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Advancing with fertilizers in Indian agriculture: trends, challenges, and research priorities

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Abstract We study the national and state-level fertilizer use trends using time series data, the influence of key policies on consumption using interrupted time series analysis, and the current research priorities using bibliometric analysis. The Retention Price Scheme raised long-term consumption; decontrol policy reduced consumption, but the concession scheme reversed the reduction; and the Nutrient Based Subsidy scheme has been reducing consumption. Continuing to formulate fertilizer policies based on research evidence, and implementing these, will help meet targets.

Keywords Fertilizer nutrient, fertilizer policy, interrupted time series, bibliometric analysis

JEL codes Q01, Q18, Q58

India is the second largest producer and consumer of fertilizers in the world—after China. In 2017, India consumed 17 million tonnes of nitrogen, 6.9 million tonnes of phosphorus, and 2.8 million tonnes of potash (Fertilizer Association of India 2019). Fertilizer use is governed by government policies (Gulati and Banerjee 2015): the Fertilizer Control Order, Retention Price Scheme, Nutrient Based Subsidy, New Pricing Scheme, decontrol, nutrient-based pricing, joint ventures abroad, neem coating of urea, Direct Benefit Transfer system for fertilizer subsidy distribution, etc. (Praveen 2017).

Fertilizer use has helped improve crop yield (Kishore et al. 2013), and the process of improvement is continual; however, its environmental effects—eutrophication, emission of greenhouse gases, and distortion in the soil nutrient balance (Adhya et al. 2016; Kanter et al. 2015)—have raised concerns over sustainability (Patra et al. 2016). As the population pressure increases and the resources available for farming decrease, increasing fertilizer use may not be enough in the future; improving the efficiency of fertilizer use is imperative (Hossain and Singh 2000).

To frame effective policy, policymakers need research evidence (Puttick 2011). The research regime in fertilizers has achieved considerable progress in areas such as fertilizer application rates, nutrient use efficiencies, yield enhancement due to fertilizers, time of fertilizer application, the right quantity of fertilizers for crops, and a region-specific recommendation of fertilizers (Chand and Pavithra 2015; Sharma and Thaker 2011). Considering the manifold research areas evolving within the broad topic of fertilizers, a scientific probe into the recent research trends will have great value in understanding whether our research priorities are in line with future challenges.

One way to achieve this is through bibliometrics, or the quantitative analysis of the available research evidence (Nafade et al. 2018). Bibliometric analysis can help to empirically document the volume of research into fertilizers, the direction of knowledge development, and identify the key research players (Zhang et al. 2019). We draw on the secondary data available and analyse the effect of key policies in regulating fertilizer use. We track the trends in fertilizer use at the national, state, and district level to identify the challenges in the future and formulate research priorities.

Data and methodology

We utilize the secondary data provided by the Directorate of Economics and Statistics (Agricultural Statistics at a Glance) and the Fertilizer Association of India (Fertilizer Statistics). We use QGIS to create state and district maps to visualize the spatial variation in fertilizer use.

In the interrupted time series analysis (ITSA) method, an outcome variable is observed over multiple, equally spaced periods before and after the introduction of an intervention that is expected to interrupt its level or trend (Linden and Adams 2011). The ITSA for a single period is

$$Y_t = \beta_0 + \beta_1 T_t + \beta_2 X_t + \beta_3 X_t T_t + \varepsilon_t$$

where, Y_t is the aggregated outcome variable measured at each equally spaced time point t; T_t is the time since the start of the study; X_t is a dummy (indicator) variable representing the intervention (pre-intervention periods 0, otherwise 1), and $X_t T_t$ is interaction term.

β_0 represents the intercept or starting level of the outcome variable; β_1 is the slope or trajectory of the outcome variable until the introduction of the intervention; β_2 represents the change in the level of the outcome that occurs in the period immediately following the introduction of the intervention, and β_3 represents the difference between the pre-intervention and post-intervention slopes of the outcome.

To estimate the effect of important policies on fertilizer use, we use the ITSA model. The model supports the adding of factor variables. We include for the period from 1972 to 2017 several factor variables: the share of high yield variety (HYV) seeds in gross cropped area (GCA) (%),share of gross irrigated area (GIA) to GCA (%),price of N, P, and K (INR per kg), output price (INR per quintal), short-term institutional credit to agriculture (INR crore), cropping intensity (%), and fertilizer subsidy (INR crore).

We review the literature to identify the future challenges. In January 2020 we conducted a literature search for research into fertilizers in India using the ISI Web of Science. We selected articles published in English-language journals between 2010 and 2020. (We excluded all other document types.) To select studies, we used the search string (TS: ('fertilizer' OR 'fertiliser') AND CU=India). The search yielded 1,887 studies.

The software tool VOSviewer enables the visualization and easy interpretation of bibliometric data (van Eck and Waltman 2010). We used VOSviewer and knowledge mapping to carry out a bibliometric analysis of the name of author(s), year of publication, journal name, article title, and citations. To identify and map the scope and structure of the subject, we performed network analysis using the co-occurrence of author keywords and co-authorship of authors and institutions, along with which the link strengths were generated.

The fractional counting approach helps to visualize proper field-normalized results. We used it to visualize the co-occurrence network of keywords and co-authorship networks of authors, institutions, and countries.

Fertilizer use trends

India is the second largest producer of nitrogen fertilizers, urea, and diammonium phosphate (DAP) in the world and the second largest consumer of nitrogen and phosphorus fertilizers. India is the third largest producer of phosphorus fertilizers. Potash fertilizers are not produced in India, but it is the fourth largest consumer, and it depends on both production and imports to ensure that the domestic supply of fertilizers is adequate. Imports have decreased recently, especially after 2010; notwithstanding, in 2018–19, imports constituted about 38% of all fertilizers consumed, 26% of nitrogen fertilizers, and 45% of phosphorus fertilizers.

