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Analyzing Fertilizer use and Nutrient Imbalance in Indian Agriculture: Causes, Consequences, and Sustainable Solutions

Suchitha S¹, Ritu Tyagi², Silambarasan³

Associate Professor, Department of Bachelor of Computer Applications, City College, Bengaluru, India¹

Assistant Professors, Department of Bachelor of Computer Applications, City College, Bengaluru, India^{2,3}

ABSTRACT: In India, there is a widely held belief that for fertilizer use to be balanced, the three main plant nutrients nitrogen, phosphorous, and potassium—must be applied in the ratio of 4:2:1. Any variation from this standard will limit agricultural production increase. Due to government perceptions shaped by tests conducted in the 1950s, incorrect fertilizer policies have been implemented. Contrary to the belief that nitrogen is used excessively in India, it was discovered that 12 main states used less nitrogen than was necessary when the actual and normative quantities of N, P, and K for each state were estimated based on the existing cropping pattern. India actually has significant deficiencies in the utilization of P and K. It suggests increasing N use in the remaining two-thirds of the states and decreasing it in one-third of them.

KEYWORDS: Fertilizer Imbalance, Nutrient Deficiency, Nitrogen Use, Phosphorus and Potassium Utilization, Agricultural Productivity in India

I. INTRODUCTION

With the development of Green Revolution technology, fertilizer use has increased dramatically in India and other parts of the world. In addition to seed and irrigation, fertilizer was found to be one of the three most crucial elements for increasing agricultural output and maintaining food self-sufficiency in India. According to empirical data, India's agricultural output growth both overall and for individual crops has fluctuated in tandem with the country's use of fertilizer (Chand and Pandey 2009). It is anticipated that fertilizer will remain essential to supplying food, feed, and fiber in the future. The application of fertilisers can significantly enhance productivity, particularly as the potential for increasing production through the expansion of arable land is nearly exhausted. Consequently, it is crucial to evaluate whether fertiliser is being utilized wisely and effectively from the perspective of output growth. In India, the total consumption of fertilisers, which includes nitrogenous (N), phosphatic (P), and potassic (K) types, rose from 2.65 million tonnes (mt) of NPK in the fiscal year 1971–72 to 28.12 mt in 2010–11. This growth represents an annual compound growth rate exceeding 6%. However, the increase varied considerably among the three essential nutrients—nitrogen, phosphorus, and potash—over different time periods. Until the mid-1990s, the usage of nitrogen grew at a more rapid pace compared to phosphorus and potash. Specifically, the growth rate of nitrogen usage was nearly double that of potash from 1971–72 to 1996–97. In the early 1970s, Indian farmers applied N, P, and K in a ratio of 6.0:1.9:1.0, which evolved to 9.5:3.2:1 by 1992. This ratio deteriorated further to 10:2.9:1 in 1996.

Following the period of 1996–97, there was a notable increase in the application of phosphatic and potassic fertilizers, which significantly outpaced the growth of nitrogenous fertilizers. Nevertheless, the overall usage of fertilizers continued to be disproportionately weighted towards nitrogen. By the fiscal year 2012–13, the ratio of nitrogen, phosphorus, and potassium (NPK) usage in India had escalated to 8.2:3.2:1, reflecting a greater imbalance than observed in the early 1970s, when the ratio stood at 6:1.9:1. In India, there is a prevailing consensus that the optimal ratio for maintaining nutrient equilibrium among nitrogen, phosphorus, and potassium is 4:2:1, with any significant deviation from this benchmark believed to negatively impact both crop yields and soil health (Tiwari 2001; NAAS 2009; Mujeri et al. 2012; Sharma 2012). This disparity was acknowledged early on, prompting official reports and academic research to voice ongoing concerns regarding the necessity to rectify the escalating imbalance (GoI 1994, 2014; Gulati and Sharma 1995).

