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Research Article

An Optimization Study of Absorption Rate of NPK Fertilization under Multi-Depth of Black Loamy Sandy Soil

Nikhil Bhende[1*], Devesh Kumar[1], Jayant Purohit[2]
[1]*Faculty of Engineering & Technology, Poornima University, Jaipur, India*
[2]*Banasthali University, Tonk, Rajasthan, India*
* *Author for Correspondence E-mail: nikhil.bhende@gmail.com*

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ABSTRACT

Sustainability is an empirical practice that focuses on social, economic, and environmental situations even for Cotton farming like systems to cater its agro-ecological problems. A suitable fertilization approach is worth implementing in cotton crop farming to get better absorbability of nutrients. However, when fertilization depth is altered to different depths its effect on absorption rate on cotton crop is unclear. An experimentation was performed on cotton crop using Black-Loamy Sandy soil of Vidarbha region of India by applying Carbamide (H2NCONH2) and Diammonium-Phosphate (NH4H2PO4) fertilization under multiple depth to determine the effect of NPK absorption rate. Three fertilizer placement depths comprising of 2 inches (FD2), 4 inches (FD4) and 6 inches (FD6) were tested. This experiment utilizes advanced IOT based sensors for measuring parameters and Lab-View framework to monitor the readings. This paper examines the effect of these parameters using Grey-based Taguchi analysis process. The scrutiny focuses on multi-response optimization of the NPK absorption rate using mini-tab software. Compared to various combinations, the optimum combination for low value of N, P & K was found as FDP = 6 inches, FQ = 40 gm-kg, SM = 70% (FDP-3-FQ-3-SM-3) gives the optimum NPK absorption rate. The projected, grey-based Taguchi method showed effective in resolving multi-response problem and such conclusions provide a practical recommendation for boosting the fertilizing policy in this region.

Keywords: Sustainability, IOT, NPK absorption rate (Nitrogen-Potassium-Phosphorous), multi-depth, optimization, Grey-based Taguchi analysis.

INTRODUCTION

As a part of the Green Revolution, when sustainable methods are implemented blend with farm mechanization techniques, it gives the best outcomes in agricultural fields. It intensifies the agro-production and focuses on minimizing chemical fertilizer usages, soil erosions, maintains soil health and overall yield quality [1]. Managing crop residue, conserving moisture in soil, timely rotation of the crops, minimum tillage are some of the conservative and sustainable methodologies in farming which helps in maintaining soil structure and quality [2]. The swift progress in technology pertaining to the cultivation of traditional crops, genetically modified crops, and the utilization of fertilizers and pesticides facilitated a boost in productivity [3]. The evolution has resulted in significant enhancements in production and operational quality at the farm level.

India is world's second largest producer of cotton behind only to China marginally. With 120.69 Lakh Hectares area under cotton cultivation, India comes first in world where China covers 27.9 Lakh Hectors of Land as of 2022-23 as per Annexure -VII Note on Cotton Sector from Ministry of Textile, Government of India. The yield per hectare of cotton in India is notably lower in comparison to the yield per hectare in other leading cotton-producing nations like China or USA. There are core agricultural climatic limiting factors faced by cotton cultivators in India. To cater low productivity issues, one requires more technological advanced genetically modified cotton seeds which are better than Bacillus Thuringiensis (BT) cotton seeds, water-nutrient management, better labour skill development and most importantly use of agricultural machines coupled with today's technologies like AI and IoT [4].

Use of fertilizer efficiently can contribute to enhance overall development of reproductive organs of cotton crop

[5][6]. The morphological characteristics of root are nutrient stress sensitive [7]. The three main content from fertilizers i.e. Nitrogen, Phosphorus and Potassium (NPK) affect cotton plant growth water absorbing capabilities, photo-synthesis accumulation and maintains soil fertility rate. The balanced amount of these nutrients under optimum soil depth with sufficient moisture influences cotton productivity. Although shallow fertilization method is widely adopted in farm but several research have proved that Deep fertilization method is beneficial in crop yields [8]. But very few studies have been conducted on the effect of shallow & deep fertilization together on crops. The timing of NPK application was postulated to influence the growth, yield, and economic returns of cotton relay cropping [9].

In agricultural settings, Internet of Things (IoT) devices offer valuable insights into various physical parameters, enhancing cultivation practices [10]. Within contemporary wireless communication, IoT stands out as a pioneering technology. Its core principle involves enabling physical objects to connect to the internet through specialized addressing schemes. The integration of several cutting-edge technologies heralds a new era in agricultural and food production, referred to as Agri-Food 4.0 [11]. The agricultural landscape is evolving, with IoT, Smart Sensor Technology, Remote Sensing, UAV, Wireless Sensor Networks (WSN) and Low Power Wide Area Networks (LPWAN), being key components. These advancements in data collection, analysis, evaluation, and application technology epitomize smart farming innovations [12].

Automation in agricultural machinery and equipment has significantly enhanced agricultural productivity compared to traditional methods [13]. The incorporation of various high-quality sensors and IoT technology throughout the agricultural production system has revolutionized farming practices, leading to reduced production costs and increased crop yields [14]. Given the potential benefits and future efficacy of IoT in smart farming, the proposed approach advocates for a model promoting large-scale analytics, real-time data collection from cotton crops, and a highly personalized online platform. This model enables the analysis and prediction of data streams, facilitating informed decision-making for farmers amidst rapidly changing environmental conditions and unforeseen events in the field [15]. Integration of sensory data with web services enables climate change anticipation for predicting crop irrigation and fertilization requirements [16].

Incorporating efficient irrigation water management, fertilizer application, fungicide, and disease prevention across several cultivars, Mentsiev et al. employed quality-effective sensors, resulting in enhanced farm yields and reduced production costs [17]. The utilization of IoT technology in agricultural farms has empowered farmers with mobile applications and high-speed internet connectivity, facilitating precise crop management through data-driven decision-making [18]. Khan et al. focused on smart farming utilizing semantic web ontologies through an IoT-based model, enabling real-time stream processing, interpretation, and reasoning in cotton crop domain [19]. This approach aims to provide cultivators with timely insights for making informed decisions. Examining the rise of IoT in agriculture underscores the significance of integrating high-speed networks and heterogeneous technologies, alongside semantic ontologies from diverse sources. The proposed model integrates open-data, semantic technologies, and linked data to achieve interoperability among sensors, processes, data sources, fields as entities, and web-based services.