Fertilizer consumption increased from 69,000 tonnes in 1950 to 5.5 MT in 1980 and to 28 MT in 2010 and decreased by about 1 MT between 2010 and 2018 (Figure 1). Nitrogen is the highest consumed primary nutrient (65% in 2018), followed by phosphorus (25%) and potash (10%). The growth rate of fertilizer consumption peaked at 23.6% in the 1960s and declined thereafter. The growth has been negative (–0.4%)—for the first time—in this decade (2010–2018).

Nitrogen is the fertilizer that we consume the most, but in the 1950s and 1960s the growth in fertilizer

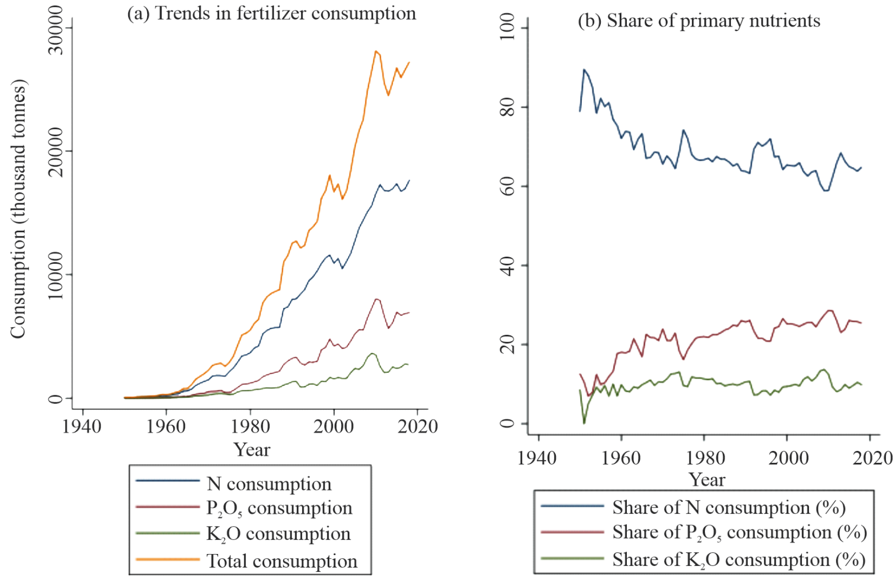

Figure 1 (a) Trends in fertilizer consumption ('000 tonnes) and (b) share of primary nutrients in total fertilizer consumption (%)

consumption was driven equally by the consumption of phosphorus and potash. In the 1960s, nitrogen consumption grew at 23%, phosphorus at 25%, and potash at 24%. The decadal growth rate in phosphorus consumption has consistently exceeded that of nitrogen since the 1980s, but the growth in potash use has been almost at par. The low growth rates this decade—0.8% (N), –1.9% (P), –3.3% (K)—indicate the beginning of a new trend in fertilizer use.

Among the states, Uttar Pradesh, Maharashtra, Madhya Pradesh, Karnataka, and Punjab were the top five fertilizer consumers. The green revolution pumped fertilizers into the cereal-centric cropping regions of the upper Indo-Gangetic Plains (IGP), and fertilizer use has long been high in these states and in southern states like Andhra Pradesh and Karnataka. However, when we analyse the state-level intensity in fertilizer use between 1980 and 2018, we can observe a transition in this pattern (Figure 2).

The northern and southern states—Punjab, Tamil Nadu, Uttar Pradesh, Karnataka, Andhra Pradesh, and Haryana, where the intensity of fertilizer use has been high, ranging from 130 kg per ha in Karnataka to more than 210 kg per ha in Punjab and Haryana—experienced the lowest growth rate in fertilizer use intensity (0.6% in Punjab, 4.5% in Haryana).

The growth rate of fertilizer use per hectare was better in the central and western states—Madhya Pradesh (5.8%), Maharashtra (4.3%), and Rajasthan (5.4%)—where the fertilizer use intensity is lower, ranging from 50 kg per ha in Rajasthan to 125 kg per ha in Maharashtra.

However, in the eastern states of Odisha, Bihar, and Assam, where fertilizer consumption has traditionally been less than in the northern and southern states, fertilizer use intensity grew at 7–8% per annum, indicating that fertilizer use is moving slowly from where it has peaked to where it has a better role to play.

The district-level fertilizer consumption maps (total consumption in tonnes and consumption in kg per hectare) points out the regional variation in fertilizer use (Figure 3). The major consumers of fertilizers are the districts in the IGP, undivided Andhra Pradesh, and Maharashtra.

Interestingly, when we check the proportion of districts (%) by the consumption of NPK per hectare, we can observe a trend supporting intensive fertilizer use. In 2000, only 7% of the districts in the country, and in 2018 about 20% of the districts, consume more than 200 kg of fertilizers per hectare. While 60% of the districts in 2018 consume more than 100 kg fertilizers per ha, only 37% did in 2000.

