Prospects of customized fertilizers in Indian agriculture

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In many countries, blanket fertilizer recommendations for different crops have caused poor nutrient supply, low nutrient use efficiency and limited crop response. In contrast, soil and area specific, customized fertilizers may help to sustain soil health by ensuring appropriate fertilization. Hence, specific customized fertilizers should be promoted to counteract the problem of expanding multi-nutrient deficiencies in Indian soils. This article discusses the manufacturing methodologies, eligibility criteria, success in Indian fertilizer industry, adoption of fertilizer recommendations and problems in marketing of customized fertilizer.

Keywords: Customized fertilizer, fertilizer policy, fertilizer grades, fertilizer subsidy, micronutrient deficiency.

THE current world population of 7.5 billion is projected to increase by one billion over the next 12 years and may reach 9.6 billion by 2050 (ref. 1). India's population is expected to be around 1.3 billion by 2020 (ref. 2) and will likely reach 1.67 billion by 2050 (ref. 3). It was also reported that foodgrain demand in India may reach 293 million tonnes (Mt) by 2020 and rise to 335 Mt by 2025 (ref. 4). Consequently, the national thrust has been on maximizing food production for the expanding population.

To feed the population of India in 2050, land productivity has to be enhanced four times along with a threefold increase in water productivity and concomitant sixfold increase in labour productivity while focusing on energy savings and low emission technologies[5]. 'Science' (11 June 2014) declared soil to be 'The final frontier'. Consequently, the need to understand soil health and its management is greater now than ever before, for which three vital reasons seem particularly important: (1) Intensification in foodgrain production did not keep pace with that of fertilizer production which indicates a decline in partial factor productivity. (2) With the implementation of nutrient-based subsidies (NBS) in 2010, the prices of P and K fertilizers have increased, reducing total fertilizer consumption and its use. Total fertilizer consumption decreased from 28.1 Mt in 2010–11 to 25.6 Mt in 2014–15 (ref. 6) and fertilizer use intensity declined from 141.3 kg ha^{-1} to 131.8 kg ha^{-1} during this period. (3) The scope of expansion of cultivated area is limited, as the competition for scarce land resources between agriculture and urban interests is limiting per capita land availability. The net cultivated area has remained virtually static at around 140–142 million ha (M ha) since 1970 and is not expected to increase beyond 143 M ha by 2050 (ref. 5), whereas the area under non-agricultural use increased by about 10 M ha since 1970–71. Unfortunately, it is often the best agricultural land that is used for urban expansion[7]. Consequently, a large amount of the required increase in foodgrain production has to be attained through enhancing the productivity per unit area[8]. To sustain production demands, the productivity of major crops has to grow annually by 3.0–7.5% (ref. 9). For each additional tonne of foodgrain produced, adequate amounts of additional plant nutrients need to be externally applied.

The regular application of fertilizers to soils has been the key in augmenting food production in India. To meet the foodgrain requirement by 2025 (ref. 10), 45 Mt of $N + P_2O_5 + K_2O$ is estimated to be required annually[11]. Of this, 35 Mt is proposed to be met from chemical fertilizers and the rest from the use of chemical residues[11]. However, the fertilizer consumption in India is quite skewed.

Moreover, the efficiency of fertilizer use is quite low. The efficiency of N-fertilizer is only 30–40% in rice and 50–60% in other cereals, while the efficiency of mineral P-fertilizer is 15–20% in most crops. The efficiency of K is 60–80%, while that of S is 8–12%. This leads to lower return on money spent per unit of fertilizer. The efficiency of micronutrients remains <5% (ref. 12). Hence, applying nutrients in the form of fertilizers requires sufficient quantities, the right form, the right time and right place for good management of Indian agriculture.

