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Awareness and Perception of Variable Rate Fertilizer Application Technology among Indian Researchers

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Regarding responsible consumption of fertilizer and sustainable food production globally, the Variable Rate Technology (VRT) gained momentum in recent days around the world and also parts of Indian research. Hence, a study was undertaken to analyze the awareness and perception of Indian researchers on VRT to understand and provide implications focusing further developments. The research group (agricultural researchers) was approached with a suitable questionnaire comprising factors under awareness - knowledge, exposure, and understanding, and under perception - benefits, essentiality, and experience. The awareness index (A_i) and perception index (P_i) were developed and assessed along with statistical analysis. Different aspects of challenges and suggestions on fertilizer management arrived and ranked. A_i and P_i were found to be 3.2 and 4.6 out of 10 respectively with a correlation coefficient of 0.78 between each other. Also, results implied that VRT research and developments was the prioritized need. Statistical analysis identified the influencing factor for the arrived indices. The novelty of the study lies in its exploration of the development and adoption level of Variable Rate Technology (VRT) in India.

Keywords: Adoption, Awareness, Perception, Precision, SDG 12: Responsible consumption and production

Introduction

Agricultural fertilizer application was a vital process in most of the crop cultivations emphasizing crop growth, yield, quality, etc. The uncertain nature of fertilizer input prices[1], environmental impacts[2], peak season demand, residual effects[3] are the major issues associated with the fertilizer sector impacting the food security. The importance of fertilizer input optimization[4] lies in responsible consumption of resources in agriculture. As well as past 5 years urea (most widely used fertilizer across the world) price is under significant fluctuation. Also, in past 5 years, Indian urea import is high, from various countries.

Amidst the diverse agricultural landscapes of India[5], where the enhancement of food productivity remains a perpetual concern, understanding the awareness and perception of this technology among agricultural researchers becomes paramount. Variable rate fertilizer application technology represents a paradigm shift in the agricultural sector, moving away from constant doses of fertilizer application across fields to a more precise, site-specific approach. It integrates various data sources, including satellite imagery[6], soil sensors, and historical yield data[7], modify the fertilizer application rates according to the specific requirements of different zones within a field (Fig. 1). By optimizing the application of fertilizers, this technology holds the promise of not only enhancing crop yields but also minimizing input costs and mitigating environmental impacts associated with excess fertilizer use.

In Austria, with 240 respondents (farmers), a study embedded with a choice experiment (VRT – satellite-based and ground-based map) was conducted. As a result, they stated a 75% of the respondents were interested in VRT.[8] Another study in the Ontario cropping system revealed a VRT adoption rate of 27%, 13%, 32%, and 19% for fertilizer, seed application, pesticide, and fungicide precipitation.[9] Among all inputs, inorganic fertilizers like urea and pesticides exerts more concern on environmental health. Fertilizers are basic necessity, while pesticides were based on the protection needs. Hence, fertilizer input optimization was more perceived to be important. Among various options of fertilizer use management (especially urea), variable rate fertilizer managemen[10] stands as a unique and universal

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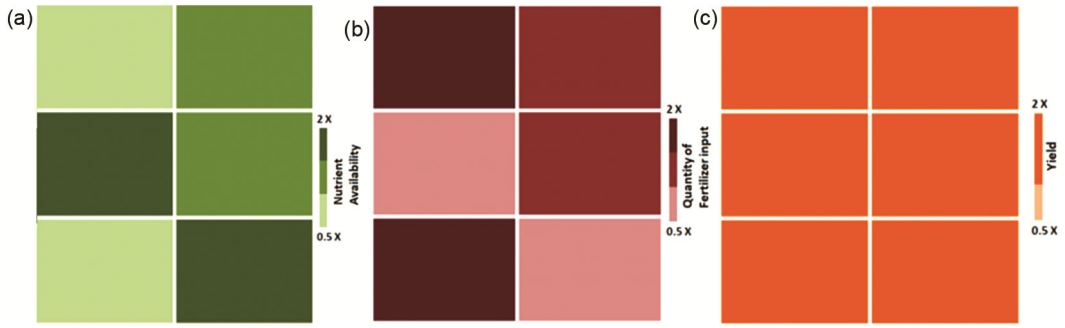

Fig. 1 — (a) In-born Nutrient variability and (b) corresponding variable rate fertilizer input in the same field to provide (c) uniform yield subjected to zonal classifications