Furthermore, a study highlighted the importance of organic fertilizers derived from livestock and sawdust products in promoting yellow poplar growth and enhancing soil quality, suggesting organic manure as a viable alternative to chemical fertilizers in seedling development systems. J. Lou et al. emphasized the selection of nitrogen-efficient cotton cultivars to enhance nitrogen use efficiency (NUE) and nitrogen uptake efficiency (NUpE), thereby reducing production costs and environmental impact. Additionally, they proposed a long-term and short-term IoT-based irrigation and fertilization scheme, utilizing optimization models to maximize economic profit and environmental benefits in precision agriculture.

MATERIALS & METHOD

A novel multilayered fertilization technique was proposed to address challenges faced by cotton farmers in Maharashtra, India, aiming to improve crop productivity by distributing fertilizers at different soil depths during various growth stages. Experimental setup involved 27 pots having 15-inch-dept, 15-inch opening diameter. Black sandy loamy soil from Waddhamna Village, Nagpur were used. Black loam soil, characterized by a blend of sand, clay, and organic matter in varying proportions, represents fertile terrain conducive to plant growth. Loam soils, renowned for their richness in minerals and humus, surpass sandy soils in fertility. Moreover, they exhibit superior irrigation and drainage capabilities compared to silty soils, while also proving less arduous to till than clay-rich soils.

For the experimentation, Bollgard II BT Cotton seeds were chosen and sowed in pots filled with black loam soil. The fertilization regimen included a blend of Di Ammonium Phosphate (DAP) and Urea, strategically employed to bolster soil fertility, and facilitate optimal crop growth. Multilayered fertilization methodology used for placing fertilizer under soil at 2 inches, 4 inches and 6 inches depth in each pot. The study also employed IoT devices such as DS18B20 temperature sensor, DF Robot moisture sensor SEN0193, RS 485 NPK sensor, and DF Robot pH Sensor SEN0161, interfaced with a microcontroller via WiFi ESP 32. LabVIEW software facilitated hardware configuration and data measurement for user interaction, demonstrating the feasibility of the proposed approach in enhancing NPK absorption efficiency in cotton crops. In the experiment, NPK sensor uses Ion-selective electrodes to directly measure the concentration of specific ions in the soil. These electrodes are designed to selectively bind with ions of interest while excluding other ions. By measuring the electrical potential generated by the selective binding of ions, the sensor can determine the concentrations of nitrogen, phosphorus, and potassium in the soil. The data for Nitrogen, Phosphorus and Potassium content in soil, then moisture content in soil and depth of fertilization are collected on per hourly basis for 22 days. The acquired data was subsequently analyzed using Statsmodels, a Python language library facilitating data exploration, statistical model estimation, and hypothesis testing. This module enabled this research in importing datasets, cleansing, and formatting data for analysis, manipulating pandas DataFrame objects, and summarizing the overall data.

Fig. 1: Actual Experimental setup using cotton crop in black sandy loamy soil with sensors.

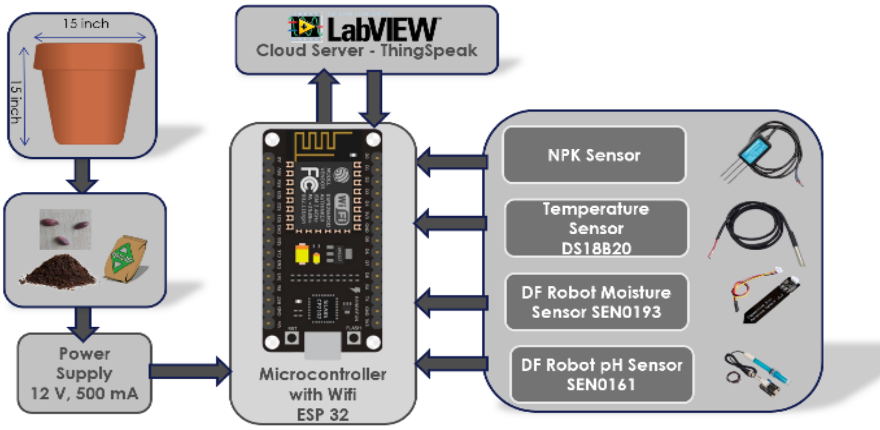

Fig. 2: Block diagram of Experimental setup.

OPTIMIZATION STUDY

Grey relational analysis (GRA) is a method commonly used in optimization studies to analyze relationships between input and output variables, especially when dealing with complex systems or situations where precise mathematical models are difficult to establish. In the context of fertilizer absorption by plants in soil, GRA can be applied to optimize various factors affecting absorption efficiency [21]. The first step is to identify the relevant input and output variables. Input variables may include factors such as fertilizer type, application rate, soil moisture, soil pH, temperature, and so on. The output variable would be the absorption efficiency of the fertilizer by the plants.

Data on the identified variables is collected through experiments or observations.

This data should cover a range of values for each input variable and corresponding output values. Since the variables may have different units and scales, they need to be normalized to bring them to a comparable scale. Normalization ensures that each variable contributes equally to the analysis [22]. Conventional normalization techniques comprise z-score normalization or min-max normalization. Grey relational coefficients are calculated to measure the degree of correlation between each input variable and the output variable. This is typically done by comparing the normalized values of each input variable with the normalized values of the output variable. Grey relational grades are then calculated based on the grey relational coefficients. These grades represent the overall relationship between each input variable and the output variable. On grey relational grades the input variables are accordingly ranked based. Variables with higher grades are considered to have a stronger influence on the output variable. Based on the rankings, the optimal values or ranges for the input variables can be determined to maximize the absorption efficiency of the fertilizer by the plants. This may involve selecting the combination of input variables that yield the highest grey relational grade.

Overall, Grey Relational Analysis offers a systematic approach to optimizing complex systems like fertilizer absorption by plants in soil, helping researchers identify key factors and their relationships to enhance efficiency and productivity [23].

RESULTS & DISCUSSION

4.1 Effect of process parameters FDP, FQ & SM on individual response:

In this section, the important process parameters, which affect the fertilizer absorption rate response, were identified, namely fertilizer depth penetration under soil (FDP), fertilizer quantity (FQ) and soil moisture (SM), and the significant responses, viz., Nitrogen (N), Phosphorus (P) and Potassium (K) were analyzed for black loamy sandy soil subjected to pH value 7.9.

This study utilized the Taguchi method to explore the influence of process parameters on individual responses. An orthogonal array was devised, accommodating each parameter at varying levels (refer to Table 1), and corresponding output responses were recorded, as delineated in Table 2.

Table 1: Process parameters with their distinct levels.