The recent transition in fertiliser policy towards a nutrient-based subsidy has primarily been driven by concerns regarding the efficacy and appropriateness of existing practices. This paper aims to explore the empirical foundations of

what is deemed the optimal composition of nitrogen (N), phosphorus (P), and potassium (K) in total fertiliser application, while also assessing its contemporary relevance in agricultural practices. Research on the balanced application of N, P, and K indicates that the widely accepted 4:2:1 ratio, which has been regarded as a fundamental guideline in India, lacks robust scientific validation and is increasingly irrelevant to current agricultural contexts. Originally formulated in the early 1960s, this norm was intended to align with the crop patterns, yield levels, and soil conditions of that era. However, significant transformations in these factors over the decades necessitate a reevaluation of fertiliser requirements, suggesting that policies governing fertiliser use and pricing should not rely on such an antiquated and empirically unsupported standard.

This study aims to determine the ideal proportions of nitrogen (N), phosphorus (P), and potassium (K) for the dominant cropping systems in India, drawing on state-specific fertilizer application guidelines developed by various state agricultural universities (SAUs) and the crop directorates of the Indian Council of Agricultural Research (ICAR). Given that the nutritional needs for N, P, and K differ across crops and soil types, the recommended ratios for these nutrients will inevitably vary across regions, reflecting the diverse cropping patterns, soil characteristics, and nutrient availability at any given time. In this context, the paper seeks to establish state-wise guidelines for the application and composition of N, P, and K, which are subsequently aggregated to formulate a comprehensive all-India standard.

The research provides an analysis of the recommended amounts of N, P, and K for each state, juxtaposing these figures with actual fertilizer usage. This comparison facilitates the identification of surpluses or deficiencies in the application of these essential nutrients at the state level. Furthermore, the paper argues that concerns regarding the imbalanced use of N, P, and K are often overstated, suggesting that policy interventions aimed at rectifying such imbalances may be unwarranted unless the specific nature of the imbalance is thoroughly understood. The study delineates scenarios where nutrient imbalances are significant and those where they are not, thereby contributing to a more nuanced understanding of fertilizer application. The structure of the paper is organized into several sections for clarity and coherence. The first section outlines the historical context of the optimal N, P, and K ratios in Indian agriculture and assesses their significance in the present landscape. The second section details the methodology employed to estimate the requirements for these nutrients, as well as the imbalances and discrepancies in fertilizer application across different states. The third section reviews trends in the utilization of N, P, and K, while the fourth section presents the calculated optimal quantities of these nutrients and contrasts them with actual usage across various states. Finally, the fifth section elaborates on the normative ratios for each state, providing a comprehensive overview of the findings.

The N, P, K ratio of 4:2:1 is widely regarded as optimal for agricultural practices in India, although tracing its exact origins proves challenging. This ratio is thought to have emerged from field trials conducted in the 1950s, prior to the Green Revolution, as noted by NAAS (2009). Prasad and Pathak, the editors of the same report, suggest that the predominant focus on nitrogenous fertilizers stemmed from the significant responsiveness of crops, particularly irrigated wheat, to nitrogen application compared to phosphorus and potassium. However, this ratio has been criticized for overlooking two critical aspects: first, during the Green Revolution, farmers utilized farmyard manure, and the native soils were already abundant in phosphorus and potassium; second, the effectiveness of applied phosphorus and potassium fertilizers was notably higher in red and lateritic soils, indicating that the NPK ratio should be adjusted based on soil type (NAAS 2009). Additionally, the fertilizer requirements for a specific state or country are influenced by various factors, including cropping patterns, yield levels, crop varieties, and evolving soil characteristics. In the early 1990s, the Indian government raised alarms regarding the deteriorating NPK ratio, emphasizing the necessity of maintaining the ideal 4:2:1 ratio to enhance crop yields (GoI 1994, 1995). In the years that followed, there has been a growing focus on the balanced application of nutrients and the reevaluation of the optimal NPK ratio tailored to specific crops and soil conditions. This shift in perspective is supported by findings from post-Green Revolution trials, which demonstrated that the response of rice to applied phosphorus was comparable to that of nitrogen, and even superior in the case of improved wheat varieties. Despite these insights, the overall fertilizer usage in India has remained disproportionately weighted towards nitrogen, highlighting the need for a more equitable distribution of nutrient application to optimize agricultural productivity.