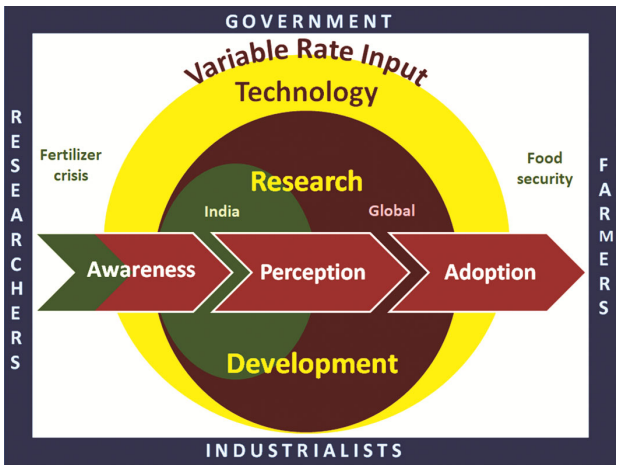

Fig. 2 — Variable Rate Technology and Indian Scenario

technology for numerous crops and regions of globe.[11] Different types of VRT fertilizer application were as follows.

1. Data acquisition: map-based (offline) or real-time (online) or hybrid (fusion of map based and real time data
2. Mode of application: Liquid or solid
3. Application mode: Ground vehicle based (Tractor/self-propelled/autonomous) or aerial based (UAVs)

In India, where agriculture sustains a significant portion of the population and is central to its economy, the adoption of innovative technologies becomes crucial to meet zero hunger and sustainable food production. As represented in Fig. 2, India was in the research phase in VRT and is still a long way through industrial developments and government implementations to attain wider adoption by farmers. Before extending the technology, commercial basis and expert availability should be ensured. Since commercial stage was not reached, currently understanding the expertise availability is a research gap. In this connection, the present study was undertaken to investigate the expert availability through understand the extent of awareness and perceptions of Indian researchers among VRT for fertilizer. The study was planned to investigate the awareness level and perception of VRT fertilizer optimization strategy among the Indian researchers through following methodology.

Methodology

The research methodology adopted for the study was explained as follows:

Sample: This study utilizes a cross-sectional survey design to derive insights from Indian researchers. The study focused on researchers (260) from agricultural sciences and agricultural engineering faculties equally. The sample comprises individuals including national and state scientists/professors (40), young researchers (35), state agricultural department employees (30), post graduate students (75) and doctoral scholars (80). A stratified random sampling approach was employed to ensure representation.

Interview schedule: The survey instrument is a structured questionnaire divided into two main parts: Basic Profile and awareness cum perception. Questions include demographic information, farming background, and questions related to the awareness and perception of VRT for fertilizer. Data collection is conducted through email to reach a wide geographical area (different parts of India viz., South India, Eastern India, North-eastern India, Western India and North India) efficiently. Participation is voluntary, and informed consent is obtained. Indices favour data processing in a way that is easy to identify and accessible to users.[12] Hence the awareness and perception indices were developed and studied using the following methodology as in Fig. 3.

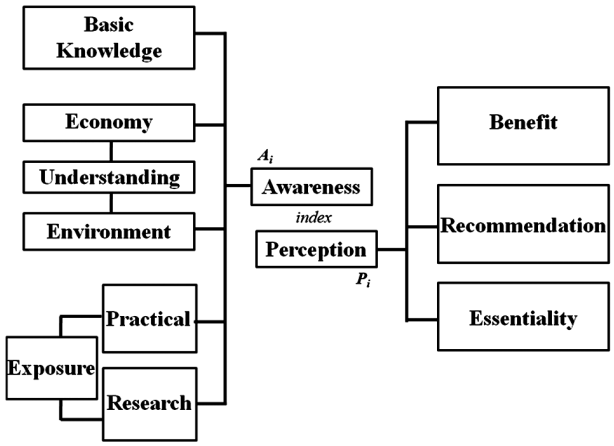

Fig. 3 — Methodology for Awareness and Perception Index Assessment

Awareness index (A_i): Four-point Likert-type scale[13,14] was used to assess the basic awareness (λ_1) among respondents. Practical exposure (λ_2), economical (λ_3), and environmental perspectives (λ_4) of VRT were taken into consideration with dichotomous rating. Research experience (λ_5) was considered in a three-scale weightage upon the individual's response. Various measures for reaching VRT towards the farming community were investigated among the respondents. The awareness index was arrived with the following Eq. (1).

$$A_i = \left\{\frac{\lambda_1}{4} + \frac{\lambda_2+\lambda_3+\lambda_4}{2} + \frac{\lambda_5}{5}\right\} \times 1.67 \quad \ldots (1)$$