In India, N, P and K sustain productivity. A so-called balanced fertilization ratio of $N : P_2O_5 : K_2O$ is commonly recommended but the actual application practice in Indian agriculture varied with time, with one closest to the so-called ideal ratio of 4.3 : 2.0 : 1.0 during 2009–10 (ref. 13). However, since 2010–11, there has been a downward trend in fertilizer consumption on account of a drop in consumption of P_2O_5 and K_2O (Table 1). Presently the $N : P_2O_5 : K_2O$ use ratio has widened to 8.2 : 3.2 : 1.0 under the current relative mineral fertilizer costs with the country's north (the Indo-Gangetic Plains) recording a very wide ratio of 30.8 : 10.1 : 1.0 (ref. 14). Systematic surveys indicate that after 1966–67, barring

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a few years, imbalance in NPK use was only 4–8% (ref. 15). Certainly, the normative ratio of 4 : 2 : 1 (N : P_2O_5 : K_2O) merits to be debated and defined for different crops and soils. Nitrogen accounted for 66% of the total N : P_2O_5 : K_2O consumption in India during 2012–13, while P_2O_5 and K_2O were 26% and a mere 8% respectively[7]. Thus, K fertilization in Indian agriculture is quantitatively far less than N and P. Moreover, Tandon[16] estimated an annual depletion of 10.2 and 5.97 Mt K_2O from Indian soils on a gross and net basis respectively. He suggested that out of the net negative NPK balance or annual depletion of 9.7 Mt, N and P depletion was 19% and 12% respectively; while as much as 69% depletion was shown for K. Further, the All India Coordinated Research Project on Long Term Fertilizer Experiments by the Indian Council of Agricultural Research has shown negative K balances even at the optimum NPK application rates across India[17]. Later, Satyanarayana and Tewatia[18] reported negative K balances across different states of India ranging from –0.1 to –1.1 Mt. Recently, a detailed study highlighted negative K_2O balances, which increased in 2011 compared to 2007, in most of the Indian States[19]. Hence, the introduced nutrient imbalance may have contributed to low factor productivity.

India has a serious problem of nutrient mining because of extractive farming practices. Due to the imbalance in use of plant nutrients, mining of nutrients is considered as one of the main causes for decline in crop yield and crop response ratio[16–21]. Negative nutrient budgets are worsened by removal of crop residues and animal dung for other purposes. Consequently, agricultural soils of India have an overall calculated annual nutrient (N + P_2O_5 + K_2O) shortfall of about 10 Mt (ref. 20). It was also estimated that this nutrient gap may widen to 22 Mt in 2025 at an overall nutrient consumption of 350 Mt (ref. 21). Besides macronutrients, there is also widespread deficiency of S and micronutrients (Zn, Cu, Mn and B). About 42% of the Indian soils are deficient in S[22], 48.5% deficient in Zn[22] and 33% deficient in B[23]. Thus, Indian soils are currently witnessing multi-nutrient deficiencies. This calls for site-specific nutrient management (SSNM) and development of customized, micronutrient fortified fertilizers[11]. In India, the concept of customized fertilizers is still in infancy. The main aim of this review is to explore the concept, current research, future challenges and other issues in marketing of customized fertilizers.

Table 1. Trends in per hectare nutrient consumption and NPK use ratio in India

Year	N (kg ha^{-1})	P_2O_5 (kg ha^{-1})	K_2O (kg ha^{-1})	Total (kg ha^{-1})	NPK use ratio
1965–66	3.70	0.85	0.50	5.05	7.4 : 1.7 : 1
1980–81	21.31	7.03	3.61	31.95	5.9 : 1.9 : 1
1990–91	43.06	17.34	7.15	67.55	6.0 : 2.4 : 1
1992–93	45.40	15.32	4.76	65.48	9.5 : 3.2 : 1
2000–01	58.92	22.74	8.46	90.12	7.0 : 2.7 : 1
2010–11	83.81	40.74	17.79	142.35	4.7 : 2.3 : 1
2013–14	86.16	28.98	10.80	125.94	8.0 : 2.7 : 1
2015–16	89.36	35.90	12.35	137.62	7.2 : 2.9 : 1