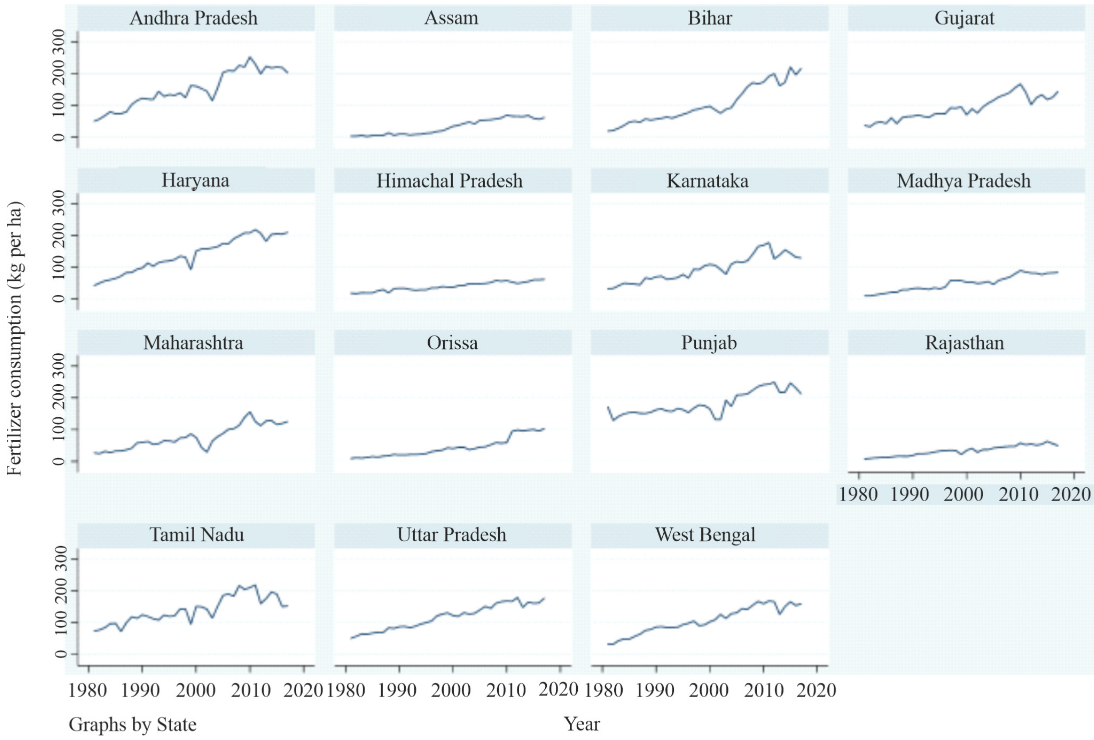

Figure 2 State-level trends in the intensity of fertilizer consumption (kg/ha) (1980-2018)

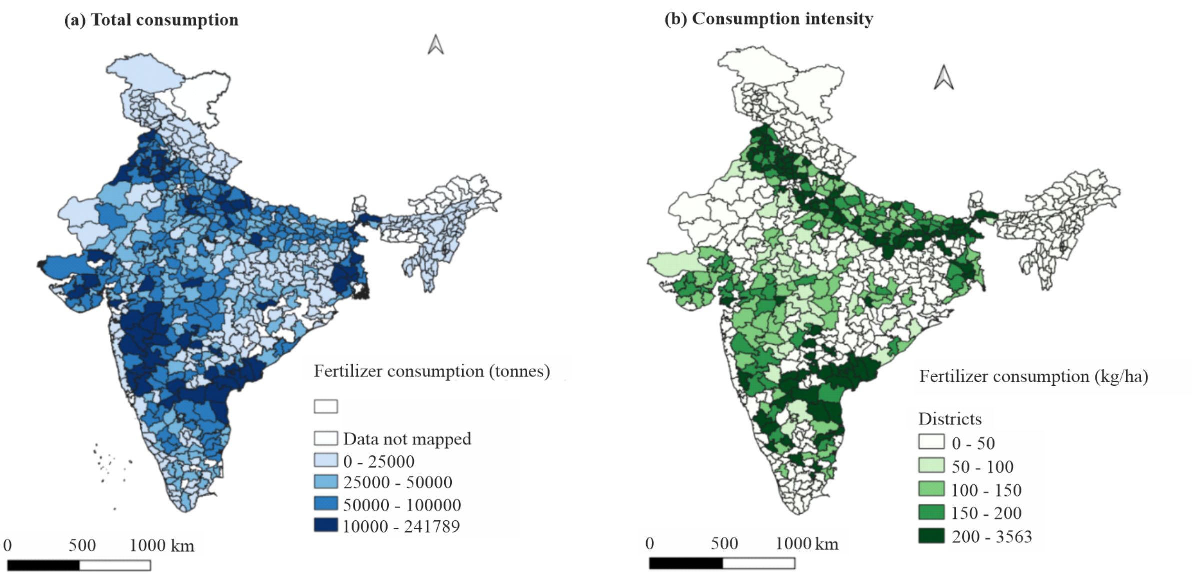

Figure 3 District level fertilizer consumption (a) total consumption in tonnes (b) consumption intensity in kg per ha (2017-18)

Effect of key policies

The Retention Price Scheme, decontrol, concession, and the Nutrient Based Subsidy were intended to directly affect nutrient consumption. We select these to test the effect of policies on fertilizer consumption. The devaluation of the rupee in 1966, and the oil price shock in 1973, made fertilizers unaffordable to Indian farmers. In 1977, the central government implemented the Retention Price Scheme, a protectionist policy that ensured each production unit a 12% post-tax return on net worth regardless of the age, location, technology, and cost of production. Cuts in the fertilizer subsidies were a part of the New Economic Policy instituted in India since 1991. To meet this end, the prices of all phosphorus and potash fertilizers were decontrolled in 1992. This reform increased fertilizer (P and K) prices and decreased consumption, to compensate which a concession scheme was announced immediately. Nitrogen fertilizers, however, remained the holy grail and enjoyed the subsidy. This led to a wide disparity in the composition of fertilizer use in the country that favoured nitrogen (Praveen 2014). The Nutrient Based Subsidy scheme was announced in 2010 to address this issue.

We carried out the ITSA separately for nitrogen, phosphorus, potash, and total fertilizer consumption (Table 1). The results suggest that the Nutrient Based Subsidy and Retention Price Scheme had a significant, long-term effect on nitrogen consumption. The Retention Price Scheme increased nitrogen consumption by 137,000 tonnes per annum, after controlling for other factors, and the Nutrient Based Subsidy decreased nitrogen consumption by 798,000 tonnes per annum. Nitrogen consumption is affected significantly by—in addition to these policies—factors like the share of gross irrigated area in gross cropped area, price of nitrogen and potash, output price, short-term institutional credit, cropping intensity, and fertilizer subsidies.