Perception index (P_i): A 4-point Likert scale was used to analyze the benefit perception of VRT(β_1) and the essentiality of VRT at the current moment (β_2), followed by a 3-point scale for suggestions of VRT to farmers (β_3). The following Eq. (2) was used to assess the P_i.

$$P_i = \left\{\frac{\beta_1}{4} + \frac{\beta_2+\beta_3}{3}\right\} \times 3.33 \quad \ldots (2)$$

Analysis: Statistics on A_i and P_i were analyzed, including correlation and multiple regression analysis through Microsoft Excel (version 2007). Correlation analysis between A_i and P_i was studied through Python programming language in the Jupyter environment in the system (8 Giga Byte installed Random Access Memory, 1 Terrabyte, Intel(R) Core(TM) i5-8250U CPU @ 1.60 GHz 1.80 GHz, 8th generation, Windows 10 PRO 64 bit operating system). Multiple regression analysis was carried out between $\lambda_{1\text{-}5}$ and A_i to study the influence of λ_n on A_i.

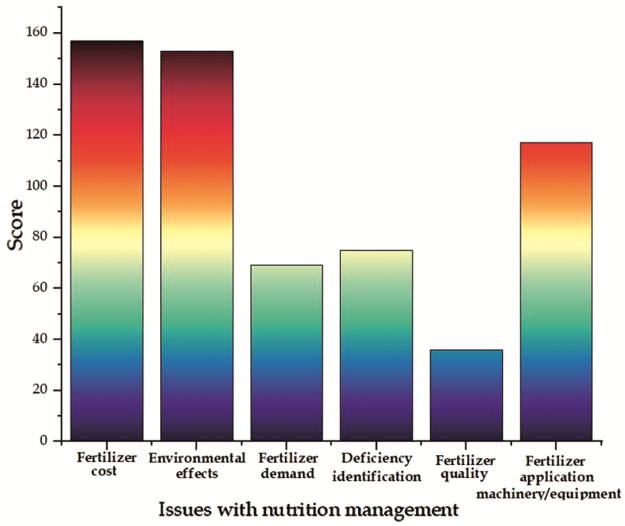

Fig. 4 — Various challenges in fertilizer management

The study adheres to ethical guidelines, ensuring participants' confidentiality and informed consent. Personal information collected, including names and contact details, will be kept confidential and used solely for research purposes.

Results and Discussion

The results of the survey were collectively described as follows with discussions.

Socio-economic characteristics of the respondents: 41% of female and 59% of male respondents were observed. 60% of the respondents are from farming backgrounds and among them, 78% are small and marginal farmers indicating the prime importance of small and marginal farmers in India[15]. In this, 95% of the respondents in the group (out of 60% of sample) with a farming background are likely to endure the practice. This shows the positive factor towards sustainable food production.

Perception of fertilizer management challenges: Among various innovations perceived on fertilizer application, R&D on machinery/equipment, Integrating the latest technologies (AI/Robotics/ML/ Big data, etc.) were represented majorly followed by changes in formulations and changes in agronomical practices. Various challenges perceived and/or aware by the respondents were explained in Fig. 4. Leaching, groundwater contamination, soil acidification, emissions, air and water pollution, volatilization, low yield, and grain quality are the major issues associated with over-fertilizer application. The majority of the samples (70%) opine that, fertilizer input optimization is significant based

