initial stage of the crops. The application of water in the forms of nutrient solution applied in the crop root zone at the time of sowing is termed as aqua-fertilization. The major advantages of aqua-fertilization technology are the energy saving, economical and they can be applied uniformly with the flexibility in formation of different grades. It also ensure optimum germination and initial root and shoot development of the plants for proper crop establishment. Application of aqueous fertilizer at root zone depth can be achieved using suitable aqua-ferti-seed-drill machine. It is capable of delivering a discharge in the range of 8000 to 10,000 l/ha. It is most suitable for sowing winter crops in dry land areas. The drill enables the user to apply aqueous fertilizer along side of the seed in moisture deficit fields at the time of sowing. Aqua-fertilization by aqua-ferti-seed-drill machine may enhance the nutrient use efficiency, crop yield and water productivity.

Keywords: Aqua-fertilization, Aqua-ferti-seed drill, Crop and water productivity, Nutrient use efficiency

1. Introduction

Arid and semi arid regions are characterized on the basis of annual rainfall to sustain agricultural production. In India, almost 53.4 per cent land area comprises arid and semi-arid regions (NATCOM, 2004). Arid regions are the areas where annual rainfall is less than 750mm and also called dry farming areas. In arid regions, crop failure is most common due to prolonged dry spells during crop period. A growing season (period of adequate soil moisture) is less than 75 days. Moisture conservation practices are necessary for crop production in this region. Semi arid regions are the areas where annual rainfall between 750mm to 1150mm with a growing period between 75 to 120 days. In spite of prolonged dry spells, crop failure is relatively less frequent in the semi arid regions. In the semi arid regions, moisture conservation practices are necessary for crop production. However, adequate drainage is required especially for vertisol. The northern arid regions in India comprise largely of the desert of Rajasthan, the Rann of Kutch and the semi-arid regions of Punjab and Gujarat. The Southern arid regions are in the rain shadow of the Western Ghats covering states of Maharashtra, Karnataka and Tamil Nadu. In terms of being prone to drought however, the semi-arid region extends to a larger area. In fact 99 districts, most of them large in size, across 14 states are declared as drought prone districts. Most of these drought prone districts are concentrated in Andhra Pradesh, Maharashtra, Tamil Nadu, Karnataka and Rajasthan, affecting 265 million people in the rural areas. The net cultivated area in India is about 142 million hectare inwhich about 65 million hectare (45%) is as net irrigated area and remaining 77 million hectare (55%) is Dryland or rain-fed area. Low and erratic rainfall coupled with extreme temperatures and intense solar radiation makes these regions the most vulnerable regions in India. Water is scarce in these regions. The groundwater tables are low, rainfall is low and the water run-off is high. The main source of water throughout the year for these regions is through small and medium stored water. Inland water resources i.e. tanks and lakes, beels, oxbow lakes, ponds etc. Arid and semi arid regions contribute 42% of the total food grain production of the country. The 75% of pulses and more than 90% of sorghum, millet and groundnut are produced from arid and semi-arid regions. Hence, agricultural output, in the rain-fed or Dryland area depends on trends of monsoon. In fact, crop cultivation in dry land is a difficult task due to uncertainty of soil moisture during sowing time. There is problem in germination of seed and good establishment of crop in the initial stage if there is moisture deficit in seed environment even though good quality seed is available as seed is a critical and basic input for enhancing agricultural production and productivity provided that it gets proper environment to germinate and grow. For proper germination and growth of plant; precise placement of seed in soil, at right sowing time is necessary. Hence, the ferti-seed drill was developed which plays a vital role in seed placement along with fertilizer for healthy initial growth. Placements of fertilizer also have greater significance in dry land agriculture. But in dry land areas the applied basal dose of fertilizer remains unavailable due to inadequate soil water to dissolve, dilute and convey it to root depth level even during the winter as well as in summer season. This problem can be solved by use of aqueous fertilizer or aqua-fertilization.

2. Content

2.1. Aqua-fertilization

The application of water in the forms of nutrient solution applied in the crop root zone at the time of sowing is termed as aqua-fertilization. The major advantages of aqua-fertilization technology are the energy saving, economical and they can be applied uniformly with the flexibility in formation of different grades. It also ensure optimum germination and initial root and shoot development of the plants for proper crop establishment. Hence, a suitable machine is required for application of aqueous fertilizer along side of seed to supplement soil moisture and nutrient requirements of different crops. Application of aqueous fertilizer at root zone depth can be achieved using suitable aqua-ferti-seed-drill machine

2.2. Tractor drawn Aqua-ferti-seed-drill machine

Dey and Indra Mani (2004) developed a tractor drawn aqua-ferti-seed drill with proper liquid fertilizer metering mechanism using peristaltic pumping system. The peristaltic pumping mechanism consisted of reel mounted with rollers at an appropriate spacing which rotated at optimum speed. With reel rotation, the rollers moved and rolled along hose created pumping action that first pulled and then pushed the solution through the flexible hoses. The performance of the machine was found satisfactory in terms of seed and aqueous fertilizer application along with good germination of the crop.

2.3. Constant head gravity fed Aqua-ferti-seed-drill machine

The constant head gravity fed Aqua-ferti-seed-drill machine was developed by Kamal Kant and Indra Mani (2008). The constant head gravity fed system mechanism consisted of a rotary pump, two symmetrically tractor (45hp) mounted water tanks of 395 mm diameter and 160 litre capacity for supplying aqueous fertilizer to another centrally mounted water tank where a constant aqueous fertilizer head was maintained. The pumping system also consisted of nine nozzles connected to nine tube carrying aqueous fertilizer directly to the nine respective furrows. The developed mechanisms were capable of delivering a discharge in the range of 8000 to 10,000 l/ha. It is most suitable for sowing winter crops in dry land areas. The drill enables the user to apply aqueous fertilizer along side of the seed in moisture deficit fields at the time of sowing. This easy to use machine is a modified version of the peristaltic pumping based aqua-ferti-seed drill developed by the Dey and Mani (2004) earlier.

2.4. Pressurized metering system based Aqua-ferti-seed-drill machine

The above both Aqua-ferti-seed-drill machines are operated at atmospheric pressure thus; allowed only limited variation in discharge rate which emerged as a limitation if large variation was required in metering system to make it suitable for wide variability in soil moisture this could be overcome by a pressurized metering system. The system required aqueous fertilizer supply at higher pressure and metered by suitable pumping arrangement with variable rotational speed. As aqueous fertilizer had physical characteristics different from water, positive displacement pump able to handle viscous fluid may serve the purpose. Pressurized metering system will prove useful for precision seeding of different crops in dry land areas by controlled application of aqua-fertilizer according to soil-moisture as well as crop conditions. In fact, pressurized metering system based aqua-ferti-drill using different nozzles will be able to supply aqueous fertilizer with different flow rates, which may further economize water requirement. Added to above, the water availability in dry land areas is scarce and carrying more water on aqua-ferti-seed-drill is a limitation. The application of appropriate amount of water as per the requirement of soil-moisture of the field is highly desirable. Hence, this can be achieved through pressurized aqueous fertilizer metering system for seed drill or planter on

Fig. 1. Pusa Aqua-ferti-seed-drill machine mounted on tractor

Fig. 2. Pusa Aqua Ferti Seed Drill (Rear View)

Fig. 3. Pusa Aqua Ferti Seed Drill (Front View)

Indian farms.

$V_1 = (FC\text{-}WP) \times \rho \times d \times w \times n \times W$

Where,

V_1 = Amount of aqueous fertilizer, vol. l/ha

FC = Field capacity, %

WP = wilting point, %

r = Density of soil, g/cc

ρ = Depth of seed placement, cm

w = Width of root spread per meter row length, cm

n = no of turns of seed drill per hectare

W = Width of seed drill, cm

2.5. Estimation of aqueous fertilizer requirement of aqua-ferti-seed-drill for selected soil-moisture-crop conditions

The requirement of aqueous fertilizer in a given soil moisture environment depends on soil texture, field capacity, wilting point and available moisture in a particular soil. The first step in this direction was to estimate the requirement of additional soil moisture which is just sufficient to meet the moisture requirement for germination. It is not possible to provide extra moisture abundantly, because moisture applicator has its own limitations w.r.t. water carrying capacity and mode of aqueous fertilizer application. Also any excess volume of water would be a hindrance in proper sowing of seed along side of aqueous fertilizer. The estimation of aqueous fertilizer may be done using the following formula.

The requirement of aqueous fertilizer for different type of soil was estimated by Lande (2008) based on above formula. An example of aqueous fertilizer requirement (litre per meter) of aqua ferti-seed drill for sandy loam soil is given in the Table 1.

Table 1. Estimation of requirement of aqueous fertilizer for sandy loam soil

Depth	**Aqueous fertilizer, l/m**			
Initial moisture, %	**Sowing depth**			
	d = 2.5 cm	**d = 5 cm**	**d = 7.5 cm**	**d = 10 cm**
4	0.34	0.67	1.01	**1.34**
8	0.25	0.50	0.76	1.01
12	**0.17**	0.34	0.50	0.67

2.6. Design of aqua-ferti-seed drill machine/ system

Design and fabrication of pressurized metering system of aqueous fertilizer or pressurized aqua-fert-seed drill machine is based on (a) rotational speed of pump, (b) line pressure and volume of aqua fertilizer delivered by pump, (c) desired nozzle sizes along with tubes. Hence, this can be achieved through an experimental set up which is suitable to meet the above requirements. Therefore, the experimental set up for pressurized metering system consisted of the following components:

a) Pump frame

b) Tank for liquid fertilizer

c) Rotary pump

d) Flow distributor

e) Pressure and volume control valve

f) Pressure gauge

g) Nozzles

h) Drive mechanism of the pump

i) Power source

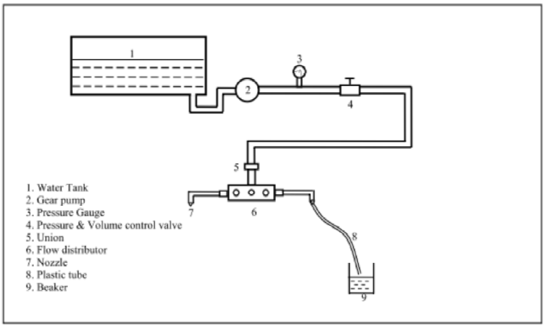

Fig.4. Schematic diagram for design of Experimental set up (Source:Lande, 2008)

2.7. Impact of Aqua-fertilization and aqua-ferti-seed drill on nutrients, crop and water productivity

Under dryland condition aqueous fertilizer is needed not just for better physical form of fertilizer from use efficiency point of view, but from standpoint of moisture. Liquid fertilizer makes nutrient rich moisture available at seeding depth during sowing time for successful germination and initial root and shoot development. Liquid fertilizers are used due to its ease in handling as well as in metering. Its use is also safe for the growth of the plants, as the concentration of the fertilizer is low. Kumar *et al.* (1996) reported that the application of liquid urea in subsoil at 10% concentration increased the nitrogen uptake by 24% more than the control. The grain yield was 22%, 15% and 15% higher than control, application of USG and prilled urea in the subsoil, respectively. XinZheng *et al.* (2004) carried out experiments in 1999-2002 in Xinjiang, China. Acid liquid fertilizer is a new special fertilizer for drip irrigation. The yield of unginned cotton increased by 270 kg/ha (7.8%) as compared with the traditional fertilizer. Fertilizer rates of 900-930 kg/ha resulted in 1725 kg ginned cotton/ha and a reduction of 35% in fertilizer use, compared with the control. Anonymous (1996) fabricated a single tyne, bullock drawn gravity flow aqua-ferti-seed drill for rain fed farming at Water Technology Centre of Indian Agricultural Research Institute. The experimental results showed that for all the crops (wheat, mustard and gram) the use of AFSD increased the yield. Kamal Kant and Indra Mani (2008) developed a tractor drawn aqua seed drill for metering of aqueous fertilizer with constant head gravity fed system with varying nozzle sizes was developed. The field experiments revealed that aqueous fertilizer application advanced germination by at least two days. Increased rate of aqueous fertilizer gave enhanced growth performance parameters in addition to better germination. For 8000 l/ha aqueous fertilizer rate, increase in germination, number of shoot per plant, number of ear head, plant height, grain yield and straw yield were 514 %, 48, 38 %, 11 %, 38 % and 60 %, respectively in comparison to those in plots with no aqueous fertilizer. Bareth *et al.* (2006) reported that Aqua-fertilization with water volume upto 30,000 lit/ha has significantly increased growth and yield of wheat over dry sowing under dryland condition. Kumar *et al.* (2013) conducted the demonstrations on aqua-ferti-seed drill at many farmers fields and observed that through the use of aqua-ferti-seed drill the beneficiary farmers could on an average save around 22 percent of irrigation *i.e* equivalent to the required pre-sowing irrigation. The saving in irrigation cost was Rs. 1800 per hectare. Besides this, the participating farmers also reported that the germination of the crop was uniform and better in demonstration plots as compared to control plots. In comparison to control plots, the demonstration plots recorded on an average increase of around 12% in yield realizing additional income of Rs. 1800-2000/- ha which was equivalent to 7 percent of total income. The maximum yield was in gram and wheat. The major role of aqua ferti seed drill was saving irrigation water required for pre-sowing irrigation. It also helped both reducing number of irrigation as the moisture provided at the time of sowing in root zone depth could sustain crop longer and weed infestation was much lower in demonstration plot in comparison to control as reported by beneficiary farmers.

3. Conclusion

Aqua-fertilization by aqua-fert-seed drill machine is a most suited technology for talking the problem of moisture deficit sowing in the arid and semi-arid regions of our country. It is capable to enhance the nutrient use efficiency, crop yield and water productivity in the dryland farming system.

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Theme 2:

Precision nutrient management in field crops

Precision nutrient management for higher nutrient use efficiency in field crops

Hardev Ram[1], R L Choudhary[2], Rakesh Kumar[1], Rajesh K Meena[1] and B L Ola[3]

[1]ICAR-National Dairy Research Institute, Karnal-132 001
[2]ICAR-National Institute of Abiotic Stress Management[2], Malegaon, Baramati, Pune, Maharashtra
[3]Directorate of Rapeseed-Mustard Research, KVK, Bansur, Alwar, Rajasthan
E-mail: devagron@gmail.com

ABSTARCT

Precision applications of nutrients are essential for balance nutrient supply and higher yields. Overall efficiency of soil applied nutrients have been reported lower than 50% for N, less than 15% for P, about 40% for K and less than 5% for micro-nutrients due to lack of synchronization between the fertilizer-nutrient release and their crop demand during vegetative growth. Further, it is evident that, nutrient variability within a field is invariably high; affecting optimum fertilizer rates, yield potential and grain quality. To bridge the bottlenecks, different strategies like development of new cultivars with higher nutrient use efficiency (NUE), best management practices (BMPs) and precision nutrient management will contribute to sustainable agricultural systems that protect and promote soil, water and air quality. Moreover, precision nutrient management could be the most important strategies to mitigate ill effects while enhancing yield and NUE.

Keywords: Green seeker, leaf colour chart, precision nutrient management, SSNM

1. Introduction

In India, food grain production over past four decades increased from 98 million tons (1967-68) to 273 million tons in 2016-17, while fertilizer used increased by more than 12 times from 1.95 million tons (1967-68) to 26.7 million tons in 2015-16 (Economic survey, 2016). As per the latest estimation by 2025 to feed ever increasing population of country we needed around 350 million tons of foodgrain with no scope for further increase in net cultivated area (141 M ha). To produce this amount of foodgrain we needed 45 MT of fertilizer nutrients as per the current growth rate of production. In such condition accelerating inputs use efficiency of nutrients, fertilizers and seeds through optimizing their supply and demand match in an efficient manner from organic and inorganic sources. Marked improvement in yield of most of field crops during the past 25-30 years is a result higher fertilizer use, adoption of multiple cropping systems, improved genotypes and expansion of the irrigation areas. Additionally, precision nutrient management approach is a sustainable option to reduce nutrient losses, improving efficiency, increasing farm profit and minimize agricultural non-point source pollution. Invariably, increasing cost of production, natural resource depletion, aggravated biotic-abiotic stresses and multiple nutrient deficiencies are the key elements that lead to declining factor productivity, shrinking marginal returns and environmental footprints. The foremost, factors causing yield losses are deficient in one or more of the nutrients needed to support healthy plants. Other important cause is mismatch between nutrient supply and demand creates imbalance or depletes the soil reserves of nutrients will negatively affect production potential. Besides these, soil acidity, alkalinity, salinity, faulty farming practices, and erosion can lead to soil degradation. To meet future demand of food and other commodities on same pace and will be a great task and depend on continued use of precision nutrient management. The basic practices used in conventional nutrient management methods are use of blanket recommendation rather than applying actual amount of nutrients removal by the soil-plants. The approach of site specific nutrient management (SSNM), a systematic approach to provide sound knowledge on "feeding crops" with nutrients as and when needed to make synergy between nutrient demand and supply under different field crops production system, is the solution to manage special variability of nutrients and better nutrient use efficiency.

2. Why precision nutrient management

Continuous use of high analysis fertilizers (containing N, P, K) has resulted in deficiency of secondary (S) and micro-nutrients (Zn, Mn and Fe) in soils and these show signs of fatigue as judged by the decline/stagnation in the yields of most of the cropping systems. Besides, to meet food demand for ever increasing population is a global challenge as recent estimate indicated that global crop demand will increase by 100 to 110% from 2005 to 2050 (Tilman *et al.*, 2011). FAO, 2009 estimated that the world will need 60% more cereal production between 2000 and 2050, while others predict food demand will double within 30 years (Glenn *et al.,* 2008). Improving NUE have been most critical and daunting research issues (Thompson, 2012).The green revolution has led to increased use of fertilizers for crop production & is still increasing without considering the quantity of output obtained per unit input. Fertilizers are essential components for proper growth and development of crop, fertilizer nutrients play an important role but use of fertilizers in an unjudicious manner can pollute the atmosphere, hydrosphere as well as lithosphere. NUE is a measure of the increase in crop yield obtained per unit fertilizer nutrient applied. It can be expressed as agronomically, physiologically, economically. NUE is most important factor for evaluating crop production systems and can be greatly affected by nutrient management as well as soil-plant-water relationships. Precision nutrient management is the dynamic, field-specific approach for nutrients management in a particular cropping system and or season to optimize the supply and demand of nutrients according to their differences in cycling through soil plant systems.

3. Major consequences of low FUE

- Loss of nutrients from agricultural ecosystem
- Eutrophication of surface water
- Pollution of ground water due to NO_3^- leaching
- Global warming due to CH_4 and nitrous oxide emission
- Decreased biodiversity
- Increased local air pollution
- Residues of heavy metals in food chain & thus causing diseases like itai-itai (Cd), Minamata (Hg), etc.
- Low net return to farmer

4. Measures of NUE

According to Dobermann (2007) NUE measured and calculated as given in Table 1 along with their applications.

5. Management strategies for increasing nutrient use efficiency

1. Optimal use of on-farm nutrient input sources such as crop residues.
2. Application of NPK fertilizers is adjusted to the location and time specific as per the needs of the crop plant.
3. Leaf color chart (LCC) based nitrogen management which ensures that nitrogen is applied at the right time and right amount needed by the crop plants which reduces wastage of N-fertilizer.

Table 1. Common NUE indices and their application

Indices	Calculation	Application
Partial factor productivity (kg harvested product per kg nutrient applied)	$PFP = Y/F$ or $PFP=(Y_0/F) + AE$	•Most important for farmers because it integrates the use efficiency of both indigenous and applied nutrients. •High indigenous soil nutrient supply (Yo) and high AE are equally important for PFP.
Agronomic efficiency (kg yield increase per kg nutrient applied)	$AE=(Y_0)/F$ or $AE=RE \times PE$	• Product of nutrient recovery from mineral or organic fertilizer (RE) and the efficiency with which the plant uses each additional unit of nutrient (PE). • AE depends on management practices that affect RE and PE.
Apparent recovery efficiency of applied nutrients (kg increase in N uptake per kg N applied)	$RE = (U-U_0)/F$	• RE depends on the congruence between plant demand and nutrient release from fertilizer. • RE is affected by the application method (amount, timing, placement, N form) and factors that determine the size of the crop nutrient sink (genotype, climate, plant density, abiotic/biotic stresses).
Internal utilization efficiency (kg yield per kg nutrient uptake)	$IE = Y/U$	• Ability of a plant to transform nutrients acquired from all sources (soil, fertilizer) into economic yield (Grain). •Depends on genotype, environment and management. • A very high IE suggests deficiency of that nutrient. • Low IE suggests poor internal nutrient conversion due to other stresses (nutrient deficiencies, drought stress, heat stress, mineral toxicities, pests)
Physiological efficiency of applied nutrients (kg yield increase per kg increase in N uptake from fertilizer)	$PE = (Y-Y_0)/(U-U_0)$	• Ability of a plant to transform nutrients acquired from fertilizer into economic yield (grain). • Depends on genotype, environment and management. •Low PE suggests suboptimal growth (nutrient deficiencies, drought stress, heat stress, mineral toxicities and pests).

F = amount of (fertilizer) nutrient applied (kg/ha); Y = crop yield with applied nutrients (kg/ha); Yo = crop yield (kg/ha) in a control treatment with no N; U = total plant nutrient uptake in aboveground biomass at maturity (kg/ha) in a plot that received fertilizer; U = total nutrient uptake in aboveground biomass at maturity (kg/ha) in a plot that received no fertilizer.

4. Use of nitrogen omission plots techniques to ensure that phosphorous and potassium is applied in the ratio required by the crop.
5. Local randomization for fertilizer application of zinc, sulphur and micronutrients are followed.
6. Selection of most efficient and economic combination of available fertilizer sources.
7. Integration with other integrated crop management (ICM) practices such as the use of quality seeds, optimum plant population, IPM practices and efficient water management.

6. The precision nutrient application based on demand of crops by using following tools and tactics and/or software:

6.1. Nutrient Omission Plot Techniques: (http://www.knowledgebank.irri.org)

The nutrient omission plot technique is used to determine fertilizer requirements of crops. In the nutrient omission plot, ample amount of all nutrients are applied except the omitted nutrient. The yield in omitted plot is related to the native soil supplying

Table 2. Design of Nutrient Omission Technique

Treatment	N-Omission	P-Omission	K-Omission	Targeted Yield plot
N	Nil	Full Dose	Full Dose	Full dose of NPK
P	Full Dose	Nil	Full Dose	
K	Full Dose	Full Dose	Nil	

capacity of the omitted nutrient. The yield will be limited by the native supply of omitted nutrient only. To calculate the nutrient requirement yield gap between target yield and yield in the omitted plot is used. Omission plots are mainly used for major nutrients such as NPK on farmers fields. The major limitation of this technique is the estimation of native supply of nutrients which may affected by climate/ weather, agronomic management and insect-pest damage of crops.

6.2. Chlorophyll meters

Chlorophyll meters are reliable diagnosis tools for tissue analysis of leaf N status. Most widely used chlorophyll meter is the hand-held Minolta SPAD-502. It estimates chlorophyll content by clamping the unplucked leafy tissue in the meter. It uses two light emitting diodes which emit red light and an infrared radiation. Both red and infrared light pass through the leaf and portion of light is absorbed and the remainder is transmitted through the leaf and a silicon photodiode detector converts it into an electrical signal. The amount of light reaching the photodiode detector is inversely proportional to the amount of chlorophyll in the path of the light.

6.3. Leaf colour charts (LCC)

LCC is a diagnostic tool which can help farmers for making appropriate decisions regarding the nitrogen fertilizer applications in standing crops. Conventionally farmer used his eye observations to know the crop nutrient status particularly nitrogen. The LCC can act as a plant health diagnostic tool to optimize the nitrogen supply of rice based cropping systems. The LCC is economical and easy to use diagnostic tool for precise N management especially in rice-wheat cropping system. Conceptually it is based on the measurement of relative greenness of plant leaves which directly co-related with its chlorophyll content. LCC is a high quality plastic strip with different shades of green colour range from light yellowish green to dark green and N applied based on the spectral reflectance of plant leaves. Now a day's six-panel LCC was used for real time N-application in rice.

7. Software for SSNM

7.1. Nutrient Expert®

Nutrient Expert® is a user-friendly and computer based decision support tool that enables nutrient recommendations for an individual farmer field in the presence or absence of soil testing data. To generate location specific nutrient recommendations, NE estimates the attainable yield of a crop based on the growing condition and determines the nutrient balance in the cropping system based on yield and fertilizer/manure applied. The algorithm for calculating fertilizer requirements was developed from on-farm experiment data using SSNM guidelines. The fertilizer requirement for a field or location is estimated from the expected yield response to each fertilizer nutrient. Nutrient Expert® also uses for split application of nutrients of a crop at critical growth stages. This software was currently freely available for wheat & maize systems in South Asia **(http://software.ipni.net/article/nutrient-expert)**

7.2. Crop Manager

Crop Manager is a computer and mobile phone based decision-making tool that provides small scale rice, rice-wheat, and maize farmers with site and season specific recommendations for fertilizer application. The tool allows farmers to adjust nutrient application to crop needs based on soil and crop management. It is easy to use by extension workers, crop advisors, and service providers based on information provided by farmers on crops and soil they advice to a farmers. (**http://cropmanager.irri.org/home**)

7.3. Green Seeker

Green seeker is a computer based optical sensors to measure and quantifies the variability of the crop inputs (N) and address field variability by applying the right amount of fertilizer, in the right place, at the right time. It help in reducing nutrients input cost by eliminating excess uses. The sensor provides precision Normalized Difference Vegetative Index (NDVI) and RED/NIR of plants. The NDVI values can be used in conjunction with other agronomic practices likes nutrient response, crop condition, yield potential, stresses, insect-pest and disease in a quantitative manner. It also used to monitor field variability during the growing season, and the effects of different doses of inputs on crop growth. It measured variability based on specific wavelengths of light and measures the light reflected from object (Plant or Soil).

7.4. Geographical Information System (GIS)

Geographic information system is a technology for handling available data regarding to geographic features of the crop field. It is an organised assembly which consist of collection of geographic data by using computer hardware and software on the one hand and precisely store, retrieve, analyze and display all form of geographically referenced information according to use. GIS can display analyze information in the form of maps that allow not only better understanding of interactions among yield, soil fertility, inset-pest, weed flora and other factors and processes that control crop yield but also provide an opportunity for decision making based on spatial variability.

7.5. Global Positioning Systems (GPS)

Global Positioning Systems (GPS) is a common tool to collect spot data for agricultural, urban, and natural resources including soil, water bodies and crops. This is satellite based information system, which accurately determines the location of object anywhere on Earth. GPS system enables farmers for judicial use of inputs such as fertilizers, sprayers, and tillage operation to reduce excess uses. They can also be used to precisely apply crop inputs based on variable rate and frequently use in soil sampling, draw weed map, disease and insect infestations in fields with yield monitors and record crop yields in fields.

8. Major benefits of precision nutrient management

i) **Higher economic returns:** Application of precision nutrients as per the demand of crops improves nutrient use efficiency resulting higher return on per unit investments. Besides, maintain higher yields by through balanced supply.

ii) **Reduced environmental pollution:** Precise application also reducing the GHG (N_2O) emission by need based application of nitrogen, thus minimizing N losses through volatilization, leaching and runoff

9. Conclusion

Precision nutrient management provides an approach for feeding crops with nutrients as and when needed to making synergy between nutrient demand and supply of different cropping system. It involves nutrient application on soil test basis, yield goals, factors influencing crop response to nutrient application. Therefore, precise application techniques are advantageous over farmer practices in optimizing nutrient feeding to crops and finally to obtained higher yield and net returns.

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Variable rate fertilizer applicator: A precision tool for higher input use efficiency

Man Mohan Deo, Prasoon Verma and Ummed Singh

ICAR-Indian Institute of Pulses Research, Kanpur, Uttar Pradesh-208 024
E-mail: anandi888@gmail.com

ABSTRACT

Soil fertility and soil productivity vary in a farm field with change in location. When fertilizer is applied by conventional methods it leads to over or under application of nutrients. Every field is heterogeneous in nature in respect of nutrient availability, some parts are rich in nutrients some parts are poor in nutrient contents. Variable rate fertilizer applicator technology is such a precision machine which considers this variability and applies the nutrients in proper amount and at right place in the field. It reduces waste, increases profit and maintains the environmental quality. There are two approaches of variable rate technology, one is map based and another is sensor based. Both these methods are useful in increasing input use efficiency.

Keywords: Precision agriculture, Sensor, Variable rate technology, Variable rate applicator

1. Introduction

India is the second largest populated country in the world and soon it will become the largest populated country exceeding China. But, we are having only 2.4% of the world land area. So, in near future to meet our food demand there will be excess pressure on our land resources as well as on other inputs. In order to justifiable use of resources, there is need of precision agriculture. The basic objectives of precision agriculture or site-specific management of agricultural inputs are to increase crop production, improve quality of the product, and protect the environment from the pollution.

2. Precision agriculture

It is defined as information and technology based farm management system which deals with application of inputs in **right amount, at right place, at right time**. It identifies analyses and manages variability present within fields for profitable, sustainable and judicious use of land resources. It can increase input use efficiency by utilizing the knowledge of variability present in the field as well as protecting it from overdoses. The main goal of the precision agriculture is to manage and distribute inputs on a site-specific basis to maximize profit and minimize losses.

3. Need for precision agriculture in India

- As India contributes 17% to the world population.
- But it accounts for only 2.4% of the total world surface area.
- Population of India has increased by more than 181 million during decade 2001-2011 slightly lower than population of Brazil fifth populous country in the world.
- For the timeliness in operation.
- To reduce labour requirement and drudgery.
- For saving inputs like fertilizer, seed, water, chemicals etc.
- To maximize long term profit.
- To improve grain quality and quantity.

In the decision making process of different types of input application, we need information about the variability of different soil attributes within a field. Researchers and manufacturers have attempted to develop real time (on-the-go) soil sensors to measure mechanical, physical and chemical soil properties based on electrical and electromagnetic, optical and radiometric, mechanical, acoustic, pneumatic, and electrochemical measurement concepts. A real time (on-the-go) spectrophotometer used for in situ measurement of reflectance spectra have the potential for making real-time predictions of various soil attributes using near infrared reflectance spectroscopy (NIRS). Based on the variability present in the field, by using real time sensor one can know the variability present in the field. Similarly, global positioning system based methods (map based) are also used for the predictions of variability present in a particular field and to apply variable rate applicator. Variable rate applicator technology (VRT) used with the global positioning system (GPS) has become a common technology that is being used in precision agriculture (Fulton *et al.,* 2005).

4. Variable rate applicator technology (VRA)

The VRA is a precision machine which increases input use efficiency by applying near optimum rates based on local soil conditions and crop requirements. This reduction of over application and under application of inputs enhances productivity and profitability while reducing environmental impacts.

There are two basic methods for implementing variable rate application (VRA) (Morgan and Ess, 2003).

i) Sensor-based VRA and

ii) Map-based VRA

Map-based VRA systems adjust the application rate of a crop production input based on information contained in a digital map of field properties, while sensor-based VRA systems use data from real-time sensors to match inputs to the needs of the soil and crop. For variable rate application of fertilizers, map-based methods are favoured over the sensor-based ones due to the lack of sufficient sensors for real-time monitoring of soil and crop conditions. The technology for VR fertilization should be able to minimize over- and under-fertilization. A granular VR fertilizer application system has to apply the right amount of fertilizer on different field spots according to the available soil fertility (Maleki *et al.,* 2008).

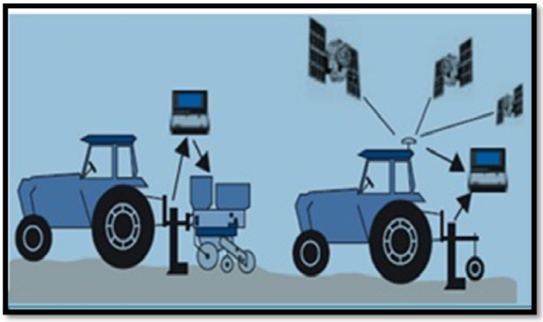

Fig.1. Approaches to use variable rate precision technology (Source: Adamchuk *et al.*, 2004)

a) Sensor based b) Map based

a) Soil sensor based Variable rate fertilizer applicator (VRA)

A soil sensor based variable rate fertiliser applicator system for on-the-go application of phosphate (P_2O_5) during maize planting was designed developed by (Maleki *et al.,* 2008).

5. Materials and methods

i) An on-the-go visible (VIS) and near-infrared (NIR) soil sensor with a measurement range of 305–1711nm. It was installed at the front of a planter-applicator for the on-the-go measurement of soil P.

ii) A previously developed VIS–NIR model was used to predict the extractable phosphorous (P-ext).

iii) A custom-built LabVIEW programme was developed to record soil spectra, predict soil P-ext, calculate phosphate during on-the-go measurement and provide the signal to the fertiliser applicator to adjust the application rate.