II. METHODOLOGY

The overarching trend in fertiliser usage across India is crucial for the development of effective fertiliser policies; however, the significance of balanced fertiliser application becomes particularly pronounced at a more localized level. This is primarily due to the variability in cropping patterns among different states, which necessitates distinct levels and ratios of nitrogen, phosphorus, and potassium (NPK) for various crops. Consequently, the national averages of N, P, and K do not accurately reflect the discrepancies in their application, a reality that is more effectively captured through

disaggregated data at the state and agro-regional levels. As a result, this paper will now concentrate on the state-level analysis. 2. To estimate the normative quantity of fertiliser required for each state, calculations were based on the area dedicated to different crops and the recommended NPK doses for those crops, as outlined in the Package of Practices provided by State Agricultural Universities (SAUs) and Indian Council of Agricultural Research (ICAR) institutes. The formulas used for this estimation are as follows:

- $Dns = \sum_{Ci=1} (Ais_w * Rns_w) + (Ais_r * Rns_r)$,
- $Dps = \sum_{Ci=1} (Ais_w * Rps_w) + \sum_{Ci=1} (Ais_r * Rps_r)$, and
- $Dks = \sum_{Ci=1} (Ais_w * Rks_w) + (Ais_r * Rks_r)$.

In these equations, Dns, Dps, and Dks represent the desired levels of nitrogen, phosphorus, and potassium in state "s," respectively, while "w" and "r" denote irrigated and rain-fed areas. Here, "A" signifies the area under crop "i" in state "s," and "R" refers to the recommended nutrient dosage. In certain states, this disaggregation was further refined to the agroclimatic region level.

The recommended application rates for nitrogen (N), phosphorus (P), and potassium (K) to crops are determined using the following formula (Prasad 2012):

Nutrient to be applied = $[\{\text{yield (t/ha)} \times \text{nutrient uptake (kg/t)}\} - \{\text{nutrient available in soil (kg/ha)}\}] \times 100/\text{NUE}$.

For instance, in the case of rice with a yield of 6 t/ha and a nitrogen removal rate of 20 kg N/t, where the soil contains 60 kg of available N/ha and the nutrient use efficiency (NUE) is 40%, the required nitrogen application would be calculated as:

$$= [(6 \times 20) - (60)] \times 100/40 = 150 \text{ kg N/ha.}$$

The values of Dns, Dps, and Dks were analyzed in relation to the actual consumption of N, P, and K across various states to assess the discrepancies in fertilizer application and to identify the differences between optimal and actual fertilizer usage.

This analysis aims to highlight the imbalances in nutrient application practices and to provide insights for improving fertilizer management strategies in agricultural systems.

III. TRENDS AND COMPOSITION OF FERTILISER USE IN INDIA

In the period from 1971 to 1972, India's total fertilizer consumption reached 2.65 million tonnes, comprising 1.79 million tonnes of nitrogen (N), 0.56 million tonnes of phosphorus (P), and 0.30 million tonnes of potassium (K). This figure steadily rose to 28.1 million tonnes by the 2010-2011 period, although a slight decrease was observed in the last three years. The distribution of N, P, and K in total fertilizer usage since 1971-72 is detailed in Table 1. The officially recognized optimal ratio of 4:2:1 indicates that nitrogen should make up 57.2% of total NPK consumption, while phosphorus and potassium should account for 28.6% and 14.2%, respectively. In the early 1970s, nitrogenous fertilizers represented two-thirds of the total, with phosphatic and potassic fertilizers contributing 21% and 11% of the total share, respectively (see Table 1). Throughout most years, nitrogen's share in total fertilizer usage remained around 65%, which is 8 percentage points above the officially recommended 4:2:1 ratio.