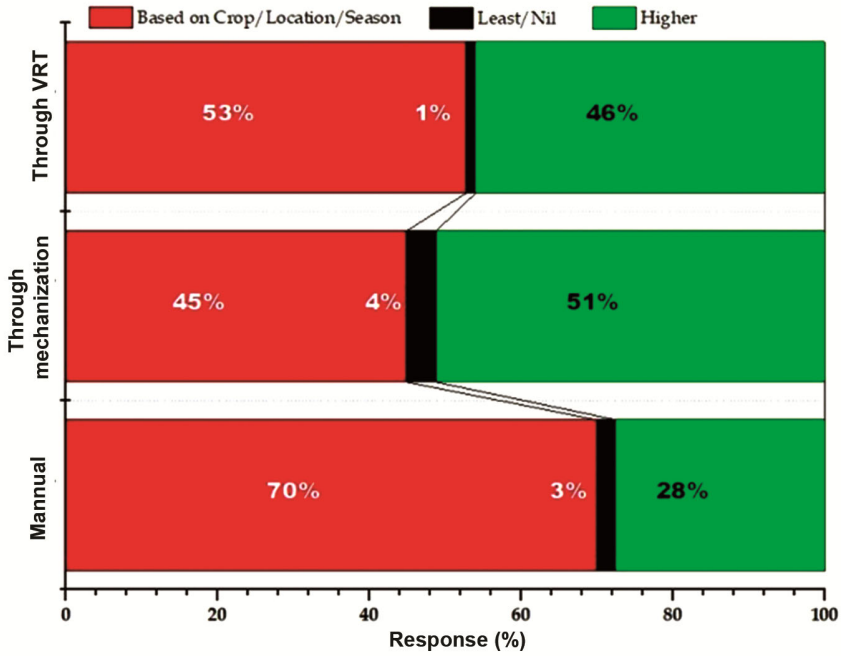

Fig. 5 — Responses on fertilizer input optimization strategies

on the crop, temporal and spatial parameters. As discussed earlier, economic importance of optimizing fertilizer use in India is significant. Hence the sample population had a better understanding of fertilizer use optimization.

Variable Rate Technology: Among the sample group, awareness about VRT was found to be 20% well aware, 48% intermediary aware and 32% not aware. But this is according to individual's opinion on awareness on VRT; hence the same was validated and discussed in the following sections through awareness and perception indices. Standardization of the VRT process for every crop differs and involves tedious research work. This indicates that the application of VRT in major crops such as paddy, wheat, sugarcane, etc may be logically correct in the sense of large-scale applicability which in turn provides maximum benefit with the least effort.

Importance of fertilizer input optimization: The importance perceived by the respondents on fertilizer input optimization and incorporation of mechanization followed by VRT is explained in Fig. 5. With the importance of agricultural mechanization[16], the optimization of fertilizer through mechanization is advocated to some extent with the facts such as reduced human error, timely application, etc. Also optimizing the fertilizer application quantity can minimize the machinery wear.[11] Based on the crop and season, fertilizer use differs, also leads to a peak consumption situations. Hence, identifying such situations and incorporating fertilizer input optimization strategies can be effective. The same was perceived by the sample groups as shown in Fig. 5.

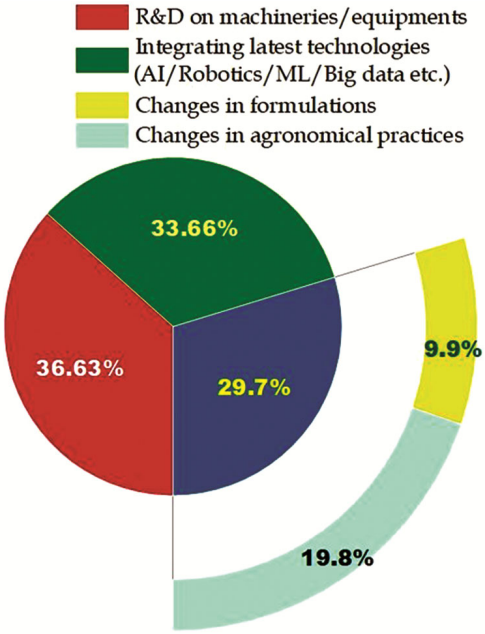

Fig. 6 — Suggestions for enhancing variable rate technology

Suggestions for favouring VRT: Various suggestions for VRT developments and adaptation were discussed in Fig. 6. Change in formulations is

also suggested by the respondents, which can signify the development of the technology. A wise example includes nano-urea liquid spray replacing granular urea[17]. Changes in agronomical practice can ease the development of VRT, and intercropping patterns, which might influence the design of machinery for fertilizer application, suitable fertilizer scheduling, weed management, and soil conservation practices.[8] Several samplings, deficiency classification, fertilizer rate assessing methodology etc., play an important role in the successful VRT utilization. Research and developments in VRT such as GPS accuracy and accessibility, integration of data acquisition tools, metering mechanisms suiting various fertilizers etc., were practical requirements for successful VRT adoption.

Awareness index: The mean awareness index was found to be 3.2 using Eq. (1), which appears to be moderate. The adjusted mean of 4.8 represented by a core group (opined awareness) also appears to be moderate. Senior researchers (average awareness index of 4) are more aware of VRT than beginner scientists (average awareness index of 2.8) in the agricultural domain. Basic statistics on the awareness index generated for each respondent were presented in Table 1. Mode represents that a significant proportion of respondents may have very low awareness levels.