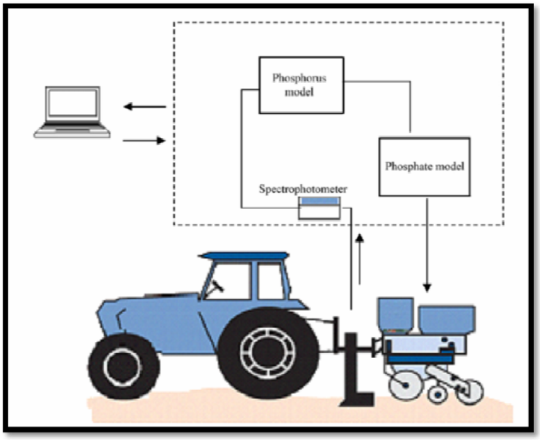

Fig.2. Sketch of soil sensor based variable rate fertiliser applicator (Source: Maleki *et al.,* 2008)

Fig.3. Developed soil sensor based variable rate Phosphorus applicator (Source: Maleki *et al.,* 2008)

iv) Alternate plots were used for VR application and for uniform-rate (UR) treatment. The number of plant leaves and grain yield were measured as growth indices that may be influenced by P deficiency.

6. Different componenets of developed VRA were as follows:

a) Planter and fertiliser applicator b) Sensor and subsoiler c) DGPS antenna and d) electrical actuator e) Roller for closing the trench made by subsoiler

7. Results

The coefficient of variation (CV) of P-ext measured on-the-go ranged from 5% to 51% while variation of phosphate ranged from 36% to 76% over the experimental plots. The average phosphate applied on VR plots was 28.75, 1.25 kg ha^{-1} less than the uniform rate (UR) (30 kg ha^{-1}) recommended according to the standard soil test. The application rate of the phosphate ranged from 0 to 100 kg ha^{-1} in the VR plots. Lower variation in plant leaves was observed in plots with VR treatment, possibly indicating better P distribution over the VR plots. The number of plant leaves variations was 25% and 31% for VR and UR plots, respectively. However, there was no significant difference between VR and UR plots. The maize yield was significantly higher (336 kg ha^{-1}) and less variable on plots that received VR treatment.(Maleki *et al.,* 2008)

8. Map based variable rate applicator technology

Map based methods involves sampling the field, running sample analysis, generating a site specific map of the properties and at last using this map to control a variable rate applicator. Map based technologies are especially good for collecting data for variables which do not fluctuate from season to season, such as organic matter and soil texture. Due to high testing costs and labor requirements, map based precision farming is not as effective for variables that are quickly changing, such as nitrogen. (Adamchuk *et al*., 2004)

Forouzanmehr and Loghavi (2012) developed and evaluated the performance of a map-based variable rate row crop granular fertilizer placement system.

Fig.4. Fertilizer hopper and metering screw assembly used for laboratory and field tests(Forouzanmehr and Loghavi., 2012)

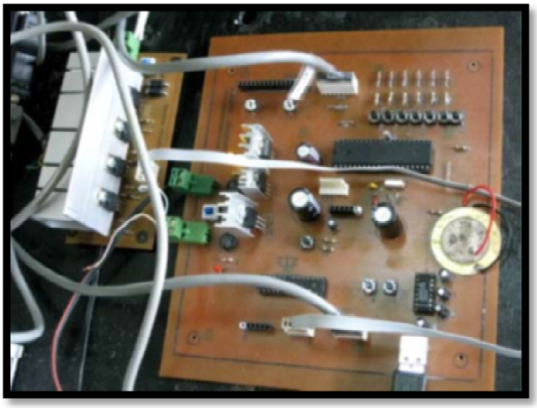

Fig.5. The main controller and the stepper motor driving circuit board (Forouzanmehr and Loghavi., 2012)

9. Components and working of VRA map based system (Forouzanmehr and Loghavi., 2012)

The applicator system consists of an AVR microcontroller for controlling the driving step motor of the fertilizer metering screw and a ground driven wheel integrated with a rotary encoder for the applicator displacement and speed measurement.

Fig.6. Two views showing the components of ground-driven wheel used for measurement of tractor travel speed and displacement (Forouzanmehr and Loghavi., 2012)

Initially, the applicator was calibrated in laboratory to derive a relationship among the step motor speed, the input frequency, and the rate of fertilizer application as a function of metering screw rotational speed. Laboratory evaluation included measurement of the lag time while changing the application rate from low to high and vice versa.

10. Results

In the field tests, a factorial experiment with a split-split design was used to investigate the effects of fertilizer type (urea and triple super phosphate), applicator forward speed (3, 6 and 9 km/s) and application rate (75, 125 and 175 kg/ha) on precision of application rate (the percent of deviation between actual and target rates). The results showed that the forward speed and the application rate both had significant effect on precision of application rate, while fertilizer type had no significant effect. The precision of application rate decreased when forward speed and application rate were increased.

11. Limitations of variable rate technology

- Time lag.
- High initial cost.
- Different sensors required for different attributes.
- Less accurate than laboratory measurement.
- Applicable to only large fields.

12. Advantages of Variable rate technology

- Low operating cost.
- On-the-go spectrophotometer have the potential to perform real time measurement of sol attributes via near infrared reflectance spectroscopy (NIRS).
- On-the-go sensors have the ability to quantify the heterogeneity of soil.
- Pre-application data analysis time requirements can be eliminated.
- Sensors produce higher data resolution than traditional sampling methods.
- No time delay between measurement and application with real-time systems.

13. Conclusion

A visible (VIS) and near-infrared (NIR) soil sensor-based variable-rate (VR) phosphorus (P) application system was successfully implemented. The developed on-the-go fertilisation system was able to update the rate of P application for level of P in the field. However, the yield of the plots that received the (variable rate) VR regime was significantly higher than that of the uniform rate (UR) regime.

Field evaluation tests showed that the developed VR fertilizer applicator was successfully able to respond to the target discharge rates with small delay time and acceptable accuracy. The overall mean value of application rate error was about 5.4%. In the most extreme case (highest discharge rate and highest travel speed), the application rate error was 9% equivalent to 15 kg/ha. With some compromise in travel speed, this VR fertilizer applicator could be integrated with row crop planters and seed drills to optimize the consumption of high demand crop fertilizers based on prescription maps.

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Nano-fertilizers: Techniques, tools and future perspectives in Indian context

Lalit Kumar, Vaibhav Kumar, P S Basu and Ummed Singh

ICAR-Indian Indian Institute of Pulses Research, Kanpur, Uttar Pradesh-208 024
E-mail: lalit1997@ymail.com

ABSTRACT

Nano-fertilizers, which are synthesized or modified form of traditional fertilizers, fertilizers bulk materials or extracted from different vegetative or reproductive parts of the plant by different chemical, physical, mechanical or biological methods with the help of nanotechnology. The role of nano-fertilizers in higher nutrient use efficiency, better quality of produce, enhanced productivity and lower cost of production are attracting benefits for promotion of such fertilizers. Among new generation of fertilizers the role of nano-fertilizers might be at upfront in the near future. Nano-fertilizers are applied precisely as per the demand of the plant, matching with the crop growth stage for nutrient and are able to provide nutrient throughout the crop growth cycle. Further, these fertilizers provide more surface area for different metabolic reactions in the plant which increase rate of photosynthesis and helps in producing more dry matter and economic yield of the crop.

Keywords: Nano-fertilizers, Nano-particles, Nano-technology, Nutrient use efficiency

1. Introduction

Nanotechnology is the manipulation of matter at nano level (1-100 nanometers) in order to produce novel materials and devices with new extraordinary properties. However, nanotechnology is not a new discipline. It is rather the merging of multiple scientific disciplines (biology, physics, chemistry, medicine and engineering) and the combination of knowledge to tailor materials at the nanoscale. Nanotechnology is very interesting because of the size dependent properties being exhibited by the material in the nanoscale regime. Following are the important nanoscale properties of various materials:

1. Enhanced surface area
2. Surface Plamon Resonance
3. Quantum confinement effect
4. Super-Paramagnetism
5. Chemical reactivity and Catalytic activity

The behaviour of matter changes significantly when the surface area to volume ratio increases so dramatically. This fact gives the nano-structured material new abilities and properties that may be more favourable than the ones of the bulk material version. A good example is that some polymers, although being insulators in the bulk form, they become semiconductors at the nanoscale.

2. History of Nanotechnology

The timeline history of developments in nanotechnology has been given in the table below.

3. Classification of nanoparticle

Nanomaterials are classified as 0, 1, 2 and 3 dimensional structures where at least one dimension is less than 100 nm. Figure 1 presents this classification and provides examples of each form of nanostructures, including clusters/spheres, nano wires, polymers, thin films and bulk specimens. Since the surface properties of nanomaterials dominate bulk, by controlling the surface/volume aspect (particle radius, film thickness or grain size), it is

Table 1. Timeline of nanotechnology

Year	Work
2000 Years ago	Sulfide nanocrystals used by Greeks Romans to dye hairs
1000 years ago	Gold nanoparticle of different sizes used to produce different colour in stained glass windows
1959	R. Feynman was presented the concept of Nanotechnology first time in his presentation "There is plenty of room at bottom"
1974	Taniguchi used the term nanotechnology for the first time
1981	IBM develops STM (Scanning Tunneling Microscope)
1985	"Buckyball'- Scientist at Rice University discover C60
1986	"Engines of Creation" – First book on nanotechnology by K. Eric Drexler. AFM (Atomic Force Microscope) was invented by Binning, Quate and Gerbe
1991	Carbon nanotube was discovered by S. Iijima
1999	"Nanomedicine" – 1st nanomedicine book was published by R. Freitas
2000	"National Nanotechnology Initiative" launched

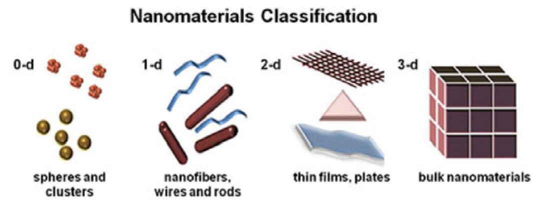

Figure 1: Classification of nanomaterials

possible to develop materials whose physical properties will be related to surface.

The identified nanomaterials are classified into following categories:

(a) Natural nanomaterias: Example- natural iron oxide particle in sediments.

(b) Nano-sized By-products: nanoparticles created as unintentional by-products of human activity: Example- carbon nanoparticles in soot.

(c) Engineered nanomaterials: Example- all manmade nanomaterials prepared intentionally.

The list of commercially exploited nanomaterials are as follows:

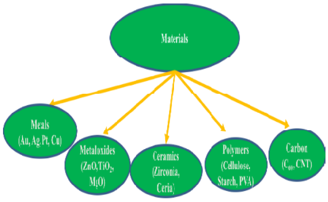

Figure 2: Classification of nanomaterials

4. Synthesis of nanomaterials

There are following approaches which are followed in production of nanomaterials.

(a) Top-down approach:

In this approach high energy is used to break down micron sized particles into nano-sized materials. The process like ball milling, homogenization, laser ablation etc. comes under this category. The disadvantage of this approach is that the size distribution of resultant particle is very wide, though this is being followed commercially for various applications. Now a day, work is going on to use enzyme degradation system for production of nanomaterials with low energy input.

(b) Bottom-up approach:

Bottom up approach refers to the build up of nanomaterial from the bottom. Here atoms/ions/molecules are used as precursors and assembled to form nanoparticle by chemical and/or self-assembly process. The main advantage of this approach is low energy requirement and narrow size distribution.

5. Tools for characterization of nanomaterials

The nanoparticle can be characterized using various technique which includes XRD (X Ray

Diffraction), FESEM (Field emission scanning electron microscope), HRTEM (High resolution transmission electron microscope), EDX (Energy dispersive X-ray spectroscopy), XPS (X-ray photoelectron spectroscope) and FTIR (Infrared transform absorption spectrometer). These techniques explain the morphology of composites, crystalline phases and average size. The morphology of the composites and particle size can be characterized by SEM, AFM and TEM. The presence of functional groups on the surface of nanotubes can be known by using FTIR, Raman, XPS and EDX. The surface area, porosity, pore size and pore distributions can be evaluated by physisorption and chemisorption analyzers. The BET isotherm is used to measure surface area and porosity (Saleh, 2016).

6. Applications of Nanotechnology in agriculture

Basically Nanotechnology is multidisciplinary science. It can be used in all the subjects such as Mathematics, Physics, Chemistry, Biology, Information technology, Mechanical engineering, Imaging technology, Food packaging, Medical sciences, Agriculture etc.

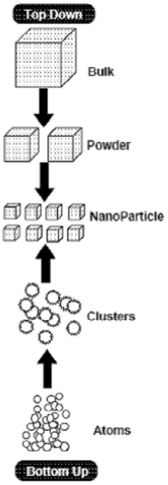

Figure 3: Synthesis of nanomaterials

Why to think use of nanotechnology in Agriculture?

The nanotechnology should be used in Agriculture because of the following reasons:

- Crop yield stagnation
- Declining organic matter in soil
- Plants are facing multinutrient deficiency
- Climate change due to global warming gives adverse effect on plant growth, development and yield.
- Shrinkage of arable land and water availability
- Shortage of labour etc.

6.1 Other applications of Nanotechnology in Agriculture:

- **Food Science and technology**: For example-The hybrid polymer (Nanosilicon embedded durethan polymer) is used to enhance the shelf life of food materials.
- **Gene therapy for plant**: In molecular biology MSN (3-nm Mesoporous silica nanoparticle) is used to transfer foreign DNA into cells and Graphene nanoribbon can be used in DNA sequencing.
- **Seed technology**: Metal oxide nanoparticles and carbon nanotube can improve the germination of seed under rainfed condition.
- **Soil remediation**: Nanoparticle based soil binder called soilset is used to avoid soil erosion.
- **Smart field System**: By the use of nanoparticles, various sensor have been designed which give increased sensitivity and early response to environmental change.These sensors monitor soil condition and crop growth.
- **Removal of heavy metals:** Ligand based nano-

coating can be utilized for effective removal of heavy metals as these have high absorption tendency.

- **Nanoparticles as pesticide:** Pest is important limiting factors for crop yields and need to be effectively controlled below threshold level.Traditional pest control involves theuse of large quantities of pesticides, resulting in environmental pollutionand additional costof production.Dilution of pesticides with nano treated water could greatly improve their efficiency. This could also reduce the quantity of chemical used and thereby reduce the cost by half of conventional pesticides. Nano-pesticides are threefold more effective than conventional pesticides.
- **Nanoparticle act as antimicrobial agents:** Fungi have developed resistance against many conventional fungicide (such as bendimizadoles and dicarboximides). Therefore, there is need to replace these fungicides with novel one to overcome this resistance.Nanoparticles have gain to importance due to their small size, shape, crystallinity, high surface area to volume ratio and subsequent increased contact with target species.Inorganic nano-oxide (ZnO, MgO, CaO) and metals (Ag, Au, Cu) are mostly used as fungicide.

7. Nanofertilizers

Nanofertilizers are synthesized or modified form of traditional fertilizers, fertilizers bulk materials or extracted from different vegetative orreproductive parts of the plant by different chemical, physical, mechanical orbiological methods with the help of nanotechnology. They are used to improve soil fertility, productivity and quality of agricultural produce. At nano scale physical and chemical properties are differing than bulk material. For Example-Rock phosphate when used in nano form may increase the availability of phosphorus to the plant because direct application of rockphosphate nano particles on the crop prevents fixation of phosphorus in the soil. It also prevents the fixation of the phosphorus with silicic acid, iron and calcium and thereby increases the phosphorus availability to the crop plants.

7.1 Conventional fertilizers versus Nanofertilizers

Conventional Fertilizers are generally applied on the crops by either spraying or broadcasting. However, one of the major factors that decide the mode of application is the final concentration of the fertilizer reaching to the plant. In practical scenario, very less concentration (much below to minimum desired concentration) reaches to the targeted site due to leaching of chemicals, drift, runoff, evaporation, hydrolysis by soil moisture, and photolytic and microbial degradation. It has been estimated that around 40–70% of nitrogen, 80–90 % of phosphorus, and 50–90%of potassium content of applied fertilizers are lost in the environment and could not reach the plant which causes sustainable and economic losses (Trenkel, 1997; Ombodi and Saigusa, 2000). These problems have initiated repeated use of fertilizer and pesticide which adversely affects the inherent nutrient balance of the soil. The world demand of fertilizer is projected to reach192.8 Mt by 2016–2017 (Heffer and Prud' home, 2012). But the large-scale use of chemicals as fertilizers and pesticides has resulted in environmental pollution affecting normal flora and fauna. Tilman *et al.* (2002) reported that excess use of fertilizers and pesticide increases pathogen and pest resistance, reduces soil microflora, diminishes nitrogen fixation, contributes to bioaccumulation of pesticides, and destroys habitat for birds. Hence, it is very important to optimize the use of chemical fertilization to fulfill the crop nutrient requirements and to minimize therisk of environmental pollution. Accordingly, it can be favourable that other methods of fertilization be also tested and used to provide necessary nutrients for plant growth and yield production, while keeping the soil structure in good shape and the environment clean (Miransari, 2011).

Nanotechnology has provided the feasibility of exploring nanoscale or nanostructured materials as fertilizer carrier or controlled-release vectors for building of the so-called smart fertilizers which enhance the nutrient use efficiency and reduce environmental pollution (Chinnamuthu and Boopati, 2009). A nano-fertilizer refers to 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. Surface coatings of nanomaterials on fertilizer particles holdthe material more strongly due to higher surface tension than the conventional surfaces and thus help in controlled release. Delivery of agrochemical substance such as fertilizer supplying macro- and micronutrients to the plants is an important aspect of application of nanotechnology in agriculture. As mentioned in Table 2, nano-fertilizers show controlled release of agrochemicals, site targeted delivery, reduction in toxicity, and enhanced nutrient utilization of delivered fertilizers. These attributes of nanoparticles are due to their high surface area to volume ratio, high solubility, and specific targeting due tosmall size, high mobility, and low toxicity (Bhargav *et al.,* 2015).

7.2 Nanofertilizers and nutrient use efficiency:

Nanofertilizers facilitate high nutrient use efficiency. This is one of the important properties of nanofertilizers. The nanofertilizers have higher surface area it is mainly due to very less size of particles which provide more site to facilitate different metabolic process in the plant system which result production of more photosynthates. Due to higher surface area and very less size they have high reactivity with other compounds. They have high solubility in different solvents such as water. Particle size of nano-fertilizers is less than 100 nm which facilitates more penetration of nano particles in to

Table 2: Comparison between Nanofertlizer enabled technologies and Conventional fertilizer application technology

S/N	Properties	Nanofertilizer enabled technology	Conventional technology
1.	Solubility and dispersion of mineral micronutrient	Nano-sized formulation of mineral micronutrients may improve solubility and dispersion of insoluble nutrients in soil, reduce soil absorption and fixation, and increase the bioavailability	Less bioavailability to plants due to large particle size and less solubility
2.	Nutrient uptake efficiency	Nano based formulation might increase fertilizer efficiency and uptake ratio of the soil nutrients in crop production and save fertilizer resource	Bulk composite is not available for roots and decrease efficiency
3.	Controlled release modes	Both release rate and release pattern of nutrients for water soluble fertilizers might be precisely controlled through encapsulation in envelope forms of semipermeable membranes coated by resin-polymer, waxes and sulfur	Excess release of fertilizers may produce toxicity and destroy ecological balance of soil
4.	Effective duration of nutrient release	Nano based formulation canextend effective duration ofnutrient supply of fertilizers intosoil	Used by the plants at the timeof delivery, the rest is converted into insoluble salts in the soil
5.	Loss rate of fertilizer nutrients	Nanostructured formulation canreduce loss rate of fertilizernutrients into soil by leachingand/or leaking	High loss rate by leaching, rainoff, and drift

the plant from applied surface such as soil or leaves. Nanofertilizers have large surface area and particle size less than the pore size of root and leaves of the plant which can increase penetration into the plant from applied surface and improve uptake and nutrient use efficiency of the nanofertilizers. Reduction of particle size results in increased specific surface area and number of particles per unit area of a fertilizer that provide more opportunity to contact nanofertilizers which leads to more penetration and uptake of the nutrient.

Fertilizers encapsulated in nano-particles will increase availability and uptake of nutrient to the crop plants. Zeolite based nanofertilizers are capable to release nutrients slowly to the crop plant which increase availability of nutrient to the crop though out the growth period which prevent loss of nutrient from denitrification, volatilization, leaching and fixation in the soil especially NO_3-N andNH_4-N. Particle size below 100 nm nano-particles can used as fertilizer for efficient nutrient management which are eco-friendly and reduce environment pollution. Main reason for high interest in fertilizers is mainly their penetration capacity, size and very high surface area which usually differ from the same material found in bulk form. This is partially due to the fact that nano particles show a very high surface: volume ratio. Thus, the reactive surface area is proportionally over-represented in nano particles compared to larger particles. Particle surface area increases with decreasing particle size and the surface free energy of the particle is a function of its size (Meena *et al.*, 2017).

7.3 Achievements of nanofertilizers

Several research study revealed that nano fertilizers enhanced growth, yield and quality parameters of the crop which result better yield and quality food product for human and animal consumption. This translates into an improvement to three major areas of production.

Yields: Several research studies revealed that application of nano-fertilizers significantly increase crop yield over control or without application of nano-fertilzerit is mainly because of increasing growth of plant parts and metabolic process such as photosynthesis leads to higher photosynthetes accumulation and translocation to the economic parts of the plant. Foliar applications of nano particlesas fertilizer significantly increase in yield of the crop.

Nutritional value: Nano fertilizers provide more surface area and more availability of nutrient to the crop plant which help to increase these quality parameters of the plant (such as protein, oil content, sugar content) by enhancing the rate of reaction or synthesis process in the plant system. Application of zinc and iron on the plant increase total carbohydrate, starch, IAA, chlorophyll and protein content in the grain. Nano-Fe_2O_3 increase photosynthesis and growth of the peanut plant.

Health: Some nutrient also responsible disease resistance to the plant and due tothe more availability of nano nutrient to the plant it prevents from disease, nutrient deficiency and other biotic and abiotic stress which indicate that nano fertilizers enhance overall health of the plant. ZnO nano-particles also helpful to plant under stress conditions.

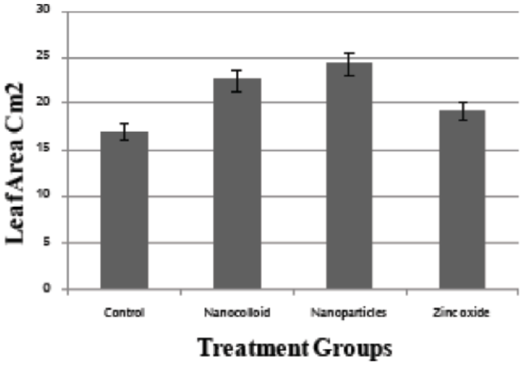

Figure 4: Comparison of mean leaf area of different treatment

8. Case study

8.1 The effects of zinc-oxide nanoparticles on growth parameters of corn (SC704) (Taheri et al., *2015):*

In this study, the three different physical forms of ZnO particles in irrigation water were used to supplement mineral poor soil. Their effect on the growth of corn (SC704) was investigated. Taheri *et al.* (2015) studied the effects of ZnO nanocolloid, ZnO nanoparticles, and micrometric ZnO particles. The concentration of nanoparticles in irrigation water was 2 ppm. The results showed that the addition of all three ZnO particle types in irrigation water improved shoot dry matter and leaf area index. The best results came from the ZnO nanoparticle treatment, which on average increased the shoot dry matter and leaf area indexes by 63.8% and 69.7% respectively.

Results: Effect of different form of ZnO on mean leaf area:

Here each treatment of ZnO the average leaf area was increased as compared to control.The maximum leaf area was reported in case of treatment with ZnO nanoparticle (Figure 4).

1. Effect of different form of ZnO on leaf dry weight:

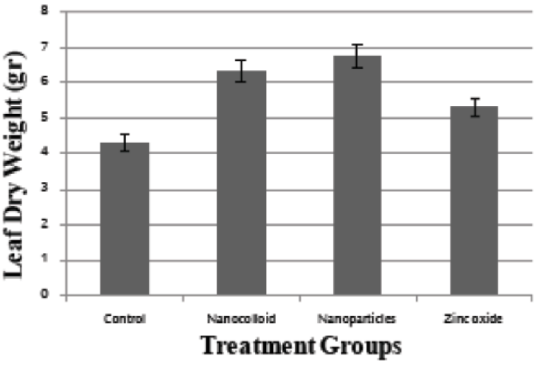

Fig. 5: Comparison of mean leaf dry weight of different treatment

Here also the similar result was found as in case of mean leaf area. The maximum leaf dry weight found in case of treatment with ZnO nanoparticle (figure 5).Based on these results, it is concluded that nano form of zincoxide can improve corn growth and leaf dry weight as compared to other form other form of zinc oxide.

8.2 Silver nano-particles enhance the growth and yield of wheat:

Present study was carried out by Hafiz et al. (2015)to determine the role of SNPs for improving (NUE) in wheat. The SNPs were synthesized chemically by reducing silvernitrate with trisodium citrate and size was 10-20 nm according to X-Ray Diffraction analysis. Completely randomized design with seven graded doses of SNPs (0, 25, 50, 75, 100, 125, 150 ppm) and four replications was employed for experimental layout. Seedlings of wheat variety NARC2009 were transplanted to pots. Pot soil was soaked with SNPs solution up to field capacity levels and distilled water was applied in control treatment. SNPs significantly enhanced most of the growth and yield attributes, NPK uptake and nutrient use efficiency of wheat. Silver nanoparticles in 25ppm concentration have showed significant improvement in maximum leaf area and highest grain yield while 75ppm concentration resulted in decrease in grain yield. So silver nanoparticles have stimulatory as well as inhibitory effect on wheat growth and yield.

8.3 Potential of copper nanoparticles to increase growth and yield of wheat:

A study was conducted in Pakistan to determine the potential of copper nanoparticles (Cu-NPs) for enhancing growth and yield of wheat (Abdul *et al.,* 2015).This study was conducted to determine the potential of copper nanoparticles (Cu-NPs) for enhancing growth and yield of wheat cultivar Millat-2011. In this study,seed germination was not affected with 0.2 to 0.8 ppm of Cu-NPsbut decreased significantly at 1ppm of Cu-NPs. In solution culture concentration of Cu-NPs higher than 2ppm proved deleterious to wheat plants. Whereas MS medium blended with low concentrations of Cu-NPs (0.2, 0.4, 0.6, and 0.8 and 1.0ppm), significantly increased leaf area, chlorophyll content, fresh and dry weight, and root dry weight as compared to control plants. When applied to soil in pots Cu-NPs (10, 20, 30, 40 and 50ppm) significantly increased growth and yield of wheat as compared with control. However, 30ppm Cu-NPs produced significantly higher chlorophyll content, leaf area, number of spikes/pot, number of grains/spike, 100 grain weight and grain yield. Results of this study reveal that Cu-NPs have the potential to enhance growth and yield of wheat but their effect is concentration dependent.

9. Conclusion

1. Nanotechnology is capable of being used in agricultural products that protect plants and monitor plant growth and detect diseases.
2. Nanotechnology guarantees a breakthrough in:

- Improving the nutrient use efficiency through nanoformulation of fertilizers.
- Breaking yield and nutritional quality barriers through bio-nanotechnology
- Surveillance and control of pest and diseases**.**

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Theme 3:

Targeting enhanced soil fertility and crop production

Quantification of nutrient losses through weeds in field crops

Baldev Ram[1], Jagdish P Tetarwal[1], R K Shivran[1], Ummed Singh[2] and C S Praharaj[2]

[1]Agriculture University, Kota, Rajasthan
[2]ICAR- Indian Institute of Pulses Research, Kanpur, Uttar Pradesh-208024
E-mail: baldev.ram@gmail.com

ABSTRACT

Weeds create an acute problem in *kharif*, *rabi* and *spring/summer* field crops. They compete for nutrients, moisture, light, space and CO_2, harbour many pests and disease eventually affect the growth, yield and quality of crop adversely. Yield losses in field crops varied from season to season, crop to crop, intercultural operations and cropping pattern but on an average 33-50 per cent in yield reduction due to weed infestation but sometimes, in rainy season led to 100 per cent yield loss due to heavy weed infestation. Out of total yield reduction in field crops weeds accounts 37 % while insects, diseases and other pests in storage are 29, 22 and 12%, respectively. Nutrient depletion by weeds in field crops ranges from 21.6-108.5 kg N/ha, 1.9-16.6 kg P/ha and 3.6-151.6 kg K/ha. Earlier weeds were controlled mechanically by hoeing and bullock/tractor drawn implements but now the use of chemical herbicide especially use of post emergence herbicides in every field crop is widespread. Technologies for weed management are in great demand by the farmers due to acute labour scarcity for manual weeding and rising cost of production. Thus, integrated weed management employing a combinations of available options including preventive, mechanical, cultural, chemical and biological methods helps in realizing the full benefits of applied fertilizers and irrigation water.

Keywords: Field crops, Nutrient removal, Weeds, Weed-nutrient competition

1. Introduction

Weeds are known to be a major biotic constraint in agricultural production systems including non-cropped lands and aquatic situations. As per the recent available estimates, more than one-third of the total yield losses due to biotic stresses are caused by weeds alone, but farmers' cannot much take care and cause hidden effects on plant growth. Besides, reducing crop yields, their infestation adversely affects produce quality, biodiversity, animal health and aesthetic value of the area. This is due to anthropogenic activities so called modern cultivation methods employing use of chemical fertilizers, irrigation, short-statured high-yielding varieties/hybrids, intensive tillage, and mono-cropping systems devoid of legumes coupled with climate change. Further, there are emerging concerns of the growing infestations of invasive weeds, herbicides resistance in weeds and their residue hazards. Sharma *et al.* (2000) gave rough estimate on crop-weed competition and suggested reduction of 33-50 per cent in yield due to weed infestation but sometimes, in rainy season led to 100 per cent yield loss due to heavy weed infestation. Therefore, weed problems are highly dynamic requires continuous monitoring and revamp of technologies for their effective management. Weeds reduce crop yields by extracting soil nutrients and water, which is available to both crops and weeds. However, weeds being hardier and well adaptor to provide intense competition with crop plants for the available resources. Therefore, good agronomic strategies are adopted to create a favourable environment for the crop by curtail weed infestation and enhancing nutrient and water availability for increased productivity. Similarly, efficient fertilizer management through appropriate source, rate, time and method of application also improves weed-control efficiency. However, their application requires technical guidance in order to avoid possible adverse effects on the environment. Exploiting positive interactions through integrated weed-fertilizer-water management in a holistic manner is essential for improving productivity and resource-use efficiency on a sustainable basis (Sharma *et al.,* 2016). Integrated weed management is the most desirable approach, the use of herbicides is gaining rapid acceptance due to their efficient weed control at much lower cost.

A. Major weed flora invades in Indian Agriculture

Weeds are one of the major biotic constraints in agricultural production. Some recent studies reveal that resurgence of some weed flora are dominating in different ecosystems. The abundance and appearance of weeds varies according to regions, crops, and management systems, which complicates management approaches. For example, *Phalaris minor* Retz., a C_3 species, is a problematic weed in wheat in the Indo-Gangetic Plains of North India. Similarly, C_3weeds in other areas include *Avena fatua* L., *Chenopodium album* L., *Cirsium arvense* (L.) Scop., *Convolvulus arvensis* L., and *Ludwigia hyssopifolia* (G. Don) Exell. Now weedy rice (*Oryza sativa* L.) is also a C_3 weed in rice growing regions in many Asian countries (Chin *et al.,* 2013; Chauhan, 2013) and major shifts of weeds revealed that (i) infestation of *Malva parviflora*, *Rumex retroflexus*, *Poa annua*, *Coronopus didymus* and *Polypogon monspeliensis* are increasing in the rice-wheat cropping zone; (ii) *Ipomea pestigridis* has become a serious weed of sugarcane in Haryana and Uttar Pradesh; (iii) the intensity of submerged weeds is increasing in rice-rice sequence in Assam; (iv) *Ambrosia artemisifolia* and *Parthenium hysterophorus* are spreading to cropping and plantation areas; and (v) *Loranthus longiflorus* is likely to be a major problem for mango orchards in south India. Added to these, some more weeds like weedy rice is emerging as a major problem in direct seeded rice (*Rao et al*., 2007). In the Cauvery delta region of Tamil Nadu, *Leptochloa chinensis* and *Marselia quadrifolia* became predominant in rice fields by replacing *Echinochloa* (Yaduraju and Kathiresan, 2003). In the eastern IGP, adoption of zero tillage has resulted in an increase in perennial weeds such as *Cyperus rotundus* and *Cynodon dactylon* (Malik and Kumar, 2014). Weeds of economic significance in major field crops are given in Table 1.