The Retention Price Scheme had an immediate negative effect on phosphorus consumption and a long-term positive effect. This may be because the Retention Price Scheme was implemented in two phases. Initially, it was introduced for nitrogen in 1977 and in 1979—after discontinuing the fixed subsidy per tonne of phosphorus—extended to phosphorus. Removing the fixed subsidy had reduced phosphorus consumption immediately, but the reduction was offset by the long-term rise in consumption (86,000 tonnes per annum). Interestingly, the decontrol of phosphorus prices could impact only an immediate negative effect on its consumption—it could not reduce consumption in the long term, because it was closely followed by the

Table 1 Fertilizer consumption as affected by key policies and control factors

Parameters	Nitrogen		Phosphorus		Potash		Total fertilizers	
	Coefficient	Standard error	Coefficient	Standard error	Coefficient	Standard error	Coefficient error	Standard
Trend	–47.88	131.44	56.34	115.77	–14.22	52.44	–197.03	285.96
RPS immediate effect	–188.17	243.93	–292.26**	122.58	–49.62	84.54	–82.56	502.73
RPS long-term effect	137.56**	64.74	86.71**	35.12	25.49	21.64	372.16***	114.72
Decontrol immediate effect	174.66	235.64	–965.38***	239.71	–402.40***	112.44	–890.83*	461.03
Decontrol long-term effect	–72.05	55.54	47.03	70.34	34.15	25.98	–61.57	131.61
Concession immediate effect			696.99	1432.99				
Concession long-term effect			1318.60**	517.52				
NBS immediate effect	565.31	452.87	98.03	504.57	–447.44**	170.52	1287.14	1034.41
NBS long-term effect	–798.37***	178.83	–1253.85***	239.83	–334.29***	64.46	–1790.42***	429.69
Share of HYV in GCA (%)	43.15	51.00	–29.93	43.67	11.42	19.36	92.83	108.50
Share of GIA to GCA (%)	312.86***	61.55	240.66**	105.93	71.53	43.56	553.01**	198.29
Price of N (INR/kg)	–238.63**	101.15	–168.78*	88.32	0.01	34.47	–295.72	224.07
Price of K (INR/kg)	–112.34**	54.79	–139.95	93.41	–73.29**	32.27	–388.13**	156.36
Price of P (INR/kg)	71.83	44.75	57.41	71.59	–5.03	27.42	150.80	120.99
Output price (INR/quintal)	1.11**	0.46	–1.62	2.51	0.12	0.30	0.94	0.98
Short-term institutional credit to agriculture (INR crore)	0.01**	0.01	–0.01	0.01	0.01***	0.01	0.02**	0.01
Cropping intensity (%)	140.65**	65.65	–30.01	72.38	–0.56	16.84	79.73	145.51
Fertilizer subsidy (INR crore)	0.01*	0.00	0.01	0.01	0.01*	0.01	0.03**	0.01
Constant	–22691.67**	7953.75	–721.65	9454.74	–1416.95	2417.33	–20753.45	18676.50

concession scheme, implemented in the 1979 rabi season.

A concession of INR 1,000 per tonne for DAP and murate of potash (MOP) increased the phosphorus concession by 1,318,000 tonnes per year in the long term. The Nutrient Based Subsidy, however, seemed to cut phosphorus consumption as well—by 1,253,000 tonnes per annum in the long term. The Retention Price Scheme could not affect potash consumption significantly. Decontrol reduced potash consumption immediately on introduction, but the reduction was not sustained in the long term. The Nutrient Based Subsidy reduced consumption in the short and long term.

The Retention Price Scheme achieved its target of raising consumption in the long term by making fertilizers available at cheaper rates. The government implemented the decontrol policy to reduce its subsidy burden; the policy reduced fertilizer consumption immediately after introduction, but the concession scheme that followed reversed the reduction in the long term by raising consumption.

The Nutrient Based Subsidy aims primarily to reduce the overuse of fertilizer nutrients and maintain the nutrient ratio balance in soils, and our findings show that the policy is performing along the expected lines. The Nutrient Based Subsidy reduced nitrogen consumption in the long term, but the reduction is less than in phosphorus consumption, which could pose a concern shortly.

Emerging challenges

Indian agriculture has traditionally been driven by indigenous methods that use locally regenerable materials for soil fertilization. Modern methods based on HYV seeds and chemical fertilizers were introduced only in the 1960s, by the green revolution (Ghosh 2004 a). Several other policies—like the Retention Price Scheme, Nutrient Based Subsidy, fertilizer subsidies, decontrol of P and K fertilizers, investment policies—directly affected fertilizer consumption. As fertilizer consumption continued to rise substantially, the elasticity of output to fertilizers dropped sharply (Kapur 2011). The response of crops to this changing input mix, however, varied by agroecosystem. The reduction in response by major crops to fertilizer nutrients in the different agroecosystems of the country is the first challenge to be addressed. Since fertilizer is input, the demand for fertilizer is a derived one; it depends on the use of land and other complementary inputs (such as irrigation, modern seeds, and soil quality that affects the yield response of crops to fertilizer use (Hossain and Singh 2000).

Projecting the demand for plant nutrients in the future country helps in formulating strategy for production, imports, and subsidies, and it is always a challenge. The largest share of the central government's agriculture budget is spent on fertilizer subsidies (Anuja 2015), though its relevance has been questioned repeatedly in policy circles, especially as fiscal constraints rise, and who benefits remains a matter of debate. To reduce leakage and improve efficiency, cost-effectiveness, and the delivery of fertilizers, the government introduced a Direct Benefit Transfer mechanism.