Green revolution and its consequences

Green revolution (GR) pulled India out of the abominable stage of being a ‘Begging Bowl’ and transformed it to a country of ‘overflowing granaries’ and a net exporter of foodgrains[24]. However, after four decades of green revolution starting in 1965–1966 Indian agriculture is again on a cross road[25]. Although food grain production has increased manyfold, the irony is that this has been achieved at the cost of deteriorating natural resources[26]. Therefore, agricultural land is under pressure to perform better and sustainability of natural resources is under question. More notably, while fertilizer consumption continues to rise substantially, the elasticity of output with respect to fertilizer use has dropped sharply[24]. As a consequence of nutrient mining, widespread deficiency of at least six nutrients, viz. N, P, K, S, Zn and B was recorded in Indian soils[27,28]. The consumption of cereal-based foods contributes up to 70% of the daily calorie intake in most developing countries including India, resulting in a high prevalence of Zn deficiency in its population[29]. An important reason for low Zn content of cereals is that 50% of the crops grow on Zn-deficient soils[30].

Multi-micronutrients deficiency – a big concern

By and large, the farmers use N, P and K as plant nutrients in crop cultivation and consequently observe increased deficiencies of micronutrients[31]. Intensive cropping with high yielding crop varieties and lack of recycling of yard manure (FYM) and composts have aggravated the situation (Tables 1–3)[32]. Micronutrient deficiencies are difficult to diagnose and consequently the problem may be termed ‘hidden hunger’ in analogy to the term used in human nutrition. On an average 43.0%, 12.1%, 5.4%, 5.5% and 18.3% of soils are deficient in Zn, Fe, Cu, Mn and B respectively (Table 2)[33–36]. Subsequently, the seeds grown on micronutrient-deficient soils contain two to three times lower micronutrients than those grown on soils adequately supplied with micronutrients[32].

Multi-nutrient deficiencies are emerging for Zn + Fe in swell-shrinking soils, Zn + Mn or Zn + Fe + Mn in alluvial soils of the Indo-Gangetic plains, Zn + Fe, Zn + B, Zn + Fe + B in highly calcareous soils of Bihar and Gujarat, Zn + B in acid leached Alfisols, red and lateritic soils of India[37,38]. Thus widespread deficiency of micronutrients can be combated by paying attention to micronutrient management[39]. Consequently, there is a need to supply these nutrients as customized fertilizers in specific regions to enhance crop growth and development.

Table 2. Deficiency status of DTPA-extractable micronutrients and hot water soluble B (HWS-B) in soils of different states of India (ref. 32)

	DTPA-extractable micronutrients					Hot water soluble B	
		% deficiency					
State	No. of samples	Zn	Fe	Cu	Mn	No. of samples	Per cent samples deficient
Andhra Pradesh	6723	22.3	16.8	1.0	1.7	3216	2.8
Assam	5216	25.5	0.0	3.8	0.0	5216	11.9
Bihar	7304	41.4	12.3	1.8	7.8	3597	33.3
Gujrat	5470	23.1	23.9	0.4	6.3	5470	17.9
Haryana	5673	15.3	21.6	5.2	6.1	5673	3.3
Himachal Pradesh	642	1.4	7.8	0.2	22.1	161	8.7
Jharkhand	443	20.3	0.0	0.5	0.0	443	56.0
Madhya Pradesh	7580	61.7	9.6	0.2	1.6	3330	2.4
Maharashtra	8278	54.0	21.5	0.2	3.8	489	54.8
Odisha	2349	22.7	1.8	0.3	1.1	2349	52.5
Punjab	2181	16.5	6.2	3.6	15.2	1083	17.5
Tamil Nadu	31080	65.5	10.6	13.0	7.9	31080	19.9
Telangana	4799	26.9	17.0	1.4	3.8	2776	16.1
Uttar Pradesh	4788	33.1	7.6	6.3	6.5	4323	16.2
Uttarakhand	2575	9.6	1.4	1.4	4.7	2575	7.0
West Bengal	2363	11.9	0.0	1.2	0.9	1849	46.9
All India	97464	43.0	12.1	5.4	5.5	73630	18.3