B. Crop yield losses due to weeds

The crop density is already set at a level that optimizes yield in a certain area and the presence of weeds will lead to an increased number of plants in that environment and consequently, will cause a reduction in the average yield of crop. Weed competition is a major constraint to crop production

Table 1. Major weeds (in order of significance) in field crops in India

Rice	Maize	Soybean	Wheat	Chickpea
Echinochloa colonum	*Echinochloa colonum*	*Echinochloa colonum*	*Phalaris minor*	*Chenopodium album*
Echinochloa crussgali	*Celosia argentea*	*Cyperus rotundus*	*Avena ludoviciana*	*Avena fatua*
Cyperus spp.	*Cyanotis axillaris*	*Euphorbia genticulata*	*Chenopodium album*	*Medicago denticulate*
Alternanthera spp.	*Euphorbia hirta*	*Commelina communis*	*Avena fatua*	*Cichorium intybus*

Source: *Rao et al.* (2007)

besides water and nutrients. It is estimated that, in general, weeds cause 5 % loss to agricultural production in most of the developed countries, 10 % loss in less developed countries, and 25 % loss in least developed countries like India under average farming conditions. In India, weeds are economically more important than insects, fungi or other pest organisms. Of the total losses caused by various pests, weeds accounts for about 37 % reduction in yield, while the losses due to insects, diseases and other pests are 29, 22 and 12%, respectively. The total economic losses will however be much higher, if indirect effects of weeds on health, biodiversity, nutrient depletion etc. are also taken into consideration. The yield loss due to weeds is caused by an assemblage of different weed species, which differ substantially in their competitive ability. Hence, the outcome of competition depends on the crop and weed species as well as their density, period of infestation levels of fertility and moisture. Broad-leaved and grassy weeds compete at different levels of intensity depending upon the competitiveness of crop, tillage system, environmental conditions, and other weeds present. In general, broad leaved weeds are more damaging to a broad leaved crop, while grassy weeds are more competitive against cereal crops. Hence, it is also difficult to control an infestation of broad-leaved weeds in a broad leaved crop than to control a grassy weed. The same theory applies to a grass crop such as wheat. The estimated yield losses due to weeds in important field crops are depicted (Table 2).

Table 2. Yield losses due to weeds in important field crops

Crops	Yield loss (%)	
	Over weedy check	Over farmers' practice
Cereals		
Direct-seeded rice	78.2	42.7
Transplanted rice	30.9	15.5
Wheat	37.5	15.7
Pearlmillet	43.4	29.7
Sorghum	35.0	18.3
Pulses		
Chickpea	46.8	32.3
Pigeonpea	31.0	31.0
Oilseeds		
Groundnut	45.0	33.0
Soybean	71.0	26.8
Mustard	83.5	17.9
Sunflower	34.0	31.7
Sesamum	41.0	15.1
Others		
Cotton	47.4	21.2
Sugarcane	68.7	12.8
Potato	28.2	18.1

Source: Data compiled from Annual Reports of AICRP-Weed Management (2003-2012)

C. Critical period of crop-weed competition

The basic idea of weed management is to provide curative treatment when economic damage is caused by weeds. Plant species growing in mixed population compete with each other for the growing limiting resources such as nutrients, water, light and carbon d dioxide etc. The empirical model developed provides an assessment of weed competition and its impact on crop growth and yield. Before planning integrated weed management it is necessary to work the critical periods of weed competition and also

Table 3. Critical period of crop-weed competition and yield losses caused by weeds in different crops

Crops	Critical period (DAS)	% reduction in grain yield
A. Cereals		
Rice (direct seeded)	15-45	15-90
Rice (transplanted)	30-45	15-40
Wheat	30-45	20-40
Maize	15-45	40-60
Sorghum	15-45	15-40
Pearlmillet	30-45	15-60
B. Pulses		
Pigeonpea	15-60	20-40
Greengram	15-30	25-50
Blackgram	15-30	30-50
Cowpea	15-30	15-30

Crops	Critical period (DAS)	% reduction in grain yield
Chickpea	30-60	15-25
Peas	30-45	20-30
Lentil	30-60	20-30
C. Oilseeds		
Soybean	20-45	40-60
Groundnut	40-60	40-50
Sunflower	30-45	30-50
Castor	30-60	30-35
Safflower	15-45	35-60
Sesamum	15-45	15-40
Rapeseed-mustard	15-40	15-30
Linseed	20-45	30-40
D. Commercial crops		
Sugarcane	30-120	20-30
Potato	20-40	30-60
Cotton	15-60	40-50
Jute	30-45	50-80
E. Vegetable crops		
Cauliflower	30-45	50-60
Cabbage	30-45	50-60
Okra	15-30	40-50
Tomato	30-45	40-70
Onion	30-75	60-70

Source: Mishra (1997)

necessity of weed free environment needed during the initial period of crop growth. This provides the active duration during which the presence of several cultivated crops in the plots is needed to be free of weeds during a very limited number of weeks each season. Generally, these critical periods vary in different crops (Table 3).

D. Nutrient losses caused by weeds

I. Competition for nutrients

It is an important aspect of crop weed competition. Weeds usually absorb mineral nutrients faster than crop plants. Usually weeds accumulate relatively larger amounts of nutrients than crop plant. Nutrient removal by weeds leads to huge loss of nutrients in each crop season, which is often twice that of crop plants. *Amaranthus* accumulate over 3 % nitrogen in their dry matter and this fall under category of nitrophylls; *Digetaria* spp. and *Achyranthes aspera* accumulates more phosphorus content of over 3.36 and 0.6 % P; *Chenopodium* and *Portuluca* are potassium lovers with content of over 4.0 % K_2O in their dry matter and *Setaria lutescens* accumulates as high as 585 ppm of zinc in its dry matter and content is about three times more than by

Table 4. Nutrient content in weeds (% dry weight)

Scientific name	Common name	Nutrient composition (%)		
		Nitrogen	Phosphorus	Potassium
Chenopodium album	Bathua	2.59	0.37	4.34
Argemone maxicana	Satyanashi	1.01	1.36	1.33
Convovulus arvensis	Hirankhuri	2.02	1.01	2.00
Melilotus alba	Safed senji	2.45	1.53	1.85
Solanum xanthocarpum	Baigan kateli	2.56	1.63	2.12
Amaranthus viridis	Jangali Cholai	3.16	0.06	4.51
Cynodon dactylon	Doob grass	1.72	0.25	1.75
Cyperus rotundus	Motha grass	2.17	0.26	2.73
Chromolaena odorata	-	3.15	0.50	1.78
Parthenium hysterophorus	Ghajar ghas	2.86	0.90	1.56
Eichhornia crassipes	Jal kumbhi	2.98	0.95	2.13
Lantana camera	Lantana	2.50	0.25	1.40
Cichorium intybus	Kasani	4.40	0.66	3.80
Cirsium arvense	Canada thistle	2.80	0.36	2.90

Source: Anonymous (2003); Harrington *et al.* (2006)

cereal crop. Nutrient removal by weeds leads to huge loss of nutrients in each crop season, and in the absence of any weeds intervention, the amount is often much higher than that of crop uptake. In fact, the N, P and K uptake by the associated weeds can be several times higher over crop in early stages of cultivation and average 7-20 % uptake done by weeds. Results of different field crops revealed that weeds remove on an average 22-162 kg nitrogen, 3-24 kg phosphorus and 21-203 kg potassium/ha. Though, weeds grown in *rabi* season having nutrient 1.01-3.16 % nitrogen, 0.06-1.63 % phosphorus and 1.32-4.51 % potassium content on an average dry weight of weeds (Table 4).

Similarly, the N uptake by *Echinochloa crusgalli* often exceeds that of *kharif* crops of rice and maize. The dominant associated weeds are generally response to N, and often the crop-weed competition for N is relatively more prominent in the agricultural field. Plant with C_3 metabolism often have higher shoot N concentrations, whereas those with C_4 metabolism tend to produce more dry matter per unit shoot N. Photorespiration occurs in C_3 plants, necessitating a greater total N concentration to maintain plant metabolism, whereas C_4 plants use CO_2 more efficiently. Some weed species require even more amount of nutrients than the crop plants to produce per unit amount of dry matter (Table 5).

Table 5. Nutrients requires for producing dry matter (kg mass/kg applied) by weeds and crop plants

Plant species	Nitrogen (kg)	Phosphorus (kg)
Crop		
Wheat	5.5	1.2
Oats	4.9	1.7
Barley	8.4	2.6
Weed		
Chenopodium album	7.6	1.6
Amaranthus retroflexus	5.1	1.4
Ambrosia artimissifolia	6.6	1.4

Source: Zimdahl (2007)

In pulses nitrogen, phosphorus and potassium are the primary plant nutrients, among which nitrogen is most important. Weeds consume greater amounts of these nutrients than crops. The most important point is that weeds require the same nutrients at same time and are often more successful in harnessing more nutrients as compared to pulses. Competition for the nutrients constitutes is an important aspect of weed-crop interaction. Nitrogen is the most important element, but competition may also be occur for other nutrients especially phosphorus, potassium and sulphur required for plant growth. Weeds usually absorb mineral nutrients faster than many of the crop plants and accumulate them in their tissues in relatively larger amounts (Table 7). As evident from nutrient consumption by weeds i.e. *Amaranthus* often accumulates over 3 % N in its dry matter.

Table 6. Effect of different weed control treatments on weed density at 75 DAS, yield attributes and grain yield in direct seeded rice

Treatment	Dose (g/ha)	Time (DAS)	No. of effective tillers/m^2	No. of filled grains/ panicle	Grain yield (t/ha)
Pendimethalin *fb* bispyribac Na + ethoxysulfuron	1000 *fb* 25+18.75	3 *fb* 25	206.7	82.0	3.83
Pendimethalin *fb* bispyribac Na + metsulfuron methyl + chlorimuron ethyl	1000 *fb* 25+4	3 *fb* 25	209.3	83.7	3.97
Weedy check	-	-	97.3	71.7	1.52
CD (P=0.05)	-	-	20.0	4.7	0.43

Source: Singh *et al.* (2016)

Harrington *et al.* (2006) found significantly higher level of sulphur (S) and magnesium (Mg) in *Cichorium intybus* and *Cirsium arvense* than in perennial ryegrass or white clover pasture crops. Competition by the weeds with crop plants depends upon weed density and type of weed flora infesting the crop. More the weed density, higher will be the competition.

II. Nutrient depletion by weeds in major *kharif* crops

a. Direct seeded rice

Sequential application of pendimethalin 1000 g/ha *fb* post emergence application of bispyribac sodium 25 g/ha + ethoxysulfuron 18.75 g/ha and metsulfuron methyl + chlorimuron ethyl 4 g/ha in rice recorded lowest weed density at 75 DAS and produced highest number of effective tillers, filled grain and grain yield as compared to all other herbicidal treatments (Table 6).

Table 7. Effect of irrigation levels on nutrient removal by weeds grown under greengram

Treatment	Nutrient depletion by weeds (kg/ha) at 60 DAS		
	Nitrogen	Phosphorus	Potassium
1 irrigation	6.50	1.45	5.50
2 irrigation	7.92	1.80	6.07
3 irrigation	7.93	1.83	6.15
4 irrigation	8.10	1.95	6.37

Source: Verma *et al.* (2008)

b. Greengram

The depletion of nutrients by weeds in greengram crop was reported by Verma *et al.*, 2008 and observed that increased number of irrigations increased the nutrient uptake and maximum uptake of N, P and K by weeds was observed under 4 irrigations. Thus more moisture in the field enable weeds luxuriant growth and weeds compete for more nutrients (Table 7).

Table 8. Effect of treatments on weed density and weed dry weight, weed control efficiency, kernels/cob and grain yield of maize

Treatment	Weed density (no./m^2) at 45 DAS	Weed dry weight (g/m^2) at 45 DAS	WCE (%) at 45 DAS	No. of kernels/ cob	Grain yield (t/ha)
Atrazine 625 g/ha-PE	5.22 (26.74)	3.42 (11.21)	89.41	384	5.65
Atrazine 500 g/ha- PoE 20 DAS	5.44 (29.06)	5.32 (27.82)	73.72	382	5.36
Tempotrione 100 g/ha + surfactant at 20 DAS	3.63 (12.68)	3.26 (10.15)	90.41	408	5.73
Tempotrione 90 g/ha + surfactant + atrazine at 500 g/ha at 20 DAS	0.96 (0.43)	0.81 (0.15)	99.86	447	7.15
Topramezone 90 g/ha + surfactant at 20 DAS	3.70 (13.19)	2.95 (8.18)	92.27	402	5.68
Topramezone 80 g/ha + surfactant + atrazine at 500 g/ha at 20 DAS	0.95 (0.39)	0.72 (0.02)	99.98	446	7.10
Halosulfuron at 67.5 g/ha + atrazine at 500 g/ha at 20 DAS	1.02 (0.53)	0.73 (0.03)	99.97	441	7.06
Atrazine 625 g/ha-PE + one manual weeding at 25 DAS	2.65 (6.50)	1.59 (2.03)	98.08	426	7.84
Current farmers' practice	6.76 (45.21)	5.16 (26.11)	75.33	377	5.35
Manual weeding twice at 20 and 40 DAS	1.40 (1.46)	0.80 (0.14)	99.07	424	6.93
Weed free check	0.71 (0.00)	0.71 (0.00)	100	457	7.35
Unweeded control	9.37 (87.26)	10.31 (105.83)	0.00	323	4.76
CD (P=0.05)	0.37	0.31	-	36.44	0.67

*Values in parantheses are original, data transformed to square root transformation "x+1"
Source: Ahmad *et al.* (2016)

Table 9. Effect of weed management practices on nutrient uptake by crop and weeds in *kharif* maize

Treatment	Yield (t/ha)		Nutrient uptake by crop (kg/ha)			Nutrient uptake by weeds (kg/ha)		
	Grain	Fodder	N	P	K	N	P	K
Weedy check	3.15	8.62	54.10	10.22	48.30	60.50	10.67	40.23
Weed free check (20, 40 & 60 DAS)	6.37	15.94	147.83	34.16	93.00	24.23	5.13	27.23
Atrazine 1.0 kg/ha PE *fb* HW 25 DAS	6.02	15.22	145.70	30.06	86.23	25.87	5.60	28.16
Atrazine 1.0 kg/ha PE *fb* 2,4 D 1.0 kg/ha at 30 DAS	5.67	14.51	135.33	25.13	80.73	34.40	6.16	32.61
Atrazine 1.0 kg/ha *fb* metsulfuron methyl 4.0 g/ha at 30 DAS	5.52	13.00	117.53	22.27	75.33	36.23	6.67	33.08
Metribuzin 0.5 kg/ha *fb* HW at 30 DAS	4.93	11.82	107.33	19.17	62.81	44.54	7.60	35.34
Metribuzin 0.5 kg/ha *fb* 2,4 D 1.0 kg/ha at 30 DAS	4.48	11.32	106.80	17.57	60.67	48.58	8.87	38.09
Metribuzin 0.5 kg/ha *fb* metsulfuron methyl 4.0 g/ha at 25 DAS	4.07	10.09	104.40	15.05	58.82	52.50	9.46	38.97
Two hoeing at 15 & 45 DAS *fb* HW at 30 DAS	5.54	14.12	130.87	24.41	75.74	33.12	6.23	31.57
CD (P=0.05)	0.62	1.69	6.93	1.94	4.33	2.92	0.96	1.88

Source: Sharma *et al.* (2016)

c. Maize

Tank mix application of post emergence herbicide tembotrione at 90 g/ha + atrazine 500 g/ha or topramezone at 80 g/ha + atrazine 500 g/ha and halosulfuron at 67.5 g/ha + atrazine 500 g/ha showed promising results in managing complex weed flora and resulting higher grain yield of maize in the plateau of Odisha (Table 8).

In *kharif* maize, pre emergence application of atrazine 1.0 kg/ha *fb* hand weeding at 25 DAS was recorded higher grain and fodder yields, nutrient uptake of 145.7 kg N/ha, 30.06 kg P/ha and 86.23 kg K/ha by maize and least nutrient depletion of 25.87 kg N/ha, 5.60 kg P/ha and 28.16 kg K/ha as compared to weedy check, respectively (Table 9). The next best effective weed management practices are atrazine 1.0 kg/ha *fb* 2, 4 D 1.0 kg/ha at 25 DAS, metribuzin 0.5 kg/ha *fb* metsulfuron methyl 4 g/ha at 25 DAS and atrazine 1.0 kg/ha *fb* metsulfuron methyl 4 g/ha at 25 DAS over weedy check.

d. Pearlmillet

Weed management practices significantly reduced the weed dry matter production and increased the weed control efficiency as compared to unweeded control. Hand weeding twice at 30 & 45 DAS significantly reduced dry matter production at harvest being on par with pendimethalin and oxadiazon each at 1.0 kg/ha + hand weeding once at 45 DAS compared to rest of the weed management practices (Table 10). Maximum nutrient depletion of 45.44 kg N/ha, 3.80 kg P/ha and 40.8 kg K/ha by weeds recorded under unweeded control plots throughout the crop season at harvest, respectively was significantly higher over rest of the weed control measures, whereas least nutrient depletion of 9.2 kg N/ha, 0.8 kg P/ha and 8.7 kg K/ha by weeds was

Table 10. Effect of intercropping systems and weed management practices on weed dry matter production and nutrient depletion by weeds in *kharif* pearlmillet

Treatment	Weed dry matter production at harvest (kg/ha)	WCE (%) at harvest	Nutrient removal by weeds at harvest (kg/ha)		
			N	P	K
Intercropping systems					
Sole pearlmillet	1333	60.42	20.72	1.73	18.39
Pearlmillet + cowpea	975	66.34	14.34	1.20	12.83
Pearlmillet + clusterbean	1023	63.98	15.64	1.28	13.93
Pearlmillet + greengram	988	64.83	14.67	1.24	12.60
CD (P=0.05)	56.22	2.13	0.75	0.06	0.71
Weed management practices					
Unweeded control	2982	0.00	45.44	3.79	40.76
Pendimethalin 1.0 kg ai/ha-PE	894	70.25	13.52	1.11	12.06
Pendimethalin 1.0 kg ai/ha-PE + HW at 45 DAS	641	78.97	9.62	0.81	8.58
Oxadiazon 1.0 kg ai/ha-PE	913	69.62	13.80	1.15	12.33
Oxadiazon 1.0 kg ai/ha-PE + HW at 45 DAS	649	77.47	9.85	0.82	8.74
Hand weeding once at 30 DAS	858	71.47	13.00	1.08	11.58
Hand weeding twice at 30 & 45 DAS	625	79.46	9.20	0.78	8.36
CD (P=0.05)	62.25	2.29	0.87	0.07	0.81

Source: Ram *et al.* (2005)

Table 11. Weed dry biomass, grain yield and economics as influenced by different weed management practices in wheat

Treatment	Total weed biomass (g/m2) at 60 DAS	Effective tillers at harvest (No./mrl)	Grain yield (kg/ha)	WCE (%) at 60 DAs	B: C ratio
Pendimethalin 500 g/ha-PE	18.69 (348.6)	50.4	2417	7.0	1.36
2, 4 D 750 g/ha-PoE	15.53 (240.7)	48.0	2685	36.0	1.55
Metsulfuron methyl 4 g/ha-PoE	17.18 (294.7)	43.3	2363	21.0	1.38
Clodinafop propargyl 60 g/ha-PoE	8.76 (76.2)	84.5	3696	80.0	2.07
Sulfosulfuron 75 g/ha-PoE	1.51 (1.8)	97.1	3756	99.0	2.12
Sulfosulfuron 75 % + metsulfuron methyl 5 % 32 g/ha-PoE	2.23 (7.1)	99.5	4265	98.0	2.38
Clodinafop propargyl 15 % + metsulfuron methyl 1 % 64 g/ha-PoE	1.00 (0.00)	92.9	4346	100.0	2.17
Metsulfuron methyl 3 % + iodosulfuron 0.6 % 14.4 g/ha-PoE	1.00 (0.00)	92.6	3930	100.0	1.88
Hand weeding at 20 & 40 DAS	2.81 (7.0)	83.3	3954	98.0	1.01
Weedy check	19.34 (373.2)	46.1	1611	-	

*Values in parantheses are original, data transformed to square root transformation “x+1

Source: Patel *et al.* (2016)

observed at harvest under hand weeding twice at 30 & 45 DAS, respectively.

e. Wheat

Application of post emergence herbicide clodinafop propargyl 15 % + metsulfuron methyl 1 % @ 64 g/ha or sulfosulfuron 75 % + metsulfuron methyl 5 % @ 32 g/ha can be used to control complex weed flora of monocot and dicot weeds in wheat especially *Phalaris minor*, *Avena fatua*, *Chenopodium album* and *Chenopodium murale* without any residual/ carryover effect on succeeding greengram, maize and pearlmillet at Anad, Gujarat (Table 11).

III. Total nutrient depletion by weeds in major field crops

The depletion of nutrients by weeds and field crops was reported by Singh (1993) and Verma *et al.*, 2008 and observed that unweeded field crops recorded minimum uptake of N, P and K and maximum by weeds. Thus under well nourished field enable weeds luxuriant growth and weeds compete for more nutrients (Table 12). The actual quantity of nutrients that is lost from a crop field due to weeds varies greatly from site to site depending upon the nature and quantum of weed infestation. As observed under

Table 12. Nutrient depletion by weeds in some field crops

Crop	Treatment	Nitrogen		Phosphorus		Potassium	
		Crop	Weed	Crop	Weed	Crop	Weed
Mungbean	Weedy	15	120	6	15	11	119
	Weedfree	105	-	43	-	81	-
Urdbean	Weedy	29	142	-	-	-	-
	Weedfree	88	-	-	-	-	-
Peas	Weedy	73	76	5.5	8	-	21
	Weedfree	114	-	69	-	-	-
Lentil	Weedy	30	71	5	14	33	105
	Weedfree	163	-	24	-	143	-
Wheat	Weedy	-	21.7	-	2.9	-	28.2
Sugarcane	Weedy	-	162.2	-	23.8	-	202.9

Source: Singh (1993) and Verma *et al.* (2008)

Table 13. Nutrient losses due to weeds in some major crops

Crop	Nutrient removal by weeds (kg/ha)				
	N	P	K	Sampling stage	References
Rice	65.4	9.6	66.2	90 DAS	Rana *et al.* (2000)
Wheat	71.8	10.4	59.1	At harvest	Jat *et al.* (2007)
Maize	52.0	-	-	60 DAS	Singh *et al.* (2007)
	60.50	10.67	40.23	At harvest	Sharma *et al.* (2016)
Pearlmillet	45.44	3.79	40.76	At harvest	Ram *et al.* (2005)
Sorghum	31.6	6.6	30.4	At harvest	Mishra *et al.* (2012)
Mustard	21.6	-	-	90 DAS	Kumar *et al.* (2012)
Sunflower	44.2	16.6	42.6	At harvest	Sankar and Subramanyam (2011)
Soybean	47.7	10.0	66.6	At harvest	Chander *et al.* (2013)
Clusterbean	108.5	15.8	151.6	At harvest	Yadav *et al.* (2011)
Greengram	28.7	1.9	15.1	At harvest	Chhodavadia *et al.* (2013)
Sesamum	45.0	6.9	3.6	60 DAS	Bhadauria *et al.* (2012)

experimental condition, in the absence of any weeding operation, a large amount of nutrients can be removed by associated weeds in the crop fields receiving recommended doses of inorganic fertilizers (Table 13). These observations clearly show that, if not controlled, weeds can offset the perceived benefit of the applied fertilizers i.e. if the quantum of fertilizer N lost through gaseous, leaching or runoff processes, which is roughly about 25-50 % of the applied quantity, is added to the amount of N lost through uncontrolled weeds, only a negligible part of the generally recommended amount of 120 kg N/ ha remains in the system for uptake by crop like rice and wheat.

2. Conclusion

Considering the diversity and complexity of weed problem, no single method of weed control whether cultural, manual, or chemical would be sufficient to provide season long sustainable weed control. Under limited nutrient conditions, competition exists between crop and weed, similarly soil type, soil fertility, soil moisture and soil reaction influences the crop-weed competition. Elevated soil fertility usually stimulates weeds more than the crop, reducing thus crop yields. An integrated weed management (IWM) system is an effective, economical, and eco-friendly approach for weed management in field crops.

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Management of rhizosphere processes for enhancing nutrient use efficiency and total factor productivity

Kaushal Kumar, Rajiv and PK Rathi

Chandra Shekhar Azad University of Agriculture and Technology,
Kanpur, Uttar Pradesh-208 002
E-mail: kaushal_scwm@rediffmail.com

ABSTRACT

Imbalance and without soil test based high input, low output, low nutrient resource use efficiency and deteriorating environmental problems reflect the typical characteristics of intensive farming system in India. How to attain synchronously optimum nutrient use efficiency as well as high crop productivity has become a great challenge in the intensive agriculture system of our country. In the last three decades, production of cereals, oilseeds, pulses, vegetables, medicinal and aromatic crops have not been enhanced proportionally as per increasing input of chemical fertilizers, leading to low nutrient use efficiency and increasing environmental problems day by day. Present conventional nutrient management strategy was highly reliant on exterior chemical fertilizer input, but overlooked exploring organic potential of proficient gaining and use of soil nutrient resources by plants inherently. Rhizosphere is the key centre of interactions among plants, soils and microorganisms; the chemical and biological processes occurring in the rhizosphere not only determine mobilization and possession of soil nutrients, but also control nutrient use efficiency by crops. The rhizosphere management strategy lays prominence on maximizing the efficiency of root and rhizosphere processes in nutrient acquisition for high yield and efficient sustainable crop production by optimizing nutrient availability to the root zone, regulating root morphological and physiological traits, and modifying rhizosphere processes and interactions. The planning of rhizosphere management are proved to be an effective approach to increasing nutrient use efficiency and crop productivity towards sustainable crop production for main crops India.

Keywords: Nutrient use efficiency, Rhizosphere processes, Rhizosphere management, Soil nutrients, Total factor productivity

1. Introduction

Plant production relies on biogeochemical processes, which are mainly driven by biotic factors. However, abiotic processes such as weathering to some extent, also contribute with the release of essential nutrients for plant growth. This is especially true for C, N and P biogeochemical processes, which are pivotal for plant production in agro-ecosystems (Drinkwater and Snapp, 2007).

Nutrient management is the science and practice intended for simulating soil, crop, weather and hydrologic factors with cultural, irrigation, and soil and water conservation practices to achieve optimal nutrient use efficiency, crop yields, crop quality, and economic returns, while reducing off-site transport of nutrients that may impact the environment. It involves matching a specific field soil, climate, and crop management conditions to rate, source, timing, and place (commonly known as the 4R nutrient stewardship) of nutrient application. Important factors that need to be considered when managing nutrients include:

(a) Application of nutrients considering the achievable optimum yields along with crop quality;

(b) Management, application, and timing of nutrients using a budget based on all sources and sinks active at the site; and

(c) Management of soil, water, and crop to minimize the off-site transport of nutrients from leaching out of the root zone, surface runoff, and volatilization or other gas exchanges.

There can be probable interactions because of differences in nutrient pathways and dynamics e.g. practices that reduce the off-site surface transport of a given nutrient may increase the leaching losses of other nutrients. These complex dynamics present nutrient managers the difficult task of achieve the best balance for maximizing profit while contributing to the conservation of our biosphere.

Significant advances have been made in soil improvement and enhancing crop yields in our country over last three decades. Improving soil fertility by fertilizers inputs to enhance crop production has been one of the important strategies in Indian agriculture since 1970. During green revolution, not only the total grain yield show a quantum jump with improved varieties and the total consumption of fertilizers but more than 60% of the increased food production was also attributed to the use of fertilizers. However, although the total consumption of fertilizers continued to increase rapidly nationwide, the total food production eventually ceased to increase proportionately. High rates of fertilizer application had resulted in both the accumulation of large amounts of N and P in soils and a sharp reduction in the effectiveness of fertilizers. Moreover, the environment gets deteriorated and became more problematical. It is due to excessively much effort has been made to increase fertilizer inputs while ignoring the potential benefits of biological processes through exploitation of soil nutrient resources by crops. Rhizosphere processes are the association between plant processes and soil processes, to some extent, determine the bioavailability of soil nutrients and nutrient use efficiency, and thus affect crop productivity and ecological effects (Zhang *et al.,* 2002, 2004). The rhizosphere management strategies lay emphasis on maximizing the efficiency of root and rhizosphere processes in nutrient acquisition towards maximum yield and efficient sustainable crop production by optimizing nutrient input in the rooting zone, regulating root growth and manipulating rhizosphere interactions (Fig. 1). Therefore, managing the rhizosphere ecosystem and rhizosphere processes can be one of the most effective approaches to enhancing nutrient-resource use efficiency and crop productivity in main cropping systems in different parts of India.

2. Content

2.1. Management of Rhizosphere for efficient Crops Nutrient use under Soil-Plant Systems

The rhizosphere, is “the field of action or influence of a root” (Lynch and Leij, 2012), is the interface between the plant and the soil, where plants acquire nutrients facilitated by biogeochemical processes. Carbon flows from the plant to the soil ecosystem as simple organic compounds providing the necessary food basis for the corresponding microbiological processes that are vital for soil ecosystem functioning (Jones *et al*., 2009). In this way, photosynthates flow rapidly from the plant to the soil feeding the rhizosphere microbiome, which in turn provides food for microbial grazers and their predators (Fitter *et al.,* 2005). The rhizosphere microbiome is abundant and diverse, with bacteria and fungi being the key players in relation to plant and soil C, N and P dynamics (Lynch, 1987; Philippot *et al*., 2013). However, bacterial and fungal grazers (protozoa, nematodes, mites and collembolans) and grazer predators (predator mites and nematodes) are also important regulators of biogeochemical processes (Bonkowski, 2004; Coleman, 2008). Both plant beneficial microorganisms (plant growth promoters and bio-control agents) and pests (root pathogens and root feeding insects) are common inhabitants of the rhizosphere (Whipps, 2001; Morgan *et al*., 2005; Raaijmakers *et al*., 2009), all affecting C, N and P biogeochemical processes in the soil. Functional traits of the beneficial rhizosphere microbiome in relation to plant nutrition and health include organic matter decomposition, P solubilization and transport, N fixation and biocontrol of root pests (Philippot *et al*., 2013).

Nutrient dynamics in the rooting zone of plant-soil systems reflect the capacity of nutrient supply and nutrient availability, and thus influence crop production in agricultural ecosystems. The strategies of root zone nutrient management for efficient nutrient resource use of main crops have been established in India. In the traditional fertilization, people have been concerned with increasing nutrient concentrations in the soil solution by excessive fertilizer application but have neglected the nutrient activation by crop roots. The new method requires dynamic monitoring of nutrient concentration in root zone for establishing suitable nutrient supply intensity at different growth stages of crops in order to realize the synchronization of crop nutrient uptake, soil nutrient supply and fertilizer input. The establishment of root zone nutrient managing approach provides an effective approach to solving the complex conflict among high-yielding crops, efficient nutrient use and protection of environment

2.2. Modifying Root Growth and Development for Improving Crop nourishment and Yield

The proliferation of root can be efficiently stimulated by altering nutrient supply intensity and composition which significantly enhances the

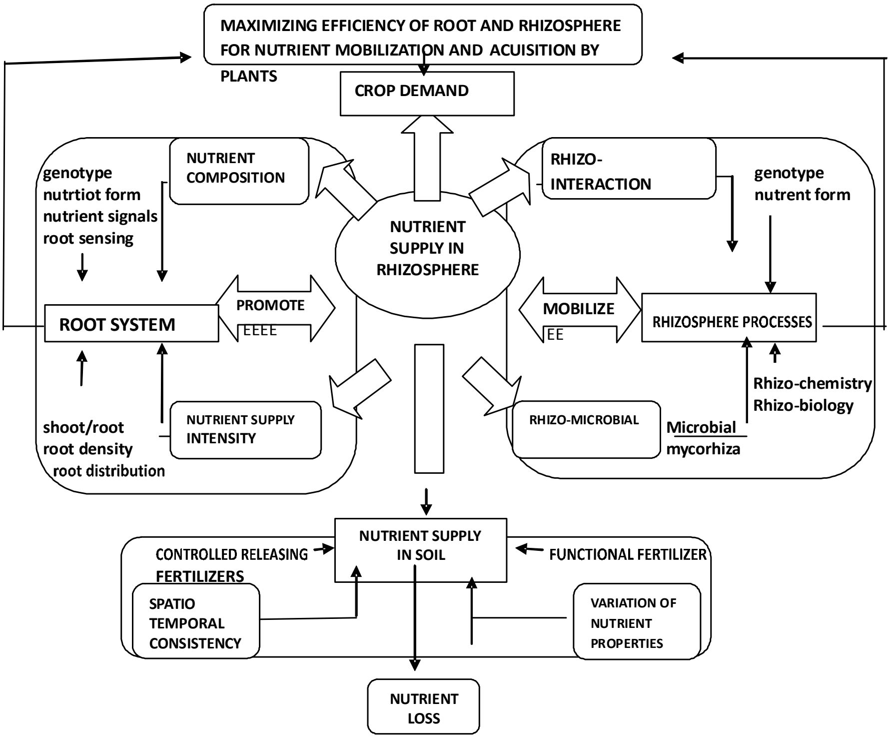

Fig.1. Management plan for rhizosphere

absorption area of soil nutrients. Severe nutrient deficiency in root zone causes stunted growth of root; undue nutrient supply to plant roots results in inhibition of root growth. The healthy root system of crops can be effectively established when soil nutrient supply intensity is kept at an optimum level. The critical level of soil nutrient supply intensity is varied at different growth stages. In north states of india, a relatively high soil nutrient supply intensity can be achieved by application of N and P as starter dose of fertilizer i.e. needed for early root establishment due to low temperature and low nutrient supply at the early seedling stage while at later phase, large quantum of nutrients from soil can be mobilized and utilized by the exhaustive root system, leading to less reliance of crops on fertilizer supply. For an intensive vegetable cropping system in which extreme nutrients are applied, it is important for efficient nutrient use to match root growth with nutrient distribution in soil profiles because large amount of nutrients could be washed away from active root zone due to irrigation. The major approaches of root system management include quantifying and monitoring the root-zone nutrient concentration required by crops at different growth stages, controlling the root-zone nutrient concentration at a suitable range through accurate fertilizer supply and matching spatial-temporal relationship between soil nutrient supply and root growth.