Over the past four decades, the evolution of fertiliser composition concerning nitrogen (N), phosphorus (P), and potassium (K) has been marked by three significant phases. The initial phase occurred during 1974-75, when nitrogen's proportion in overall fertiliser consumption surged to 68.64%, escalating further to 74.3% by 1975-76. This period coincided with the oil crisis, which led to a dramatic increase in global fertiliser prices, rising two to four times within a single year in nominal terms. Notably, the price hike was more pronounced for nitrogenous fertilisers, particularly urea, compared to potassic and phosphatic varieties. Despite this, the impact on the usage of phosphorus and potassium was more substantial than on nitrogen. Following this peak, nitrogen's share in total fertiliser use gradually diminished, reaching a low of 63.2% by 1991-92, the lowest level recorded up to that time. In 1992, the government acknowledged the necessity to curtail subsidies, as highlighted in a report from the Government of India in 1993.

The deregulation of prices, distribution, and movement of phosphatic and potassic fertilizers took effect on August 25, 1992. In contrast, urea, which is the primary nitrogenous fertilizer in India, experienced no significant changes,



although its price was lowered following trials with dual pricing strategies. This shift in fertilizer policy during the mid-1992 period led to a notable increase in the prices of phosphorus (P) and potassium (K) fertilizers, both in absolute terms and relative to nitrogen (N) prices in the fiscal year 1992-93. Consequently, this policy-driven alteration in the relative pricing of N, P, and K fertilizers reversed the previously declining trend in the share of nitrogen in total fertilizer consumption.

Following the implementation of this policy change, the proportion of nitrogen in total fertilizer usage, which had been decreasing since the mid-1970s, began to rise again after 1991-92. This trend indicates a significant shift towards an increased share of nitrogen, accompanied by a decline in the shares of phosphorus and potassium, thereby highlighting an imbalance in fertilizer application that was influenced by policy decisions. The data clearly illustrates that the adjustments made in fertilizer policy had a direct impact on the distribution of fertilizer types used in agricultural practices.

Table 1: Trend in Fertiliser Use and Its composition

| Year | Total Use of NPK, Share '000 Tonne | N % | Share P % | Share K % |
|---------|---------------------------------------|-------|--------------|--------------|
| 1971-72 | 2,657 | 67.67 | 21.00 | 11.33 |
| 1972-73 | 2,768 | 66.44 | 20.99 | 12.57 |
| 1973-74 | 2,839 | 64.42 | 22.90 | 12.68 |
| 1974-75 | 2,573 | 68.64 | 18.34 | 13.06 |
| 1975-76 | 2,894 | 74.26 | 16.14 | 9.61 |
| 1976-77 | 3,411 | 72.03 | 18.62 | 9.35 |
| 1977-78 | 4,286 | 67.97 | 20.23 | 11.81 |
| 1978-79 | 5,117 | 66.84 | 21.61 | 11.55 |
| 1979-80 | 5,255 | 66.57 | 21.90 | 11.53 |
| 1980-81 | 5,516 | 66.68 | 22.01 | 11.31 |
| 1981-82 | 6,067 | 67.07 | 21.79 | 11.14 |
| 1982-83 | 6,401 | 66.27 | 22.39 | 11.34 |
| 1983-84 | 7,710 | 67.50 | 22.44 | 10.05 |
| 1984-85 | 8,211 | 66.81 | 22.97 | 10.21 |
| 1985-86 | 8,474 | 66.80 | 23.66 | 9.54 |
| 1986-87 | 8,645 | 66.12 | 24.05 | 9.83 |
| 1987-88 | 8,784 | 65.08 | 24.90 | 10.02 |
| 1988-89 | 11,040 | 65.68 | 24.65 | 9.67 |
| 1989-90 | 11,568 | 63.85 | 26.05 | 10.10 |
| 1990-91 | 12,546 | 63.74 | 25.67 | 10.59 |
| 1991-92 | 12,728 | 63.21 | 26.09 | 10.69 |
| 1992-93 | 12,155 | 69.33 | 23.40 | 7.27 |
| 1993-94 | 12,366 | 71.07 | 21.58 | 7.35 |
| 1994-95 | 13,563 | 70.10 | 21.62 | 8.29 |
| 1995-96 | 13,876 | 70.79 | 20.88 | 8.33 |
| 1996-97 | 14,308 | 72.00 | 20.81 | 7.20 |
| 1997-98 | 16,195 | 67.34 | 24.19 | 8.48 |
| 1998-99 | 16,773 | 68.36 | 23.85 | 7.78 |
| 1999-00 | 18,070 | 64.16 | 26.55 | 9.29 |
| 2000-01 | 16,631 | 65.31 | 25.33 | 9.36 |
| 2001-02 | 17,360 | 65.15 | 25.24 | 9.60 |
| 2002-03 | 16,094 | 65.08 | 24.97 | 9.95 |
| 2003-04 | 16,631 | 66.60 | 24.80 | 9.60 |
| 2004-05 | 18,399 | 63.67 | 25.13 | 11.20 |
| 2005-06 | 20,340 | 62.55 | 25.58 | 11.86 |
| 2006-07 | 2,1651 | 63.61 | 25.60 | 10.78 |
| 2007-08 | 22,570 | 63.89 | 24.44 | 11.68 |
| 2008-09 | 24,909 | 60.58 | 26.12 | 13.30 |
| 2009-10 | 26,486 | 58.82 | 27.46 | 13.71 |
| 2010-11 | 28,122 | 58.88 | 28.62 | 12.50 |
| 2011-12 | 27,790 | 62.25 | 28.48 | 9.27 |
| 2012-13 | 25,804 | 69.86 | 23.07 | 7.02 |
| 2013-14 | 23,959 | 68.97 | 22.70 | 8.24 |