Process Parameters	Level-1	Level-2	Level-3
Fertilizer Depth Penetration (FDP)	2 in	4 in	6 in
Fertilizer Quantity (FQ)	20 gm	30 gm	40 gm
Soil Moisture (SM)	40%	50%	60%

Moreover, within Taguchi assessment, the signal-to-noise (SN) ratio stands as a pivotal measure for evaluating process superiority and efficacy. A heightened SN ratio signifies superior performance or output, being the ratio linking the signal indicating the desired output, and the noise, indicative of deviation from said response. The SN ratio is derived by dividing the mean response value by the noise standard deviation. The primary aim of Taguchi analysis lies in maximizing the SN ratio by pinpointing key influencing parameters or factors on the response and ascertaining optimal factor combinations. Taguchi classifies the SN ratio into 3 separate categories: larger-the-better, nominal-the-better, and smaller-the-better. In this investigation, all three responses for lowest impact response of NPK absorption were considered under the smaller-the-improved criteria and are computed utilizing equation 1.

$$SN = -10 * \log\left[\frac{\sum Y^2}{n}\right] \quad (1)$$

where n is the number of investigations, and Y is the acquired data for each response. Consequently, the Signal-to-Noise (SN) ratio for each parameter was ascertained and graphed utilizing the Taguchi methodology within Minitab software. The impacts of these constraints were subsequently examined and deliberated upon in the coming sections.

Table 2: A structured orthogonal array comprising process parameters alongside their corresponding output responses.

Test No	Process Parameters			Output Response		
	FDP	FQ	SM	N	P	K
1	2	20	50	10.394	20.787	31.181
2	2	20	50	10.663	21.326	31.989
3	2	20	50	10.813	21.625	32.438
4	2	30	60	10.611	21.222	31.834
5	2	30	60	10.390	20.780	31.171
6	2	30	60	10.409	20.819	31.228
7	2	40	70	10.240	20.480	30.720
8	2	40	70	10.076	20.153	30.229
9	2	40	70	10.037	20.074	30.111
10	4	20	60	9.958	19.915	29.873
11	4	20	60	9.896	19.792	29.688
12	4	20	60	9.965	19.930	29.895
13	4	30	70	9.864	19.728	29.593
14	4	30	70	10.004	20.009	30.013
15	4	30	70	9.522	19.045	28.567
16	4	40	50	9.691	19.381	29.072
17	4	40	50	9.836	19.671	29.507
18	4	40	50	9.758	19.516	29.274
19	6	20	70	9.045	18.089	27.134
20	6	20	70	9.311	18.622	27.933
21	6	20	70	9.243	18.485	27.728
22	6	30	50	8.848	17.695	26.543
23	6	30	50	9.292	18.583	27.875
24	6	30	50	8.991	17.982	26.973
25	6	40	60	9.402	18.804	28.206
26	6	40	60	9.016	18.032	27.048
27	6	40	60	9.478	18.956	28.434

4.1.1 Effect of N content in soil:

Nitrogen plays a crucial role in stimulating growth and achieving abundant yields by facilitating optimal photosynthetic activity within foliage. In cotton cultivation, nitrogen holds significant importance as it serves as a fundamental constituent in the synthesis of proteins, thereby fostering robust growth and physiological maturation. The provision of nitrogen fosters vegetative expansion and can enhance boll formation by promoting increased node and fruiting positions. Moreover, an ample nitrogen supply can positively influence lint weight, thereby contributing to enhanced yields. The nitrogen present in numerous straight and compound fertilizers typically exists in the ammonium form (NH_4^+ cation). However, under various soil conditions such as aeration, temperature, and drainage, it undergoes rapid conversion by soil bacteria into nitrate (NO_3^- anion) through the process of nitrification.

The main effect plot for means and SN ratio graph of N content of soil was obtained using the Minitab software (2021) and is presented in Fig. 7. The main effect plot represents means for each group within a defined categorical variable where FDP line signifies greater variations compared to FQ & SM. A higher SN ratio indicates a smaller variation difference between the desirable output and measured output. In Fig. 7 (a), it was observed that the highest mean SN ratio for N was achieved with 6 inches of FDP, 40 gm-kg of FQ, 70% of SM. Therefore, the predicted optimal process parameters for achieving an optimum N content in soil using the Taguchi method were identified as FDP-3-FQ-3-SM-3 i.e., FDP = 6 inches, FQ = 40 gm-kg, SM = 70% as 6 inches depth provides better fertilizer content retention which causes roots to absorb more nutrients from it, 40 grams of N per kg of soil makes sure maximum quantity availability for crop and upto 70 % moisture in soil provides access to humidity for roots in greater depths and thereby ample supply of minerals.

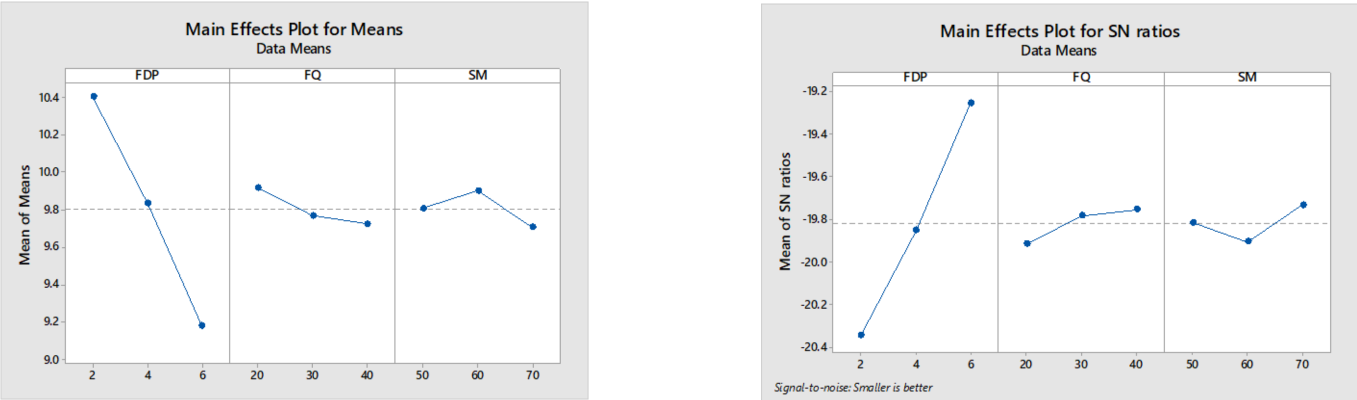

Fig. 3: Main effects plot for Mean and SN ratio of N content in soil.