Site specific application of nutrients can significantly encourage root proliferation (Shen *et al.,* 2005). Field experiment results demonstrated that localizes application of N and P considerably improved the maize growth, including increased biomass of shoots and roots, leaf area, chlorophyll content and nutrient uptake because large number of lateral roots were induced at the local root zone at seedling stage. Root growth and root system establishment are imperative for resource capture and acquisition such as water and nutrients and thus regulate nutrient use efficiency by crops.

2.3. Manipulation of rhizosphere processes for improvement of crop nutrition and yield

Rhizosphere act as an interface between roots and soils and also as centre of interactions among plants, soils and microorganisms. The biological and chemical processes occurring in the rhizosphere determine mobilization and acquisition of soil nutrients and even control NUE by crops (Zhang, 2006). Studies revealed that localized application of super phosphate combined with amonical N remarkably enhanced crop growth because its supply induced an evident rhizosphere acidification leading to increased availability of soil phosphate, protein release and carbohydrate exudation from cluster root of white lupin can effectively mobilize sparingly soluble phosphorus in soil through altering rhizosphere processes. Nitrogen and Phosphorus nutrient application in maize can be significantly enhanced by fababean intercropped by maize through rhizosphere interaction due to strong rhizosphere acidification of fababean (Li *et al*., 2008). Inter-specific below ground interaction and rhizosphere effect between intercropped species play an vital role in yield advantage of intercropping. Using crop genotype with efficient nutrient utilization that can mobilize soil nutrients in the root zone may be an effective approach to increasing nutrient use efficiency and crop productivity. An alternative strategy for rhizosphere management is to employ beneficial symbiotic association between potential in assisting the host plants to take-up scarce and immobile nutrients, particularly P . However, how to explore the biological potential of mycorrhiza in intensive farming system will be a challenge for rhizosphere management. To develop the method for dual inoculation with mycorrhiza fungi and rhizobia is promising for improving nutrients use efficiency and crop productivity.

3. Conclusion

Biotic interactions in the rhizosphere drive biogeochemical processes and modulate plant nutrient availability in agro-ecosystems. However, in order to improve our understanding on the role of the rhizosphere in C, N and P biogeochemical processes a more holistic and functional approach is required. In conclusion, the strategies of rhizosphere management may improve nutrient use efficiency and crop productivity via exploitation of biological potential for nutritional enhancement and regulation of rhizosphere processes by crops through technological innovation and application. The strategies are proved to be an effective tool to attain sustainable agricultural production for major crops in India scenario.

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Seaweed extract (biostimulant): An alternative solution to supplement fertilizer response

Doongar R Chaudhary and Arup Ghosh

CSIR-Central Salt and Marine Chemicals Research Institute (CSIR-CSMCRI), Gijubhai Badheka Marg,
Bhavnagar 364 002, Gujarat, India
E-mail: drchaudhary@csmcri.res.in

ABSTRACT

Seaweeds and seaweed products are widely used in agricultural crop production due to the presence of a number of plant growth stimulating constituents. Recent demands of organic farming inspired the application of organic amendments like seaweed extracts in agriculture. The beneficial effects of seaweed extract application in crops are many and diverse such as stimulation of seed germination, enhancement of vigor, shoot and root growth, improved nutrient uptake and fertilizer use efficiency, abiotic and biotic stress tolerance. Here, effort has been made to exploit the potential of the low carbon foot print seaweed extracts application in Indian agriculture through multi-institutional, multi-crop field trials.

Keywords: Biostimulants, Organic farming, Plant growth stimulation, Seaweed extract

1. Introduction

Seaweeds refer to any large marine benthic algae that are multicellular, macrothallic, and differentiated from most algae that are of microscopic size (Smith, 1944). Seaweeds (macroalgae) are aquatic plants belonging to the plant kingdom *Thallophyta* (Nabti *et al.,* 2017; Dhargalkar *et al.* 2001) and these are regarded as an under-utilized bio-resource, however, many seaweeds are used as sources of food, industrial and therapeutic applications. Technologies have has also been developed to yield polysaccharides, potassic fertilizer, bio-stimulants simultaneously (Mondal *et al.,* 2013).There is a long history of coastal population to fertilize nearby land using seaweeds (McHugh, 2003). Usually wet seaweeds are very heavy therefore these are not transported to far inland. Several places in the world, different practices are carried out to utilize the seaweeds for soil improvement in ancient time, like drifted seaweed, sundried seaweed, mix the seaweeds with sand, composted seaweed, milled seaweed etc (McHugh, 2003). Mostly, these seaweeds are green, red and brown seaweeds (*Ascophyllum*, *Sargassum*, *Ecklonia*, *Fucus* etc.); and are used as soil additives and work as soil conditioner and fertilizer. These days, seaweed extract have realized the broader application in the agricultural field and market than seaweed based soil conditioners. These extracts from seaweeds are sold as such or concentrated form, are easy to transport, applied/sprayed in diluted form and act more rapidly. Nowadays, there are several seaweed products under different brand names such as Maxicrop (United Kingdom), AlgeaFert (Norway), Goëmar GA 14 (France), Kelpak 66 (South Africa), Kelpman (Canada), Seasol (Australia), SM 3 (United Kingdom), SM 6 (United Kingdom) Seacrop (United States), Algistim (India), Biozyme (India), Techzyme (India), Seamac (United Kingdom), ALGATON (Spain), Nitrozime (United States) and SAGARIKA (India). Presently commercial seaweed extracts are prepared from mainly from *Ascophyllumnodosum*, *Laminariaspp.*, *Eckloniamaxima*, *Sargassum* spp., *Durvillaeaspp.*, *Fucus serratus*, *Enteromorpha intestinalis*, *Ulva lactuca*, *Gracilaria edulis* and *Kappaphycusalvarezii* (Anand *et al.,* 2017; Craigie *et al.,* 2010; Gandhiyappan and Perumal 2001; Nabti *et al.,* 2017; Rathore *et al.* 2009; Stirk and van Staden, 1997; Yaseen *et al.,* 2017). Commercially available seaweed extracts are derived from seaweeds, although their species, extraction procedure varies and constituents vary. These extracts are aqueous preparations ranging in color from almost colorless to an intense dark brownish-black also differ in odors, viscosities, solids, and particulate matter contents (Craigie *et al.,* 2010). The methods for preparation of extracts from seaweed are rarely published by the manufacturers, being held as proprietary information. Generally, extracts are prepared by processes using water, alkali or acid, or by physically disrupting the seaweed by milling/ grinding (Craigie *et al.,* 2010, Ghosh *et al.,* 2015).

2. Content

2.1. Seaweed application in agriculture for plant growth

Seaweed extracts are known to contain a wide range of bioactive compounds as well as essential plant nutrients (Craigie *et al.,* 2010; Ghosh *et al.,* 2015; Mondal *et al.,* 2015; Nabti *et al.,* 2017; Rathore *et al.* 2009). Plant growth promotion by seaweed extracts is often observed due to result of many components that may work synergistically at different concentrations, but the mechanisms of stimulation of plant growth are not entirely known in many cases (Rathore *et al.,* 2009; Nabti *et al.,* 2017). Liquid extracts obtained from seaweeds contains major and minor nutrients, amino acids, vitamins, cytokinins, auxin, gibberellin and ABA like growth promoting substances, quaternary ammonium compounds like glycine betaine and choline chloride (Mondal., 2015; Mooney and Van Staden, 1986).Thus, these extracts stimulate growth and yield of plants (Rama Rao,1991; Rathore *et al.,* 2009; Pramanick *et al.,* 2014a; 2014b), develop tolerance to environment stress (Zhang *et al.,* 2000; 2003), increase nutrient uptake from soil (Turan and Köse, 2004; Verkleij,1992) and enhance antioxidant property (Verkleij,1992). Betaines and other related quaternary ammonium compounds act as anti-stressors in both biotic and abiotic stress condition (Zhang *et al.,* 2003). For example, glycine betaine has been shown to act as an osmo-protectant (Storey and Wyn Jones,1975) to enhance water utilization efficiency and water foot print (Naresh *et al.,* 2017). Bio-stimulants, even those containing minerals, are not able to supply all the essential nutrients in the quantities as required by plant (Schmidt *et al.,* 2003) but bio-stimulants can enhance the effectiveness of fertilizers (Frankenberger and Arshad, 1995) and improve fertilizer use efficiency. In recent years, use of seaweed extract have gained the popularity due to their potential use in organic and sustainable agriculture through integrated nutrient management, as a means to avoid excessive fertilizer applications and to improve mineral absorption (Naresh *et al.,* 2017). Unlike, chemical fertilizers, extracts derived from seaweeds are bio-degradable, non-toxic, non-polluting, non-hazardous and have a very low carbon footprint (Anand *et al.,* 2017; Ghosh *et al.,* 2015). Application of 50% recommended rate of chemical fertilizers in conjunction with seaweed extract brought significant reduction in climate change impact per tonne of rice production (Sharma *et al.,* 2017). Similarly, there was marked reduction in global warming potential per unit of produce with the use of seaweed extracts even along with 100% recommended dose of chemical fertilizers in maize (Singh *et al.,* 2016).

Crop plant response to seaweed application as manure or foliar application of extract exhibited a wide range of responses which are well documented in a number of reviews (Craigie *et al.,* 2010; Crouch and Van Staden, 1992; 1994; Nabti *et al.* 2017;Verkleij 1992). Positive responses include improved germination, photosynthesis, nodulation, root development, leaf quality, general plant vigor, yield, biomass, quality of produce and resistance to pathogens and pests have been reported in many crop plants (Jadhao *et al.,* 2015; Khan *et al.* 2009; Layek *et al.,* 2015; 2017; Mondal *et al.,* 2015;

Pramanick *et al.,* 2017; Raverkar *et al.,* 2016; Shah *et al.,* 2013; Trivedi *et al.,* 2017; Zodape *et al.,* 2009; 2011). Application of seaweed extracts promote root growth and development and was also observed that root-growth promoting effects were more prominent when extracts were applied at an early crop growth stage (Jeannin *et al.,* 1991; Metting *et al.* 1990; Trivedi *et al.,* 2017). Applications of seaweed extracts to vegetable and floriculture crops at the time of transplanting also reduce transplant shock in the seedlings (Aldworth and van Staden 1987; Crouch and van Staden 1992; 1994; Khan *et al.* 2009). Application of seaweed extracts to plant also improves the chlorophyll content compared with untreated plants which results from reduced chlorophyll degradation, which might be caused by glycine betaines present in the seaweed extract (Mondal *et al.,* 2015; Whapham *et al.* 1993). Application of seaweed extracts also enhanced nutritional content in terms of protein, oil, and carbohydrate (Mondal *et al.,* 2015; Raverkar *et al.,* 2016; Rathore *et al.,* 2009; Singh *et al.,* 2016).

Besides improvement in growth and development of plants by seaweed application, seaweeds also influence the physical, chemical, and biological properties of soil, especially when applied to soil. Seaweeds and seaweed extracts enhance soil health by improvement in water holding capacity and promote the growth of microbes (Khan *et al.* 2009; Naresh *et al.,* 2017). Seaweeds are rich source of polyuronides (alginatesand fucoidans) which have gelling and chelating abilities along with hydrophilic properties (Cardozo *et al.,* 2007), results in improvement in soil water holding capacity, aeration and soil structure (Khan *et al.* 2009).

Many studies have suggested that seaweed products stimulate abiotic stress (salinity, drought and temperature) tolerance in plants and bioactive substances of seaweeds impart in stress tolerance and enhance the growth of plant performance (Craigie *et al.,* 2010; Khan *et al.* 2009; Nabti *et al.,* 2017). The mechanisms of bioactive compounds of seaweeds for stress are largely unknown. Though, a number of research reports suggested that the beneficial anti-stress effects of seaweed extracts may be related to cytokinin activity and betaines (Mondal *et al.,* 2015; Zhang *et al.,* 2000; 2003; Zhang and Ervin, 2004). Apart from abiotic stress, seaweed extracts also have been shown to enhance plant defense against pest and diseases (Agarwal *et al.,* 2016; Allen *et al.,* 2001).

2.2. Seaweed extract application in Indian agricultural crops

Central Salt & Marine Chemicals Research Institute (CSIR-CSMCRI), Bhavnagar devised raft

Table 1. Nutrient content in Kappaphycus seaweed sap

Constituents of formulation of Kappaphycus sap	Amount (mg L^{-1})
Na^+	198
K^+	33654
Ca^{2+}	321
Mg^{2+}	1112
Zn^{2+}	4.7
Mn^{2+}	2.1
Fe^{2+}	86

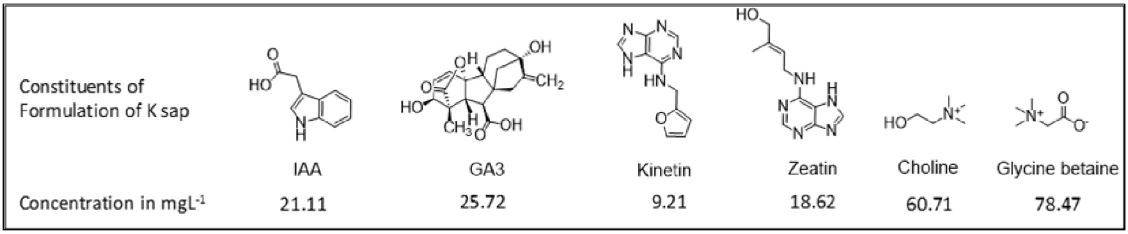

Fig.1. Content of plant growth regulators in Kappaphycus sap (extract) [Mondal *et al.,* 2015]

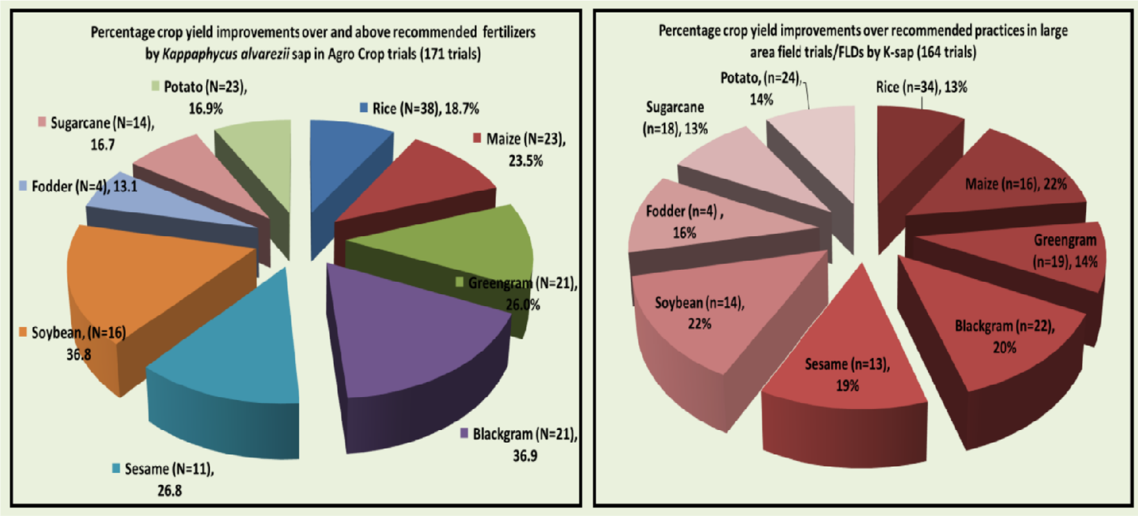

Fig.2. Percentage improvement in crop yields over recommended dose of fertilizers by Kappaphycus sap in (left) Agro trials (right) field/FLDs

method of seaweed cultivation and has also invented (Eswaran *et al.*, 2005; US Patent) a technology for production of sap of the seaweed, *Kappaphycus alvarezii*, along with a residue that yields kappa carrageenan. The sap derived from fresh *Kappaphycus alvarezii* is an effective bio-stimulant. Its constituents are given in Table 1 and Figure 1 below:

It is inexpensive which makes it suitable for broad acre crops; and its price point makes it affordable and within the means of a small and marginal farmer. Seaweed extract application protocol was standardized and demonstrated in varied agro-ecological situations on a Pan-India scale and the performance of *Kappaphycus* sap was validated on agricultural crops through extensive optimization and multi-locational multi-crop demonstration trials (during the years 2011-2017) undertaken in farm and farmer's field at more than 40 locations across 20 states of our country in collaboration with State Agricultural Universities and ICAR Institutes. The CSIR-CSMCRI mandated collaborative study revealed that at usage level of 5-15%, the increase in crop yield production by use of Kappaphycus extract over and above recommended dose of fertilizers from these studies ranged from 13 to 37% across different crops (Figure 2). Studies at molecular level indicated that the seaweed bio-stimulant is capable of ameliorating soil moisture stress and can reduce the diminution in crop yield under drought stress. It has also been shown to stimulate soil microbes which may play a vital role in mineral cycling of soil nutrients making them more available to plants. A recent study by ICAR-IISR, Lucknow has shown it to be effective in reducing the usage of chemical fertilizers by 25% in sugarcane.

3. Conclusion

In conclusion, Seaweed extracts have been proven to be low cost, organic bio-stimulant that can significantly enhance the agricultural productivity in a sustainable manner.

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Potential of biochar in soil carbon sequestration and adaptation to climate change

G Venkatesh, K A Gopinath and V Visha Kumari

ICAR-Central Research Institute for Dryland Agriculture, Hyderabad-500059, Telangana
E-mail: ka.gopinath@icar.gov.in

ABSTRACT

The unused crop residue in India is becoming an issue of concern due to inefficient crop residue management practices. Current availability of unused surplus residues in India is estimated at 120-150 million tons / annum. Of this, about 93 million tons of crop residues are burned in each year, these unused residues are valuable resources for production of biochar. Addition of biochar to soil enhances nutrient use efficiency, improves microbial activity as well as it can be used for soil and water conservation in rainfed areas to minimize reliance on external amendments for ensuring sustainable crop production.

Keywords: Biochar, Carbon Sequestration, Climate change

1. Introduction

Huge quantities of unused crop residue in India are becoming an issue of concern due to inefficient crop residue management practices. Current availability of unused surplus residues in India is estimated at 120-150 million tons / annum. Of this, about 93 million tons of crop residues are burned in each year, these unused residues are valuable resources for production of biochar (Srinivasa Rao *et al.,* 2013). For more effective utilization and disposal of crop residue, a novel and alternate way is gaining importance on use of thermo-chemical process (slow pyrolysis) to convert crop residue into "biochar". Biochar production helps to reduce the weight and volume of crop residue and make the product easier to handle compared with that of fresh and un-carbonized crop residue. Idea of using biochar as a tool for countering climate change and improving soil health is a recent development, yet its origins extend back to the discovery of Dark Earths, or Terra Preta de Indio (Portuguese for "Black Earth of the Indians"). Biochar is the carbon-rich solid product, produced by thermal decomposition of organic matter under limited supply of oxygen (O_2) or oxygen-free environment, and at relatively low temperatures (<700°C) through a process called pyrolysis (Lehmann *et al.,* 2006). Biochar appears to be one promising source of renewable and stable carbon to increase the rate of carbon sequestration in soil. Currently, however, very little biochar is produced and utilized in modern Indian agriculture. Use of crop residue for producing biochar for improving soil quality as well as crop productivity in the Indian farming systems may be ecologically promising.

1.1. Need for Recycling of Crop Residue into Biochar for Use in Indian Agriculture (adapted from Venkatesh et al., *2015)*

- To improve soil health through efficient use of crop residue as a source of soil amendment/ nutrients
- To improve soil physical properties viz. bulk density, porosity, water holding capacity, drainage etc, through incorporation of biochar
- Substantial amounts of carbon can be sequestered in soils in a very stable form

- Addition of biochar to soil enhances nutrient use efficiency and microbial activity
- To enhance soil and water conservation by using the biochar in rainfed areas
- Minimize reliance on external amendments for ensuring sustainable crop production
- Mitigation of greenhouse gas emissions by avoiding direct crop residue burning by farmers
- To enable destruction of all crop residue borne pathogens

1.2. Constraints in Recycling of Crop Residue *(adapted from Venkatesh* et al., *2015)*

- Unavailability of farm labour, higher wage rates for collection and processing of crop residue
- Lack of appropriate farm machines for on-farm recycling of crop residue
- Inadequate policy support/incentives for crop residue recycling

2. Content

2.1. Methodology of preparation

Biochar can be produced from a number of methods. The ancient method for producing biochar was the "pit" or "trench" method (Odesola *et al.,* 2010). The common processes include slow and fast pyrolysis, and the most successful approach for high-yield biochar production is via slow pyrolysis. Under slow pyrolysis, a biochar yield between 25% - 35% can be produced (Hussein *et al.,* 2015); fast pyrolysis processes aim at production of bio-oil and the amount of biochar formed is nearly 12% of the total biomass (Cheng *et al.,* 2012). The cook stove, earth mound kilns and drum kilns are the traditionally used for biochar production in India (Srinivasa Rao *et al.,* 2013). Number of biochar kiln has been designed, developed and used for making biochar

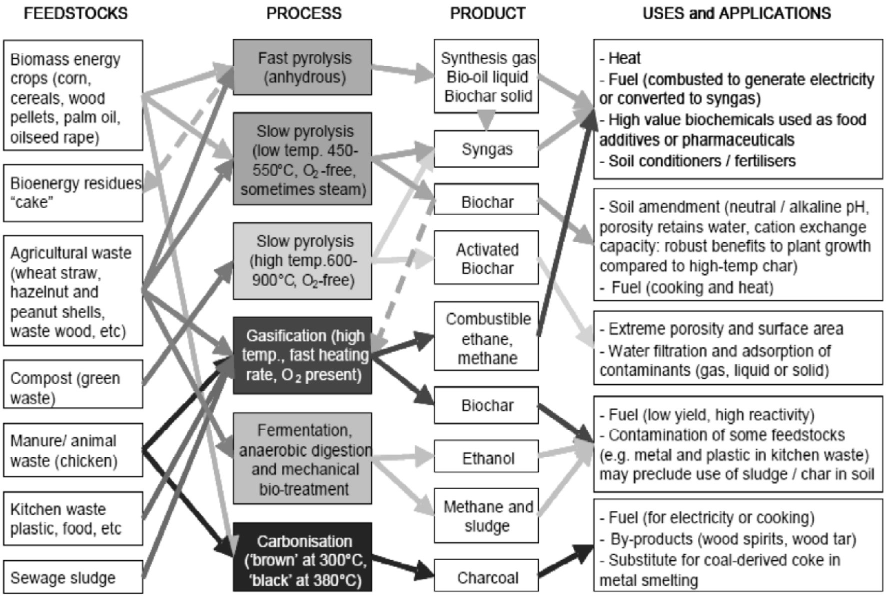

Fig. 1. Summary of pyrolysis processes in relation to their common feed stocks, typical products, and the applications and uses of these products

from the crop residue and forest biomass (Venkatesh *et al.,* 2013; Gangil and Wakudkar, 2013; Reddy, 2012) in India. A summary of biomass conversion processes (Masek, 2009) is presented in Fig. 1.

2.2. Biochar Application Method

Biochar application methods have a substantial impact on soil processes and functioning. Biochar application methods must be based on extensive field testing. Various methods of biochar application in soil were mixing the biochar with fertilizer and seed, applying through no till systems, uniform soil mixing, deep banding with plow, top-dressed, hoeing into the ground, applying compost and char on raised beds, broadcast and incorporation, mixing biochar with liquid manures and slurries (Hussein *et al.,* 2015).

2.3. Biochar Application Rates

Availability and type of crop residue, nature of biochar, application rate, soil type, crops to be applied, labour, time, climatic and topographic factors of the land, and the preference of the farmer may determine to employ one-time application of large quantity or frequent application of smaller quantity biochar (Venkatesh *et al.,* 2015). Past studies have found that rates between 5 to 50 t/ha have often been used successfully (Lehmann and Rondon, 2006).

2.4. Benefits of Biochar Incorporation in Soil

Transforming a low-value crop residue into a potentially high-value carbon source and its soil application has several important benefits (Venkatesh *et al.,* 2015)

2.5. Bio-char and Greenhouse Gas Emissions Reduction to Tackle Climate Change

Apart from carbon sequestration, there are other environmental benefits that can be derived from the application of biochar in soils which include reduction in the emission of non-CO_2 GHGs by soils (Table 1). According to Bracmort (2010), cropland soils and grazing lands are a major agricultural source of N_2O emission. When applied to the soil, biochar can lower GHG emissions of cropland soils by substantially reducing the release of N_2O (Lehmann *et al*. 2003). Reduction of N_2O and CH_4 emission as a result of biochar application is seen to attract considerable attention due to the much higher global warming potentials of these gases compared to CO_2 (Steiner, 2010). Rondon *et al*. (2005) reported a 50% reduction in N_2O emissions from soybean plots and almost complete suppression of CH_4 emissions from biochar amended acidic soils in the Eastern Colombian Plains. Yanai *et al*. (2007), however, reported an 85% reduction in N_2O emission from re-

Physical properties	**Chemical properties**	**Biological properties**
• Decreases bulk density, improves soil workability, reduces labour and tractor tillage and minimizing fuel emissions • High negative charge of biochar promotes soil aggregation and structure • Positive effect on crop productivity by retaining plant available soil moisture due to its high surface area and porosity	• Liming effect provides net carbon benefit compared to standard liming • Enhance the fertilizer use efficiency, reduce the need for more expensive fertilizers and improves the bioavailability of phosphorus and sulphur to crops • Reduce leaching of nutrients and prevents groundwater contamination • Carbon negative process, stable carbon, longer residence period and reduces Green House Gas emissions from soil	• Enhances the abundance, activity and diversity of beneficial soil bacteria, actinomycete and arbuscular mycorrhiza fungi • High surface area, porous structure and nutrient retentive capacity of biochar provides favorable microhabitats by protecting them from drought, competition and predation

wetted soils containing 10% biochar, compared to soils without biochar as cited in Steiner (2010). Spokas *et al*. (2009) also found a significant reduction in N_2O emission in agricultural soils in Minnesota; while Sohi *et al*. (2010) found an emission suppression of only 15%.Various workers have reported reduction of ammonium losses on application of biochar to soils. In a pot trial with rice plants, Lehmann *et al*. (2003) found that the addition of fresh biochar reduced ammonium losses by 10%. Biochar increased N retention when combined with ammonium sulphate (NH_4SO_4) fertilizer on highly weathered soils with extremely low cation exchange capacity (CEC) (Steiner *et al*. 2008), and increased plant uptake of fertilizer N on biochar plots (De Gryze *et al*. 2010). Biochar from municipal biowaste also caused a decrease in emissions of nitrous oxide in laboratory soil chambers (Yanai *et al*. 2007). Additions of 15 g kg^{-1} of soil to a grass and 30 g kg^{-1} of soil to a soil cropped with -soybeans completely suppressed methane emissions (Rondon *et al*. 2005). Such information emphasizes the need for further studies to aid the development of biochar as a tool for decreasing non-CO_2 GHG emissions from soil. More research is needed to understand the interactions between biochar, site specific soil, climatic conditions, and management practices that alter the sink capacity of soils (Fig .2)

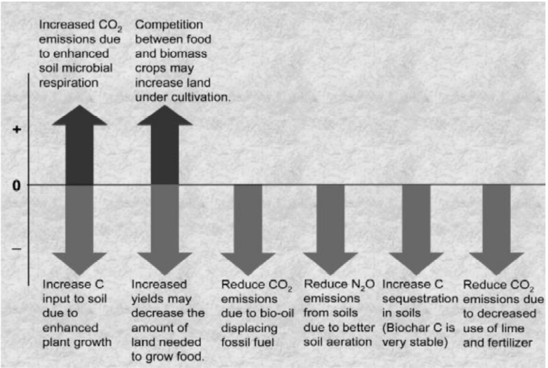

Fig.2. Net impact of biochar applications in soil on greenhouse gas emissions. Adapted with changes from Rogovska *et al*.(2008).

2.6. Influence of Biochar on Nutrient Use Efficiency

Knowledge on the link between biochar function and its interaction with nutrient elements and crop roots may throw light on understanding fertilizer use efficiency. The enhanced nutrient retention capacity of biochar-amended soil not only reduces the total fertilizer requirements but also copes up the climate and environmental impact on crops. Biochar significantly increases the efficiency and reduces the need for traditional chemical fertilizers with sustainable crop yields. Addition of biochar to soil alters important soil chemical qualities; soil pH increased towards neutral values, typically increased soil cation exchange capacity. Glaser et al. (2002) observed increasing trend of bio-available P and base cations in biochar applied soils. Biochar application boosts up the soil fertility and improves soil quality by raising soil pH, increasing moisture holding capacity, attracting more beneficial fungi and microbes, improving cation exchange capacity and retaining nutrients in soil (Lehmann et al., 2006). The immediate beneficial effects of bio-char additions on nutrient availability are largely due to higher potassium, phosphorus and zinc availability and to a lesser extent of calcium and copper (Lehmann et al., 2003). Biological nitrogen fixation by common beans was increased from 50 to 72% of total nitrogen uptake with increasing rates of biochar additions (0, 31, 62, and 93 t C ha^{-1}) to a low-fertility Oxisol (Rondon et al., 2007). A beneficial impact of biochar on the plant-available phosphorus has been observed in soils enriched with biochar, which in contrast to ammonium, is not a characteristic generally associated with soil organic matter (Steiner et al., 2007).

2.7. Influence of Biochar on Soil Microbial Activity

Biochar provides a suitable habitat for a large and diverse group of soil microorganisms. A higher

Table 1. The effect of biochar additions on soil health and GHG emission under different soil types

Soil type	**Biochar source**	**Rate of biochar addition (t ha^{-1})**	**Impact of biochar addition on soil health and GHG emission**	**Reference**
Anthrosol	Wheat straw	10 and 40	SOC increased by 57 %, total N content was enhanced by 28 % in the 40 t ha^{-1} without N fertilization; Total N_2O emissions decreased by 40-51 % and 21-28 %, respectively in biochar amended soils; Emission factor (EF) was reduced at 40 t ha^{-1}.	Afeng et al. (2010)
Sandy	Green cuttings	1, 10 and 40	Increased CEC, exchangeable K, total N, available P at biochar addition of 10 t ha^{-1}; 10 and 40 t ha^{-1} of biochar increased the water holding capacity of the sandy soil by 6 % and 25 %	Glaser et al. (2014)
Calcareous	Rice husk and shell of cotton seed	30, 60 and 90	Decreased soil bulk density, increased exchangeable K and water holding capacity at 90 t ha^{-1}	Liang et al. (2014)
Silty loam	Oak wood	7.5	Reduced soil bulk density by 13 % and increased soil-C by 7 %; Cumulative N_2O emission was decreased in the biochar-amended soil (by 92 %)	Mukherjee et al. (2014)
Sandy loam	Maize stover, Pearl millet stalk, Rice and Wheat straw	20	Maize biochar enhanced the soil available N and P; Wheat biochar increased the soil available K; Rice biochar being relatively labile in soil fuelled the proliferation of microbial biomass.	Purakayastha et al. (2015)

retention of microorganisms in biochar amended soils may be responsible for greater activity and diversity due to a high surface area as well as surface hydrophobicity of both the microorganisms and biochar (Farrell *et al.,* 2013). A strong affinity of microbes to biochar can be expected since the adhesion of microorganisms to solids increases with higher hydrophobicity of the surfaces. Biochar is an effective to activate living things and improve natural environment. Carbonized biomass such as rice husk charcoal or wood ash have been valuable material as soil amendment. Applied biochar may provide habitats for growth of soil dwelling microorganisms (Tong *et al.,* 2014) and protect them against natural predators (Thies and Rillig, 2009).