After the initial policy distortion, the share of nitrogen began to decline once more after 1996-97, ultimately reaching 58.8% by 2009-10, which was marginally above the officially recognized standard of 57.2%. The shares of phosphorus and potassium were also close to the accepted norms at the national level, although disparities existed among different states. On April 1, 2010, the government launched the nutrient-based subsidy (NBS) policy aimed at promoting balanced fertilizer application. While the NBS was implemented for phosphorus and potassium, it did not extend to urea, leading to a renewed distortion in pricing favouring nitrogen. Within just two years of the NBS's introduction, the nitrogen share surged by 11 percentage points, from 58.8% to 69.8%, effectively negating any progress made towards achieving a balanced use of nitrogen, phosphorus, and potassium. The analysis of fertiliser composition over the past forty years indicates that, in response to specific pricing structures, farmers have made efforts to correct the disparities in fertiliser application. Nevertheless, external shocks and alterations in fertiliser policy have consistently led to a significant increase in the proportion of nitrogenous fertilisers, while the shares of phosphorus and potassium have diminished within the overall fertiliser usage. Contrary to the intended objectives of the policy reforms aimed at balancing the use of nitrogen, phosphorus, and potassium, the outcomes have been counterproductive, exacerbating the existing imbalances instead.

IV. ACTUAL AND NORMATIVE USE AT STATE LEVEL

The current levels of fertilizer application across various states, along with the optimal quantities determined by multiplying the area cultivated with different crops by the recommended doses of nitrogen (N), phosphorus (P), and potassium (K) from agricultural research institutes during the triennium of 2009–10 to 2011–12, are detailed in Table 2. The data reveals that states such as Andhra Pradesh, Assam, Punjab, Bihar, Haryana, and Jharkhand have exceeded the recommended levels of nitrogenous fertilizer use, while Odisha's application is close to the optimal amount. Conversely, other states are utilizing nitrogen below the suggested norms, highlighting a significant imbalance characterized by both surplus and deficiency in nitrogen application. For example, Andhra Pradesh's normative nitrogen requirement was estimated at 1,138 thousand tonnes, yet the actual usage reached 1,884 thousand tonnes, resulting in an excess of 746 thousand tonnes.

