**NPK Sensor-Based Soil Health Management in Smart Agriculture**

**Abstract:**

Soil health is deteriorating due to excessive use of fertilizers. As a part of smart agriculutr, NPK sensor can improve the soil fertility status. A study was carried out to evaluate efficacy of the fertilizer sensors during the winter season (2024) at the Guava (*Psidium guajava L*) Farm, Baruipur, South 24 Parganas, West Bengal, India. The total nitrogen was ranging from 215.5 kg ha-1 to 224.3 kg ha-1 which indicated the low nitrogen content in soil (<280 kg ha-1). The available phosphorus status (P2O5) in the plots was high (>90 kg ha-1) whereas the available potassium (K2O) was medium (150-340 kg ha-1). The average total nitrogen for T1 required per plant was 614.04 g whereas in T2 the average nitrogen requirement was 128.2 g (Tab.-5). The application frequency was more in T2 (5). The N sensor saved the 79% nitrogen. The average amount phosphorus was 367.28 g per plant in T1 whereas it was 120.32 g. The P sensor saved 67.24% phosphorous fertilizer. Average potassium fertilizer applied for T1 without NPK sensor, was 508.62 g per plant whereas it was only 122.7g for T2.  It was found that sensor resisted the excess use of potassic fertilizers and saved 75.87 %. The yield was increased by 99.69 % in T2 (23.012) compared to T1(11.524). Overall total of fertilizers decreased (72.37%) when it utilized the NPK sensors for soil health monitoring in smart agriculture.

**Key Words**: Smart Agriculture, NPK Sensor, Soil Health

**Introduction**

Smart agriculture is being promoted by the technology to optimize and improve agricultural practices. It involves the application of sensors, internet of things, data analytics, automation, and other technologies to monitor and manage various aspects of farming, like soil conditions, irrigation, and crop health.  Application of technology in modern agriculture is becoming more essential, especially when it comes to controlling major plant nutrients like nitrogen (N), phosphorus (P), and potassium (K) which directly involve in crop productivity (Al-Mamun et al., 2021; Potdar et al., 2021; Yohannes et al., 2024). Excessive use of fertilizers in conventional farming results in financial inefficiency and environmental pollution (Hafsi et al., 2014; Leghari et al., 2016). Use of NPK sensors strengthens farmers to make accurate, data-driven decisions by giving them real-time information on soil nutrient management (Zhang et al., 2021). Mapping of Macro - nutrient requires development of sensors (Ramane et al., 2015). NPK sensors temporal and spatial study are the most essential part of temporal and spatial study from crop management (Ramane et al., 2015; Kulkarni et. al., 2014). According to Pooniya et al., (2018) and Eli et al., (2019), sensor helps fertilizer application with crop needs, lowering environmental pollution including phosphorus runoff and nitrogen leaching. Automated nutrition management made possible by NPK sensors coupled with Internet of Things (IoT) devices (Ahmed et al., 2021; Sangwan et al., 2022). According to Mohanty et al., (2020) and Park et al., (2017), these sensors also improve fertilizer recommendations by making sure nutrients are only supplied when necessary, increasing agricultural productivity and environmental sustainability. According to Lee et al., (2021) NPK sensors are crucial for smart agriculture in the context of climate change due to their exceptional precision and flexibility in response to changing environmental conditions (Ahmed et al., 2020; Ada˜o et al., 2020). The study was conducted to evaluate the efficacy of NPK sensors for soil health management in smart agriculture.

**Materials and Methods**

The study was undertaken during the winter season (2024) at the Guava (*Psidium guajava L*) Farm, Baruipur, South 24 Parganas, West Bengal, India. The experiment was laid out in Randomized Block Design with two treatments and five replications. The treatments constituted of T1: Control, T2: NKP Sensor. The plot size for each treatment and replication was 5m x 4 m with plant spacing 2.5m x 2m. Guava thrives well in tropical and sub-tropical climate. The variety of guava was Allahabad Safeda and four years old tree. The study location belongs to sub-tropical climate and new alluvial soil. The soil is loamy. Total nitrogen content of the soil sample has been estimated by using alkaline KMnO4 titration method (Subbiah and Asija, 1956). Available phosphorus content of soil samples has been determined either by extracting samples with Olsen extractant (0.5M NaHCO3 adjusted to pH 8.5), or by Bray and Kartz No. 1 extractant (0.3N NH4F in 0.025 N HCl). Olsen method of extraction has been selected for the soils having pH 6.0 and above while Bray and Kartz no.1 extractant was used for soils having pH below 6. The colour intensity has been recorded by stannous chloride reduced molybdophosphoric blue colour method in the hydrochloric acid system using spectrophotometer. The available phosphorus content has been determined by plotting the reading on the standard curve (Jackson, 1976). The soil sample has been extracted with the neutral ammonium acetate for potassium estimation. The filtrate has been ignited by using flame photometer. The recorded reading has been plotted on the standard curve to get the content of available potassium in the soil sample (Hesse, 1971).