4.1.2 Effect of P content in soil:

Phosphorus constitutes a vital element within nucleic acids, phospholipids, and high-energy phosphate compounds, thereby exerting a pivotal influence on root development, fruit and seed maturation, and the ability of plants to resist diseases. Insufficient phosphorus levels have been observed to impede plant growth, leading to diminished yield and compromised quality. Just like in N, the mean effect plot illustrates the mean values for each group categorized within specific variables, where the FDP plot indicates a higher degree of variability compared to FQ and SM.

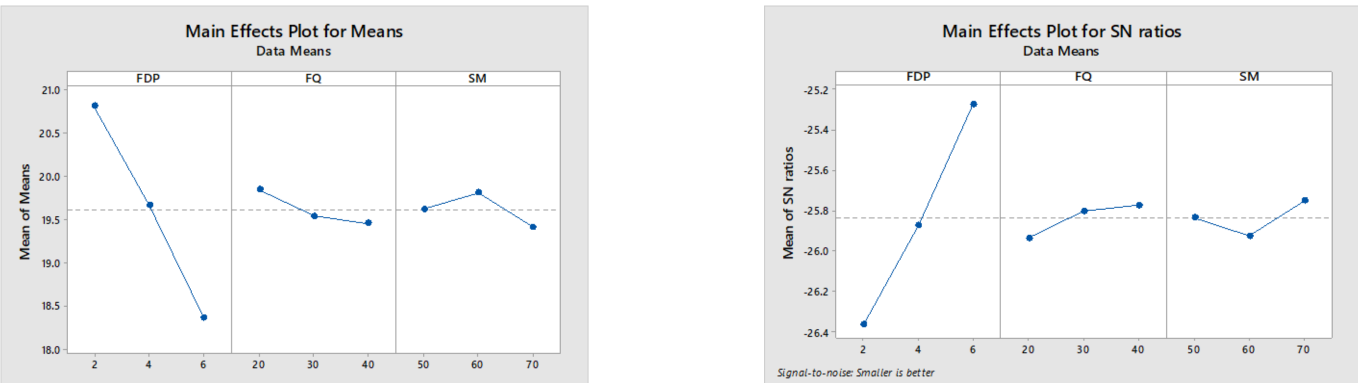

Fig. 4: Main effects plot for Mean and SN ratio of P content in soil.

A higher signal-to-noise (SN) ratio denotes a smaller disparity between the measured output and desired output. In Figure 4, it was logged that the highest mean SN ratio for Phosphorus (P) was attained with 6 inches of FDP, 40 grams of FQ, and 70% of SM. Consequently, the model process parameters for accomplishing an ideal P content in soil using the Taguchi method were determined as FDP-3-FQ-3-SM-3, namely FDP = 6 inches, FQ = 40 gm, SM = 70%. A depth of 6 inches for FDP enhances fertilizer retention, thereby facilitating greater nutrient absorption by roots. Additionally, applying 40 grams of phosphorus to the soil ensures a maximum quantity requirement for crops, while maintaining up to 70% soil moisture content which is an optimum humidity conditions in soil.

4.1.3 Effect of K content in soil:

Potassium assumes a pivotal role in diverse physiological mechanisms within plant systems, encompassing pivotal functions in photosynthesis, enzyme activation, and water homeostasis. Optimal potassium concentrations exhibit the capacity to augment cotton plant development, thereby fostering heightened crop yield. Furthermore, potassium supplementation correlates with enhanced fiber attributes in cotton, notably bolstering fiber length, tensile strength, and uniformity. Facilitating water uptake and management, potassium contributes significantly to regulatory processes within plant physiology. Notably, cotton crops fortified with potassium fertilizers demonstrate heightened resilience to environmental adversities, including drought, salinity, and temperature fluctuations. Moreover, potassium serves as a catalyst in activating enzymes implicated in plant defense mechanisms, thereby fortifying cotton plants against specific diseases and pests. The presence of sufficient potassium levels generally confers increased resistance to adverse biotic factors.

Moreover, adequate potassium levels foster enhanced assimilation of essential nutrients like nitrogen and phosphorus, thereby promoting comprehensive nutrient utilization and optimizing plant vitality. Nevertheless, prudent application of potassium fertilizers is imperative, necessitating adherence to recommended dosage guidelines predicated on thorough soil assessments and crop-specific requirements. Excessive potassium application bears the potential for inducing nutrient imbalances, soil salinity concerns, and financial ramifications. Furthermore, the efficacy of potassium fertilizers is contingent upon variances in soil composition, climatic conditions, and agronomic practices.

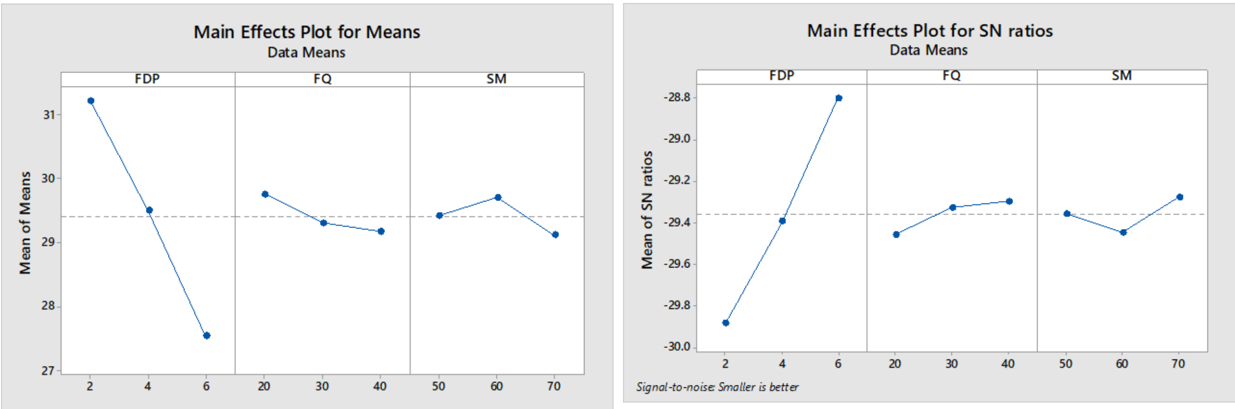

Fig. 5: Main effects plot for Mean and SN ratio of K content in soil.