In contrast, West Bengal and Kerala exhibited a shortfall in nitrogen fertilizer application, with normative levels set at 1,412 thousand tonnes and 227 thousand tonnes, respectively, while actual usage was only 753 thousand tonnes and 116 thousand tonnes—merely half of what is necessary for their current cropping systems. On a national scale, the total normative nitrogen requirement for India was approximately 17 million tonnes, which closely aligns with the actual nitrogen usage. Additionally, the normative phosphorus requirement for the country was around 9.46 million tonnes, whereas the actual application was about 7.65 million tonnes. Our analysis indicates that the phosphorus usage in Madhya Pradesh, Uttar Pradesh, and West Bengal falls significantly short of the recommendations tailored to their existing cropping patterns.

Table 2: Normative and Actual Use of N, P and K, Triennium Ending 2011–12

| State | Normative Use: Thousand Tonne | | | | Actual Use: Thousand Tonne | | | |
|------------------|-------------------------------|-----|-----|-------|----------------------------|-----|-----|-------|
| | N | P | K | Total | N | P | K | Total |
| Andhra Pradesh | 1,138 | 679 | 474 | 2,291 | 1,884 | 984 | 433 | 3,300 |
| Assam | 124 | 90 | 70 | 284 | 140 | 52 | 72 | 265 |
| Bihar | 688 | 368 | 245 | 1,301 | 921 | 265 | 136 | 1,322 |
| Chhattisgarh | 498 | 298 | 208 | 1,005 | 323 | 167 | 61 | 552 |
| Gujarat | 1,247 | 450 | 456 | 2,153 | 1,198 | 483 | 174 | 1,855 |
| Haryana | 807 | 339 | 202 | 1,348 | 996 | 350 | 51 | 1,397 |
| Himachal Pradesh | 82 | 43 | 33 | 158 | 33 | 11 | 11 | 54 |
| Jharkhand | 84 | 51 | 42 | 177 | 97 | 45 | 14 | 156 |

In regions such as Gujarat, Karnataka, Punjab, and Tamil Nadu, the actual application of phosphorus significantly exceeded the recommended levels. The total potassium usage across the nation was recorded at 3.26 million tonnes, while our analysis suggests that the ideal potassium requirement for India stands at 6.6 million tonnes. With the exception of Tamil Nadu and Assam, potassium utilization in all other states fell short of the optimal levels. This discrepancy highlights the need for improved management and application of potassium to meet the agricultural demands across the country.



4.1 Extent of Excess and Deficit Use

At the national level, there was a shortfall in the application of all three categories of plant nutrients, although the deficiency for nitrogen (N) was minimal, as indicated in Table 3. The degree of deficiency ranged from 3.3% for nitrogen to 51% for potassium (K), with significant disparities observed among different states. Among the 20 major states, Andhra Pradesh, Haryana, and Punjab were notable for their excessive use of total fertilizers, surpassing the necessary amounts. However, despite this over-application, these states still experienced a deficiency in potassium.

| State | N | P | K | Total |
|-------------------|--------|--------|--------|--------|
| Andhra Pradesh | 65.52 | 44.83 | -8.73 | 44.02 |
| Assam | 12.81 | -41.70 | 2.97 | -6.85 |
| Bihar | 33.88 | -28.09 | -44.61 | 1.57 |
| Chhattisgarh | -35.09 | -44.05 | -70.52 | -45.09 |
| Gujarat | -3.94 | 7.38 | -61.90 | -13.85 |
| Haryana | 23.32 | 3.36 | -74.83 | 3.58 |
| Himachal Pradesh | -60.30 | -74.12 | -67.19 | -65.48 |
| Jharkhand | 15.95 | -11.74 | -67.91 | -11.98 |
| Jammu and Kashmir | -23.06 | -43.73 | -59.33 | -35.41 |
| Karnataka | -1.43 | 1.94 | -39.27 | -10.98 |
| Kerala | -48.72 | -63.60 | -73.91 | -63.90 |
| Madhya Pradesh | -10.51 | -43.52 | -75.78 | -35.70 |
| Maharashtra | -7.96 | -9.25 | -14.43 | -9.57 |
| Odisha | 0.69 | -11.56 | -52.70 | -16.66 |
| Punjab | 44.86 | 12.15 | -72.31 | 19.38 |
| Rajasthan | -37.68 | -50.04 | -74.42 | -43.99 |
| Tamil Nadu | -4.44 | 4.82 | -0.06 | -1.38 |
| Uttarakhand | -27.95 | -59.96 | -77.66 | -45.08 |
| Uttar Pradesh | -6.63 | -27.31 | -75.21 | -24.80 |
| West Bengal | -46.68 | -35.59 | -50.20 | -44.72 |
| Others | -73.96 | -84.65 | -89.91 | -81.56 |
| All India | -3.31 | -19.14 | -51.09 | -17.44 |