Organic fertilizers and biofertilizers are being promoted through public intervention, but farm-level adoption, and diffusion across states, is lower than the projection (Ghosh 2004b). Chemical fertilizers emit nitrous oxide and leach soil nutrients; improving the adoption of organic fertilizers and biofertilizers would reduce the environmental costs. The grand challenge is to raise food production and lower the environmental externalities by reducing fertilizer use where it is excessive and raise it where it is needed. Manoeuvring nutrient subsidies is one way, and enquiries in this line will be challenging for future researchers, as specific case studies are crucial to set the course of action.

Are the current research priorities on fertilizers in line with the challenges?

We portray the latest research trends on the topic "fertilizers" in India as explored by applying the bibliometric approach to the bibliographic data collected from Web of Science core collection. The bibliometric technique helps to find out the research trend, focus, and the most influential authors, institutions, and countries in research on a topic. We identified and extracted the details of 1,887 studies on fertilizers published between 2010 and 2020 carried out, or based, in India on India. Together these were cited 14,625 times, each item being cited 7.75 times on average.

The total citations and the sum of the times cited (Figure 4) show a steadily increasing trend, indicating the

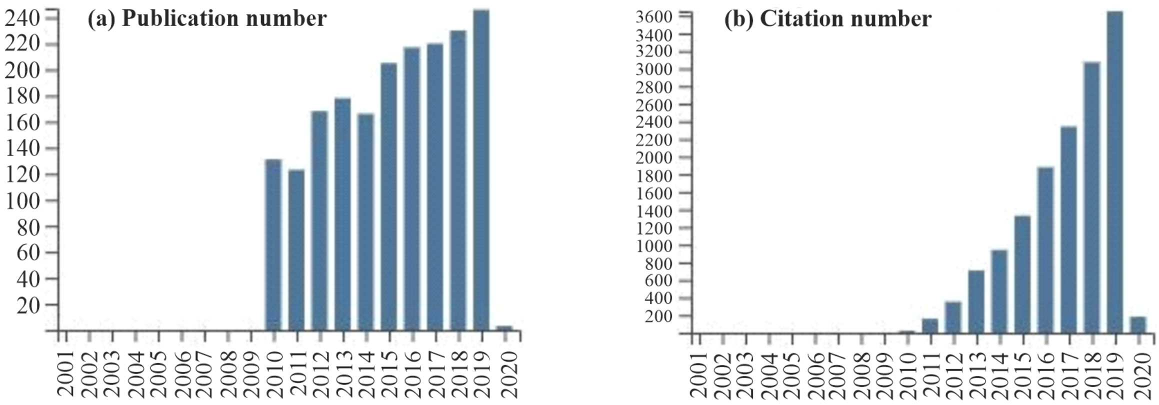

Figure 4 Research trends on fertilizers (a) number of publications (b) number of citations (2010-2020)

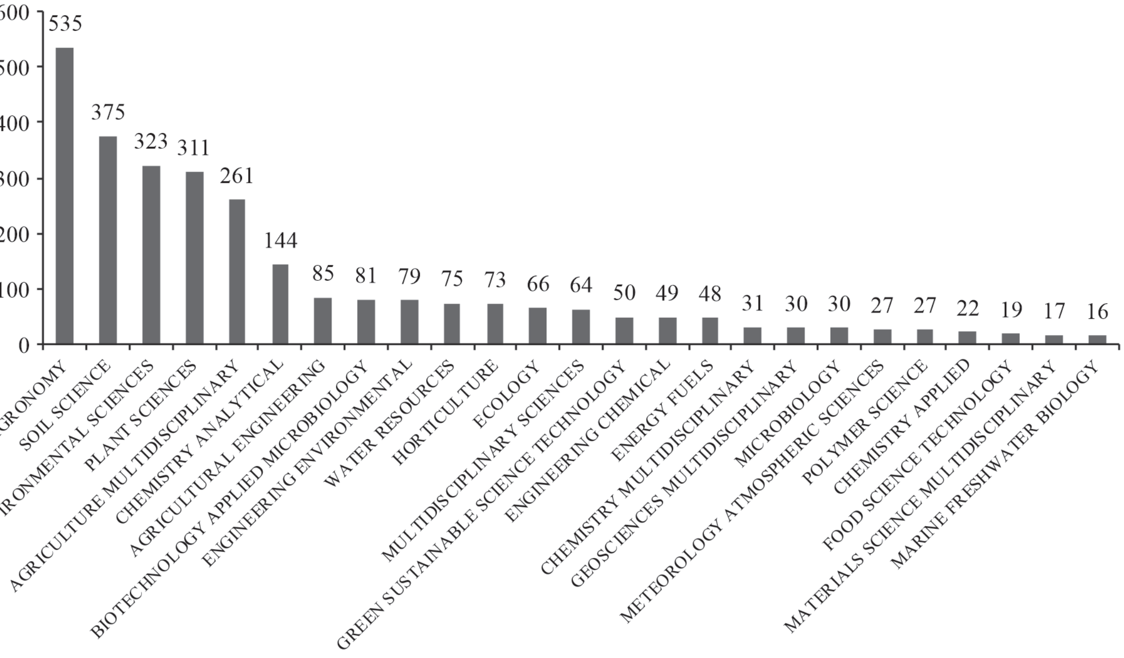

Figure 5 Subject wise number of publications

importance of the research on fertilizers. Agronomy has a 28% share in the number of publications, followed by soil science (20%), environmental science (17%), plant sciences (16%), and agriculture multidisciplinary (13%) (Figure 5). Of all the studies on fertilizers in the 10-year period (2010–2020), 144 were cited more than 25 times, 37 more than 50 times, and 3 studies were cited more than 100 times. The high level of citations points to the research attention that good publications on fertilizers attract.

Influential articles and journals

The articles that are cited the most are identified as being influential (Table 2). The most widely cited Indian studies on fertilizers published between 2010 and 2020 deal primarily with the treatment of the fertilizer industry wastes, greenhouse gas emissions, conservation agriculture, climate change mitigation, the effect of fertilizers on soil organic carbon, and the utilization of biofertilizers for biofortification.