Just like in nitrogen & phosphorus fertilizers, FDP lines indicate greater variation compared to FQ and SM in mean effect plot. A higher S/N ratio signifies a smaller disparity between the measured output and desired output. In Figure 5, it was noted that the highest mean SN ratio for Potassium (K) was attained with 6 inches of FDP, 20 grams of FQ, and 60% of SM. Consequently, the optimum process parameters for accomplishing an ideal P content in soil using the Taguchi method were determined as FDP-3-FQ-3-SM-3, namely FDP = 6 inches, FQ = 40 gm-kg, SM = 70%. A depth of 6 inches for FDP enhances fertilizer retention, thereby facilitating greater nutrient absorption by roots. Additionally, applying 40 grams for each crop ensures a maximum quantity availability for crops, while maintaining up to 70% soil moisture content which is more than average humidity conditions in soil.

4.2 Effect of process parameters on NPK combined response:

The precise range of critical parameters for NPK Absorption Rate holds significant importance, as an incorrect choice may detrimentally affect the efficiency of nutrient uptake. Nonetheless, the exhaustive consideration of all potential parameters and the determination of optimal process parameters to enhance output replies can be both time-intensive and financially burdensome. Consequently, this investigation employs a approach of statistics rooted in Grey-based Taguchi assessment to discern the optimal combination of parameters for multiple responses. Taguchi analysis integrates the principles of Gray-based method and Taguchi's strong design approach with those theory of grey system. Within this methodological framework, individual responses (multiple responses) are transformed into a singular response, encapsulating the collective impact of all responses. The procedural steps for conducting a grey-based Taguchi analysis are delineated as follows:

Problem Definition: The initial step entails delineating the problem necessitating resolution. Adequate depth of fertilizer placement in the soil emerges as a critical parameter influencing the NPK absorption rate in crops. Neglecting this aspect detrimentally impacts overall performance, thereby emerging as a primary concern in agricultural practices. Thus, the objective is to optimize the NPK absorption response in cotton plants by identifying the most influential parameters fostering N, P, and K absorption rates.

Factor Identification: Factors potentially influencing the stated problem are identified. These factors, also termed variables or parameters, for cotton crop NPK absorption response are recognized as Fertilizer Depth Placement (FDP), Fertilizer Quantity (FQ), and Soil Moisture (SM).

Level Determination: The subsequent step involves determining the levels for each factor, representing the various values each factor can assume. For each factor influencing NPK absorption rate, three distinct levels were established, as depicted in Table 1, adhering to standard practices in cotton farming.

Orthogonal Array Creation: An orthogonal array is constructed to plan the investigation systematically. This matrix confirms that each level of every factor undergoes testing several times equitably, minimizing experimental error thereby. The present study utilizes Taguchi analysis to generate an orthogonal array employing Minitab, as delineated in Table 2.

Data Compilation: Based on the orthogonal array data generated, with each test corresponding to a row in the matrix. The response variable for each test, representing the optimized outcome, is recorded. A validated numerical model was employed to simulate NPK absorption rates in accordance with the orthogonal array, with the resulting outcomes depicted in Table 2.

Data Analysis: Following data collection, statistical methodologies are employed for data analysis, aiming to ascertain the most influential factors. Specified data analysis procedures are expounded upon in Section 4.1 and 4.2.

Optimal Settings Determination: Once the most major factors have been identified, the optimal settings for these factors are established. These settings represent values conducive to optimizing the response variable. In this investigation, Analysis of Variance (ANOVA) was utilized to pinpoint the most pivotal factors in minimizing the response variable. Further elaboration on the specified analysis is provided in Section 4.2.

4.2.1 Data Analysis:

Analysis of data holds paramount importance within the framework of the Grey-based Taguchi method, serving as a pivotal process for ascertaining the optimal levels of input parameters essential for maximizing NPK absorption rate performance while simultaneously minimizing resource expenditure. This phase of data analysis serves to amalgamate several responses into a singular corresponding response, effectively encapsulating the collective impact of all responses. Consequently, the amalgamated effect of the many responses, namely Fertilizer Depth Placement (FDP), Fertilizer Quantity (FQ), and Soil Moisture (SM), is transformed into a unified equivalent response known as Grey Relational Grade (GRG). The Grey Relational Grade values thus obtained facilitate the identification of substantial factors and their respective levels influencing structural performance. This section proves invaluable for the optimization of multiple response parameters, prognostication of NPK absorption rate performance, and enables researchers to analyze NPK absorption rate with enhanced efficacy while streamlining resource utilization.

4.2.1.1 Metod of Normalization:

Normalization process stands as a pivotal stage in grey-based Taguchi method, primarily aimed at mitigating the challenge posed by scale disparities among diverse factors. During this phase, raw data undergoes transformation into a state of normalization,

wherein each element is scaled to a range spanning from 0 to 1. This transformation is achieved through a prescribed relationship, ensuring uniformity in the treatment of disparate factors:

$$X_i(t) = \frac{\max Yi(t) - Yi(t)}{\max Yi(t) - \min Yi(t)} \quad (3)$$

where the normalized response value for i = 1, 2, ... Is represented by Xi(t) and the min and max values of $Yi(t)$ are represented by min $Yi(t)$ and max $Yi(t)$, respectively. Method of normalization serves the critical function of ensuring parity among various parameters or factors during analysis, irrespective of their disparate units of measurement or scales. This process involves transforming the data into a standardized format, where each element is scaled to a range from 0 to 1. By normalizing the data, comparisons regarding the relative influence of each element on the response variable become more straightforward.

Table 3: Normalization (NPK) table for output response.

Test No.	**Process Parameters**			**Normalize (NPK) value of output response**		
	FDP	FQ	SM	N	P	K
1	2	20	50	0.786684	0.786684	0.786684
2	2	20	50	0.923834	0.923834	0.923834
3	2	20	50	1	1	1
4	2	30	60	0.897455	0.897455	0.897455
5	2	30	60	0.784987	0.784987	0.784987
6	2	30	60	0.794741	0.794741	0.794741
7	2	40	70	0.708482	0.708482	0.708482
8	2	40	70	0.625276	0.625276	0.625276
9	2	40	70	0.605174	0.605174	0.605174
10	4	20	60	0.564801	0.564801	0.564801
11	4	20	60	0.533418	0.533418	0.533418
12	4	20	60	0.568533	0.568533	0.568533
13	4	30	70	0.517303	0.517303	0.517303
14	4	30	70	0.588634	0.588634	0.588634
15	4	30	70	0.343342	0.343342	0.343342
16	4	40	50	0.428923	0.428923	0.428923
17	4	40	50	0.502714	0.502714	0.502714
18	4	40	50	0.463189	0.463189	0.463189
19	6	20	70	0.100254	0.100254	0.100254
20	6	20	70	0.235793	0.235793	0.235793
21	6	20	70	0.201018	0.201018	0.201018
22	6	30	50	0	0	0
23	6	30	50	0.225869	0.225869	0.225869
24	6	30	50	0.072858	0.072858	0.072858
25	6	40	60	0.282103	0.282103	0.282103
26	6	40	60	0.085666	0.085666	0.085666
27	6	40	60	0.320696	0.320696	0.320696

Moreover, normalization aids in mitigating potential biases stemming from differences in scaling when factors exhibit varying scales. In pursuit of optimizing the impact response of NPK absorption rate, the "smaller the better response" criterion is adopted for analysis. The results of the normalization steps are illustrated in Table 3, facilitating a lucid graphical depiction of the transformed data.