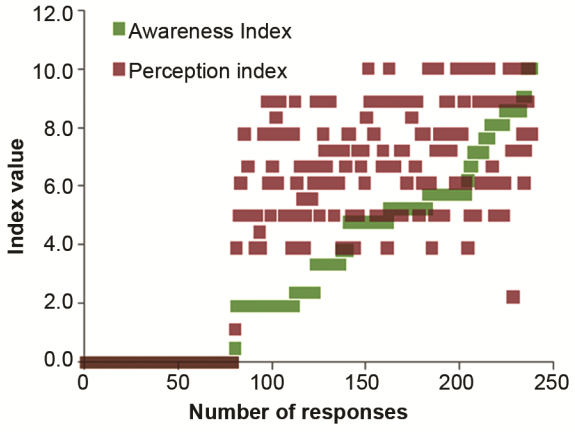

Fig. 7 — Scatter plot of awareness and perception index

Table 1 — Correlation and Regression Analysis on A_i

Parameter	Correlation coefficient	Regression coefficient
λ_1	0.84	2.75
λ_2	0.68	2.05
λ_3	0.87	1.30
λ_4	0.88	1.82
λ_5	0.52	1.35

The range and standard deviation indicate considerable variability in awareness scores among the surveyed population. Platykurtic distribution, the positive skewness, and the right-skewed distribution suggest that a subset of respondents has higher-than-average awareness, possibly indicating that certain factors are influencing a select group. Those factors might include other research interests, environmental advocacy, the laggard nature of inventions and the attention of government and NGOs on fertilizer consumption. The scatter plot for the awareness and perception index is shown in Fig. 7.

It is observed that the awareness index was most influenced by the environmental benefits of the VRT (Table 2), followed by economic benefits, and lastly the research experience representing the scanty awareness through research exposure. This signifies the need for enhancing the selective research initiatives regarding VRT in the country. Adoption of VRT in allied research experiments and evaluation processes, trial approaches, feasibility testing by any researcher can aid in increasing research based awareness

Perception index: Mean and adjusted mean represent a moderately good perception of VRT. Most of the factors resemble A_i, except skewness which is negatively skewed. Though the perception level was better than the awareness level, increasing awareness might catalyze the positive perception.[18]

The correlation coefficient between A_i and P_i was found to be 0.79 and R^2 of 0.62. Adjusted R^2 found to be 0.61 and standard error was 2.20. These results describe regression analysis showing a positive relationship between A_i and P_i but canonical correlation plot (Fig. 8) shows a scattered positive relationship. The variance in the dependent variable is explained by the predicted model with R^2 of 62.02%

Table 2 — Statistics on Awareness index (Ai) and Perception index (Pi)

S. No.	Parameter	A_i	P_i
1.	Mean	3.2	4.6
2.	Adjusted mean	4.8	6.8
3.	Median	2.4	5.00
4.	Mode	0	0
5.	Skewness	0.42	−0.18
6.	Kurtosis	−0.98	−1.44
7.	Range	0-10.0	0-10.0
8.	Standard Deviation	2.92	3.57
9.	Variance	8.54	12.77

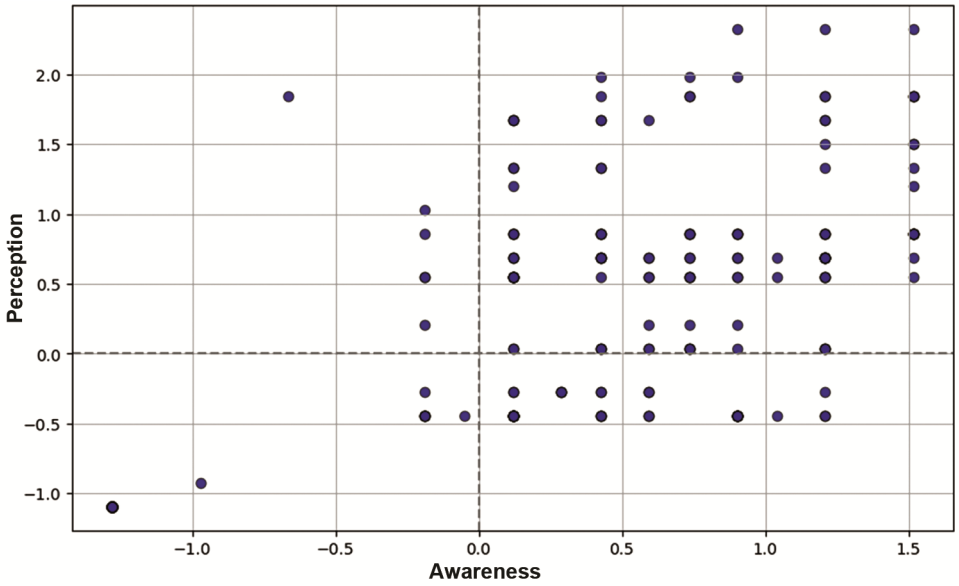

Fig. 8 — Canonical Correlation Coefficient (CCC) Plot for perception (X) and awareness index(Y)