2.8. Soil Water Conservation through Use of Biochar as Soil Amendments

The mineral and organic components of soil contribute to soil water holding capacity, but only the latter can be actively managed. Water is held more tightly in small pores, so clayey soils retain more water. The lower soil bulk density generally associated with higher soil organic matter is a partial indication of how organic matter modifies soil structure and pore size distribution. The intrinsic contribution of biochar on soil physical parameters such as wetability of soil, hydraulic conductivity, water infiltration, water retention, macro-aggregation and soil stability are invariably related to SA, porosity, BD and aggregate stability and are critically important in tropical environments in combating erosion, mitigating drought and nutrient loss and in general to enhance groundwater quality. Several studies have reported alterations in WHC and water retention in biochar-amended soils with as low as 0.5% (g g^{-1}) biochar application rate sufficient to improve WHC. A long-term column study indicated that biochar-amended Clarion soil retained up to 15% more water, and 13% and 10% more water retention at “100 kPa and “500 kPa soil matric potential, respectively, compared to unamended controls (Laird et al., 2010).

Tryon (1948) reported that application of biochar increased AWC in sandy soil, no effect in a loamy soil, and decreased moisture content in a clayey soil. Such a response may be attributed to the hydrophobic nature of the charcoal and to alterations in PSD. Because the soil moisture retention may only be improved in coarse-textured soils, a careful choice of biochar/soil combination needs to be taken into consideration (Tryon, 1948).

2.9. Impact of Biochar on Crop Productivity

Several workers have reported that biochar applications to soils have shown positive responses for net primary crop production, grain yield and dry matter(Table 2) (Spokas *et al.* 2009). The impact of biochar application is seen most in highly degraded acidic or nutrient depleted soils. Low charcoal additions (0.5 t ha$^{"1}$) have shown marked impact on various plant species, whereas higher rates seemed to inhibit plant growth (Ogawa *et al.* 2006). Crop yields, particularly on tropical soils can be increased if biochar is applied in combination with inorganic or organic fertilizers (Glaser *et al.* 2002).

2.10. Soil C Sequestration by Biochar

Carbon sequestration is the capture and subsequent storage of carbon to prevent it from being released to the atmosphere. The global carbon cycle is made up of flows and pools of carbon in the Earth's system. The important pools of carbon are terrestrial, atmospheric, ocean, and geological. The carbon within these pools has varying lifetimes, and flows take place between them all. Carbon in the active carbon pool moves rapidly between pools. In order to decrease carbon in the atmosphere, it is necessary to move it into a passive pool containing stable or inert carbon. Biochar provides a facile flow of carbon from the active pool to the passive pool. In comparison to burning, controlled carbonization, converts even larger quantities of biomass organic matter into stable C pools which are assumed to persist in the environment over centuries (Glaser *et al.* 2001). The conversion of biomass carbon to biochar leads to sequestration of about 50% of the initial carbon compared to the low amounts retained after burning (3%) and biological decomposition (less than 10–20% after 5–10 years) (Lehmann *et al.* 2006).

According to Gaunt and Lehmann (2008), *terra preta* soils suggest that biochar can have carbon storage permanence in the soil for many hundreds to thousands of years. Large amounts of carbon in biochar may be sequestered in the soil for long periods estimated to be hundreds to thousands of

Table 2. Summary of experiments assessing the impact of biochar addition on crop yield

Authors	Study outline	Results summary
Yamato *et al.* (2006)	Maize, cowpea and peanut trial in area of low soil fertility	*Acacia* bark charcoal plus fertilizer increased maize and peanut yields (but not cowpea)
Chan *et al.* (2007)	Pot trial on radish yield in heavy soil using commercial green waste biochar (three rates) with and without 'N'	100 t ha^{-1} increased yield x3; linear increase 10 to 50 t ha^{-1} - but no effect without added N
Rondon *et al.* (2007)	Enhanced biological N_2- fixation (BNF) by common beans through bio- char additions. Colombia	Bean yield increased by 46% and biomass production by 39% over the control at 90 and 60 g kg^{-1} biochar, respectively.
Kimetu *et al.* (2008)	Mitigation of soil degradation with biochar. Comparison of maize yields in degradation gradient cultivated soils in Kenya.	doubling of crop yield in the highly degraded soils from about 3 to about 6 tons/ha maize grain yield

years (Lehmann *et al.* 2006). Compared with other terrestrial sequestration strategies, such as afforestation or re-forestation, carbon sequestration in biochar increases its storage time (Ogawa *et al.* 2006). Production and application of biochar to farm soils can tackle many global and domestic policy issues. Nevertheless, the application of biochar at the farm level is discouragingly slow, largely due to financial constraints.

2.11. Biochar to Counter Climate Change

Biochar has the potential to counter climate change because the inherent fixed carbon in raw biomass that would otherwise degrade to greenhouse gases is sequestered in soil for years. In recent years the use of surplus organic matter to create biochar has yielded promising results in sequestration of carbon. Lehmann *et al.* (2006) estimated a potential global C-sequestration of 0.16 Gt yr^{-1} can be achieved from biochar production from forestry and agricultural wastes. In India, biochar from residues of maize, castor, cotton and pigeon pea can sequester about 4.6 Mt of total carbon annually in soil, making it a carbon sequestering process (Venkatesh *et al.,* 2015). A number of studies have reported on environmental benefits of biochar additions which will reduce emission of non-CO_2 greenhouse gases from soil that could be due to inhibition of either stage of nitrification and / or inhibition of denitrification, or promotion of the reduction of N_2O; increases CH_4 uptake from soil (Rondon *et al.,* 2006).

2.12. Constraints to adopt Biochar Systems

With limited studies in different soil type, climatic zone and land use situations, it is difficult to predict the agronomic effects. Due to the heterogeneous nature of biochar, cost of production of biochar for research and field application is likely to remain a constraint until commercial-scale pyrolysis facilities are established (Sparkes and Stoutjesdijk, 2011). Some of the practical constraints on use of biochar in agricultural systems were ; once applied to soil, remains permanent, unavailability of enough biochar, dry biochar on soil surface is liable to wind erosion, response of local communities to adopt biochar systems (Adtiya *et al.,* 2014); unavailability of farm labour, higher wage rates for collection and processing of crop residue, lack of appropriate farm machines for on-farm recycling of crop residue and inadequate policy support / incentives for crop residue recycling (Srinivasa Rao *et al.,* 2013; Venkatesh *et al.,* 2015) .

3. Conclusion

Efficient, sustainable disposal of organic waste remains a key issue in rural farm areas and in urban societies. Most wastes are either burnt or end up in landfill, which degrades the environment and also produces large amounts of GHGs. The production of biochar from farm wastes and their injection into farm soils offers multiple environmental and financial benefits Biochar production and application in soils has a very promising potential for the development of sustainable agricultural systems in India, and also for global climate change mitigation. There is significant availability of non-feed biomass resources in the country as potential feedstock for biochar production. However, to promote the application of biochar as a soil amendment, and also as a climate change abatement option, research, development and demonstration on biochar production and application mentioned below seem to be very vital. First, a baseline study comprising compilation of data on non-feed biomass resources in India needs be conducted. Second, a review of current non-feed biomass utilization and thermo chemical conversion technologies, particularly slow pyrolysis also has to be carried out. It is also relevant to create awareness among the various biochar stakeholders such as farmers, agricultural extension officers, research scientists and fertilizer wholesalers, and to build their capacities in biochar production and application technologies through the development and implementation of training programmes. Since there are both agronomic and environmental benefits that could be derived from the production and application of biochar in soil, implementation of agricultural schemes involving the application of biochar should first be critically evaluated in the form of a pilot or demonstration project. This could then be transformed into large-scale schemes throughout the country. Participatory approach could be adopted in conducting on-farm trials using the biochar that would be produced. Finally, a business plan for national scale-up biochar production and application project could be prepared based on available carbon finance opportunities in the country.

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Techniques of nutrient supplementation in cereal based organic production system

Dinesh Kumar

ICAR-Indian Agricultural Research Institute, New Delhi 110 012
E-mail: dineshctt@yahoo.com

ABSTRACT

India is the second most populous country in the world and presently inhabiting 1.21 billion people. It is projected that India would be the most populous country in year 2025 and have 1.6 billion people in the year 2050. The increased population would need more food from the ever-shrinking cultivated lands. In recent times the best fertile and productive lands have become casualty of expanding urbanization and industries. Presently India is producing about 260 million tonnes of food grains annually and would require about 294 million tonnes in 2020. It is not as simple as it looks to produce additional food grains in a shorter period, particularly under severely depleted soil fertility. Restoration of depleted soil fertility is going to be the key to sustain the food security in India. Hence, it is going to be a difficult task to feed the increasing number of people on sustainable basis unless we sufficiently feed the soil. In this paper, techniques for nutrient supplementation in cereal based organic system is discussed.

Keywords: Cereals, Nutrient, Organic farming, Soil fertility

1. Introduction

1.1. *Soil fertility in India*

The increased food grain production in India has not been free of cost. When an agricultural produce is harvested, essential plant nutrients are removed and for conserving soil fertility the removed plant nutrients should be returned back to the soil. For each tonne of cereal grain harvested, 20-27 kg N (nitrogen), 10-19 kg P_2O_5 (phosphorus) and 22-48 kg K_2O (potassium) are removed besides sizeable amounts of secondary and micronutrients and a larger part of these nutrients are never returned back to the soil. There is a deficit of about 5 million tonnes of $N+P_2O_5+K_2O$ fertilizers per year. Thus we are continuously mining our soils and making them less fertile for the future generations.The status of nutrients, particularly in their available forms, is generally used to assess the soil fertility status in India. The soil testing laboratories prepare soil fertility maps based on the soil test data using organic carbon as an index of available nitrogen, Olsen's and Bray's method for available phosphorus and neutral normal ammonium acetate for potassium estimation. Available nutrient status in the soils is generally classified as low, medium and high which are generally followed at the National level and are given in **Table 1**.

Table1. Rating chart of essential nutrients in soil

Nutrient	low	medium	high
Organic carbon (%)	< 0.5	0.5-0.75	> 0.75
Available nitrogen (N) (kg/ha)	< 280	280 - 560	> 560
Available phosphorus (P) (kg/ha)	< 10	10 - 24.6	> 24.6
Available potassium (K) (kg/ha)	< 108	108 - 280	> 280

ha: hectare (10,000 metre square land area)

One scientific study (**Table 2**) computed the nutrient index values and prepared a soil fertility map for N, P and K using 3.65 million soil analysis data collected from 533 soil testing labs representing 450 districts in the country. It was suggested that most of the Indian soils were low in nitrogen (63%), low (42%) to medium (38%) in phosphorus and medium (37%) to high (50%) in available potassium fertility. Overall, most of the Indian soils are deficient in nitrogen, contain moderate levels of phosphorus and medium to high levels of potassium. It is estimated that nearly half of the soils on which food crops are grown, are deficient in zinc (Zn). Next to Zn, boron (B) (33%) and iron (Fe) (15%) deficiencies are also limiting the crop production to a large extent.

Table 2. Level of soil fertility in Indian soils

	Percent districts as		
Nutrient	**Low**	**Medium**	**High fertility**
Nitrogen	63	26	11
Phosphorus	42	38	20
Potassium	13	37	50

Source: Motsara (2002)

The ability of a soil to sustain higher crop production is greatly influenced by its soil organic matter (SOM) content as it determines soil's ability to supply nutrients, store water, resist physical degradation and degrade pollutants. Research results from some long-term experiments in rice-wheat cropping system (RWCS) showed that soil organic C in 0-15 cm depth declined over time despite adequate nitrogen, phosphorus and potassium fertilization. Further, one research study suggested that in the major RWCS belt in India the soil organic carbon(SOC) declined from 0.5% in 1960's to 0.2% in 1990s (Sinha et al., 1998). The decreased levels of plant nutrients and SOM/SOC in soils are a serious threat to sustainable food production in the country. Considering the declining status of plant nutrients in Indian soils, there is urgent need to overcome the declined soil fertility so that efficient strategies can be adopted to restore or improve it.

The decline in soil fertility is more severe under intensive cropping systems (two or more crops per year). The reduced nutrient supply limits the crop growth, yields and hence profits. Maintenance/restoration of soil fertility is therefore an important aspect of crop production. Nutrients are continuously removed from the soil by crops in addition to losses by leaching, erosion and other routes. It therefore becomes imperative that sound soil and crop management practices are followed to restore, maintain and improve the soil fertility for sustained crop production and food security in the country.

1.2. Organic farming and soil fertility

It is believed that organic farming could help in restoring the degraded soil fertility, particularly by increasing the organic matter content. But it has to deal with the scarcity of readily available nutrients in contrast to inorganic farming which rely mostly on chemical fertilizers. To sustain the productivity and soil health of an organic farming system, management of soil organic matter is critical. No one source of nutrient usually suffices to maintain soil organic matter at a desired level as it depends upon availability, market prices and alternative uses. Besides, the inputs used to supplement nutrients do not uniformly supply the nutrients and thus presenting additional challenges in meeting the nutrient requirement of crops in organic production system. The aim of nutrient management in organic systems is to optimize the use of on–farm resources and minimize losses.

2. Content

2.1. Options for nutrient management

The following guidelines have been suggested by the National Programme on Organic Production (2014):

- Sufficient quantities of biodegradable material of microbial, plant or animal origin produced on organic farms shall form the basis of the nutrient management programme to increase or at least maintain its fertility and the biological activity within it.
- Fertilization management should minimize

nutrient losses. Accumulation of heavy metals and other pollutants shall be prevented.

- Non synthetic mineral fertilizers and brought-in bio fertilizers (biological origin) shall be regarded as supplementary and not as a replacement for nutrient recycling.
- Desired pH levels shall be maintained in the soil by the producer.
- The certification programme shall set limitations to the total amount of biodegradable material of microbial, plant or animal origin brought onto the farm unit, taking into account local conditions and the specific nature of the crops.
- The certification programme shall set procedures which prevent animal runs from becoming over manuring where there is a risk of pollution.
- Mineral fertilizers shall only be used in a supplementary role to carbon based materials. Only those organic or mineral fertilizers that are brought into the farm (including potting compost) shall be used when, the circumstances demand in accordance with Table 3.
- Permission for use shall only be given when other fertility management practices have been optimized.
- Manures containing human excreta (faeces and urine) shall not permitted to prevent transmission of pests, parasites and infectious agents.
- Mineral fertilizers shall be applied in their natural composition and shall not be rendered more soluble by chemical treatment. The certification programme may grant exceptions. These exceptions shall not include mineral fertilizers containing nitrogen.
- The certification programme shall lay down restrictions for the use of inputs such as mineral potassium, magnesium fertilizers, trace elements, manures and fertilizers with a relatively high heavy metal content and/or other unwanted substances, e.g. basic slag,

Table 3. List of nutrient sources along with their condition of use in organic farming in India (NPOP, 2014)

Inputs	Condition for use
Matter Produced on an Organic Farm Unit	
Farmyard & poultry manure, slurry, cow urine	Permitted
Crop residues and green manure	Permitted
Straw and other mulches	Permitted
Matter Produced Outside the Organic Farm Unit	
Blood meal, meat meal, bone meal and feather meal without preservatives	Restricted
Compost made from any carbon based residues (animal excrement including poultry)	Restricted
Farmyard manure, slurry, cow urine (preferably after control fermentation and/or appropriate dilution) "factory" farming sources not permitted	Restricted
Fish and fish products without preservatives	Restricted
Guano	Restricted
Human excrement	Prohibited
By-products from the food and textile industries of biodegradable material of microbial, plant or animal origin without any synthetic additives	Restricted
Peat without synthetic additives	Prohibited conditioning for soil

Inputs	**Condition for use**
Sawdust, wood shavings, wood provided it comes from untreated wood	Permitted
Seaweed and seaweed products obtained by physical processes extraction with water or aqueous acid and/or alkaline solution	Restricted
Sewage sludge and urban composts from separated sources which are monitored for contamination	Restricted
Straw	Restricted
Vermicasts	Restricted
Animal charcoal	Restricted
Compost and spent mushroom and vermiculate substances	Restricted
Compost from organic household reference	Restricted
Compost from plant residues	Permitted
By products from oil palm, coconut and cocoa (including empty fruit bunch, palm oil mill effluent (pome), cocoa peat and empty cocoa pods)	Restricted
By products of industries processing ingredients from organic agriculture	Restricted
Minerals	
Basic slag	Restricted
Calcareous and magnesium rock	Restricted
Calcified seaweed	Permitted
Calcium chloride	Permitted
Calcium carbonate of natural origin (chalk, limestone, gypsum and phosphate chalk)	Permitted
Mineral potassium with low chlorine content (e.g. sulphate of potash, kainite, sylvinite, patenkali)	Restricted
Natural phosphates (e.g. Rock phosphates)	Restricted
Pulverised rock	Restricted
Sodium chloride	Permitted
Trace elements (Boron, Ferrous, Manganese, Molybdenum, Zinc)	Restricted
Wood ash from untreated wood	Restricted
Potassium sulphate	Restricted
Magnesium sulphate (Epson salt)	Permitted
Gypsum (Calcium sulphate)	Permitted
Silage and silage extract	Permitted excluding Ammonium silage
Aluminum calcium phosphate	Restricted
Sulphur	Restricted
Stone meal	Restricted
Clay ((bentonite, perlite, zeolite)	Permitted
Microbiological Preparations	
Bacterial preparations (biofertilizers)	Permitted
Biodynamic preparations	Permitted
Plant preparations and botanical extracts	Permitted
Vermiculate	Permitted
Peat	Permitted

rock phosphate and sewage sludge. All synthetic nitrogenous fertilizers are prohibited.

Inorganic agriculture the maintenance of soil fertility may be achieved through the recycling of organic material whose nutrients are made available to crops through the action of soil microorganisms. Many of these inputs are restricted for use in organic production. In Table 3 “restricted” means that the conditions and the procedure for use shall be subjected to condition. Factors such as contamination, risk of nutritional imbalances and depletion of natural resources shall be taken into consideration.

“Factory” farming refers to industrial management systems that are heavily reliant on veterinary and feed inputs not permitted in organic agriculture.

The following options are suggested for nutrient management of cereal-based cropping systems under organic management.

2.2. Efficient crop rotation

The benefits of good crop rotation are increased organic matter, nitrogen supply and improved structure of soil. These effects are observed especially with deep rooted legumes or crops capable of bringing plant nutrients from the lower layers of soil and leaving them as crop residues in the upper layers. Nutrients so fetched can be utilized by shallow rooted crops. Deep rooted crops also contribute to increased permeability of soil at lower depth to air and water. The other benefits of crop rotations are keeping soil under crop cover for most of the year, control of run-off, soil erosion and efficient use of fertilizers.

Practices like planned crop rotations, green manuring, composting, intercropping, companion cropping, mulching etc. are commonly followed on organic farms due to their benefits on soil health. Supplemented fertilization through chemicals like powdered rock phosphate, green sand, gypsum, dolomite, etc. can be followed to supply plant nutrients crop rotations to optimize nitrogen fixation, efficient management of crop residues and exploration of the soil by developing rooting systems and management methods that limit nutrient losses is an efficient approach that improve soil fertility and crop production. The inclusion of legumes has been found beneficial in almost all cropping systems across the globe. Extensive research has been conducted to evolve methodologies to measure nitrogen fixation in annual, forage and tree legume species and exploit these benefits in cropping/farming systems. Including legumes into various cropping systems can lower the demand of nutrients for associated as well as the succeeding crops. However, more research is needed to obtain quantitative information of the effects of grain legumes on nitrogen economies of the organic cropping system.

2.3. Crop residues

In recent years with the development of rice-wheat cropping system and mechanization of agriculture, rice and wheat straw, especially, the rice straw has become surplus and is mostly burned on the field. Research is on and the data have been generated which show that incorporation of rice and/ or wheat straw may or may not increase the crop yield but it does improve soil fertility. Addition of crops residues into soil also enhances biological activities in soil. Thus in the long run crop residue helps in giving sustained production and improves soil fertility.

2.4. Green manuring

The practice of green manuring for improving soil fertility and supplying a part of nutrient requirement of crop is age old. Depending on the crop grown the N contribution by green manure crops varies from 60-280 kg/ha. Leguminous green manures can fix large quantities of atmospheric N_2 which generally can accumulate about 100 kg N ha^{-1} in 50-55 days but can reach up to more than 200 kg N ha^{-1}. The problem with green manure crops is that they compete with cash crops for space, time, water and other inputs.

2.5. Bulky organic manures

Manures like farmyard manure, composts, vermicomposts, green manures and pressmud, etc. containing small proportion of plant nutrients and greater proportion of organic matter are considered as bulky organic manures. Before the introduction of high-yielding varieties (HYVs) of crops, organic manures were the main nutrient sources in Indian agriculture. The use of organic manures not only provides plant nutrients but also improves soil physical, chemical and biological properties. Although the cattle population has increased in recent years, but the availability of organic manures has not increased substantially in the country. Alternative use of cattle dung as fuel is the major constraint in increasing availability of organic manures in India. The plant nutrient supply from use of organic manures can be increased by developing biogas plants and agro-forestry for providing alternative sources of fuel to the villagers, the addition of crop residues, recycling of city and urban wastes and adding nutrient value through proper composting. According to an estimate, 25% nutrients needs of Indian agriculture can be met by utilizing various organic resources. Hence, the available organic sources of nutrients can be suitably used in organic production.

2.6. Biofertilizers

Biofertilizers are low-cost agricultural inputs, environment friendly, used as seed and soil inoculation. Some biofertilizers fix atmospheric N and while others increase the availability and uptake of nutrients. These biofertilizers increase crop yields tremendously (Table 4).

2.7. Soil and water conservation

Soil and water conservation can greatly reduce losses of plant nutrients through runoff and leaching. In addition, water harvesting techniques and the development of irrigation leads to the increased efficiency of nutrient use. These operations require the cooperation of the entire farming community in a region and must therefore be carefully examined, while developing nutrient management systems. Thus while poor plant nutrient management by individual farmer's results in a decrease in soil fertility because of heavy mining; an oversupply of nutrients may pollute inland water resources, estuaries and underground water. Protection of soil against erosion through soil and water conservation means is necessary to enhance/ restore soil fertility and hence, productivity of organic systems.

It has now been more or less established that too much disturbing the soil through tillage operations is not required to obtain good crop yields. Tillage has positive effects, but it also triggers

Table 4. Contributions of commonly used biofertilizers

Group	Crops	Contribution
Rhizobium strains	Legumes like pulses, groundnut, soybean	10-35% yield increase, adds 50-200 kg N/ha
Azotobacter	Soil treatment for non-legume crops including dry land crops	10-15% yield increase, adds 20-25 kg N /ha.
A*zospirillum*	Non-legumeslikemaize, barley, oats, sorghum, millet, sugarcane, rice etc.	10-20% yield increase
Phosphate solubilizers	Soil application for all crops	5-30% yield increase
Blue-green algae and Azolla	Rice/wet lands	20-30 kg N /ha, Azolla can give biomass up to 40-50 tonnes and fix 30-100 kg N /ha
Mycorrhizae (VAM)	Many trees, some crops, and some ornamental plants	30-50% yield increase, enhances uptake of P. Zn, S and water

excessive organic matter degradation, disrupts soil structure, and can cause compaction. Low-input tillage methods help to reduce disturbances to soil structure and biota. Conservation tillage, which of course, would differ from soil to soil, is beneficial for conserving organic matter as well as nutrient supply to the crop. This also reduces soil erosion. Exact tillage prescription for different soils would be different. Data generated through different ICAR projects in the country have shown that even zero tillage is equally good for wheat under specific cropping sequences and soil types.

3. Conclusion

Organic production systems largely exclude the use of synthetic fertilizers. Practices like adoption of suitable crop rotations, efficient nutrient management through combination of organic sources of nutrients and bio-fertilizers is the key to sustain the production under organic systems of cereal crops.

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Liquid bio-fertilizers for sustainable pulse production

Krishnashis Das and M Senthilkumar

ICAR-Indian Institute of Pulses Research, Kanpur, Uttar Pradesh-208 024
E-mail: krishnashis38@gmail.com

ABSTRACT

Plant growth promoting rhizobacteria (PGPR) are a group of microorganisms which colonize root surfaces and play significant role in plant growth and development. Inoculation of legume seeds with beneficial microbes has been an age old practice. The best organism when identified and selected for inoculation requires appropriate formulation, which is an important determinant for the potential success of the inoculant. Commercial inoculants formulations or bio-fertilizers are of two types such as solid carrier based or liquid formulations. Carrier based formulations have its own disadvantages, like availability of good quality carrier material, labour intensive production process, survival of microbes on carrier material, storage at low temperature and shorter shelf life. Liquid inoculants simplify the production process as there is no need to prepare and amend a carrier and the application to seeds or field is much easier. Use of different additives as cell protectants increases the product shelf life. As higher cell titer is obtained in liquid bio-fertilizers, high cell loading per seed is achieved and thus dosage requirement is reduced. With increasing trends in social awareness towards eco-friendly organic farming, liquid bio-fertilizers provide excellent choice for improving plant growth and productivity.

Keywords: Additives, Inoculants, Microbial formulation, PGPR

1. Introduction

The world population is growing at an alarming rate. In order to feed these ever growing population, the countries have to increase the per unit area productivity. According to United Nations Food and Agriculture Organization (FAO) estimations, the average demand for the agricultural commodities will be 60 percent higher in 2030 than present time and more than 85% of this additional demand will be from developing countries (Pindi, 2012). The green revolution brought amazing consequences in food grain production but with insufficient concern for agricultural sustainability. For over half a century, the world has relied on the concept of increasing crop yields through application of chemical fertilizers. Indiscriminate use and heavy dependence on chemical fertilizers for future agricultural needs are likely to result in further loss in soil fertility and negative impact on beneficial soil micro-biota. Imbalanced use of fertilizers have also shown negative impact on crop productivity, soil and water contamination, crop susceptibility to diseases and ultimately loss in economy (Savci 2012; Cristina et al. 2013). In this critical situation, microorganisms have emerged as the potential solution towards increasing crop productivity in an eco-friendly and sustainable manner. Plant growth promoting rhizobacteria (PGPR) were first defined by Kloepper and Schroth (1978) to describe rhizospheric microorganisms which colonize plant roots and enhance plant growth. Microbial bio-fertilizer is “a substance which contains living microorganisms which, when applied to seed, plant surfaces, or soil, colonizes the rhizosphere or the interior of the plant and promotes growth by increasing the supply or availability of primary nutrients to the host plant (Vessey, 2003)”. These microorganisms occur in soils naturally, but their populations are often scanty. In order to increase the crop yield, the desired microbes from rhizosphere are isolated and artificially cultured in adequate count and mixed with suitable carriers to prepare microbial inoculants or bio-fretilizer. Inoculation of seeds with beneficial microbes has been an age old practice. Practice of 'naturally inoculated' soil with legume seeds in the 1800s and the subsequent grant of first patent, "Nitragin," (Nobbe and Hiltner, 1896) have led to the development of technologies world-wide for legume inoculation with *Rhizobium* sp. Success of soybean inoculants inspired researchers all over the globe to explore microbial community for development of bio-inoculants for other crops.

2. Why bio-fertilizers?

In India bio-fertilizers were introduced along with soybean since Indian soils were devoid of rhizobia nodulating the soybean crop. Since then, use of bio-fertilizers is gaining momentum, especially with emphasis on organic farming and sustainable agriculture. It is a low cost technology with a high cost-benefit ratio and an integral input of organic farming. Bacterial bio-fertilizers can improve plant growth through several different mechanisms: (i) mobilization of soil nutrients (macro as well as micro-nutrients), making them available for the plant to be used, (ii) synthesis of phytohormones, and growth regulators, (iii) protection of plants under stressful conditions, or (iv) defense against plant pathogens, reducing plant diseases or death. Use of bio-fertilizers also improves soil health and productivity and reduces the environmental pollution caused by the harsh manufacturing processes of chemical fertilizers. Several plant growth-promoting rhizobacteria (PGPR) are being used worldwide as bio-fertilizers, for improving crop yield and productivity.

3. Types of Bio-fertilizer

Once the best organism identified and selected for inoculation requires appropriate formulation, which is an important determinant for the potential success of the inoculants. The technical optimization of an inoculant formulation is independent of strains used, since most of the strains of same bacterial species share many physiological properties, it may be assumed that a technological process developed for a particular strain is readily adaptable to another strain of same species with only minor modifications. Formulation typically consists of establishing viable bacteria in a suitable carrier together with additives that aid in stabilization and protection of microbial cells during storage, transport and at the target. The formulation should also be easy to handle and apply so that it is delivered to target in most appropriate manner and form, one that protects bacteria from harmful environmental factors and maintain or enhance the activity of the organisms in the field.

Commercial microbial formulations used now-a days are mainly of two types-solid (carrier based) and liquid. Solid inoculant is prepared by mixing broth culture, containing high microbial population with a suitable carrier material. A number of factors determine the choice of carrier material like: (i) it should allow the addition of bacterial nutrients, (ii) it must have a high water-holding capacity, (iii) it should allow easy sterilization, (iv) it must have a good pH buffering capability, (v) it must be non-pollutant and biodegradable and (vi) it must allow easy handling by the farmer (Garcia-Fraile et al., 2015). A diverse array of soil materials (peat, charcoal, volcanic pumice, clays), organic materials (composts, plant by-products), or inert materials (perlite, vermiculite, bentonite, kaolin, silicates) are used as carrier all over the world (Smith 1992, Brockwell and Bottomley, 1995; Stephens and Rask, 2000, Temprano et al., 2002, Malus et al., 2012). Major disadvantages of carrier based bio-fertilizers are their short shelf life and poor quality because of poor survival of the organisms under adverse conditions, high contamination and unpredictable and inconsistent ûeld performance. The cost is also a negative factor for carrier based bio-fertilizers as its production is energy and labor intensive involving mining, drying, milling, sieving and correcting pH of the carrier materials (Kumaresan and Reetha, 2011; Velieni and Brahmaprakash, 2011).

4. Liquid bio-fertilizers

An attractive alternative is the use of "Liquid Bio-fertilizers". Apart from containing the desired microorganisms and their nutrients, liquid bio-fertilizers also contain special cell protectants or substances that encourage the formation of resting spores or cysts for longer shelf life (Chandra et al., 2005), protect the cells against seed toxicity after seed application; provide better resistance against abiotic stress, high temperature (up to 55° C), desiccation and osmotic shocks. As higher cell titer is obtained in liquid bio-fertilizers, high cell loading per seed is achieved and thus dosage requirement reduces by 10 folds as compared to carrier based bio-fertilizer (Brar et al., 2012). Additives used in the preparation of liquid inoculants have been selected based on their ability to protect bacterial cells in package and on seeds at extreme conditions such as high temperature, desiccation and toxic condition of seeds and seed chemicals. Most of the additives are high molecular weight polymers with good water solubility, non-toxicity and complex chemical nature (Deaker et al., 2004) and are able to limit heat transfer, posses high water activities (Mugnier et al. 1985). Polymers that are soluble in liquid inoculant formulations are convenient for batch processing of inoculants and make seed application a simpler process for farmers. Some of the polymers which are presently used in preparation of liquid inoculants includes polyvinyl pyrrolidone (PVP), methyl cellulose, polyvinyl alcohol, polyethylene glycol, gum Arabica, trehalose, glycerol, Fe-EDTA, sodium alginate, tapioca flour etc. (Singleton et al., 2002; Tittabutr et al. 2007).