4.2.1.2 Grey Relational Coefficient (GRC):

The GRC i.e. Grey Relational Coefficient serves as a statistical instrument within Grey-based Taguchi method, employed to assess the association between response variable and different factors. The level of resemblance quantifies between the ideal and observed response arrangements, thereby facilitating the association of factors with the greatest impact on the response variable desired. The GRC can be presented, mathematically, as follows:

$$\xi = \frac{\Delta\min + \varphi \times \Delta\max}{(\varphi \times \Delta\max) + \Delta i} \quad (4)$$

$$\Delta i = X_o - X_i(t) \quad (5)$$

Where the max. normalized value is represented by X0 and identification coefficient (0.5) is represented by φ. In eq. (4) calculated GRC was achieved, and it is illustrated in Table 4.

Table 4: Grey Relation Grade and Grey Relation Coefficient for NPK absorption rate.

Test No.	Grey Relation Coefficient			GRG	Rank
	FDP	FQ	SM		
1	2	20	50	0.388595	23
2	2	20	50	0.351164	26
3	2	20	50	0.333333	27
4	2	30	60	0.357793	25
5	2	30	60	0.389108	22
6	2	30	60	0.386177	24
7	2	40	70	0.413742	21
8	2	40	70	0.444335	20
9	2	40	70	0.452417	19
10	4	20	60	0.469571	16
11	4	20	60	0.483831	15
12	4	20	60	0.467931	17
13	4	30	70	0.491495	14
14	4	30	70	0.459291	18
15	4	30	70	0.592879	10
16	4	40	50	0.538257	11
17	4	40	50	0.498646	13
18	4	40	50	0.519108	12
19	6	20	70	0.832980	4
20	6	20	70	0.679538	7
21	6	20	70	0.713248	5
22	6	30	50	1	1
23	6	30	50	0.688829166	6
24	6	30	50	0.872816109	2
25	6	40	60	0.639301594	8

26	6	40	60	0.853729182	3
27	6	40	60	0.609239355	9

4.2.1.3 Grey Relational Grade:

The Grey Relational Grade (GRG) constitutes a metric for the comprehensive assessment of process parameters via the Grey-based Taguchi method approach. It is derived by averaging the Grey Relational Coefficients (GRC) pertaining to all factors under scrutiny within the analysis. GRG furnishes a singular numerical measure encapsulating the collective performance of the examined parameters, facilitating their ranking based on relational efficacy. A superior parameter signifies a higher GRG value sets within the designated orthogonal array, whereas inferior performance is indicated by a lower GRG value. The expression for GRG value can be articulated as follows:

$$\boldsymbol{GRG} = \frac{1}{\mathrm{n}}\sum_{t=1}^{n} \xi\mathrm{i(t)} \quad (6)$$

Where, the number of response parameters is represented by n. The Grey Relation Coefficient is represented by $\xi i(t)$. The GRG values for the response data, namely Fertilizer Depth Placement (FDP), Fertilizer Quantity (FQ), and Soil Moisture (SM), are computed using equation (6) and depicted in Table 6 for NPK absorption rate. However, to extend beyond the scope of the L27 experimental design and determine the optimal parameter set, it becomes imperative to build a GRG table. To achieve this, mean GRG values for each parameter and level pertaining to NPK absorption rate are computed and presented in Table 5.

Upon examination, it becomes apparent that the parameter exerting the most substantial influence is the depth at which fertilizer is placed, as evidenced by the smaller delta value. This directly implies a higher rate of nutrient absorption by crops. Subsequently, both fertilizer quantity and soil moisture emerge as substantial parameters in terms of their present influence.

4.2.1.4 Ranking

In Grey-based Taguchi method, rankings play a crucial role in discerning the desired response variable, which is the most effective parameter, thereby enhancing decision making and optimizing performance in agricultural applications. The computed Grey Relational Grade (GRG) encapsulates the collective impact of all output responses. Subsequently, each parameter calculated for the GRG values, ranked accordingly to their relative performance, facilitating objective identification of the most effective parameter without the need for manual comparison considering across all factors in the analysis. Tables 4 to 6 depict the ranking of achieved GRG values for NPK absorption rate.

Table 5: Mean GRG for NPK absorption Rate

Response Table for GRG							
Para	**Level-1**	**Level-2**	**Level-3**	**Min**	**Max**	**Delta**	**Rank**
FDP	0.39074	0.50233	0.76552	0.39074	0.76552	0.37477	1
FQ	0.47201	0.58204	0.49687	0.47201	0.58204	0.1100	2
SM	0.57675	0.51740	0.56443	0.51740	0.57675	0.0593	3

Rankings presented in Table 5, prove that test 22 secures the highest rank. Subsequently, the process parameters related with test 22, specifically a fertilizer depth penetration of 6 inches, a fertilizer quantity of approximately 30 gm, and 50% soil moisture, can be inferred as the optimum parametric set yielding the best results for the given multiple responses. Similarly, Table 8 reveals that Fertilizer Depth Placement (FDP) exerts the most pointed influence, followed by Fertilizer Quantity (FQ) and Soil Moisture (SM). Furthermore, FDP, FQ, and SM are observed at level-3, level-2, and level-1 respectively as the maximum mean GRG values. Consequently, FDP of 6 inches, FQ of 30 gm and SM of 50% are identified as more significant compared to other levels.

It's noteworthy that these findings signify optimal fertilizer absorption when placed at a substantial depth of 6 inches, which enhances nutrient uptake by crops. Presently, in cotton farming practices, fertilizers are typically applied at depths below 2 inches. However, due to shallow fertilization, some fertilizers are absorbed by nearby weeds or degraded by sunlight, leading to wastage. Additionally, the standard practice of applying an average quantity of 30 gm in cotton cultivation ensures proper nutrient balance. Moreover, maintaining soil moisture at around 50% availability is crucial for optimum plant growth.