Table 3. Deficiency status of multi-micronutrients in soils of different states of India (ref. 32)

	Two micronutrients				Three micronutrients		
State	Zn + Fe	Zn + Cu	Zn + Mn	Zn + B	Zn + Fe + Mn	Zn + Cu + Mn	Zn + Fe + B
Andhra Pradesh	6.40	0.40	0.61	0.81	0.16	0.03	0.16
Assam	0.00	1.50	0.00	4.47	0.00	0.00	0.00
Bihar	4.01	0.89	2.67	16.49	1.1	0.1	1.25
Gujrat	6.00	0.24	2.30	4.83	0.86	0.00	1.30
Haryana	6.38	2.22	1.80	0.74	0.85	0.37	0.46
Himachal Pradesh	0.00	0.00	0.31	0.00	0.00	0.00	0.00
Jharkhand	0.00	0.00	0.00	11.74	0.00	0.00	0.00
Madhya Pradesh	7.56	0.12	1.35	1.50	0.59	0.01	0.24
Maharashtra	12.32	0.11	2.74	30.47	1.82	0.06	0.20
Odisha	0.34	0.17	0.26	12.22	0.04	0.00	0.17
Punjab	1.79	1.93	4.68	1.85	0.46	0.28	0.18
Tamil Nadu	8.45	10.69	6.00	13.50	1.71	2.12	1.38
Telangana	6.21	0.58	0.92	2.05	0.33	0.13	0.47
Uttar Pradesh	2.99	2.46	2.34	6.80	0.77	0.48	0.67
Uttarakhand	0.27	0.62	0.93	0.78	0.12	0.31	0.00
West Bengal	0.00	0.55	0.47	3.73	0.00	0.04	0.00
All India	6.29	3.97	3.04	8.63	1.01	0.76	0.86

Customized fertilizers

The nature and extent of micronutrient deficiencies vary with soil type, crop genotype, management and agro-ecological conditions[40]. Therefore, there is a need to promote balanced fertilization to improve nutrient use and enhance crop productivity for food and nutritional security[41]. Multi-micronutrient mixtures facilitate the application of a wide range of plant nutrients to satisfy specific crop requirements at different growth stages, particularly under SSNM practices[42].

Recent research conducted in various countries including India has demonstrated limitations of blanket fertilizer recommendations widely practiced across Asia[43–46]. One-farm research has clearly demonstrated the existence of large field variability in soil nutrient supply, nutrient use efficiency and crop response. Further, low efficiency of resources and fertilizer inputs impacts production costs with serious environmental consequences[8]. Hence, it was hypothesized that future gains in productivity and input use efficiency will require more knowledge-intensive soil and crop management technologies tailored to specific characteristics of individual farms or fields to manage between and within farm variability[47].

To correct deficiencies in plant nutrient application, the development of new fertilizer technologies is needed as most of the present fertilizers were developed more than four decades ago. Over the past 25 years, no new efficient