Table 3: State-wise Excess/Deficit of NPK %: (Normative–Actual)/Normative

| | N | P | K | Total | N | P | K | Total |
|-------------------|--------|-------|-------|--------|--------|--------|-------|--------|
| Jammu and Kashmir | 95 | 57 | 29 | 181 | 73 | 32 | 12 | 117 |
| Karnataka | 1,043 | 655 | 651 | 2,349 | 1,028 | 668 | 395 | 2,091 |
| Kerala | 227 | 164 | 349 | 740 | 116 | 60 | 91 | 267 |
| Madhya Pradesh | 1,080 | 1,181 | 449 | 2,710 | 967 | 667 | 109 | 1,742 |
| Maharashtra | 1,745 | 1,176 | 654 | 3,575 | 1,606 | 1,067 | 560 | 3,233 |
| Odisha | 313 | 177 | 176 | 666 | 316 | 156 | 83 | 555 |
| Punjab | 951 | 375 | 235 | 1,561 | 1,377 | 421 | 65 | 1,863 |
| Rajasthan | 1,335 | 742 | 130 | 2,206 | 832 | 371 | 33 | 1,235 |
| Tamil Nadu | 673 | 270 | 298 | 1,241 | 643 | 283 | 298 | 1,224 |
| Uttarakhand | 162 | 75 | 51 | 288 | 117 | 30 | 11 | 158 |
| Uttar Pradesh | 3,210 | 1,436 | 1,085 | 5,731 | 2,997 | 1,044 | 269 | 4,310 |
| West Bengal | 1,412 | 762 | 764 | 2,938 | 753 | 491 | 381 | 1,624 |
| Others | 114 | 82 | 73 | 270 | 30 | 13 | 7 | 50 |
| All India | 17,030 | 9,469 | 6,675 | 33,174 | 16,466 | 76,578 | 3,264 | 27,387 |

The prevailing belief is that farmers in India tend to overapply nitrogen fertilizers. However, this assertion holds true only for six specific states: Andhra Pradesh, Assam, Bihar, Haryana, Jharkhand, and Punjab. In contrast, both Karnataka and Odisha demonstrate nitrogen usage that aligns closely with the recommended levels. Furthermore, in twelve other states, nitrogen application falls below the optimal recommendations set forth by State Agricultural Universities (SAUs) and the Indian Council of Agricultural Research (ICAR), with deficiencies ranging from 4.4% to 60%. In terms of phosphorus (P) usage, farmers in Haryana are reported to apply 45% more than the recommended

levels. Other states also exceed the optimal phosphorus application, with increases of 3.4% in Haryana, 4.8% in Tamil Nadu, 7.4% in Gujarat, and 12% in Punjab. Conversely, in several states, phosphorus application is significantly below the recommended doses, with deficiencies ranging from 9% to 64%. Notably, farmers in Assam have a slight excess of 3% in potassium (K) usage, while Tamil Nadu shows no significant deviation from the desired levels. However, most other states exhibit a potassium deficiency ranging from 8.7% to 78%. The overall analysis indicates that the national picture of nitrogen, phosphorus, and potassium (NPK) usage does not reflect the significant variations at the state level. Less than one-third of the states are characterized by excessive nitrogen application, while a substantial two-thirds are underutilizing it. Additionally, only one-fifth of the states report excess phosphorus usage. The area of cultivation facing nitrogen deficiency is considerably larger than that experiencing excess application. Therefore, it is essential to implement policies aimed at reducing nitrogen use in the six states identified while simultaneously promoting its application in the remaining states.