These results offer practical suggestions for optimizing the usage of NPK fertilizers across all stages of plant growth. Similar outcomes are derived from the GRG's mean Signal-to-Noise ratio (SN ratio), which signifies the combined effect of all NPK responses; refer to Figure 6 for further details.

4.2.2 ANOVA (Analysis of Variance):

ANOVA, or Analysis of Variance, stands as a fundamental statistical technique frequently employed in investigative research to discern differences among least two or more than two groups. This technique entails dissecting the total variance in the data into 2 distinct components: variation between groups and their variation within groups.

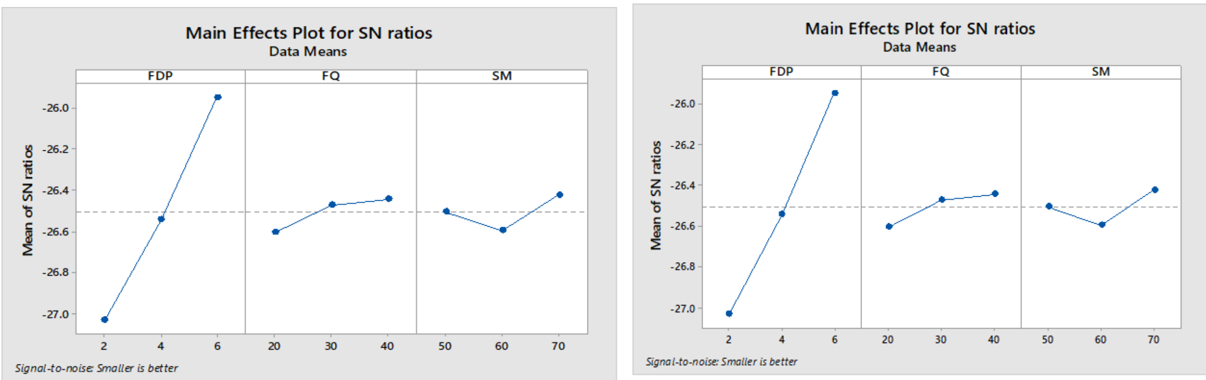

Fig. 6: Mean SN ratio of GRG for combined NPK effect

The variance between groups delineates disparities in mean values across the compared groups, while the variance groups within, termed "error," encompasses differences within each group not attributable to the treatment. Analysis of Variance computes an F-value, representing the treatment variance to error variance ratio. A significant F-value indicates notable differences between the compared groups. Typically, the significant influence of input parameters on output responses is evaluated using F-value.

In this study, data for the GRG from Grey Relational Analysis (GRA) were used to construct the table of ANOVA through Minitab software, as depicted in Table 6.

Table 6: The constituents of CNG.

Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**	**Contribution (%)**
FDP	2	1.76926	0.88463	36.00	0.027	95.21
FQ	2	0.04476	0.02238	0.91	0.523	2.41
Nitrogen	2	0.04437	0.02218	0.90	0.526	2.38
Error	2	0.04914	0.02457			
Total	8	1.90754				

The findings indicate that for NPK absorption rate, fertilizer depth penetration (FDP) emerges as the most influential parameter, contributing 95.21% to the overall variance. This is followed by fertilizer quantity (FQ) and soil moisture (SM) with contributions of 2.41% and 2.38% respectively.

The substantial contribution of FDP can be attributed to prevalent practices in cotton cultivation, where shallow fertilization methods are often employed. Such practices impede adequate nutrient uptake by crops, thereby amplifying the significance of FDP. Conversely, the contributions of FQ and SM are relatively low, owing to their alignment with standard practices in cotton cultivation.

Maintaining the appropriate quantity of fertilizer is imperative, as excessive amounts can elevate soil temperature, leading to soil degradation and detrimentally impacting plant health. Conversely, reducing fertilizer quantities may result in undernourished crops. Similarly, optimizing soil moisture levels is crucial, as excessive watering can lead to fertilizer runoff, while insufficient watering can hinder plant growth. Achieving the right balance is essential for optimal plant health and nutrient absorption.

CONCLUSION:

The given research work portrays an experimental and mathematical analysis of the multilayered fertilization method on black loamy sandy soil with cotton crop and its responses on NPK absorptions rate. Real time data obtained using IOT based sensors for measuring parameters like NPK content in fertilizers, moisture, temperature, and pH of soil. Data sets were imported, cleaned, prepared, analyzed and statistically summarized using Python's Panda Data frame software. Furthermore, an assessment of the impact of process parameters on individual output variables was conducted, leading to the identification of the optimal combination. Subsequently, the grey-based Taguchi optimization method was employed to ascertain the optimal configuration of process parameters, taking into account the collective influence of all output variables. The findings of the study can be summarized as follows:

- Using Taguchi method, the optimum combination for obtaining the low value of N, P & K was found as FDP = 6 inches, FQ = 40 gm, SM = 70% (FDP-3-FQ-3-SM-3).
- This indicates NPK is better absorbed by cotton plant under maximum depth thereby getting low value measured in soil. Also, under these circumstances, the amount of fertilizer quantity and water content in soil were utilized in highest limit.
- The grey-based Taguchi analysis was utilized to examine the influence of process parameters on combined NPK responses. It was determined that the optimal combination for low value of N, P & K was found as FDP = 6 inches, FQ = 40 gm, SM = 70% (FDP-3-FQ-3-SM-3). Fertilizers like urea and DAP constitute NPK as combined main nutrient ingredient for soil. Hence, individual and combined output have no change in their results and must be similar in approach.
- Based on the analysis of variance (ANOVA) findings for the GRG value, it was revealed that the parameter exerting the most significant influence was the FDP, contributing 95.21% to the total variance., followed by FQ and SM with contributions of 2.41% and 2.38% respectively. Using deep fertilization techniques has a significant impact on plant growth and thus FDP plays an important role in contributing to this analysis. Also, FQ and SM contributions in this analysis are low due because their values are practically used in cotton farming practices.
- This study concludes that the Multilayered Fertilization method affects the nutrient uptake from the cotton crop compared to conventional fertilization method performed by the Vidarbha farmers. The position of fertilization appears to have affected the absorption rate of N, P and K in the cotton plant. Also, the effect of other parameters like amount of fertilizer, temperature, moisture, and pH value is significantly the same.