Bacteria respond to not only the type of polymer in liquid inoculants and its concentration in a medium. *Pseudomonas* maintained highest population density in the presence of PVP formulations, but population density of *Acinetobacter* was highest in the presence of PEG. In general, the addition of various osmolytes at the concentration of 1% or higher results in maintaining a population higher than 0.5% level of amendment (Dayamani, 2010). Liquid inoculants can be produced by a simple fermentation process, packed directly from the fermentor aseptically, and stored after addition of additives at proper concentration. It minimizes the production cost by avoiding processing and sterilization of solid carrier material. The complete sterilization could be achieved with liquid formulations and any contamination during the storage can be easily detected (Brahmaprakash and Sahu, 2012). Liquid inoculants could be produced with minimum labour, space and energy and also the quantity of inoculum required is less compared to carrier based formulations, hence easier for farmers to handle. The liquid inoculants developed can maintain population of *Rhizobium* sp., *Azotobacter* sp., *Azospirillum* sp. and PSB up to the level of 10^8 cells per ml (Velieni and Brahmaprakash, 2011).

5. Bio-fertilizer production scenario in India

It has been estimated that in India the money spent on bio-fertilizers and bio-pesticides is around USD 1.5 billion (Garcia-Fraile et al., 2015). With the increasing trend of organic farming and environmental awareness the use of bio-fertilizers is expected to increase in the coming years. There are over 100 bio-fertilizer producers in the country. One of the key suppliers of bio-fertilizers worldwide, Biomax, is based in India. Biomax commercializes several products containing microorganisms (i. e. Life®, Biomix®, Biozink®, Biodine®) that are recommended for a broad variety of plants able to fix atmospheric nitrogen, solubilize phosphate, iron, magnesium and zinc and that play an active role in organic matter degradation. Other large bio-fertilizer manufacturing companies are also present in India: Ajay Biotech Ltd., National Fertilizers Ltd., Madras

Fertilizers Ltd., Gujarat State Fertilizers & Chemicals Ltd., T. Stanes & Company Ltd., Camson Bio Technologies Ltd., Rashtriya Chemicals & Fertilizers Ltd. Beside this several research institutes like TNAU, IARI, NBAIM are producing liquid bio-fertilizers for various crops.

6. Future prospects and Challenges

With the increased popularity of bio-inoculants, new technologies have emerged focusing mainly towards cost effectiveness, better stability and longer shelf life. Rebah et al. (2007) reported the use of wastewater sludge with heavy metal content below legal limits as growth medium and dehydrated sludge as carrier material which can reduce the cost of inoculant production. New formulation technologies such as:

- Water-in-oil emulsions technology for developing liquid formulations is beneficial for those organisms which are particularly sensitive to desiccation (Vandergheynst et al., 2007).
- Biofilm based formulations both single and fungal-bacterial have shown good potential as the biofilm formation naturally protects organisms and helps in its survival and growth under adverse soil conditions (Jayasinghearachchi and Seneviratne, 2004).
- Application of nanotechnology may open a new class of biofertilizers. Entrapment of bacterial cells in nanostructures leads to improved stability and high surface area. Nanoformulations may contribute to enhanced stability of biofertilizers with respect to desiccation, temperature, and UV inactivation (Khot et al., 2012, Malus et al., 2012). Further research in needed to address the biosafety issues related to transgenic and nanoformulations.

Adoption of liquid bio-fertilizers in large scale faces several challenges. Bacteria introduced to soil may fail to establish in sufficient numbers in the rhizosphere because of competition from native microbiota. Different environmental and soil factors like drought, lack of sufficient irrigation, high salinity and soil erosion may quickly diminish the introduced bacterial population. Most important constraints for adoption of bio-fertilization in India have been attributed to poor quality of inoculants produced, lack of knowledge about inoculation technology for extension personnel and farmers; effective inoculants delivery/supply system and lack of committed policy to exploit bio-fertilizers successfully (Brahmaprakash and Sahu, 2012). Lack of proper monitoring and quality control are also major problems in popularization of bio-fertilizer technologies.

7. Conclusion

As long as the human population continues to increase the world will have to deal with an escalating demand for food. The Green Revolution increased agricultural production worldwide, saving about one billion people from starvation and undernourishment, and was attributed to the development of chemical fertilizers, along fertilizer responsive varieties. But injudicious use of chemical fertilizers have depleted soil health and increased risks of environmental hazards. Bio-fertilizers provide an excellent solution to improve soil health and productivity in a sustainable manner. PGPR bacteria promote plant growth not only by supplying nutrients to the plant, but also by producing phytohormones, inducing stress resistance, or preventing pathogen-induced plant diseases. Thus, the development of the bio-fertilizer market and the promotion of bacterial inoculations in the field is an environmentally friendly way to meet the worldwide need to raise crops yields. Proper governmental policies and well coordinated efforts from researches, agronomists and farmers are much needed for wide adoption of bio-fertilizer technologies and its success in farmer's field.

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4R Nutrient stewardship for sustainable pulse production in India

Sudarshan Dutta[1] **and Ummed Singh**[2]

[1]*International Plant Nutrition Institute, South Asia (East India and Bangladesh) Program*
[2]*ICAR-Indian Institute of Pulses Research, Kanpur 208 024, Uttar Pradesh, India*
E-mail: sdutta@ipni.net

ABSTRACT

During green revolution era (1960s) farmers in India replaced pulse rotations and organic sources of plant nutrients with synthetic fertilizers. Presently, a sizeable amount of farmers are dependent on synthetic fertilizers for survival and crop production. Due to injudicious use of chemical fertilizers in recent decades fertilizers have been prone to various environmental hazards. To deal with such hazards, 4R Nutrient Stewardship represents an innovative approach to fertilizer best management practices (BMPs). The 4Rs imply there are four aspects to every fertilizer application and it provides a framework to assess whether a given crop has access to the necessary nutrients. It implies right source at the right rate, at the right time, and in the right place, which helps in identifying opportunities to improve fertilizer efficiency.

Keywords: 4R nutrient stewardship, Micronutrients, Phosphorus, Pulses, Sulphur

1. Introduction

India is considered asone of the highest pulse producing countries in the world, still we need to spend more than Rs. 232 billion annually (Ali, 2016) to import pulses to meet the domestic consumption needs, asespecially pulse crops play a lead role in meeting the protein requirement of vegetarian population of India. Main inefficiency lies in lower average productivity (0.76 ton ha^{-1}) compared to world average (0.9 ton ha^{-1}). Therefore, it is a high time to reach the highest potentiality to narrow down the demand-supply gap. Imbalanced fertilizer application leading to lower nutrient use efficiency, environmental hazard and soil health deterioration is a major threat in India for sustainable pulse production (Singh *et al.,* 2017). Introduction of pulses as legumes in cropping system has proved to be beneficial in multiple dimensions such as entrapping atmospheric nitrogen in soil, increasing nutrient use efficiency, improving physical and biological health of soil (Lupwayi *et al*., 2011) and breaking the cycle of pests and weeds (Yadav *et al*., 1998).Therefore, inclusion of pulses has important agronomical benefits. The balanced fertilizer application can be considered as the pathway aiming at enhancing the productivity to reduce yield gaps for all crops including pulses. The ***4R Nutrient Stewardship*** can be considered as way forward for implementation of balanced fertilizer application. In order to honor the spirit of the United Nation's declaration of 2016 as the 'International Year of Pulses (IYP)' and FAO's (Food and Agriculture Organization)efforts to popularize pulse as major nutrient resource over the world population,the present study highlights the general guidelines of 4R Nutrient Stewardship for popular pulses where 4 R stands for ***Right source*** of fertilizer, ***Right rate*** of application, ***Right time*** of application and ***Right method*** or ***place*** of application of all macro, secondary and micro nutrients.

2. 4R Nutrient Stewardship Guidelines for Macronutrients

2.1. Nitrogen

Nitrogen is considered as one of the most important nutrients for all the crops including pulses. In the case of pulses lower nitrogen availability in soil may cause "Nitrogen hunger" causing lower nodulation and reduced yield; whereas, N application in such soil has shown remarkable yield growth. Lower doses of N application at early growth stages are recommended due to an interrelated factor. Lower N application ensures high nodulation and atmospheric N fixation that enables pulses to meet their 80-90% of N requirement. To meet rest of the 10-20%, different fertilizers are recommended depending on the cropping system as well as soil texture, varying overall from 15-20 to 35-40 kg ha^{-1}.

2.2. Phosphorus

Being an important constituent of cell's energy currency (ATP and ADP) and involvement in metabolism, enzymatic reactions, root proliferation and atmospheric N assimilation, award Phosphorous a prime position in nutrient management. Several studies, searching right source of P fertilizers, revealed some interesting facts. Such as, in case of green gram combined application of farm yard manure (FYM) at 10 t ha^{-1} and P_2O_5 at 30 kg ha^{-1} through diam-monium phosphate (DAP) has proved to facilitate yield, rhizosphere microflora and nutrient availability (Chesti and Ali , 2012). On the other hand, SSP (single super phosphate) was reported to be superior over DAP in terms of nodulation, yield, N and P uptake and P availability with better agronomic and recovery efficiency (Singh *et al.,* 2012). Chickpea was found to be more efficient than other pulses in taking up P from soil, as it secretes more acid that helps in solubilizing Ca-P secondary minerals in the soil (Thiyagarajan *et al*., 2003). Majumdar and Govil (2015) suggested that response quartiles of large data sets from their studies observing P response of pulses over a 10-year period across Indiacould be effectively used to determine the right rate of P application to pulses.

Proper placement of P fertilizer is important due to its lower mobility in soil. Studies suggested that placement of P fertilizers depend on pulse crop's root structure. Such as, placement of P at 15 cm soil depth significantly increased the yield in pigeonpea due to its long root and long crop duration;whereas, placement at 7.5 cm performed better in the case of greengram and cowpea due to sorter root length (Singh *et al.,* 2012). In a different study Singh *et al.,* 2012 suggested that full basal application of P benefits nodule initiation, multiplication and proliferation; whereas, split application of P (50% P as basal + 50% P as top dressing at branch initiation) reduced P fixation and improved P use efficiency.

Table 1. Yield response and net return on P fertilizer application in different pulses

Crop	**P_2O_5 applied**	**Yield increase due to P_2O_5 (kg ha^{-1} ±SE)**	**Net return due to P_2O_5 (Rs. ha^{-1})**	**Net return, (Rs. Rs^{-1} invested on P_2O_5)**	**Response kg^{-1} of P_2O_5 applied (kg kg^{-1})**
Chickpea (5)	147	445±91	16,020	3.68	3.29
Chickpea (26)	68	640±60	23,051	12.89	11.53
Greengram (6)	58	221±19	7,956	4.91	4.39
Greengram (3)	59	127±3	4,560	3.75	3.36
Pigeon pea (9)	111	460±41	16,572	5.09	4.55
Blackgram (5)	72	129±33	4,658	2.09	1.87
Blackgram (7)	90	106±20	3,821	1.90	1.70
Cowpea (1)	20	139	5,004	7.77	6.95

Price of P: Rs. 32/- kg^{-1} of P_2O_5; Average minimum support price of pulses: Rs. 36/- kg^{-1} of grain; Numbers in parentheses represent the number of studies in a particular crop.
Source: Majumdar and Govil (2015)

2.3. Potassium

Inadequate use of K fertilizer results significantly in lowering productivity with poor crop quality of pulses in India (Majumdar and Govil, 2013). A regular K fertilization in Alfisols and maintenance of K dose in Inceptisol is essential for chickpea production in India due to low non-exchangeable as well as exchangeable K, respectively.

3. Stewardship of Secondary and Micronutrients

Pulses are second largest consumer of Sulphur(S) after oilseedsas this nutrient is considered as the 4th most important plant nutrient after N, P & K. Besides,S has synergistic effect on other essential nutrient uptake and antagonistic effect on unwanted toxic elements like Selenium (Se) (Singh *et al*., 2015; Singh *et al*., 2016). Sulphur plays a vital role in pulses in maintaining quality thorough reducing N:S ratio in plants and accelerating metabolic pathway of protein synthesis, thus adding value in pulses upholding them as the major source of protein for vegetarian population throughout the world. Therefore, 4R Stewardship guidelines are must to follow to optimize S supply to pulses, as S deficiency is wide spread in India (Ganeshamurthy and Saha, 1999).

Among all straight S fertilizers (suchas Gypsum, pyrite, cosavet, elemental S and sulphuric acid etc.) and complex S fertilizers (suchas SSP, potassium sulphate, ammonium sulphate, sodium sulphate, etc.) ammonium sulphate has been voted as the most efficient source of S by several studies. In neutral to slightly alkaline soil, easily soluble ammonium sulphate, potassium sulphate and sodium sulphate are considered more suitable sources of S. In S-deficient soils (e.g. calcareous soils), instant release of S is more necessary to correct the deficiency symptoms immediately, that can be fulfilled by readily soluble source like ammonium sulphate rather than gypsum which is less soluble (Singh *et al*., 2016).

The residual effect of S applied to the main crop shows a detrimental effect to the succeeding crop unless a right source and rate of S is applied to the main crop (Singh *et al*., 2016). Based on different crop response analysis, application of 20 – 40 kg S ha^{-1} in the form of sulphate-S is necessary to supply an adequate amount of S to the pulses. It was found that placement of S fertilizers along with other fertilizers at the time of sowing gives better yield and use efficiency (Aulakh, 2003). However, if elemental S (S^0) is used as source of S, then applying S in the soil at 3-5 weeks prior to sowing is recommended so that sufficient amount gets oxidized to meet the plant needs.

Calcium (Ca) and Magnesium (Mg) left significant impact on pulse yield in acidic soils (Thiyagarajan *et al*., 2003). In fact Mg requirement of legumes are higher than cereals and oilseeds. Effect of Zinc (Zn) application differs on different pulses due to inconsistent sensitivity of the crops to Zn. Though, in most of the studies on different pulses revealed that yield was benefited due to Zn application. Gupta and Sahu (2012) reported that combined soil application of micronutrients such as iron ($FeSO_4$@ 10 kg ha^{-1}), boron (borax @ 10 kg ha^{-1}), zinc ($ZnSO_4$ @ 25 kg ha^{-1}), molybdenum (ammonium molybdate @ 1.0 kg ha^{-1}) had substantial improvement in grain yield of chickpea and uptake of N, P, K, S, Zn, Fe, and B. In case of Boron (B), optimum rate (varying from 0.5-2.0 kg B ha^{-1} as borax) depends on soil B status, genotypes and ecosystem. Such as in Arid and Semi-arid part of the world B toxicity has been observed remarkably. On the other hand, Bdeficiency has also been reported in India (Odisha, Bihar, Uttar Pradesh and Gujarat). Soils derived from granite, igneous, acidic and metamorphic sedimentation, strongly weathered (acrisols and ferrasols), coarse textured (arenosols) and shallow (lithosols) soils suffer from B deficiency. High sensitivity of legumes and pulses to B deficiency demand optimization of B application.

4. Conclusion

As very limited number of farmers follow the balanced fertilizer application technique for pulses, highlighting the fact that there is a huge untapped potentiality in productivity enhancement of pulses in South Asia through proper nutrient management. The 4R Nutrient Stewardship provides socio-economic and environment friendly guidelines for managing macronutrients, secondary elements, and micronutrientsof major pulses grown in different parts of India keeping in view differences in growing conditions.The present study highlights the 4R Nutrient Stewardship Principles in nutshell.

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Steps towards self-sufficiency in pulse production in India

N P Singh, C S Praharaj and Ummed Singh

ICAR-Indian Institute of Pulses Research, Kanpur, Uttar Pradesh-208024
E-mail: npsingh.iipr@gmail.com

ABSTRACT

In India, over a dozen pulse crops viz., chickpea, pigeonpea, cowpea, mungbean, urdbean, lentil, French bean, horse gram, field pea, moth bean, lathyrus, *etc*. are grown in one or the other part of the country. Pulse seeds contain from 16 to 50% protein and provide one third of all dietary protein nitrogen. Therefore, pulses in combination with cereals provide one of the best solutions to protein calorie malnutrition, especially in the developing countries. Beside proteins, these are also an important source of the 15 essential minerals required by man. Despite so much important in human health and nutrition, the global food legume production has witnessed only a marginal annual increase of 0.95 % with fluctuations only from 40.78 to 70 million tonnes. Slow growth in global pulses production along with rising population, diversified uses for end products and improved purchasing capacity of people has put tremendous pressure on per capita availability of pulses. Besides, decreasing cultivable land and factor productivity, biotic and abiotic stresses, and unavailability of quality seeds have further strained the pulses supply chain.

Keywords: Farmers income, Pulses, Self-sufficiency, Soil health

1. Introduction

ICAR-Indian Institute of Pulses Research is endeavoring for scalingup of the productivity goals consistently on sustained basis through its multifarious efforts. Ever since its inception as a full-fledge Institute from 1993, it provides an appropriate platform for equitable access to information, knowledge and genetic material to develop improved technology and enhanced pulses production through undertakingBasic and Strategic Research on pulses. The main emphasis is on improving productivity and quality in pulses. Appropriate strategies also aimed at disseminating the technologies generated and for capacity building on regular basis.

While doing this, we always acknowledge international support and country's effortsin pursuing our much cherished mission i.e., *realizing self-sufficiency in pulse sector*. On this account, the role of FAO declaring *2016 as the International Year of Pulses* was immense as it led to the beginning of a new era in pulses. As aresult, *International Year of Pulses* (IYP) was officially launched at Indian Institute of Pulses research (IIPR) Kanpur on March 13th 2016 by honourable Union Minister of Agriculture and Farmers Welfare. From this day we travelled through at least 23 important events relating to IYP including several workshops, symposiums, conferences, training and brainstorming meetings. This added the required boost to country's agriculture as a whole and pulse sector in particular. Following culmination of these countrywide activities including the "*Closing Ceremony of IYP and Review of various Government initiatives for enhancing pulses production"* at Agra (Uttar Pradesh in India) on 22nd December 2016, we really achieved a lot.It may be worthwhile to mention that India has created a history by record production of pulses to the tune of 22.4 million tonnes in 2016-17.

The major achievement of IYP is formation of "*Pulse seed hubs*" both in SAUs and ICAR Institutes and KVKs so as to cater seed-needs of farmers. Targeting at 1.5 lakh quintals additional seed production per year, it is expected that self-sufficiency in pulses production could not be a distant dream today. Reinforcing this, we have also strengthened our existing breeder seed programme. Ample provision for a buffer stock of 20 lakh tonnesof pulses is also kept to meet the seed related contingencies. We have also taken steps to ensure appropriate demand for the commodity by appropriate policy decision concerning MSP, market assess,storage, PDS and above all, trade gap (opened up exports). Therefore, the major stepstaken towards achieving self-sufficiency in pulses includes implementing the recommendations put forth by IYP meets. These include increasing genetic gains through novel technology like transgenic technology, incorporating photothermalinsensivity and breeding short-duration varieties for increasing cropping intensity, conservation agriculture and strategic practicable technologies, research on storage structures and minimization of storage losses, promoting participatory and demand driven research and appropriate policy support (lowering distress sale etc).

2. Targeting self-sufficiency

The pulse requirement in the country is projected at 32 million tonnes by the year 2030 and 39 million tonnes by the year 2050 at an annual growth rate of 2.2%requiring specific and all round efforts and strategic steps in research, generating innovations, its dissemination, and commercialization along with capacity building. Keeping in view the availability of land, population growth rate and technological innovations, projections have been made. For every 5-year interval productivity is to be enhanced by an round 80 kg/ha over the previous year to achieve a final productivity rate of 950 kg/ha by 2025 and 1335 kg/ha by 2050 following expanding the existing area by around 4 million ha under pulses.

Since in most of the pulses there is *large gap between the potential yield and the realized yield,* the actual productivity gains in different pulses are considerably lower as compared to their potential yield as well as that realized on farm demonstrations (Table 1). One of the most important reasons behind low productivity in pulses is that these are generally grown in poor and marginal lands with minimum inputs and it is our serious concern that about 87% of the pulses cultivation in the country is rainfed. One single innovation or technology could do wonder is life saving or supplementary irrigation to be applied once during the most critical stage of the crop if rain fails. The reasons for lower productivity also include use of old and pests & disease susceptible varieties,use of home-saved seedsyear-after-year and that too through broadcasting instead of line sowing. This cause sub-optimum plant population in the fields and the consequence is low yield. Farmers often don’t use pre-emergence herbicides

Table 1: Yield gap in different pulse crops

S. No.	Crop	Potential Yield (Kg/ha)	Realized yield (Kg/ha)	Present Status (Kg/ha)
1.	Chickpea	1800	1435	1014
2.	Pigeonpea	1800	1433	792
3.	Mungbean	1400	843	432
4.	Urdbean	1300	890	596
5.	Lentil	1400	1047	797
6.	Fieldpea	2500	1394	1105
7.	Lathyrus	1200	772	742
8.	Cowpea	1300	794	814
9.	Horsegram	800	536	415
10.	Mothbean	1100	831	280

Source: IIPR, Pulse (FLDs); Present status is the average yield at national level to control the initial weed growth causing substantial yield loss due to weeds. Cost reduction is not actually possible since farm mechanization is of low priority in pulses cultivation. Therefore, poor variety performance along with improper management of the crop has resulted in a stagnant low yield.

Besides poor yield realization, the constraints in pulses as a profitable enterprise are many. Deficit in pulses availability is attributed to a number of underlying factors such as ever-increasing population, geographical shift (from North to South and Central Zone), abrupt climatic changes, complex disease-pest syndrome, socio-economic conditions of the farmers and lesser market opportunities. Pulse production in India today is generally undertaken by small and marginal farmers, mostly as subsistence farming. Limited availability of cultivable land, stagnation in cropping intensity due to absence of irrigation facilities and depleting natural water resources, have relegated pulses to poor returns. Cultivation of pulses on poor soils under rainfed conditions with minimum inputs and management have often led to yield losses (biotic & abiotic causes) right from field to disposal. Besides this, high influence of environmental factors and G×E interaction are the major production constraint in pulses which lead to a partially gain in productivity in most of the pulses.

Both Research and Development activities of the Institute have been further strengthened towards increasing the productivity mainly through protection of the pulse crops against diverse and dynamic biotic and abiotic stresses.Among diseases, fusarium wilt coupled with root rot complex is probably the most widespread disease causing substantial yield losses in chickpea. Similarly, fusariumwilt, sterility mosaic and phytophthora blight in pigeonpea, yellow mosaic, cercospora leaf spot and powdery mildew in both mungbean and urdbean and the rust and wilt in lentil cause considerable losses.Besides weed problem, gram pod borer in chickpea and pigeonpea, pod fly in pigeonpea, whitefly, jassids and thrips in dry beans cause severe damage to crops among pests. Similarly, among abiotic stresses, drought and high temperature at terminal stage, cold as well as sudden drop in temperature coupled with fog during the reproductive phase and soil salinity/alkalinity wreak a havoc towards potential expression of crops. Other socio-economic constraints include inadequate seed replacement rate, limited policy directives and incentives and poor storage facilities of the farm produce including infestation due to storage pests supplement to the existing problems.

On basic sciences involving pulses, the role of salicylic acid on increasing nitrogen index balance (NBI), chlorophyll and flavonol under drought (PEG induced) was established while anthocyanin content was high in leaves without salicylic acid pre treatment. Similarly, it was confirmed that NDVI value - an essential physiological tool for detecting plant health through remote sensing- for promising chickpea genotypes (ICC 12916, ICC 15868, ICC 14880, RSG 896, JG 12 and ICCV 37) were invariably higher. Compatibility of beneficial bacterial isolates with *Mesorhizobium* was also confirmed.

During these years, technology demonstration and promotion of pulses was made through diversified projects and activities that included Farmers' FIRST (covering 1077 farmers and 173.44 ha area), Soil Health Cards, promotion of pulses in NEH Region, Seed Production (62 ha of green gram and 73 ha of blackgram), registering farmers under e portal '*DalhanSandesh*' and communicating through voice based SMS advisory service and conduct of demonstrations (230 in *kharif* on pigeonpea and urdbean while 860 in *rabi* on chickpea, fieldpea and lentil), designing Commodity profile for pulses (CPP Portal), registering Copyright for software and filing Trademark of PulsExpert and developing farmers friendly website e-*DalhanGyanManch* and *ChanaMitra* app., and organizing training programmes (15 no.) and exposure visits (44 no.) regularly for farmers.

Besides all these, international collaboration with ICRISAT, ICARDA and World Vegetable Centre, the Institute is presently hosting 47 number of externally funded projects on frontiers areas of pulses research from DBT, DST, ICAR National Fund, Bill and Melinda Gates Foundation, ACIAR, UPCAR and many others. The Institute has identified major R&D issues as per the recommendations of the RAC which are being addressed with integration of conventional approaches with cutting edge technologies.

3. Achieving Self-sufficiency

The institute has continuously striving for developing high yielding and stable varieties and novel technologies to realize self-sufficiency on pulses. Notably among them is developing 15 most promising varieties of pulse crops for cultivation in different parts of the country during last 3 years. These include 4 in chickpea (IPC 2004-01, IPC 2004-98, IPC 2005-62 & IPC 2006-77), 4 in fieldpea (IPFD 10-12, IPFD 11-5, IPFD 12-2 & IPFD 6-3) 3 in lentil (IPL 316, IPL 526 & IPL 520), 2 in mungbean (IPM 410-3 & IPM 205-7) and one in pigeonpea (IPA 203) and urdbean (IPU 07-3). A hybrid of pigeonpea, IPH 09-5, has also been developed which is currently under evaluation in NEPZ region.

Besides these the institute has also developed 4 land mark varieties of pulses with specific features and unique characteristics *viz.* IPL 220(high Fe and Zn fortified lentil variety), IPH 09-5 (early duration pigeonpea hybrid), IPM 205-7 (Virat, a Super early mungbean variety), IPFD 10-12 (green seeded fieldpea varieties).

Towards developing MAS products using genomic resources, draft genome sequence of chickpea and pigeonpea is available that provides a resource for trait improvement, development of transgenics in chickpea and pigeonpea for insect (Pod borer) resistance using Bt gene (Cry 1Ac & Cry 1Aabc) in DCP 92-3 (Chickpea) and Asha (Pigeonpea) genotypes, respectively.Significant advancement was achieved in development of transgenic chickpea and pigeonpea events for insect resistance (IR) trait through genetic engineering technology. Requisite Permit Letters were obtained from Genetic Engineering Appraisal Committee, Ministry of Environment, Forest and Climate Change and Review Committee on Genetic Manipulation, Department of Biotechnology, Ministry of Science and Technology, Government of India to conduct *Event Selection Trial* of five transgenic chickpea and five transgenic pigeonpea events.

On pulses protection, 15 chickpea genotypes were found resistant against wilt (*Fusarium oxysporum* f.sp. *ciceri*) for five years while 13 chickpea accessions were moderately resistant to wilt for last 2 years. Similarly, in pigeonpea, 12 lines showed resistance to wilt (*Fusarium udum)* while five genotypes (ICPL99044, ICPL 20095, ICPL 87051, ICPL 99009, and ICPL 99055) were resistant to wilt. In chickpea, 14 lines of chickpea were moderately resistant against dry root rot (*Rhizoctonia bataticola*) while five advanced lines showed resistance for more than 2 years. On *Ascochyta* blight resistance, 10 chickpea genotypes were moderately resistant; and on Botrytis grey mold (BGM), three genotypes (RSG 957, BGD 128 and AKG 1216) showed resistant reaction while 8 genotypes (NBeG 03105, GNG 1969, GL 13001, CSJ 824, IPC 2015-75, CSJK 43, DBGV 506 and NB3G 440) were moderately resistant. For resistance to root knot nematode *Meloidogyne javanica,* the study confirmed the resistance in 26 genotypes/lines of pigeonpea, 14 of mungbean, 15 of urdbean, 34 of lentil, 19 of fieldpea 24 of chickpea and 15 accessions of wild *Vigna* accessions. Similarly, seven chickpea genotypes (Phule G-12110, Phule G-0405, RSG-963, PG 0104, CSJK-114, CSJK-96 and BG-3059) were moderately resistant against lesion nematode. On management of *M. vitrata*, sorghum as border crop showed lowest larval webbing per five plant (0.97) in pigeonpea. Sorghum as border crop also resulted in highest population of *Coccinella septumpunctata* (0.8/5 plant) and *Cheilomenessexmaculata* (1.13/ 5 plant) in pigeonpea.The institute has also developed Diagnostic Kits “LYMVs PCR Diagnostic Kit” for identification of viruses causing yellow mosaic disease and Multiplex-PCR “LYMVs Mplex” for the accurate identification of the viruses causing YMV in pulses.

Keeping in view of importance of management considerations in scaling pulses productivity, sustained efforts are made for popularization/ adoptionof improved agro-techniques involving Broad bed/BBF planting for kharif pulses, precision tillage using laser leveler, drip-fertigation in long duration pigeonpea, sprinkler irrigation in chickpea and lentils, popularization of most remunerative pigeonpea + soybean - lentil in Central India, zero till seed drill for resource poor farmers, refined rice fallow technologies for pulses, improved post emergence herbicides (Imazethapyr and Quizalofop-ethyl at 80-100 g/ha POE at 20-25 days after sowing) for better weed control and supplementary (and life saving) irrigation using pond technology. Improved cropping systems like, rice-wheat-mungbean, pigeonpea-wheat and maize/sorghum/pearl millet-chickpea/ lentil, seed inoculation with improved *Rhizobium* and PSB strains, balance fertilization, resource conservation aided technologies/practices like, residue retention, crop sequence, tillage and suitable herbicides for efficient weed control, other resource conserving practices like, ridge & furrow system and seed priming).

It is also established in a rice based long-term experiment that continuous cropping of rice-wheat-mungbean led to significant enhancement in soil enzymatic activities like, phospahatse (acid and alkaline), â-Glucosidase, arylsulfatase, microbial biomass C and microbial biomass N. Among nutrient management, INM consisting of incorporation of crop residues, FYM @ 5 t/ha along with biofertilizers in conjunction with half of NPK dose proved better over balanced inorganic fertilization (NPKSZnB). As in previous years, inclusion of pulses in the cereal based cropping system enhanced the system productivity as well yield of component crops.

Since cost is the major consideration for success of any technology or practice, greater emphasis is made towards decreasing cost of cultivation and increasing farm output/income through mechanical harvesting of chickpea (like, GBM 2, NBeG 47 and HC 5 with >20 cm ground clearance) and Dal recovery by IIPR Mini Dal Mill. Besides these, new transfer of technology (TOT, MGMG, Farmers First) models are in vogue for rapid dissemination and adoption of suitable agro-technologies.

It is established that biopesticide has a definite role in protection of plants (being economic and effective). Similarly, seed inoculation with *Trichoderma* at sowing could be immensely helpful against several soil/seed borne pathogens. Besides this, biofertilizers like, *Rhizobia* can provide 25-30 % chemical fertilizer equivalent N in pulse crops, and contribute to plant growth. Provisions for skill enhancement programs in rhizobium application, seed production, seed treatment, production and application of biocontrol agents, could be made for ensuring better acceptance of these critical production technologies among farm families.

All these have significant impact and bearing on scaling productivity levels in pulses. It has been demonstrated that improved varieties of pulses have a positive impact to the tune of 15-20 % in increasing pulses production in all major pulse crops including chickpea, mungbean, urdbean and lentil while in pigeonpea, improved varieties increase the yield by 10-12%. Complementing these efforts, the initiatives taken by the Government/ICAR on policy support on key issues decides rather shift the dynamics of stable production in pulses. An example of MSP can be cited here (Table 2).The development and dissemination of technologies, good quality seed to the pulse growing farmers, favourable weather conditions, government support and policy initiatives and willingness of farmers have together led to this

Table 2. MSP (INR/q) of major Pulse crops in India during last 3 years

Crop	(2014-15)	(2015-16)	2016-17
Pigeonpea	4350	4425*	4625**
Mungbean	4600	4650*	4800**
Urdbean	4350	4425*	4575**
Chickpea	3175	3425#	4000
Lentil	3075	3325#	3950

*Bonus of Rs 200 per quintal is payable over and above MSP; # Bonus of Rs 75 per quintal is payable over and above MSP; ** Bonus of Rs 425 per quintal is payable over and above MSP.

unprecedented growth. The frontline demonstrations clearly indicated the potential of new technologies.

Currently, chickpea alone shares about 45% of the total pulses production of the country followed by pigeonpea, mungbean, urdbean and other pulses. However, irrigated pulses comprising of mungbean, urdbeanand fieldpea can largely compensate the projected yield gap. There is an ample scope of horizontal expansion in area of these crops in Indo-Gangetic plains during Spring/Summer season as well in rice fallows of southern India. Recently developed short duration varieties of pulses enabled extensive cultivation of chickpea in central and south India, and summer mungbean in Rajasthan and western Uttar Pradesh. The geographical shift in pulses is an indication of their potentialities to adapt to diverse climatic conditions (favouring their production) thus enabling their future expansion in new niches. In addition, an area of about 11.695 m ha in India remains fallow after rice harvest, of whicharound 82% lies in the Eastern India and the rest falls inthree southern states *viz*., Tamil Nadu, Karnataka andAndhra Pradesh. These areas have a vast potential tocultivate low input and low water requiring upland pulsecrops like lentil, chickpea, lathyrus, mungbean andurdbean. Besides this, scope does exist in growing pulses in inter-row spaces in wide-row crops viz., sugarcane, pearl millets, and sorghum which could brought at least a couple of million hectares under horizontal expansion through appropriate cropping systems involving pulses.