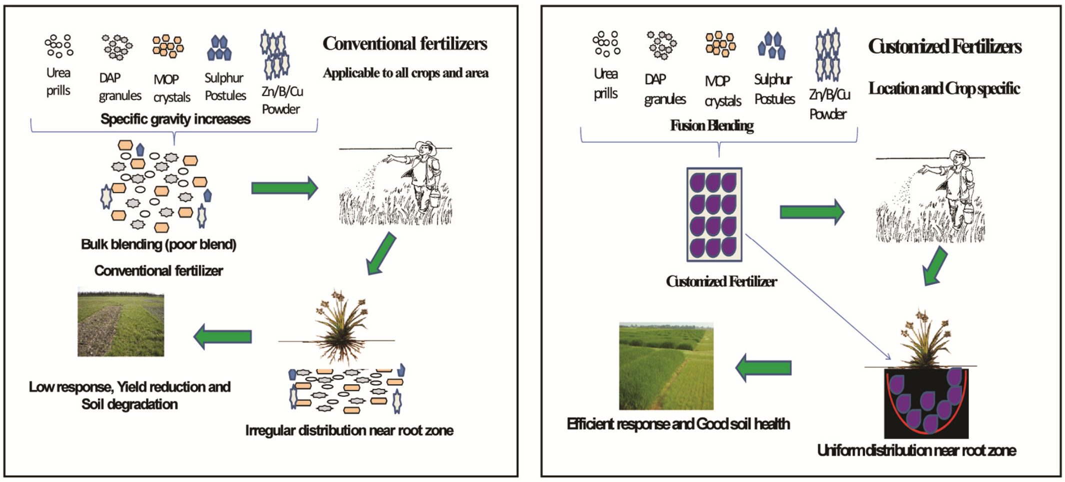

Figure 1. Diagram showing differences between conventional versus customized fertilizers.

fertilizer product has been developed, especially one which is affordable for farmers in less developed countries, like India[48].

Fertilizer subsidy

In 1973 mineral fertilizers were included in the Essential Commodity Act (ECA) of 1955 through an amendment by the Government of India (GoI). The year 2010–11 was a landmark year in the history of the Indian fertilizer sector, since NBS was introduced with effect from 1 April 2010 for phosphate other than single super phosphate (SSP)[49]. SSP was brought under the NBS scheme with effect from 1 May 2010. NBS has brought a major breakthrough in policy since the 1970s as (i) it caused a shift from product-based subsidy regime to NBS, (ii) the subsidy per unit remained fixed, and (iii) it promoted the development of customized fertilizers.

In addition, fortified fertilizers with secondary and micronutrients (B and Zn) are eligible for a separate per tonne subsidy to encourage their application along with primary nutrients[50].

Intervention of government policies

Customized fertilizer was included in the Gazette in 2006 under clause 20 B of the Fertilizer Control Order (FCO) of 1985. In 2008 customized fertilizer policy guidelines were issued. All the provisions of FCO of 1985 and ECA (1955) shall be applicable for manufacture and sale of customised fertilizer.

Definition of customized fertilizers

Customized fertilizers are defined as multi-nutrient carriers designed to contain macro, secondary and/or micronutrient both from inorganic sources and/or organic sources. These are manufactured through a systematic process of granulation with stringent quality checks, satisfying the crop's nutritional needs, specific to site, soil and stage validated by a scientific crop model, capability developed by an accredited fertilizer manufacturing/marketing company[48].

Such fertilizers also include water-soluble specialty fertilizer as customized combination products. Manufacturers or marketers are expected to use software tools such as the Decision Support System for Agro Technology Transfer (DSSAT) Crop Model to determine the optimal grades of customized fertilizer. Customized, crop, soil and area specific fertilizers may contribute to maintaining soil health[51] (Figure 1).

In order to overcome the limitations of soil test-based blanket fertilizer recommendations, the concept of SSNM was introduced which is specific to soils and crops, yield-oriented and takes into account nutrient interactions with the aid of models such as Quantitative Evaluation of Fertility of Tropical Soils (QUEFTS) and Soil Test Crop Response (STCR). Undoubtedly, customized fertilizers can magnify the prospects of SSNM and precision agriculture.

Manufacturing methodologies of customized fertilizers

Three processes are involved in manufacturing of customized fertilizers: bulk blending, compound granulation and complex granulation. Bulk blending involves pure mixing of solid fertilizers to obtain the desired nutrient ratio. It only requires a warehouse and weighing and mixing equipment[48]. Due to the high cost involved in manufacturing of customized fertilizers through bulk blending, this method appears to be a remote option for producing customized fertilizers in India[48].