We consider an article cited more than 25 times 'highly cited'. Table 3 presents the bibliometric details of the influential journals publishing highly cited articles on fertilizers. The lead journals identified are *Field Crops Research*, *Soil & Tillage Research*, *Bioresource Technology*, *Plant and Soil*, and *Nutrient Cycling in Agroecosystems*.

Table 2 Most influential articles

Title	Authors	Journal	Year	Total citations	Average per year
Adsorption studies on the removal of hexavalent chromium from aqueous solution using a low-cost fertilizer industry waste material	Gupta, Vinod K; Rastogi, Arshi; Nayak, Arunima	*Journal of Colloid and Interface Science*	2010	413	37.55
Effects of rice straw and nitrogen fertilization on greenhouse gas emissions and carbon storage in tropical flooded soil planted with rice	Bhattacharyya, P; Roy, K S; Neogi, S; Adhya, T K; Rao, K S; Manna, M C	*Soil & Tillage Research*	2012	119	13.22
Does conservation agriculture deliver climate change mitigation through soil carbon sequestration in tropical agroecosystems?	Powlson, David S; Stirling, Clare M; Thierfelder, Christian; White, Rodger P; Jat, M L	*Agriculture Ecosystems & Environment*	2016	93	18.60
Long-term manuring and fertilizer effects on depletion of soil organic carbon stocks under pearl millet-cluster bean-castor rotation in western India	Srinivasarao, Ch; Venkateswarlu, B; Lal, R; Singh, A K; Kundu, S; Vittal, K P R; Patel, J J; Patel, M M	*Land Degradation & Development*	2014	92	13.14
Biofortification of wheat through inoculation of plant growth-promoting rhizobacteria and cyanobacteria	Rana, Anuj; Joshi, Monica; Prasanna, Radha; Shivay, Yashbir Singh; Nain, Lata	*European Journal of Soil Biology*	2012	83	9.22

Table 3 Top 10 journals publishing highly cited articles

Journal	Number of highly cited articles	Total citations of highly cited articles	Citation per highly cited article	Journal impact factor
Field Crops Research	11	450	40.9	4.308
Soil & Tillage Research	10	555	55.5	4.601
Bioresource Technology	9	543	60.3	7.539
Plant and Soil	7	377	53.9	3.299
Nutrient Cycling in Agroecosystems	6	266	44.3	2.450
Agriculture Ecosystems & Environment	4	260	65.0	4.241
Biology and Fertility of Soils	3	136	45.3	5.521
Ecological Engineering	3	129	43.0	3.512
European Journal of Soil Biology	3	185	61.7	2.285
Geoderma	3	153	51.0	4.848

Field Crops Research published 11 highly cited articles, the largest number of all journals. *Soil & Tillage Research* has the most citations and *Agriculture Ecosystems & Environment* the highest average citations per article.

Research focus on fertilizers

We used a co-occurrence network of author keywords to identify research focus and interests (Figure 6). 'Crop yield' occurred 123 times, indicating that crop yield is the prime focus of fertilizer research. Soil fertility (73), rice (69), wheat (63), economics (51), and nutrient uptake (50) are the other important themes.

We used the keywords to map the co-occurrence network and find linkages between research themes. We used VOSviewer to map seven clusters and the linkages between the keywords.

The first cluster is formed around 'crop yield' and 18 other research themes (the effects of fertilizers on crop yield, the economics of fertilizer application, nutrient uptake, soil properties, soil health, etc.).

The second cluster (18 themes) of the co-occurrence network map, surrounding 'rice', is concerned with the productivity and profitability of rice, nitrogen use efficiency, sustainability, the nutrient balance effect of climate change, water productivity, tillage, etc.

The third cluster (16 themes) focuses on the effect of the application of chemical and organic fertilizers, biofertilizers, and micronutrients on wheat and on soil quality.

The fourth cluster (16 themes) studies the environmental effects of fertilizer application, such as global warming and the emission of nitrous oxide and methane, and the management of soil organic carbon (by practising conservation agriculture and using farmyard and poultry manure, and crop residue and biomass).

The fifth cluster (12 themes) studies adsorption, biochar utilization, heavy metals contamination, and the management and disposal of hazardous materials like wastewater.

The sixth cluster studies ways to improve grain yields (using fertilizers) and nutrient use efficiency (using types of irrigation).

The seventh cluster studies the fertility and nutrient uptake of soil types.

The network map based on the bibliometric data helps to identify institutions that can produce quality research evidence especially when many organizations study a topic. Figure 7 shows the co-authorship network of the organizations that research fertilizers.