4. Doubling farmers' income by 2022

Pulses as a candidate crop, contributes immensely towards doubling farmers' income through diminishing cost of production, scaling per unit productivity, efficient marketing networks and successful technology delivery mechanisms by giving emphasis sustainable intensification and crop diversification, climate resilient production technologies backed with strong research outputs in pulses can contribute towards doubling the farmers' income. On this account, many important aspects could reinforce our efforts in doubling farmers' income by 2022. Besides policy support, these includes ways and means in reducing cost of production and enhancing income through scaling productivity

Our target is to scale productivity and decrease cost of production as both could invariably lead to increased output efficiency. Inclusive technological options suiting diverse agro-ecologies of the country, raising fertilizer/nutrient use efficiency, use of neem coated urea and other appropriate value added ferilizers (customized fertilizers based on crop need), promoting life saving and supplementary irrigation to the crops with low consumptive water requirement like, pulses, use of alternative options in application of resources (like, microirrigation, blending or mixed application of techs, site specific management of nutrients, and other quality agrochemicals/products), early season weed control reducing competition from weeds, small scale adoption of farm mechanization, if possible and bringing additional uncultivated /fallow areas, utera or field bunds (pigeonpea planting) etc and last but not the least crop/cropping system intensification (Table 3) could reinforce our efforts in long-term scaling in farm (and farmers') income and stability in production.

For enhancing income through scaling productivity, technological interventions available following research in pulses (through inclusive

Table 3. Popular intercropping systems capable of large scale promotion and adoption

Intercropping systems	States
Soybean+ pigeonpea/urdbean	Madhya Pradesh, Maharashtra
Pearl millet/sorghum + pigeonpea	Karnataka, Andhra Pradesh, Gujarat, Maharashtra
Groundnut + pigeonpea	Gujarat
Groundnut/sorghum/pearl millet + urdbean/ mungbean/ cowpea	Bihar, Maharashtra, Madhya Pradesh, Karnataka, Gujarat, Uttar Pradesh, Rajasthan
Sugarcane + cowpea/mungbean/urdbean	Uttar Pradesh, Maharashtra, Karnataka Andhra Pradesh, Tamil Nadu
Cotton + urdbean/mungbean/cowpea	Punjab, Haryana, Madhya Pradesh, Gujarat, Andhra Pradesh, Maharashtra

breeding, biotechnological and management efforts) offer viable options for scaling existing yields and better stress tolerance (abiotic and biotic). Large scale promotion and adoption of these scientific technologies by farmers needs to be ascertained on regular basis for realizing desired and targeted goals in both production and income**.** Assured availability of quality seed of suitable crop/variety at appropriate time which could be one the major factors for enhancing productivity and farm income from pulses in the country. In this context, certain historic steps like, strengthened breeder seed production (BSP), creation of seed hubs in major pulse producing regions of the country and above all, opening up of new biopesticides and biofertilizercentres aiding in realizing productivity targets, are welcome policy interventions aimed at both increased productivity of pulses as well as enhancing farmers' income. Further, improving farmers' access to the quality seed produced by these hubs remains the key for translating these efforts for income enhancement for farmers.

All these efforts should complement and supplement to policy support which could possibly through linking pulses to welfare schemes (Public Distribution System, Mid Day Meal, Integrated Child Development Services) where pulses could be a part, would address the issues of protein energy malnutrition among the vulnerable population. In an endeavor, the states of Andhra Pradesh, Tamil Nadu, Himachal Pradesh, Punjab and Chhattisgarh have diversified their PDS with inclusion of pulses as a means to curb the nutritional deficiency among the poor. Besides these, building farmers' Associations/ Institutions, post-harvest processing through small scale pulse efficient milling units especially at the village level, Need based support in storage infrastructure, Supporting with MSP and procurement policies, necessary arrangements for scaling up skill development in processing are other key areas needed to be implemented.

Containing the externalities, supporting inputs supply chains and tapping for special niche segment, like Kabuli *chickpea and rajmash* (high value pulses catering to a special market segment) offers new opportunities for tapping the untapped potential of these commodities through demand in international markets. Another little explored area is *organic food production*, and its market *(with premium)*in India which is estimated to grow at 25-30 per cent needs required impetus. Organic pulse production in selected ecologies in India needs to be promoted for harnessing the demand of organic pulses in national as well as international markets for augmenting farm returns further. Both knowledge and skill enhancement of farmers are handy for promotion of organic pulse production.

Thus, we have concrete and definite avenues in reducing cost of production and enhancing income through scaling productivity so as to double the farm income by 2020 and realize self-sufficiency in pulses. With existing resources and infrastructure, achieving the history in production of pulses to the tune of 22.95 million tones during 2016-17 is the cherished milestone in realizing self-sufficiency in pulses sector.

5. Conclusion

With the advent of modern techniques and availability of alien variations, precise and target-oriented research in genetic improvement of pulses has been underway globally towards development of high yielding, input responsive, early maturing, and high nutrition varieties in pulses. This has led to production expansion of major pulses throughout the world. However, this much only is not sufficient to meet the ever increasing demand. Intensified efforts must be initiated not only to increase the area and production of pulses but also to increase nutrient use efficiency, best management practices and nutritional enrichment of pulses.

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Biofortified lentil for nutritional security

Jitendra Kumar, Debjyoti Sen Gupta and Ummed Singh

ICAR-Indian Institute of Pulses Research, Kanpur, Uttar Pradesh-208 024
E-mail: jitendra73@gmail.com

ABSTRACT

The term ‘biofortification’ was coined by Steve Beebe as “a technique to improve the nutritional value of crop plants through genetic selection”. The post ‘BIOCASSAVA program, the ongoing second phase involves lentil bofortification for micronutrients. Genetic biofortification could also be more effective in producing pulses like lentil with high micronutrients concentration. Here in this article we will concentrate on genetic biofortification efforts in lentil with an emphasis on Indian lentil breeding programs.

Keywords: Biofortification, Lentil, Micronutrients, phenotyping

1. Introduction

Mineral nutrients are important to human body for its normal function. It has been shown that more than 20 minerals are required for performing the normal fuction of human body (White and Broadley, 2005. The most important minerals are calcium (Ca), phosphorus (P), sodium (Na), chlorine (Cl), potassium (K), magnesium (Mg), iron (Fe), copper (Cu), cobalt (Co), iodine (I), zinc (Zn), manganese (Mn), molybdenum (Mo), fluoride (Fl), chromium (Cr), selenium (Se), sulphur (S), boron, silicon, arsenic, and nickel (Murray et al., 2000; Eruvbetine, 2003).). It has been shown that deficiency of micronutrients affects more than two billion population worldwide (Welch and Graham, 1999), which is rampant in Sub-Saharan Africa and South Asia. Micronutrient malnutrition is commonly known as “hidden hunger” and causes many health hazards including low birth weight, anemia, learning disabilities, increased morbidity and mortality rates, low work productivity, and high healthcare costs especially in developing nations (Batra and Seth 2002, Welch and Graham 1999). Although deficiency of any of these essential elements can be seen in world population, iron (Fe), zinc (Zn), selenium (Se), and iodine (I) deficiencies are predominant in rural areas of Southeast Asia. Recent estimates indicate that about 60% world population are Fe deficient (Yang *et al.* 2007) and 33% are Zn deficient (Hotz *et al.,* 2004) and 15% are Se deficient (FAOSTAT 2007). Zn deficiency is generally prevalent in areas where soil is generally poor in available form. These areas include India, Pakistan, China, Iran, and Turkey (Hotz *et al.* 2004, Khan *et al.* 2008). Pre-school children, and pregnant woman are mostly affected by Fe and Zn deficiencies due to excessive reliance on cereal-based diets which are low in these essential micronutrients. In India, every year, 330,000 children die due to vitamin A deficiency and 22,000 people, mainly pregnant women, from severe anemia. Besides, 6.6 million children are borne mentally impaired every year due to Iodine deficiency; intellectual capacity is reduced in 15% people due to Iodine deficiency; and 200,000 babies are born every year with neural tube defects due to folic acid deficiency (Kotecha 2008). Development of staple food cultivars with enriched micronutrients is one of the viable options for combating global micronutrient malnutrition (Thavarajah *et al.* 2011).

2. Lentil: A whole food solution to malnutrition

Lentil (*Lens culinaris* subsp. *Culinaris*

Medikus*)* is a cool-season food legume. It is mostly cultivated in warm temperate, subtropical, and tropical regions of 52 countries on 3.6 million ha area with annual production of 3.6 million tons (FAOSTAT, 2011). India is the major lentil producer in the world with 0.9 million tons of production harvested from 1.6 million ha area. Past research in Canada and the United States has shown that lentil is an ideal crop for micronutrient biofortification and it can provide a solution to combat global micronutrient malnutrition (Thavarajah *et al.* 2011). It is rich source of protein and other minerals including iron, zinc, selenium, folates, carotenoids, and vitamins (Thavarajah *et al.* 2011, Johnson *et al.* 2013, Sen Gupta *et al.* 2013). It has been shown that these values of micronutrients in 100 g lentil seeds can provide a minimum of 41 to 113% of the recommended daily allowance (RDA) of Fe, 40-68% of the RDA of Zn and 77-122% of the RDA of Se. Besides lentils have been shown to rich in Beta-carotene and found 2-12 ìg/g in lentils grown in USA. Phytic acid (PA) is an anti-nutrient and high PA levels reduce mineral bioavailability. Lentils are naturally low in PA (2.5-4.4 mg/g) and these levels are lower than the level of PA found in other crops such as rice (1.22-2.23 mg/g), soybean (1.77-4.86 mg/g) , wheat (1.24-2.51 mg/g), maize (3.3-3.7 mg/g) and common bean (0.52-1.38 mg/g). Low PA is a favorable factor to increase lentil mineral bioavailability. These observations clearly show that lentils could be an ideal crop for micronutrient biofortification and a possible whole food solution to the global micronutrient malnutrition (Thavarajah *et al.* 2011).

3. Techniques involved biofortification research

Plant hybridization and generation advancement: Crossing between donor line (high micronutrient concentration) and recipient genotype (low in micronutrient concentration) and development of F_1. The generated true F_1s are advanced to next filial generation progressively.

Phenotyping for micronutrients:

As in any bioforfication research phenotyping for micronutrient concentration are of utmost importance. Phenotyping can be done using Atomic Absorbtion Spectrophotometer (AAS) or inductively coupled plasma-optical emission spectroscopy (ICP-OES). Mineral (Fe, Zn, Cu, Ca, Mg) concentrations in lentil seeds were determined using a previously described modified HNO_3-H_2O_2 method (Alcok *et al.* 1987; Thavarajah *et al.* 2010. Upon complete digestion the tubes were removed from the digestion block, the volume was adjusted to 10 mL, and then filtered (Whatman No. 1 filter papers) using a vacuum system. Mineral concentrations of the filtrates were measured using inductively coupled plasma-optical emission spectroscopy (ICP-OES) or AAS.

Selection of desired plants: Plants will be selected based on the breeding objectives. This cycle of advancement of generation and selection of plants based on phenotyping (as well as geneotyping) data will be repeated until the selected plants derived line become stable.

Multi-location trial and release: Selected lines undergo multiplication and field trials under multi-location trials. Lines with yield superiority as well as high in micronutrient concentration are generally recommended for release and cultivation by the farmers.

4. Role of environmental conditions in development of biofortified cultivars

The soil and environmental conditions such as pH, temperature, radiation, precipitation, organic matter, and soil texture affect the concentration and solubility of micronutrients to plant roots (Tisdale and Nelson 1975; Cakmak 2008; Joshi *et al.* 2010). Therefore knowledge of optimal lentil growing conditions can help to harvest the highest amount of that particular compound during mass cultivation of biofortified crops. Breeding for nutritional traits may also be complicated by environmental conditions, particularly growing locations. Therefore, it is required to have knowledge of environment and genotype × environment interactions in order to develop stable biofortified cultivars or to design location specific breeding of traits in any particular biofortification program. In lentil, accumulation of PA, Fe, and Zn in the seeds are known to vary with weather (rainfall and temperature), location and soil conditions (Thavarajah *et al.* 2009; Thavarajah *et al.* 2010; Thavarajah *et al.* 2015). A few number of studies were conducted to know effects of genotypes, years, locations and their interactions on different nutritional traits in lentil ((Thavarajah *et al.* 2009; Thavarajah *et al.* 2010; Thavarajah *et al.* 2015; Sen Gupta *et al.* 2013; Jha *et al.* 2015). It has been shown that concentration of micronutrients varies from one geographical region to other region when global lentil samples were studied (see Thavarajah *et al.* 2011a). For example, high concentrations of Fe observed in seed sample of Syria (63 mg/kg), Turkey (60 mg/kg), USA (56 mg/kg), and Nepal (50 mg/kg), while it was low in seed samples of Australia (46 mg/kg) and Morocco (42 mg/kg). Similarly higher Zn was found in lentils grown in Syria (36 mg/kg), Turkey (32 mg/kg), and USA (28 mg/kg) and lowest in Australia (18 mg/kg) and Morocco (27 mg/kg). In case of Se a survey showed that genotypes belonging to Nepal and Australia samples have higher Se concentrations (180 and 148 µg/kg, respectively) compared to genotypes pertaining to Syria, Morocco, and Turkey (22, 28, and 47 µg/kg, respectively) (Thavarajah *et al.* 2011a). In another study, Turkish land races showed higher amount of Ca in their seeds (0.48-1.28g/kg), while lentil samples grown in Indian conditions showed richness in Fe (37-156 mg/kg) and Zn (26-65 mg/kg) concentration in their seeds (Karakoy *et al.* 2012; Kumar J unpublished data).

The multi-location testing of varieties/advanced lines of lentil in Bangladesh, Ethiopia, India, Nepal, and Syria showed significant genotype-by-environment (G×E) interaction for Fe and Zn (HarvestPlus 2014). It has been observed that Fe concentration is more sensitive to environmental fluctuations compared to seed Zn concentration. These studies identified few genotypes with stable high-iron and zinc concentrations such as IPL 320 and L4704 in India (HarvestPlus 2014). Kumar et al. (2014b) have also reported that Fe concentration is more sensitive to environmental conditions compared to Zn in a multi-location study. The evaluation of seven lentil genotypes over four locations along with a farmers' field survey conducted in Bangladesh revealed significant genotype and location differences for seed Se concentration but genotype × location interaction was non-significant (Rahman *et al.* 2013). In Australia, similar results were obtained when 12 genotypes were evaluated over seven locations (Rahman *et al.* 2013; Rahman *et al.* 2014). Recently, genotype (G) × environmental (E) interactions for folate concentration in 10 lentil cultivars of USA has been studied over two years, which showed a significant year × location interaction effect on lentil folate concentration (Gupta *et al.* 2013). Similarly the significant G x E interaction was also reported by Jha *et al.* 2015. In another study, the impact of temperature has been shown on PA, Fe and Zn concentration among mature seeds of eleven lentil genotypes. This study was conducted under simulated long term temperature regimes representative of Saskatoon, Canada (decreasing temperatures) and Lucknow, India (increasing temperatures). In this study, PA and Zn concentrations in lentil seeds have been observed significantly higher in the rising temperature regime (8.8 mg/g and 69 mg/kg, respectively) than in the decreasing temperature regime (6.7 mg/g and 61 mg/kg, respectively). Fe concentrations followed the same trend (116 vs. 113 mg/kg). Therefore, if the lentil cultivars with lower concentration of PA needed to be developed, the cooler temperatures of temperate summers might be an important factor. In other crop, like wheat, breeding for high Zn concentration is complicated by environmental conditions, particularly soil composition (Trethowan 2007). Overall, most of studies suggested that micronutrient concentrations of the grain or seed are largely influenced by the genetic and environmental factors. Hence further studies should be conducted under different environmental conditions for validating the results. Moreover, nutritional traits such as folate, Se and Zn which are highly influenced by conditions of local environments, location specific biofortified cultivars can be developed by utilizing the genetic variability for these traits (Gupta *et al.* 2013). This becomes more important under the changing climatic conditions where increase in winter temperature patterns can facilitate the increase of concentration of anti-nutrients such as PA. Therefore success in global hidden hunger will depend upon the genetic biofortification to develop cultivars having high concentration of Fe and Zn and low level of anti-nutrients.

5. Current status of biofortified lentil breeding worldwide

In 2004, the HarvestPlus Challenge Program was officially founded by the Bill and Melinda Gates Foundation and other donors. In 2012 HarvestPlus became component of the CGIAR Research Program on Agriculture for Nutrition and Health (A4NH). Hence, lentil landraces have been shown a potential genetic resource for biofortification. Initiative has been taken by the Con-sultative Group on International Agricultural Research (CGIAR) through HarvestPlus Challenge Program on development of biofortified lentils that are rich with iron, zinc, and provitamin A (Hotz and McClafferty 2007). During second phase of HarvestPlus program, International Center for Agricultural Research in the Dry Areas (ICARDA) took lead for developing the biofortified lentils. This program has focused to develop the high yielding lentil cultivars with high concentration of Fe and Zn. Initially, efforts had been made to identify the biofortified varieties in lentil through screening of existing released varieties. In this direction, released varieties of different countries (i.e. Bangladesh, Ethiopia, Nepal, Morocco, Turkey, Syria, Lesotho and Portugal) were screened for Fe and Zn concentration under this program. As a result, number of released varieties has been found to possess high iron and zinc concentrations along with good agronomic performance. These varieties or cultivars were in fast-tracking and has been being used as biofortified varieties of lentil for economically poor regions of the world. Also, these varieties are being disseminated to farmers on a fast track mode through national programs. For example, in Bangladesh, the Government has taken a massive dissemination program to promote promising lentil varieties (Barimasur 5 and Barimasur 6) having high Fe and Zn. Similarly in Nepal lentil varieties such as Khajurah1, Khajurah 2, Sishir and Shital are spreading fast in the Terai region of Nepal. In India, the variety Pusa Vaibhav rich in Fe is being grown by farmers in its North-west plain zone (ICARDA 2012). In future, more biofortified varieties of lentil would be released for general cultivation in different countries. For example, in Nepal, variety ILL 7723 has been recommended by the National Variety Release Committee and can be released for farmers' cultivation (HarvestPlus 2014). In Indian Institute of Pulses Research (IIPR), one lentil variety, IPL 220 has been identified for release which is rich in iron and zinc.

6. Conclusion

This chemical composition of lentil seeds indicates that lentils contain balance amount of proteins, high quality carbohydrates, macro and micro nutrients, vitamins and fibers. The chemical properties of lentil grains have been described earlier under different sections. In summary, lentils are a good source of both soluble and insoluble firbers, rich in vitamin B-complex, iron, zinc and selenium. Richness of lentils with zinc prevent stunting and impaired physical and mental growth of pre-school children. Daily consumption of lentils can meet almost

90% of the folic acid requirement per day. Lentils are skin friendly, especially in powder form for scrubbing and cleaning. In some parts of Indian sub-continent, powered lentil is used instead of soap, especially for young children. Therefore, it is complete meal in itself and is suitable for use as a whole food. The consumption of lentils can help to overcome the problem of global malnutrition among poor populations. Now lentils have been gaining increasing attention for health benefits as human diet, and are considered to be an excellent source of dietary antioxidants largely due to their high level of bioactive phytochemicals. Also in developed western countries, where lentils are consumed less, it has been highly recommended to diversify food by to incorporating lentil in diet. Therefore, attentions have been paid on development of biofortified lentil and in future biofortified lentil may be released for cultivation in India for combating the mal-nutritional problem among poor people.

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Zinc in food and nutrition security

Soumitra Das[1] and Andrew Green[2]

[1]Zinc Nutrient Initiative, International Zinc Association, New Delhi, India, and
[2]Zinc Nutrient Initiative, International Zinc Association, Durham, North Carolina, USA
E-mail: sdas@zinc.org

ABSTRACT

Zinc has emerged as the most widespread micronutrient deficiency in soils and crops worldwide, resulting in severe yield losses and deterioration in nutritional quality, adversely impacting human health. Almost half of the soils in the world are deficient in zinc. India is not an exception. About 40 per cent soil samples analysed for available zinc were found deficient in India.There is a high degree of correlation between zinc deficiency in soils and that in human beings. About one-third of the world's population suffers from zinc deficiency. To replenish the zinc taken up by the crops and to enrich the grains and edible parts with zinc, higher and sustainable use of zinc containing fertilizers is inevitable.However, zinc use efficiency is abysmally low and generally it does not exceed 2-5% in crops, which continues to be a challenge.Innovative and futuristic products like Nano-zinc fertilizers have potential in enhancing the nutrient use efficiency. Efforts should be made to explore and develop such innovative products through further research and development, so that the farmers, the ultimate beneficiary, get the maximum benefit out of such innovative fertilizer products. The paper describes the role of zinc in food and nutrition security and highlights the next generation zinc fertilizers to enhance the zinc nutrient use efficiency.

Keywords: Food security, nutritional security, zinc fertilizer, zinc nanoparticles, zinc use efficiency

1. Introduction

Zinc is one of the 17 essential elements necessary for the normal growth and development of plants. It is among eight micronutrients essential for plants. Zinc plays a key role in plants as a structural constituent or regulatory co-factor of a wide range of different enzymes and proteins in many important biochemical pathways. These are mainly concerned with carbohydrate metabolism, both in photosynthesis and in the conversion of sugars to starch, protein metabolism, auxin (growth regulator) metabolism, pollen formation, maintenance of the integrity of biological membranes and resistance to infection by certain pathogens.

Zinc deficiency in plants retards photosynthesis and nitrogen metabolism, reduces flowering and fruit development, prolongs growth periods, resulting in delayed maturity, results in lower yield and poor produce quality and, results in sub-optimal nutrient-use efficiency. Some of the common deficiency symptoms of zinc in plants are, light green, yellow or bleached spots in interveinal areas of older leaves, the emerging leaves are smaller in size and often termed as "little leaf", the internodal distance in case of severe deficiency becomes so short that all the leaves appear to come out from the same point, termed as "rosetting".

2. Zinc in Soils

Zinc has emerged as the most widespread micronutrient deficiency in soils and crops worldwide, resulting in severe yield losses and deterioration in nutritional quality. It is estimated that almost half of the soils in the world are deficient in zinc. Since cereal grains have inherently low concentrations, growing these on the potentially zinc deficient soils further decreases grain zinc concentration.

India is not an exception. About 40 per cent soil samples analysed for available zinc were found deficient in India (Fig.1). There is a significant response to applied zinc in the soils deficient in zinc. In India, zinc is considered the fifth most important yield limiting nutrient after N, P, K & S in upland crops, whereas in lowland crops like rice, it is next to N.

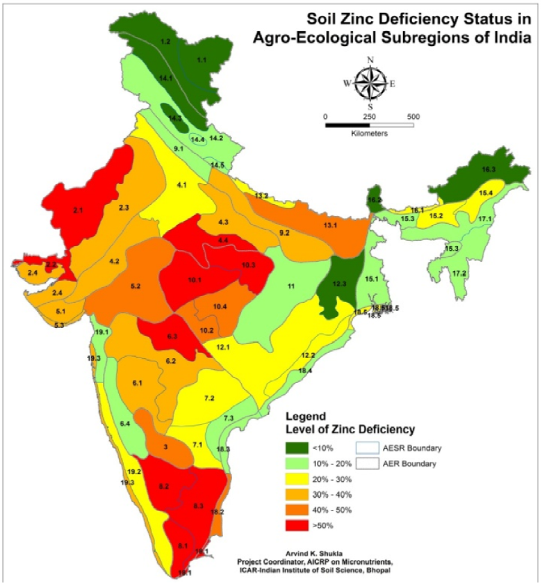

Fig.1 Soil zinc deficiency status in India (Shukla and Tiwari, 2016)

The reasons responsible for the increase of incidences of zinc deficiency include large zinc removals due to high crop yields and intensive cropping systems, lesser application of organic manures, use of high analysis fertilizers, and increased use of phosphatic fertilizers resulting in P induced zinc deficiency and the use of poor quality irrigation water.

3. Critical Level of Zinc

The critical level of zinc in soils in India is considered as 0.6 ppm. However, there is a growing concern that it should be increased to 1.2 ppm or higher. In that case, the level of zinc deficiency would be escalated to higher deficiency level than what is being reported today.

At present, about 40% soils in India are classified as Zn deficient, on the basis of the existing critical limit of Zn (0.6 mg Zn kg^{-1} soil). However, crop response to applied Zn has been observed in soils above the critical limit also. Therefore, it is generally believed that critical level of Zn is site specific and one critical limit may not represent every soil type or crop.

It could be observed from the results presented in Table 1that depending upon the soil types and crops grown, the critical limit of Zn ranged widely, with as high as 1.24 mg Zn kg^{-1} in soybean crop inUttarakhand state.

Table 1 Refined critical limit of Zn for some soils and crops at different locations

S.No.	Location	Crop	Zn (mg kg^{-1})	
			Soil	Plant
1	Akola, Maharashtra	Soybean	0.65	24.3
2	Coimbatore. Tamil Nadu	Maize	0.90	24.8
3	Pantnagar, Uttarakhand	Lentil	1.20	9.6
4	Pantnagar, Uttarakhand	Chickpea	1.20	19.2
5	Nainital, Uttarakhand	Soybean	1.24	22.3

(Shukla and Tiwari 2016)

4. Zinc in Human Health

Zinc is an essential nutrient for human health. There is no life without zinc. Recently, zinc deficiency-especially in infants and young children under five years of age - has received global attention. Zinc deficiency is the fifth leading cause of death and disease in the developing world. According to the World Health Organization (WHO), about 800,000 people die annually due to zinc deficiency, of which 450,000 are children under the age of five.

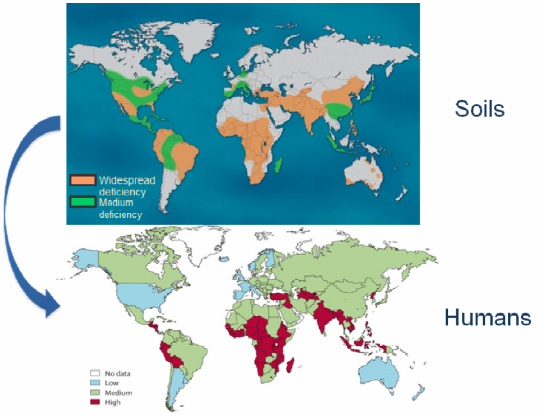

Fig. 2. Worldwide zinc deficiency in soils and humans (Alloway 2008)

It is estimated that 60-70% of the population in Asia and Sub-Saharan Africa could be at risk of low zinc intake, in absolute numbers, this translates into about 2 billion people in Asia and 400 million people in Sub-Saharan Africa (Prasad 2006). There is a high degree of correlation between zinc deficiency in soils and that in human beings (Fig.2). It is estimated that about one-third of the world's population suffers from zinc deficiency.

Zinc is vital for many biological functions in the human body. The adult body contains 2-3 grams of zinc. It is present in all parts of the body, including: organs, tissues, bones, fluids and cells. It is vital for more than 300 enzymes in the human body, activating growth - height, weight and bone development, growth and cell division, immune system, fertility, taste, smell and appetite, skin, hair and nails and vision.

Some of the reported symptoms due to zinc deficiency in humans, especially in infants and young children, are diarrhoea, pneumonia, stunted growth, weak immune system, retarded mental growth and dwarfism, impaired cognitive function, behavioural problems, memory impairment, problems with spatial learning, and neuronal atrophy.

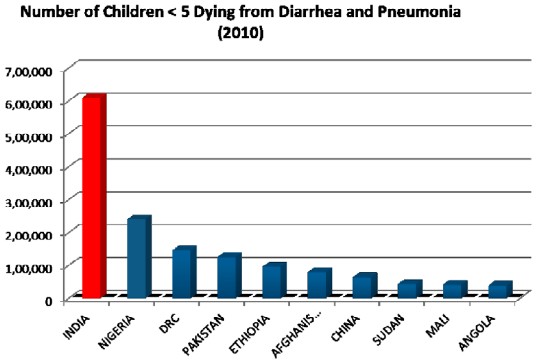

Fig. 3. Deaths from diarrhea and pneumonia in children under 5 (UNICEF 2012)

The widespread zinc deficiency has led to zinc malnutrition in the humans, especially in the developing nations, like India. The country-wise deaths from diarrhoea and pneumonia in children under five depicts that the casualty due to zinc deficiency in India is alarmingly high, even higher than the Sub-Saharan African countries or the neighbouring countries (Fig. 3). This has drawn the attention of the government and policy makers in India and generated the awareness on the critical role of zinc in human health.

5. Zinc Malnutrition - Possible Solution

The possible solution to the zinc malnutrition in the humans may be i) Food supplementation, ii) Food fortification or iii) Biofortification. The former two programmes require infrastructure, purchasing power, access to market and healthcare centres and uninterrupted funding, which have their own constraints. In addition, such programmes will most likely reach the urban population, which is easily accessible, especially in the developing countries. Alternatively, the latter programme, Biofortification - fortification of crops especially food crops with zinc - is the best option for alleviating zinc deficiency. It will cater to both the rural and urban populations. It could be achieved through two approaches, Genetic biofortification and Agronomic biofortification.

There is a developing field of research on the biofortification of plant foods with zinc. This involves both the breeding of new varieties of crops with the genetic potential to accumulate a high density of zinc in cereal grains (genetic biofortification) and the use of zinc fertilizers to increase zinc density (agronomic biofortification). Although the plant breeding route is likely to be the most cost effective approach in the long run, the use of fertilizers is the fastest route to improve the zinc density in diets. In order to replenish the zinc taken up by the improved cultivars, higher and sustainable use of fertilizers is inevitable (Das and Green 2016).

Ideally, the cereal grains should contain 40 – 60 mg/kg zinc, whereas, it is only 10 – 30 mg/kg zinc (Cakmak 2008). This needs to be rectified on an urgent basis.

6. Crop Response to Zinc Fertilizers

Crop response to zinc has been observed in all crops under almost all types of soils and agro-climatic conditions. While the response was found to be higher in grain crops like rice, fruit and vegetable crops also responded well to applied zinc. Extent of crop response depends on the status of zinc in that soil. Higher the zinc deficiency in soils, higher the crop response would be to applied zinc. Based on over 15,000 on-station field trials conducted all over India, the overall range of crop response to zinc was of the following scale (Singh 2008):

- Cereals: 420 – 550 kg ha^{-1} (15.7 – 23.0 %)
- Pulses: 170 – 460 kg ha^{-1} (7.3 – 28.2 %)
- Oilseeds: 110 – 360 kg ha^{-1} (11.4 – 40.0 %)
- Fodders: 90 – 4620 kg ha^{-1} (5.0 – 34.0 %)

The response of pulses to soil applied Zn in 28 field trials conducted in different soils of Bihar showed that the response range varied from 33 to 860 kg ha^{-1} in lentil and chickpea, whereas the average response was from 50 to 450 kg ha^{-1} in green gram and peas, respectively (Table 2).

Zinc biofortification trials conducted at Kanpur on pigeon pea during kharif 2009–2010 revealed that application of Zn enhanced the pigeon pea grain yield by 13 % over no Zn. In Bhopal, the increase in yield was 22 % with soil Zn application, whereas it was 64 % with soil + foliar Zn application (Table 3).

Field experiments on rice and wheat in India showed that application of zinc-enriched urea (up to 3% Zn) significantly enhanced both grain Zn concentration and grain yield in rice and wheat

Table 2 Response of pulses to Zn application on farmers' fields

Crop	No. of field trials	Response range (kg ha^{-1})	Average response (kg ha^{-1})
Chickpea	9	130 – 860	390
Peas	2	180 – 710	450
Greengram	1	50	50
Blackgram	6	100 – 520	330
Lentil	9	33 – 440	240
Boad bean	1	250	250

(Singh *et al.* 2011)

Table 3 Effect of Zn biofortification strategies on grain and zinc concentration in different cultivars of pigeonpea at Kanpur and Bhopal

Cultivar	Grain yield (t ha^{-1})		Zinc concentration (mg kg^{-1})	
	-Zn	+Zn	-Zn	+Zn
		Kanpur		
LRG 38	1.90	2.00	49.0	63.0
JKM 7	1.80	1.90	43.0	66.0
BSMR 736	1.80	1.90	22.0	34.0
Pusa 9	2.40	2.60	18.0	23.0
		Bhopal		
ICPL 87119	1.84	1.99	27.8	41.8
T 15-15	1.46	1.55	32.3	44.6
VirsaArhar 1	1.53	1.76	32.8	38.7

(Shukla and Tiwari 2014)

(Shivay *et al.* 2008).