Compound granulation is commonly known as 'steam granulation' or 'physical granulation'. The raw materials required for this method are available in solid form. Granulation is formed by the agglomeration process and requires the use of water, steam and heat in the dryer. In

Table 4. Formulations of customized fertilizers as approved by GoI as on 1 November 2011 (ref. 52)

Formulation	Crop	Region	Fertilizer company
7N20P18K6S0.5Zn*	Sugarcane	Western UP	TCL**
10N18P25K3S0.5Zn	Wheat	Western UP	TCL
8N15P15K0.5Zn0.15B	Rice	Western UP	TCL
8N16P24K6S0.5Zn0.15B	Poatato	Western UP	TCL
15N32P8K0.5Zn	Rice	Andhra Pradesh	NFCL
18N33P7K0.5Zn	Rice	Andhra Pradesh	NFCL
18N27P14K0.5Zn	Rice	Andhra Pradesh	NFCL
18N24P11K0.5Zn	Rice	Andhra Pradesh	NFCL
23N12K	Rice	Andhra Pradesh	NFCL
27N10K	Rice	Andhra Pradesh	NFCL
11N24P6K3S0.5Zn	Rice (basal)	Adilabad, Nizamabad, Karimnagar, Warangal Medak, Ranga Reddy Nalgonda (All in A.P.)	NFCL
14N27P10K0.5Zn	Maize	Adilabad, Nizamabad, Karimnagar, Warangal Medak, Ranga Reddy Nalgonda (All in A.P.)	NFCL
22N12K	Rice	Adilabad, Nizamabad, Karimnagar, Warangal Medak, Ranga Reddy Nalgonda (All in A.P.)	NFCL
18N14K	Maize	Adilabad, Nizamabad, Karimnagar, Warangal Medak, Ranga Reddy Nalgonda (All in A.P.)	NFCL
10N20P10K5S2Mg0.5Zn0.3B0.2Fe	Grape (basal) and sugarcane	Nasik, Pune, Ahmednagar, Aurangabad	Deepak F.
20N10P10K5S2Mg0.5Zn0.3B0.2Fe	Grape, rice, pomegranate, sugarcane, tomato	Nasik, Pune, Ahmednagar, Aurangabad, Dhule, Jalgaon	Deepak F.
15N15P15K5S2Mg0.5Zn0.3B0.2Fe	Grape, cotton, onion, banana, potato	Nasik, Pune, Ahmednagar, Aurangabad, Dhule, Jalgaon	Deepak F.
10N20P20K3S2Mg0.5Zn0.3B0.2Fe	Sugarcane, citrus	Nasik, Pune, Ahmednagar, Aurangabad, Dhule, Jalgaon	Deepak F.
15N15P15K0.5Zn0.2B	Groundnut	Andhra Pradesh	Corom. Int.
20N15K0.5Zn0.2B	Maize	Andhra Pradesh	Corom. Int.
16N22P14K4S1Zn	Rice (basal)	E&W Godavari Krishna, Western Delta of Guntur (All in AP)	Corom Int.
14N20P14K4S0.5Zn	Maize	Karimnagar, Warangal, Nizamabad	Corom Int.
17N17P17K4S0.5Zn0.2B	Groundnut (basal)	Anantapur, Chittoor Kadappa, Kurnool, Mahabubnagar	Corom Int.
12N26P18K5S0.5Zn	Rice and wheat	Uttar Pradesh	Indo-Gulf
8N18P26K6S1Zn0.1B	Potato	Uttar Pradesh	Indo-Gulf

*%N, P_2O_5, K_2O, S, Mg, Zn, B and Fe. TCL, Tata Chemicals Ltd.; NFCL, Nagarjuna Fertilizers and Chemicals Ltd; Deepak F., Deepak Fertilizers; Corom Int., Coromandel International Ltd.

fact, almost all Asian countries are following the route to steam/physical granulation for NPK production and this method may also be the most effective way for India to produce customized fertilizers[48].