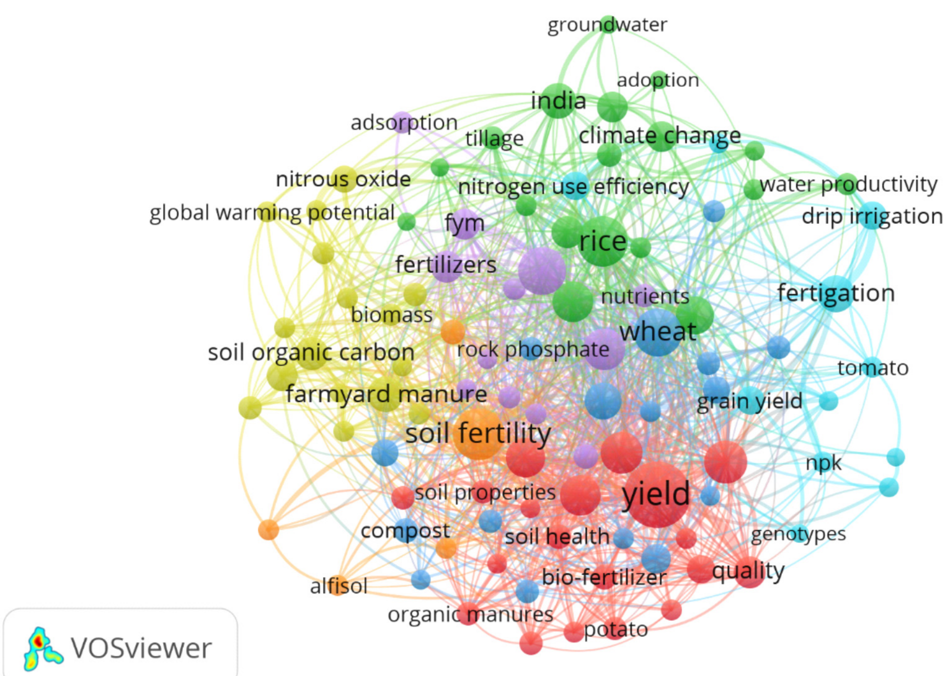

Figure 6 Co-occurrence network of the most frequently used author keywords

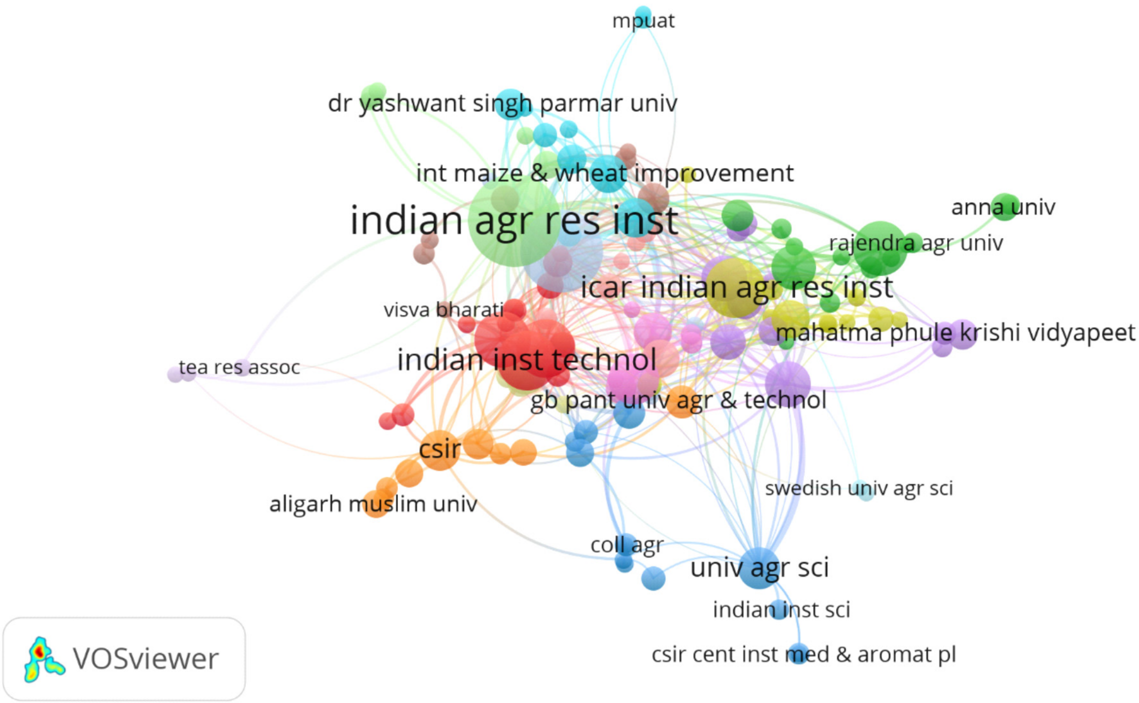

Figure 7 Co-authorship network between organizations

Over 1,400 organizations worldwide published articles on fertilizer research in India. The key international organizations are CIMMYT, Ohio State University, and International Rice Research Institute (IRRI).

The ICAR-Indian Agricultural Research Institute published 204 documents that were cited 1,696 times. The other key organizations are Punjab Agricultural University, Indian Institute of Soil Science, Central Research Institute for Dryland Agriculture, Bidhan Chandra Krishi Viswavidyalaya, and ICAR. The link strength values were the highest for ICAR-IARI (95) and Punjab Agricultural University (40), pointing towards their linkage with other organizations for fertilizer research.

The co-occurrence network of author keywords shows that researchers are focused primarily on the food security of the country, as indicated by the extensive research on rice and wheat yield. They are studying most of the challenges that we identified, such as the externalities of fertilizer application, the possibilities of reducing such negative effects through the conjunctive use of biofertilizers and organic fertilizers, nutrient use efficiency, and crop yield response to fertilizers. Research is under way to recommend location-specific fertilizers based on soil quality and their nutrient absorption capacity.

However, we detected the absence of high-quality social science research on fertilizers. Research is needed in social dimensions and ground-level evidence, as it can form the foundation for sound policies on fertilizers.

Conclusions

This paper tests the effect of key policies on fertilizer consumption in India and tracks the transition in its trends. We use national and state-level time series data for the period between 1972 and 2017. We conduct a bibliometric analysis to identify the research focus on fertilizers in India and juxtapose it with the emerging challenges.

It is widely accepted that the use of chemical fertilizers is increasing, but our study identifies that in this decade (2010–2020), the growth in the use of fertilizer nutrients has been low or negative. This is a new, country-level trend.

Importantly, the rate of growth in fertilizer use intensity across states is such that fertilizer use is moving slowly from where it has peaked to where it has a better role to play. Our analysis finds that the key policies have been effective in manoeuvring fertilizer consumption. Our bibliometric analysis finds that the research being undertaken now focuses on the challenges that we need to address soon. However, no high-quality social science research has been conducted on fertilizers from India during the study period the absence of is a caveat identified.