Thus, from the study it is recommended that for better fertilizer use efficiency, farmers must practice multilayered fertilization techniques if appropriate machine or setup is available to place the fertilizer in appropriate depths.

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REFERENCES

[1] Daum, T. (2023). Mechanization and sustainable agri-food system transformation in the Global South. A review: Agronomy for Sustainable Development, 43(1), 16.

[2] Somasundaram, J., Sinha, N. K., Dalal, R. C., Lal, R., Mohanty, M., Naorem, A. K., ... & Chaudhari, S. K. (2020). No-till farming and conservation agriculture in South Asia–issues, challenges, prospects and benefits. Critical Reviews in Plant Sciences, 39(3), 236-279.

[3] Araya, T., Ochsner, T. E., Mnkeni, P. N., Hounkpatin, K. O. L., & Amelung, W. (2024). Challenges and

constraints of conservation agriculture adoption in smallholder farms in sub-Saharan Africa: A review. International Soil and Water Conservation Research.

[4] Kumar Pradhan, A., Kumar, D., Chaurasia, H., Murmu, S., Samal, I., Kumar Bhoi, T., ... & Mondal, B. (2024). Crop Monitoring System Integrating with Internet of Things and Artificial Intelligence. In Artificial Intelligence and Smart Agriculture: Technology and Applications (pp. 193-208). Singapore: Springer Nature Singapore.

[5] Bai, Z., Xie, C., Yu, J., Bai, W., Pei, S., Li, Y., ... & Yin, F. (2024). Effects of irrigation and nitrogen levels on yield and water-nitrogen-radiation use efficiency of drip-fertigated cotton in south Xinjiang of China. Field Crops Research, 308, 109280.

[6] Zhang, Z., Qiu, S., Thistlethwaite, R. J., Yao, X., Tan, D. K., Wang, D., & Yang, G. (2024). Optimizing nitrogen application methods and frequency to increase cotton yield in summer direct sown condition. Industrial Crops and Products, 213, 118468.

[7] Ding, B., Cao, H., Bai, Y., Guo, S., Zhang, J., He, Z., ... & Liu, H. (2024). Effect of biofertilizer addition on soil physicochemical properties, biological properties, and cotton yield under water irrigation with different salinity levels in Xinjiang, China. Field Crops Research, 308, 109300.

[8] Li, Z., Liu, H., Wang, T., Gong, P., Li, P., Li, L., & Bai, Z. (2024). Deep vertical rotary tillage depths improved soil conditions and cotton yield for saline farmland in South Xinjiang. European Journal of Agronomy, 156, 127166.

[9] Shilpa, Sharma, A. K., Chauhan, M., & Bijalwan, P. (2024). Plant growth promoting rhizobacteria, organic manures, and chemical fertilizers: impact on crop productivity and soil health of capsicum (Capsicum annuum L.) in North Western Himalayan region. Journal of Plant Nutrition, 47(3), 448-467.

[10] Duguma, A. L., & Bai, X. (2024). Contribution of Internet of Things (IoT) in improving agricultural systems. International Journal of Environmental Science and Technology, 21(2), 2195-2208.

[11] Sharifmousavi, M., Kayvanfar, V., & Baldacci, R. (2024). Distributed Artificial Intelligence Application in Agri-food Supply Chains 4.0. Procedia Computer Science, 232, 211-220.

[12] Munaganuri, R. K., & Yamarthi, N. R. (2024). PAMICRM: Improving Precision Agriculture through Multimodal Image Analysis for Crop Water Requirement Estimation Using Multidomain Remote Sensing Data Samples. IEEE Access.

[13] Nijak, M., Skrzypczyński, P., Ćwian, K., Zawada, M., Szymczyk, S., & Wojciechowski, J. (2024). On the Importance of Precise Positioning in Robotised Agriculture. Remote Sensing, 16(6), 985.

[14] Singh, N., Sharma, A. K., Sarkar, I., Prabhu, S., & Chadaga, K. (2024). IoT-based greenhouse technologies for enhanced crop production: a comprehensive study of monitoring, control, and communication techniques. Systems Science & Control Engineering, 12(1), 2306825.

[15] Kalimuthu, T., Kalpana, P., Kuppusamy, S., & Sreedharan, V. R. (2024). Intelligent decision-making framework for agriculture supply chain in emerging economies: Research opportunities and challenges. Computers and Electronics in Agriculture, 219, 108766.

[16] Cyriac, R., & Thomas, J. (2024). Smart Farming with Cloud Supported Data Management Enabling Real-Time Monitoring and Prediction for Better Yield. In Intelligent Robots and Drones for Precision Agriculture (pp. 283-306). Cham: Springer Nature Switzerland.

[17] Mentsiev, A. U., Gerikhanov, Z. A., & Isaev, A. R. (2019, December). Automation and IoT for controlling and analysing the growth of crops in agriculture. In Journal of Physics: Conference Series (Vol. 1399, No. 4, p. 044022). IOP Publishing.

[18] Yadav, S., Garg, D., & Luthra, S. (2021). Development of IoT based data-driven agriculture supply chain performance measurement framework. Journal of Enterprise Information Management, 34(1), 292-327.

[19] Khan, F. A., Abubakar, A., Mahmoud, M., Al-Khasawneh, M. A., & Alarood, A. A. (2019). Cotton crop cultivation oriented semantic framework based on IoT smart farming application. International Journal of Engineering and Advanced Technology, 8(3), 480-484.

[20] Luo, J., & Zhou, J. J. (2019). Growth performance, photosynthesis, and root characteristics are associated with nitrogen use efficiency in six poplar species. Environmental and experimental botany, 164, 40-51.

[21] Han, W., Sun, J., Zhang, K., Mao, L., Gao, L., Hou, X., ... & Gong, D. (2023). Optimizing drip fertigation management based on yield, quality, water and fertilizer use efficiency of wine grape in North China. Agricultural Water Management, 280, 108188.

[22] Yu, J., Hou, P., Gao, Q., Tan, Q., Jiang, D., Dai, T., & Tian, Z. (2024). Optimizing nitrogen fertilizer and straw

management promote root extension and nitrogen uptake to improve grain yield and nitrogen use efficiency of winter wheat (Triticum aestivum L.). Archives of Agronomy and Soil Science, 70(1), 1-17.

[23] Zhang, Y., Wang, Y., Zang, H., Yao, J., & Ma, H. (2023). Analysis of Heavy Metal Pollution in Soil along the Shuimo River by the Grey Relational Method and Factor Analysis. Metals, 13(5), 878.