Chemical granulation is also called 'slurry granulation' or 'complex granulation'. NPKs are produced by a chemical reaction between ammonia and either sulphuric or nitric acid to form either ammonium sulphate or ammonium nitrate. This is granulated with the addition of discrete K_2O either in solid form or a liquid form. The process of granule formation comprises accretion plus agglomeration. This method is not convenient when many customized NPK grades are to be produced[48].

Quality of customized fertilizer

For basal application, customized fertilizers should be granular in size with at least 90% of the material between 1 and 4 mm IS sieve and the material passing through sieve having size ≤1 mm IS sieve should not exceed 5% (clause 20B of FCO, 1985). The moisture content should not exceed 1.5%. For foliar application, however, 100% water solubility is required. Different formulations prepared by different industries are given in Table 4.

Further, the effects of different grades of customized fertilizers on growth and yield of different crops are summarized in Table 5.

Issues in marketing of customized fertilizers

Ten most important issues which hinder the marketing of customized fertilizers are: (i) high cost of customized fertilizers without proper subsidy given by GoI, (ii) existence of diversity in product mix between producers, (iii) absence of healthy competition among fertilizer industries to avoid indiscriminate and imbalanced use of fertilizer,

Table 5. Effect of different customized fertilizers on growth and yield of different crops in India (refs 53–61)

Formulations	Crop	Location	Remarks
$20N17P_2O_511K_2O3S0.4Zn$	Finger Millet	UAS, Benglauru	Recorded higher net returns and B : C ratio[53]
20N12P10K4S0.25Mg0.5Zn0.5Fe	Onion	ARS, Sangli, Maharashtra	Improved soil fertility, bulb yield and higher net monetary returns[54]
20N10P10K5S2Mg0.5Zn0.3B0.2Fe	Pomegranate	MPKV, Rahuri, Maharashtra	Found to be beneficial for increasing yield and quality[55]
11N18P9K5.3S0.7Zn	Wheat	IGKV, Chhattisgarh	Produced highest grain yield and increased uptake of N, P, K, S and Zn[56]
16N24P9K5S0.7Zn	Wheat	PAU, Ludhiana, Punjab	Improved plant height, effective tillers, grain and straw yield, agronomic efficiency of N, B : C ratio and net returns[57]
$14N21P_2O_58K_2O0.6Zn$	Rice	IGKV, Raipur	Produced highest grain yield and increased uptake of N, P, K and Zn[58]
$14N21P_2O_58K_2O0.6Zn$	Rice	IGKV, Raipur	Recorded the highest growth, grain yield, net return and B : C ratio[59]
$14N21P_2O_58K_2O0.6Zn$	Rice	IGKV, Raipur	Failed to provide considerable yield advantage and uptake of nutrients[60]
7.5N30P7.5K1.5S1.5Zn	Rice	KVK, SVPUAT, Baduan, UP	Resulted in increased plant height, spike length, grain and straw yield[61]

(iv) improper allocation of raw material among fertilizer industries, (v) necessity of investing heavy capital in state of the art manufacturing facility for customized fertilizer, (vi) no long term assurance from the government to keep the policy intact throughout the years, (vii) limited awareness and very low affordability of customized fertilizers among the farmers, (viii) segmentation and promotion in marketing, (ix) time consuming manufacturing, and (x) uncertainty in response when fertility is restored in the field.

Conclusions

Customized fertilizers facilitate the application of the complete range of plant nutrients in the right proportion to suit the specific requirements during different stages of crop growth. At present, balanced, efficient nutrient management with special emphasis on INM is being advocated through the SSNM approach. In this context, customized fertilizers could contribute promoting SSNM in order to achieve the maximum FUE of the applied nutrients in a cost-effective manner. Future research by public–private–partnerships should address the required grades of customized fertilizers that may need to be standardized once every three years.

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