V. STATE-WISE NORMATIVE RATIO OF FERTILISER USE

As initially highlighted, it is essential to reassess the established norm for the NPK mix in light of the significant changes in cropping patterns and agricultural methodologies. Given the current agricultural landscape in India, a thorough examination of the 4:2:1 ratio is warranted, as it requires discussion and potential redefinition (GoI 2001; Prasad 2012). Furthermore, the national norm reflects an aggregate scenario that may not accurately represent the specific conditions at the state level. This paper aims to estimate the normative fertilizer use ratios for various states, taking into account state-specific and crop-specific recommendations alongside the prevailing cropping patterns. The findings regarding the normative ratios and actual usage of nitrogen, phosphorus, and potassium across states are detailed in Table 4, utilizing a three-year average to account for annual fluctuations. The analysis indicates that the optimal ratio for the balanced application of N, P, and K in India should be adjusted to 2.6:1.4:1, based on the current cropping patterns and the recommended fertilizer doses from State Agricultural Universities (SAUs). This proposed norm diverges significantly from the existing standard, which suggests that nitrogen should represent 52% of the total fertilizer applied, while phosphorus and potassium should account for 28% and 20%, respectively. In contrast, the traditional 4:2:1 ratio implies that nitrogen should make up 57.8%, with phosphorus and potassium at 28.6% and 14%, respectively. This discrepancy highlights the need for a reevaluation of fertilizer application practices in light of contemporary agricultural demands.

The state-level analysis conducted in this study reveals that the current 4:2:1 norm aligns closely with the estimated norm only within the traditional Green Revolution regions of north-west India. This correlation is expected, as the existing norm was derived from agronomic trials conducted in this area, primarily focusing on wheat and paddy crops that dominate the local cropping systems. In contrast, the optimal NPK mix for other states, excluding Rajasthan, suggests a lower proportion of nitrogen and a higher proportion of phosphorus and potassium than what the 4:2:1 ratio indicates. This finding underscores the necessity for tailored fertilizer recommendations that reflect the unique agricultural contexts of different states across India.

VI. CONCLUSIONS

The future of agricultural productivity will increasingly depend on the effective use of fertilizers, especially as critical resources such as land and water are under significant pressure. To achieve optimal nutrient application, it is essential to implement policies that support this goal. Historically, fertilizer policies in India have focused on decreasing the proportion of nitrogen (N) while increasing the shares of phosphorus (P) and potassium (K) in total fertilizer consumption. This approach is grounded in the belief that the ideal nutrient ratio of N, P, and K should be 4:2:1, with any deviation from this standard potentially hindering productivity growth. However, this established norm can also lead to negative consequences. The analysis presented in this paper argues that the current NPK ratio lacks a scientific basis in the present context. Such guidelines are only relevant when considered at a more granular level and when nutrients are applied in sufficient quantities. Consequently, the prevailing fertilizer policy, which promotes a balanced application of N, P, and K based on outdated and insufficient norms, is resulting in misguided recommendations. Furthermore, applying a uniform standard across the country is inappropriate, as the optimal nutrient ratios vary significantly by state, influenced by factors such as crop types and soil fertility. The findings indicate that while farmers have made efforts to correct the imbalance in NPK usage, external shocks and policy inconsistencies have reversed these positive trends. It is noteworthy that the fertilizer policy reforms initiated in 1992 and the Nutrient-Based Subsidy (NBS) scheme of 2010, which were intended to reduce nitrogen usage and enhance the application of P and K, inadvertently promoted an imbalance by encouraging higher nitrogen use relative to phosphorus and potassium. The paper also provides estimates of the necessary N, P, and K application levels for current cropping patterns at the state level, based on recommendations from State Agricultural Universities (SAUs) and Indian Council of Agricultural



Research (ICAR) institutes, revealing that a significant number of states either overapply nitrogen or fall short of the required levels.

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