7. Zinc Use Efficiency

To replenish the zinc taken up by the crops and to enrich the grains and edible parts with zinc, Zn fertilizers, such as zinc sulphates (hepta and mono hydrates), Zn-EDTA, fortified fertilizers, customized fertilizers, micronutrient mixtures, etc. are being used. However, the zinc use efficiency is abysmally low and does not exceed 2-5% in crops, which continues to be a challenge.

Application of Nano technology in developing new innovative products like Zn-nanoparticles is the need of the hour. It may also address the so called antagonistic effect of Zn with P. Nanoscale or nanostructured materials as fertilizer carrier or controlled-release products for building of the so-called 'smart fertilizers' can enhance the nutrient use. Nano-fertilizers can precisely release their active ingredients in responding to environmental and biological demands.

However, the uptake, translocation, and fate of Nano-particles in plant system are largely unknown resulting in the rise of various ethical and safety issues surrounding the use of Nano-fertilizers in plant productivity. A systematic and thorough quantitative analysis regarding the potential health impacts, environmental clearance, and safe disposal of Nano-materials can lead to improvements in designing applications of Nano-fertilizers (Rai *et al.* 2015).

8. Soil-Plant-Animal-Human Continuum

Analysis of Zn content in soil, crop, animal and human blood serum established a strong relationship and interdependence among soil-plant-animal-human continuum, as depicted in Table 4.

Table 4 Soil Zn status vs Zn content in crops and its effect on serum Zn level in human blood

Location	Zn level in soil	No. of people tested	Mean Zn status (ppm)			
			Soil	Plant	Blood Serum	
					Men	Women
Ranga Reddy (Andhra Pradesh)	Deficient	18	0.37	18.2	0.49	0.52
	Sufficient	44	0.69	26.7	0.55	0.65
East Godavary (Andhra Pradesh)	Deficient	16	0.45	13.6	0.84	0.97
	Sufficient	44	1.12	25.9	1.08	1.06

(Singh *et al.* 2009)

Table 5 Yield increase and benefit-to-cost ratio on some key crops in India

S.No.	Crop	Zn rate (kg ha^{-1})	Yield increase (kg ha^{-1})	Value of increase (Rs)	Benefit : Cost Ratio
1	Wheat	5.25	1430	20,735	24:1
2	Rice	8.40	1102	14,987	11:1
3	Maize	6.30	1521	19,925	19:1
4	Chickpea	10.00	855	32,063	18:1
5	Lentil	2.62	440	16,500	38:1
6	Groundnut	5.50	690	25,875	28:1
7	Mustard	6.30	230	8,625	8:1
8	Cotton	5.60	430	16,125	17:1

(Data source: Rattan *et al.* 2008)

9. Economics of Zinc Fertilizer Use

Many reports are available showing significant cost-benefit effects of zinc fertilizers for resource-poor farmers, especially in regions where soil zinc deficiency is of particular concern. Table 5 shows that the benefit-to-cost ratio was as high as 38:1 for lentil farming, revealing that zinc application was remunerative to the farmers.

10. Challenges and Way Forward

The key challenges in promoting zinc in balanced fertilizer 1) Development of new and innovative zinc fertilizer products for higher use efficiency, e.g.,Nano zinc fertilizers, 2) Generating site specific database on 'Soil – plant – animal – human continuum study on zinc'(a multidisciplinary approach), 3) Quality of zinc fertilizers available in the market, 4) Availability of zinc fertilizers at the time of need of the farmers, 5) Awareness of the extension and promotional workers, and, 6) Last mile delivery - awareness of the farmers. And above all, a supportive and conducive policy environment from the government is needed for encouraging the balanced fertilizer use by the farmers in India.

11. Conclusions

Zinc deficiency in crops and humans is a critical issue and a global challenge. The sustainable solution is to increase use of zinc in balanced fertilizer use, so that the soil health as well as food and nutrition security are ensured. At present, the zinc use efficiency is very low, which does not exceed 2-5 %. Next generation fertilizers like nano zinc fertilizers have potential in enhancing the nutrient use efficiency. Efforts should be made to explore and develop such products through further research and development, so that the farmers, the ultimate beneficiary, get the maximum benefit out of such innovative fertilizer products.

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Scaling conservation agriculture based resource conservation technologies with special emphasis to higher nutrient use efficiency

U P Singh

Banaras Hindu University, Varanasi, Uttar Pradesh, India-221005
E-mail: udaipratap.singh1@gmail.com

ABSTRACT

Conservation Agriculture (CA) based systems involves minimum soil disturbance, need based residue retention/organic soil cover and sensible diversified crop diversification. CA based resource conservation technologies (RCTs) is helpful in improving the nutrient use efficiency and biological processes of the soil for better soli health. RCTs facilitate the precise nutrient management opportunity and site specific nutrient management option for higher sustainable profitability and productivity of the crop. Crop residue of diversified crops in combination with minimum soil disturbance through CA based RCT options helps in biological nitrogen fixation of nutrient which ultimately favors the availability of required nutrients to plant in available form.

Keywords: Conservation agriculture, RCTs, Nutrient use efficiency, Soil health

1. Introduction

The Indogangetic plain of India is about 13% of geographical coverage and produces around 50% of food grain for 40% of total population in India. Soil which earlier shows rarely single nutrient deficiency symptom now deficient in many nutritional elements. Long term fertility studies have shown reduction in soil organic matter content, particularly in soil that have higher level of soil organic matter earlier (Abrol and Gupta, 1998). Farmer generally apply too much nitrogen, little P and K that result in sudden outbreak of pest and diseases beside lodging, It is major cause of yield reduction and poor grain quality due to lodging and it also lead to N leaching into water sources that get polluted over time. To meet the growing need for fertilizers due to the rise in food requirement for ever multiplying population on the one hand and an increasing environmental and atmospheric pollution on the other, improving nutrient-use efficiency (NUE) appears to be a viable solution.

CA systems of production has proper approach to soil system management and sustainable system intensification, which depend on three key principal- minimum soil disturbance, residue retention and diversified crop rotations. These three principles ensures conservationists and farming community for better maintenance of natural resource base and enhancement of quality of environment for longer period . CA comprising minimum mechanical soil disturbance, organic mulch cover, and crop species diversification, is now practiced globally on all continents and all agricultural ecologies, including in the various temperate environments (Derpsch and Friedrich 2009, and Kassam *et al.* 2010).

2. CA based Resource conservation technologies

Resource conservation technology is broad term that refers to any management approach or technology that increases factor productivity including land, labour, capital and inputs. RCTs includes wide range of practices no till/minimum tillage, surface seeding, skip furrow irrigation ,intercropping ,water harvesting and supplemental irrigation, mulching and residue management live fences and vegetative barriers. All the RCTs may not be computable with CA.(e.g. land leveling in presence of residue) Conservation Agriculture (CA) involves integration of minimal soil disturbance, residue retention and sensible/profitable cropping /farming system. Zero till is one of the feasible option among the resource conserving technologies (RCTs) for advancing the wheat sowing. Direct seeded rice (DSR), unpuddled transplanted rice (UTR), surface seeding (SS) and raised bed planting system (BP) are the other CA based RCTs options to optimize the natural resources and inputs for the sustainability of RW cropping system and crop diversification in the eastern region.

3. Role of RCTs for improving nutrient-use efficiency

Considering the deterioration of water and air quality due to excessive chemical /fertilizer use for fulfilling the increasing demand of food, fiber and fuel, improvement in nutrient use efficiency (NUE), is an essential goal for current agriculture. For sensible nutrient management, the best way is to apply nutrients from the right nutrient source, at the right rate, in the right place, and at the right time. Four Rights (4Rs) which can facilitate appropriate nutrient management practice for improved and resource use efficient crop production systems (Kinsey and Walters, 2006). Certain resource conserving technologies, such as laser land levelling, zero or minimum tillage, direct seeding, permanent or semi-permanent residue cover, furrow irrigated raised bed (FIRB) technology, direct seeded rice (DSR), precision farming techniques, use of leaf color chart (LCC), chlorophyll meter, Rice Wheat Crop Manager (RWCM), Green Seeker (GS), site specific nutrient management (SSNM), brown manuring and new varieties etc that use plant nutrients more efficiently, have shown to increase crop yields as well as NUE. For example, the use of optical sensors like Green Seeker, chlorophyll meter and FIRB saved 25–50 % N. Even laser levelling has been reported to increase NUE by 6–7 % in India. Hence the use of rational CA based resource conserving technologies should be facilitated and supported for the sustainability of agricultural production and the natural resource base.

4. Approaches for higher NUE

4.1 Zero tillage

Zero till system refers to planting crops with minimum of soil disturbance. In this, seed are placed directly into narrow slits 2-3 cm wide and 4-7 am deep made with a drill fitted with chisel, “inverted T” or double disc openers without land preparation. It provides opportunity for side placement of nutrients to the seed which ultimately helps in enhancement of nutrient use efficiency and avoideing nutrient losses. It has been found that zero-till technology benefited the eastern farmers more in terms of higher productivity gains and larger reductions in cost of cultivation. It is for this reason the resource poor, small and marginal farmers of the eastern Gangetic plains have begun adopting resource conserving technologies now. It was observed that benefits of zero till technology can be further improved by introducing paired-row planting, controlled traffic, single basal deep placement of N (80% of recommended dose and balance 20% on need base) using Leaf color charts (LCC), and leaving some crop residues to cover the soil surface. (Singh *et al.* 2009)

4.2 Furrow Irrigated Raised Bed (FIRB) Planting

Furrow Irrigated Raised Bed (FIRB) planting provides opportunity to promote crop diversification, it also saves irrigation water by 25-35%, saves fertilizer and seed rate up to 25%. It facilitates easy and appropriate nutrient placement in soil and reduces the loss occurred by immobilization in the soil hence improve the NUE and reduce the quality of fertilizer required. It also helps in decreasing weed infestation and drainage of excess water. Bed planting system has promoted crop diversification through mungbean, pigeon pea and vegetable and development of more innovative cropping systems (eg. Sugarcane + wheat/chickpea/ Indian mustard in north-west; and Rice – potato/ winter maize/boro rice in eastern Gangetic plains) (Singh *et al.,* 2005)

4.3 Site Specific Nutrient Management

Site-specific nutrient management (SSNM) is the dynamic, field-specific management of nutrients in a particular cropping season to optimize the supply and demand of nutrients according to their differences in cycling through soil-plant systems." Aims of SSNM are provide a locally-adapted nutrient best management practice tailored to the field- and season-specific needs for a crop, increase in yield, high efficiency of fertilizer use, improve profitability, improve marketable crop quality, reduce input costs and improve environmental balance (Gill *et al.* 2010).

4.4 Rice Wheat Crop Manager (RWCM)

Rice–Wheat Crop Manager (RWCM) is a decision support system tool developed by International Rice Research Institute (IRRI) for SSNM. It is a plant based SSNM approach which is dynamic, farm-specific management of nutrients in a particular crop or cropping system to optimize the supply and demand of nutrients according to their need for higher NUE. In this approach, nutrients are applied as per RWCM recommendation with the appropriate amount and need based timing as per need of the crop variety, soil, soil condition, cropping history. It has been observed that it save the substantial quantity of the fertilizer and increase the yield.

4.5 Green Seeker (GS)

It is crop sensing based system tool which helps in effective and precise management of nutrient. With green seeker we can apply nutrient in field at right time, in right place and in right amount which ensure the location specific management of nutrients in a particular crop.

4.6 Leaf Color Chart (LCC)

Optimal N supply matching with the actual crop demand is thus vital for improving crop growth and maximizing production. Among the various strategies available for N management, leaf colour chart (LCC) for real-time N management in rice is a simple, easy and inexpensive option. Shukla *et al.* (2004) reported LCC3 as the critical shade for applying fertilizer N to DSR in north western India. Critical value for transplanted rice is reported to 4. It is a cheap and simple tool in which every 7 to 10 days interval field is monitored and fertilizer is applied @23 kg N/ha(50 kg urea /ha) when more than 6 leafs out of 10 shows below the critical value. Leaf color charts saved 13 – 17% N and farmers are adopting this practice.

4.7 Laser Land Leveling

It is a precursor of CA based RCTs and a process of smothering land surface from its average elevation using laser equipped dragged buckets. It leveled the surface having 0 to 0.2 % slope so that there is uniform distribution of water may takes place and thus enhances resource use efficiency. Advantages of laser land leveling is uniform distribution, increases resource (Nutrient and water) use efficiency, reduces cost of production and enhances productivity

4.8 Brown manuring

If green manure legume is grown as a intercrop with rice, is saves irrigation water .green manure crop of legumes like sunhemp, cowpea at 20-25 DAS can be killed by herbicide such as 2,4-D without adverse effect on rice but do not use broad spectrum herbicide they may kill young rice seedling. It controlled weeds, Create surface mulch and fixed atmospheric nitrogen and ultimately improve the nutrient use efficiency in DSR rice establishment systems.

4.9 Control release fertilizer

Control release fertilizer are available that have an ultra thin membrane polymer coating that encapsulate the urea granule. The release of nutrients through this polymer membrane occurs in predictable manner. It also provide opportunity for placement of fertilizer with seed and it contributed in improving NUE by reducing losses occurred by leaching and volalization.(Shoji and Kanno, 1994).

4.10 Chlorophyll meter (SPAD)

The chlorophyll meter is a non destructive and reliable tool to quickly determine N between chlorophyll content and leaf N status and this helps to determine right time application of N in rice and wheat (Peng *et al.* 1996)

4.11 Fertigation

In micro-irrigation, fertilizers can be applied through the system with the irrigation water directly to the region where the plants roots develop. This process is called fertigation and it is done with the aid of special fertilizer injectors installed at the head control unit of the system, before the filter. The element most commonly applied is nitrogen directly in root zone of the plant and results in less need of fertilizers and maintain the higher NUE.

5. Climate regulation

Reduction in net emissions of N_2O and CH_4 from soils has been observed as a result of CA based resource conservation practices. It is also important to note that there can be considerable impacts of CA compared to conventional agriculture with changes in the intensity of mechanical tillage, which ultimately leads to less irrigation, and possibly less N fertilization and the associated reduced use of fossil fuels with CA. (FAO, 2008).

6. Soil Health and Conservation Agriculture

CA system are basically concern with in soil health and function which should be managed by the farmers with a long-term perspective, and the evolving nutrient management practice should respond to the changing nutrient needs of the soil and cropping system as a whole. Soil health is the capacity of soil to function as a living system, with ecosystem and land use boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and promote plant and animal health. (Chaboussou, 2004) CA system focuses on interaction of the soil organic matter and crop yield significantly. Enhancement in nutrient availability in soil can be achieved by maintaining proper organic matter on soil surface throughout the growth period of the crop. Healthy soil reduces the cost incurred on the nutrient (Habte, 2006). CA systems maintains higher levels of biomass production in crop rotation to develop and maintain an adequate mulch cover, soil organic matter, soil biodiversity and their functions, to raise moisture and nutrient availability capacities, to enhance nutrient supplies, to enrich the soil with nitrogen in the case of legumes, and to protect the soil surface.

7. Conclusion

Conservation Agriculture involves integration of minimal soil disturbance, residue retention and sensible cropping/farming system. Zero tilled sowing, unpuddled transplanted rice, surface seeding, raised bed planting system, laser leveling, RWCM, LCC, SSNM, green seeker, brown manuring are some efficient techniques used to optimize the natural resources and inputs for the sustainability of cropping systems, crop biodiversity, soil health and nutritional security. To sustain soil physical, chemical & biological properties and to enhance the nutrient status of the soil, CA based RCTs can be an efficient tool. Conservation based RCTs options through minimum tillage, residue retention and crop diversification is a potential way for enhancing NUE, organic carbon, biological activity and soil health to sustaining productivity and profitability for future.

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DIVISION OF CROP PRODUCTION
ICAR-Indian Institute of Pulses Research
Kanpur, Uttar Pradesh-208 024

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Contact details of Course Director and coordinators

Organisers	Photo
Course Director **Dr Ummed Singh** Senior Scientist (Agronomy) Division of Crop Production ICAR-Indian Institute of Pulses Research, Kanpur, Uttar Pradesh-208 024 Phone: 2580994/95 (Ext. 3016) Mobile: +91-8765860963; +91-8953709779 Email: Ummed.Singh@icar.gov.in singhummed@yahoo.co.in drummedsingh@gmail.com	
Course Coordinator **Dr C. S. Praharaj ARS, FISA** Principal Scientist (Agronomy) & Head Division of Crop Production ICAR-Indian Institute of Pulses Research, Kanpur, Uttar Pradesh-208 024 Mobile: +91-8601262840 Office: +91-512-2580994/95 (Ext. 3008) E-mail: cspraharaj@icar.org.in cspraharaj@gmail.com	
Course Coordinator **Dr Narendra Kumar** Principal Scientist (Agronomy) Division of Crop Production ICAR-Indian Institute of Pulses Research, Kanpur, Uttar Pradesh-208 024 Mobile: +91-9695241110 Office: +91-512-2580994/95 (Ext. 3006) E-mail: narendra.kumar1@icar.org.in nkumar.icar@gmail.com	

DIVISION OF CROP PRODUCTION
ICAR-Indian Institute of Pulses Research
Kanpur, Uttar Pradesh-208 024

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Participants

S.No.	Name and address of participant	E-mail and contact no.	Photo
1.	DR ARVIND KUMAR SINGH Junior Scientist-cum-Asstt. Professor (Agronomy) Department of Agronomy,Faculty of Agriculture, Birsa Agricultural University, Kanke, Ranchi, Jharkhand-834006	E-mail: aksbau@gmail.com Mob: 9431315705	
2.	DR AMRIT TAMANG Assistant Professor (Soil Science) Department of Soil Science and Agricultural Chemistry, Faculty of Agriculture, Uttar Banga Krishi Viswavidyalaya, Pundibari, Cooch Behar-736165, West Bengal	E-mail: tamang_amrit@rediffmail.com Mob: 8100906370; 9083918775	
3.	DR RAJESH KUMAR SHIVRAN Assistant Professor (Agronomy) Agriculture University, Borkhera, Baran Road, Kota, Rajasthan-324001	E-mail: rshivranars2007@gmail.com Mob: 9414927819	
4.	DR. ANIL KUMAR DHAKA Assistant Professor (Agronomy) Department of Agronomy, College of Agriculture, CCS Haryana Agriculture University, Hisar, Haryana-125004	E-mail: dhakaanilkumar@yahoo.in Mob: 9416074166	
5.	DR. BISWAJIT SARKAR Subject Matter Specialist (Agronomy) Howrah Krishi Vigyan Kendra (BCKV), Vill+P.O-Jagatballavpur, Dist.-Howrah, West Bengal-711408	E-mail: biswajitkvk@gmail.com Mob: 9434600586	

S.No.	Name and address of participant	E-mail and contact no.	Photo
6.	DR. MD PARWAIZ ALAM Assistant Professor (Agronomy) Department of Agronomy, Ranchi Agricultural College, Birsa Agricultural University, Kanke, Ranchi, Jharkhand-834006	E-mail: prwzalam66@gmail.com Mob: 9431325365	
7.	DR. SHYAMAL KHEROAR Assistant Professor (Agronomy) AINP on Jute & Allied Fibres, Uttar Banga Krishi Viswavidyalaya, Pundibari, Cooch Behar, West Bengal-736165	E-mail: kheroarshyamal@gmail.com Mob: 9932981948	
8.	DR. CHANDRA SHEKHAR SINGH Jr. Scientist-cum-Asstt. Professor (Agronomy), Department of Agronomy, Birsa Agricultural University, Kanke, Ranchi, Jharkhand-834006	E-mail: cssingh15@gmail.com Mob: 9431314755	
9.	MR. BINOD KALITA Scientist (Agronomy) RARS, Assam Agricultural University, Telipra, Gossaigaon, Kokrajhar, Assam-783360	E-mail: binod_kalita05@rediff.com Mob: 9435169659	
10.	DR. KARMAL SINGH Assistant Professor (Agronomy) Cotton section, Department of Genetics and Plant Breeding ,CCS Haryana Agriculture University, Hisar, Haryana-125004	E-mail: karmalsingh@gmail.com Mob: 9812700110	
11.	DR. PARTHA SARATHI PATRA Assistant Professor (Agronomy) Uttar Banga Krishi Viswavidyalaya, Pundibari, Cooch Behar, West Bengal-736165	E-mail: parthaagro@gmail.com Mob: 9933347123	

S.No.	Name and address of participant	E-mail and contact no.	Photo
12.	DR. SANDEEP SEVAKRAM HADOLE Assistant Professor (Soil Science) Division of Soil Science and Agril Chemistry, College of Agriculture, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola, Maharashtra-444104	E-mail: hadolesandeep@yahoo.com Mob: 9921400399	
13.	DR. AVINASH KESHAV KOLAGE Assistant Professor (Agronomy) Mahatma Phule Krishi Vidyapeeth (MPKV), Rahuri, Maharashtra-	E-mail: avikolage@gmail.com Mob: 09881329539; Office:02426233449	
14.	MR BAJRANG LAL OLA SMS (Agronomy) Directorate of Rapeseed & Mustard Research-Krishi Vigyan Kendra, Bansur, Alwar-II, Rajasthan-301 402	E-mail: bajrangola@gmail.com Mob: 09602757361;9887291983 Office. 01461-232096	
15.	DR R L CHOUDHARY Scientist (Agronomy) School of Edaphic Stress Management ICAR-National Institute of Abiotic Stress Management (NIASM), Baramati, Pune, Maharashtra- 413 115	E-mail: Rl.choudhary@icar.gov.in ramlalkherwa@gmail.com Mob: 9860950259	
16.	DR PRANA VIR SINGH Scientist (Agronomy) Krishi Vigyan Kendra, Chandra Shekhar Azad University of Agriculture & Technology, Farrukhabad, Uttar Pradesh	E-mail: kvkfarrukhabad@gmail.com Mob: 9450342609	
17.	DR. SARVENDRA KUMAR Subject Matter Specialist (Agronomy) Sam Higginbottom Institute of Agriculture, Technology & Sciences (SHIATS), Allahabad, Uttar Pradesh	E-mail: sarvendra.kumar6@gmail.com Mob: 8737941063	

S.No.	Name and address of participant	E-mail and contact no.	Photo
18.	DR. SHISHIR KUMAR Subject Matter Specialist (Agronomy) Sam Higginbottom Institute of Agriculture, Technology & Sciences (SHIATS), Allahabad, Uttar Pradesh	E-mail: shishir.agro@gmail.com Mob: 9455689277	
19.	DR SUBHASH CHANDRA SINGH Scientist (Agri. Extension) Krishi Vigyan Kendra, Chandra Shekhar Azad University of Agriculture & Technology, Kannauj, Uttar Pradesh	E-mail: subhashsinghcsa@gmail.com Mob: 8840625972; 9415701721	
20.	DR KAMAL KANT SMS (Agril. Engineering) Krishi Vigyan Kendra, Chandra Shekhar Azad University of Agriculture & Technology, Hathras, Uttar Pradesh	E-mail: kamalkant.iari@gmail.com Mob: 7905749091	
21.	DR PUSHPA DEVI SMS (Food & Nutrition) Krishi Vigyan Kendra, Chandra Shekhar Azad University of Agriculture & Technology, Hathras, Uttar Pradesh	E-mail: kamal_iari@rediffmail.com Mob: 9452629071	
22.	DR. CHAITANYA PRASAD NATH Scientist (Agronomy) ICAR-Indian Institute of Pulses Research, Kanpur, Uttar Pradesh-208024	E-mail: cpnath4@gmail.com Mob: 7318177223	
23.	MR KALI KRISHNA HAZRA Scientist (Agronomy) ICAR-Indian Institute of Pulses Research, Kanpur, Uttar Pradesh-208024	E-mail: kalikrishna123@gmail.com Mob: 8953455970	

DIVISION OF CROP PRODUCTION
ICAR-Indian Institute of Pulses Research
Kanpur, Uttar Pradesh-208 024

ICAR sponsored short course '***Enhancing Nutrient Use Efficiency through Next Generation Fertilizers in Field Crops***' held at ICAR-IIPR, Kanpur, Uttar Pradesh during November 21-30, 2017

Schedule

Date	Time (Hrs)	Topic of Lecture	Resource person
21-11-2017 Tuesday	9.30-10.30 Hrs	**Registration of the participants**	Mr Kailash Chandra/ Mr Gajraj
	10.30-12.00 Hrs	**Inaugural function**	Prof. Narendra Mohan, NSI
	12.00-12.30 Hrs	**High Tea**	
	13.00-14.00 Hrs	Next Generation Fertilizers-Introduction and Future Perspectives in Indian Context	Dr Ummed Singh, IIPR
	14.00-15.00 Hrs	**Lunch break**	
	15.00-16.00 Hrs	Acquaintance with soil and plant samples	Dr Ummed Singh/ Mr R S Mathur
	16.00-17.00 Hrs	Steps towards self sufficiency in pulse production in India	Dr N P Singh, Director
22-11-2017 Wednesday	10.00-11.00 Hrs	Techniques of nutrient supplementation in organic production system of cereals	Dr Dinesh Kumar, IARI
	11.00-12.00 Hrs	Technological interventions for higher water and nutrient productivity in field crops	Dr C S Praharaj, HOD, CPD, IIPR
	12.00-12.15 Hrs	**Tea**	
	12.15-13.15 Hrs	Enhancing nutrient use efficiency through differential formulations of fertilizers having slow release matrix	Dr Lalit Kumar, IIPR
	13.15-14.15 Hrs	**Lunch break**	
	14.15-15.15 Hrs	Delivering secondary (Ca, Mg and S) nutrients to the field crops-Physiological perspectives	Dr P S Basu, IIPR
	15.15-15.30 Hrs	**Tea**	
	15.30-17.00 Hrs	Practical demonstration of NDVI, IRGA and Leaf Spectrometry	Dr P S Basu, IIPR

Date	**Time (Hrs)**	**Topic of Lecture**	**Resource person**
23-11-2017 Thursday	10.00-11.00 Hrs	Sustaining Crop Productivity and Human Health through Micronutrient Fertilization	Dr Masood Ali, Ex-Director, IIPR
	11.00-12.00 Hrs	Maximizing Fertilizer Use Efficiency for Sustainable Agriculture	Dr K N Tiwari, IPNI
	12.00-12.15 Hrs	**Tea**	
	12.15-13.15 Hrs	Aqua-fertilization: An easy approach for higher nutrient productivity under arid and semi-arid region	Dr D S Gurjar, WTC
	13.15-14.15 Hrs	**Lunch break**	
	14.15-15.15 Hrs	Zinc in Soil, Plant and Human Nutrition: Zinc Nutrient Initiative	Dr Soumitra Das, IZA
	15.15-15.30 Hrs	**Tea**	
	15.30-17.00 Hrs	Designing plant types for higher nutrient acquisition	Dr Sanjeev Gupta, PC, MULLaRP, IIPR
24-11-2017 Friday	10.00-11.00 Hrs	Plant-microbe interaction for improving P use efficiency of pulses	Dr M. Senthilkumar, IIPR
	11.00-12.00 Hrs	Techniques and future perspectives for developing nutrient use efficient chickpea cultivars	Dr S K Chaturvedi, IIPR
	12.00-12.15 Hrs	**Tea**	
	12.15-13.15 Hrs	Nutri-Farms: An Easy Approach to Mitigate Malnutrition and Ensure Nutritional Security in Developing Countries	Dr Purushottam, IIPR
	13.15-14.15 Hrs	**Lunch break**	
	14.15-15.15 Hrs	Present status and future perspectives of coated fertilizers in India and World	Dr Shantanu Kar, Coromandel
	15.15-15.30 Hrs	**Tea**	
	15.30-17.00 Hrs	Practical Analysis of P in Plant and Soil Samples	Dr C S Praharaj/ Mr R S Mathur, IIPR
25-11-2017 Saturday	10.00-11.00 Hrs	Efficient resource conservation technologies for higher nutrient use efficiency in pulse systems	Dr Narendra Kumar, IIPR
	11.00-12.00 Hrs	Role of customized fertilizers for higher nutrient use efficiency	Dr Ummed Singh, IIPR
	12.00-12.15 Hrs	**Tea**	

Date	Time (Hrs)	Topic of Lecture	Resource person
	12.15-13.15 Hrs	Participatory Technology Development: Futuristic tools for higher nutrient use efficiency and technology dissemination	Dr Rajesh Kumar, IIPR
	13.15-14.15 Hrs	**Lunch break**	
	14.15-15.15 Hrs	Demonstration of Drip Fertigation for Higher NUE	Dr C S Ptraharaj/Mr Krishna Autar
	15.15-15.30 Hrs	**Tea**	
	15.30-17.00 Hrs	Practical exercise on coating materials for seed and fertilizer coatings	Dr Lalit Kumar/ Dr G K Srivastava, IIPR
26-11-2017		**Sunday**	
27-11-2017 Monday	10.00-11.00 Hrs	Heavy metals restraining nutrient use efficiency in cereals and pulses	Dr M L Dotaniya, ICAR-IISS/ Dr Ummed Singh
	11.00-12.00 Hrs	Determination of Organic Carbon in Soil Samples	Dr Ummed Singh/Dr C S Praharaj
	12.00-12.15 Hrs	**Tea**	
	12.15-13.15 Hrs	Quality analysis of fertilizers samples	Dr Ummed Singh/ Dr C S Praharaj
	13.15-14.15 Hrs	**Lunch break**	
	14.15-15.15 Hrs	Customized fertilizers in India and World-Industry Perspectives	Dr Kanwar Singh, TCL
	15.15-15.30 Hrs	**Tea**	
	15.30-17.00 Hrs	Estimation of Nitrogen in Plant and Soil Samples Using Automatic Nitrogen Analyser	Dr Ummed Singh/Mr R S Mathur
28-11-2017 Tuesday	10.00-11.00 Hrs	Biofortified lentil for nutritional security	Dr Jitendra Kumar, IIPR
	11.00-12.00 Hrs	Liquid fertilizers vis-à-vis soluble fertilizers for higher fertilizer use efficiency	Dr C S Praharaj, IIPR
	12.00-12.15 Hrs	**Tea**	
	12.15-13.15 Hrs	Nano-fertilizers: Techniques, tools and future perspectives in Indian context	Dr Lalit Kumar, IIPR
	13.15-14.15 Hrs	**Lunch break**	

Date	Time (Hrs)	Topic of Lecture	Resource person
	14.15-15.15 Hrs	Visit to Kanpur Fertilizers Limited, Panki, Kanpur	Er. Prasoon Verma/Dr Ummed Singh
	15.15-15.30 Hrs	**Tea**	
	15.30-17.00 Hrs	Visit to Kanpur Fertilizers Limited, Panki, Kanpur	Er. Prasoon Verma/Er Manmohan Deo
29-11-2017 Wednesday	10.00-11.00 Hrs	Scaling resource conservation technologies with special emphasis to higher nutrient use efficiency	Dr U P Singh, BHU
	11.00-12.00 Hrs	Determining K Content in Soil and Plant Samples	Dr C S Praharaj/Mr R S Mathur
	12.00-12.15 Hrs	**Tea**	
	12.15-13.15 Hrs	Determining S Content in Soil and Plant Samples	Dr Ummed Singh/ Mr R S Mathur
	13.15-14.15 Hrs	**Lunch break**	
	14.15-15.15 Hrs	4R nutrient stewardship in cereals and millets	Dr S Dutta, IPNI
	15.15-15.30 Hrs	**Tea**	
	15.30-17.00 Hrs	Estimation of Micronutrient in Plant and Soil Samples Using AAS	Dr Ummed Singh/ Mr R S Mathur
30-11-2017 Thursday	10.00-11.00 Hrs	Quantification of nutrient losses through weeds in field crops	Dr Baldev Ram, AU, Kota
	11.00-12.00 Hrs	Participatory research: Futuristic tools for higher resource use efficiency and transfer of technology	Dr S S Singh, Director, ATARI, Kolkata
	12.00-12.15 Hrs	**Tea**	
	12.15-13.00 Hrs	Online Submission of Feedback at CBP Vortal	Er. Manmohan Deo
	13.00-14.00 Hrs	**Lunch break**	
	14.00-16.00 Hrs	**Valedictory Function**	

Venue: Training & Communication Centre, IIPR, Kanpur

Ummed Singh
Course Director

ICAR-Indian Institute of Pulses Research
Kanpur, Uttar Pradesh-208 024
Web site : http://www.iipr.res.in

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