Table 3 — Various awareness studies in the Indian farming domain

Factor	Level of awareness	Sample description
Basic agricultural equipment[20]	95%	Farmers
Artificial Intelligence in agriculture: importance, benefits, and utilization[21]	22.83%	Farmers: Khorda district of Odisha, India
Government schemes on agriculture[22]	55.6%	Farmers: Dhenkanal district, Odisha, India
Precision agriculture technologies[23]	−70%	Farmers: Punjab, India
Vertical farms[24]	57.50%	Urban citizens: India
Digital technologies in agriculture[25]	37.72 – 47.73%	Farmers: Nalgonda, Jagtial and Warangal districts of Telangana, India
Kisan call centre[26]	10%	Farmers: Karnataka, India
Pigeon pea production technologies: Pre-sowing irrigation[27]	86.88%	Farmers: Marathwada and Vidarbha regions of Maharashtra, India

The '–'sign indicates the 'not aware' category.

and adjusted $R^2$with a lower standard error value explains a good fit. The paired t-test result shows that the perception index is significantly higher than the awareness index. This is comparable with previous studies expressing contrasting levels of awareness and perception.[19]

Various awareness studies in the Indian farming domain are listed in Table 3. From interpretations, it is visualized that advanced and digital technologies are at a lesser adoption level by the farmers. Hence, along with digital technologies, VRT holds a good scope for adoption by farmers shortly. However, from this study, it is evident that research and developments are to be accelerated to explore the findings on the diverse landscape of India.

Various studies about the development of VRT for fertilizer were done in more than 20 countries worldwide. But a robust machinery and/or package of machinery/equipment on the same was not extended. A major drawback in the adaptation and extension of the technology was the higher cost of data acquisition.[11] A suitable low-cost sensing system integrated with a fertilizer applicator can produce a cheaper technology.

Suggestion towards the adoption of VRT among farmers: 1. Reducing the data acquisition cost. 2. Design and development of low-cost VRT machinery/equipment. 3. Use of custom hiring models for operation UAV based VRT. 4. Subsidies/rewards as initial encouragement to lead farmers. 5. Tie-up with industries to attract corporate social responsibility based funding for investment on VRT technology.

Next to research and developments of fertilizer applicators, integrating the latest technologies such

as 5G technology[28], drones[29], robotics[30] with VRT can catalyze the success of the technology, increase the efficiency and also decrease the latencies with existing technology was suggested by the respondents. Technology in input formulation such as nano-fertilizers[31] also catalyzes the VRT feasibility.

Implications from the study: From the study, the following implications were observed.

- Need for VRT in India is significantly higher
- Awareness index and perception index was assessed to be 3.2 and 4.6 depicting that still VRT is not under a complete focus for researchers
- A positive linear relationship exists between awareness and perception index, which infers that individuals aware of VRT have a good positive perception.
- Significant difference between awareness and perception index, where perception index is significantly higher represents the possibility that individuals who are not aware of VRT also have a good positive perception.
- Crop-specific research and developments in zonal/regional approach are required
- Popularizing environmental and economic importance to core and allied research groups
- Formulation of commercial models of VRT extension
- Development of standards for VRT-based systems
- Extension of full-fledged VRT system towards farmers through economical incentives, commercial availability of sales and service

Conclusions

The awareness and perception of variable rate technology were found among the respondents (Indian researchers). Senior scientists are more aware than young researchers according to this study. Perception of researchers on variable rate technology was better than the awareness. This stated the lack of technology research and reach, a strong need for investigations and robust developments facilitating the impactful growth in the precision farming sector. Research investigations are required to be enhanced for a wide range of exploration. Advanced technologies are at a lesser adoption level by the farmers currently. With increase in adoption of such technologies, VRT also holds a good scope for adoption by farmers in near future. Wider adoption of VRT yields environmental benefits through reasonable resource utilization and consumption of fertilizer and economic benefits for the stakeholders.

Conflict of interest: Authors hereby declare that no conflict of interest.

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