The findings from this study have some policy implications, especially concerning future reforms.

Policymakers targeted a reduction in the excessive use of chemical fertilizers was, but the low growth in nitrogen consumption in this decade and the negative growth in phosphorus and potash should be viewed in the context of soil nutrient balance. Care should be taken so that phosphorus and potash consumption does not fall low enough to upset the nutrient balance.

The growth in the intensity of fertilizer use in the eastern states has been high. That is heartening because the base level of fertilizer use in these states is low. Enough support should be extended to regions where the base level of fertilizer use is low so that we can reap the benefits of the higher intensity of fertilizer use.

The policies have had significant, long-term effects on fertilizer consumption because the reform measures have been well thought, framed, and implemented.

Academia considers fertilizer research important, as evidenced by the multidisciplinary nature, and growth, of high-quality literature. However, effort needs to be made to generate high-quality social science research based on ground-level data and on better stakeholder feedback to assess the impact of policies.

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References

Adhya, T, T Sapkota, and R Khurana. 2016. *AFOLU emissions*. Version 1.0 dated July 15, 2016, from GHG platform India: GHG platform India-2007-2012 National Estimates - 2016 Series. http://ghgplatform-india.org/data-and-emissions/afolu.html

Anuja, V. 2015. *Fertiliser quality in India -an assessment of fertiliser quality control, farmers' awareness and determinants of consumer choice*. Dissertation submitted to London School of Economics and Political Science, London, United Kingdom. http://www.academia.edu/download/43140221/Fertiliser_Quality_in_India.pdf

Chand, R, and S Pavithra.2015. Fertiliser use and imbalance in India. *Economic & Political Weekly* 50 (44): 98–104. https://www.epw.in/journal/2015/44/special-articles/fertiliser-use-and-imbalance-india.html

Fertilizer Association of India. 2019. *Fertilizer statistics 2018-19*. FAI, New Delhi.

Ghosh, N. 2004a. Reducing dependence on chemical fertilizers and its financial implications for farmers in India. *Ecological Economics* 49 (2): 149-162. doi:10.1016/j.ecolecon.2004.03.016

Ghosh, N. 2004b. Promoting biofertilisers in Indian agriculture. *Economic and Political Weekly* 39 (52): 5617–5625. https://www.epw.in/journal/2004/52/review-agriculture-review-issues-specials/promoting-biofertilisers-indian

Gulati, A, and P Banerjee. 2015. *Rationalising fertilizer subsidy in India: key issues and policy options.* Working Paper 307. Indian Council for Research on International Economic Relations. pp 1-9. http://icrier.org/pdf/Working_Paper_307.pdf

Hossain, M, and V P Singh. 2000. Fertilizer use in Asian agriculture: implications for sustaining food security and the environment. *Nutrient Cycling in Agroecosystems* 57 (2):155-169. doi.org/10.1023/A:1009865819925

Kanter, D R, Zhang X, and D L Mauzerall. 2015. Reducing nitrogen pollution while decreasing farmers' costs and increasing fertilizer industry profits. *Journal of Environmental Quality* 44(2): 325-335. doi: 10.2134/jeq2014.04.0173

Kapur, D. 2011. The shift to cash transfers: running better but on the wrong road? *Economic and Political Weekly* 46 (21): 80-85. https://www.epw.in/journal/2011/21/perspectives-cash-transfers-special-issues-specials/shift-cash-transfers-running

Kishore, A, K V Praveen, and D Roy. 2013. Direct cash transfer system for fertilisers. *Economic and Political Weekly* 48(52): 54-63. https://www.epw.in/journal/2013/52/review-rural-affairs-review-issues/direct-cash-transfer-system-fertilisers.html

Linden, A, and J L Adams. 2011. Applying a propensity score based weighting model to interrupted time series data: improving causal inference in programme evaluation. *Journal of Evaluation in Clinical Practice* 17(6): 1231-1238. doi: 10.1111/j.1365-2753.2010.01504.x.

Nafade V, M Nash, S Huddart S, T Pande, N Gebreselassie, C Lienhardt, and M Pai. 2018. A bibliometric analysis of tuberculosis research, 2007–2016. *PloS One* 13 (6): e0199706. doi.org/10.1371/journal.pone.0199706

Patra, S, P Mishra, S C Mahapatra, and S K Mithun. 2016. Modelling impacts of chemical fertilizer on agricultural production: a case study on Hooghly district, West Bengal, India. *Modeling Earth Systems and Environment* 2(4): 1-11. doi.org/10.1007/s40808-016-0223-6

Praveen K V. 2017. Indian fertilizer policies: revisiting the odyssey and lessons from abroad. *Current Science* 113 (7): 1246-1254. doi: 10.18520/cs/v113/i07/1246-1254

Praveen, K V. 2014. Evolution and emerging issues in fertilizer policies in India. *Economic Affairs 59* (2): 163-173. doi: 10.5958/j.0976-4666.59.2.016

Puttick, R. 2011.*Using Evidence to Improve Social Policy and Practice: Perspectives on how research and evidence can influence decision making*. NESTA. https://www.nesta.org.uk/sites/default/files/using_evidence_to_improve_social_policy_and_practice.pdf

Sharma, V P, and H Thaker H. 2011. Demand for fertilisers in India: determinants and outlook for 2020. *Indian Journal of Agricultural Economics* 66 (4): 638-661. https://ageconsearch.umn.edu/record/204787?ln=en

Van Eck, N J, and L Waltman. 2010. Software survey: VOSviewer, a computer program for bibliometric mapping. S*cientometrics* 84(2): 523-538. doi:10.1007/s11192-009-0146-3

Zhang, X, R C Estoque, H Xie H, Y Murayama, and M Ranagalage. 2019. Bibliometric analysis of highly cited articles on ecosystem services. *PloS One* 14 (2): e0210707. doi.org/10.1371/journal.pone.0210707