During the study, data were recorded and analyzed through the formulas by using Microsoft excel.

**Result and Discussion**

The major nutrient (NPK) content in the soil of study area for each plot was estimated before the inception of experiment in the month of October, 2024 (Table:1-3). The total nitrogen was ranging from 215.5 kg ha-1 to 224.3 kg ha-1 which indicated the low nitrogen content in soil (<280 kg ha-1). The available phosphorus status (P2O5) in the plots was high (>90 kg ha-1) whereas the available potassium (K2O) was medium (150-340 kg ha-1). The sensors were placed in the T2 plots with its five replication. The sensors’ result was not similar to the soil testing report. Therefore, the reading of NPK sensors was calibrated with the establishment of correlation between soil result and readings of sensors (Fig. 1-3). It showed that N Sensor reading was highly correlated with the soil result (R2= 0.945) but, P sensor reading was moderately correlated (R2= 0.8132). K sensor had good correlation with soil testing result (R2= 0.9499). This helped to find the exact NPK status at the real-time and specific location.

Table -1: Calculation of total nitrogen (kg ha-1)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Treatment | R1 | R2 | R3 | R4 | R5 |
| T1 | 224.3 | 219.8 | 218.7 | 221.1 | 217.9 |
| T2 | 223.1 | 218.2 | 220.8 | 215.5 | 219.3 |
| N Sensor | 201.4 | 205.7 | 198.8 | 195.6 | 204.2 |

Fig.1: Correlation between N sensor reading and soil test report

Table -2: Calculation of Initial soil P2O5 (kg ha-1)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Treatment** | **R1** | **R2** | **R3** | **R4** | **R5** |
| T1 (Lab. tested) | 153.4 | 150.1 | 153.8 | 157.4 | 156.1 |
| T2 (Lab. tested) | 154.2 | 149.8 | 153.4 | 158.6 | 155.7 |
| P Sensor (Recorded) | 148.3 | 147.1 | 150.2 | 154.3 | 153.2 |

Fig.2: Correlation between P sensor reading and soil test report

Table -3: Calculation of Initial soil K2O (kg ha-1)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Treatment | R1 | R2 | R3 | R4 | R5 |
| T1 (Lab. tested) | 324.5 | 319.8 | 327.6 | 330.2 | 324.5 |
| T2 (Lab. tested) | 325.3 | 321.4 | 328.6 | 320.5 | 317.8 |
| K Sensor (Recorded) | 256.7 | 254.3 | 262.7 | 249.5 | 245.6 |

Fig.3: Correlation between K sensor reading and soil test report

**Nitrogen fertilizer**

The recommended dose was 1.0:1.0:1.0 NPK kg per year for each four years old guava plant. During winter season (October to March) two split doses @ 250 gm each component for each plant had been recommended. The soil in study area contained low level of nitrogen (<280 kg ha-1). The 25% dose was increased for each plot. In T1 the usual application of NPK fertilizers was carried out for two times at the interval of three months (Tab.-4). The average total nitrogen for T1 required per plant was 614.04 g whereas in T2 the average nitrogen requirement was 128.2 g (Tab.-5). The application frequency was more in T2 (5). The N sensor saved the 79% nitrogen from wastage and environmental pollution (Fig. 4).

Table -4: Nitrogen Fertilizers Application for T1 (g per plant)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Replication | 1st Dose (2nd October) | 2nd dose (2nd January) | Total Fertilizers (g) | Average amount (g) |
| R1 | 312.5 | 312.5 | 625.0 | 614.04 |
| R2 | 306.2 | 306.2 | 612.5 |
| R3 | 304.7 | 304.7 | 609.4 |
| R4 | 308.0 | 308.0 | 616.1 |
| R5 | 303.6 | 303.6 | 607.2 |

Table -5: Nitrogen Fertilizers Application for T2 (g per plant)

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Replication | 1st Dose (2nd October) | 2nd dose (15th November) | 3rd dose (10th December) | 4th dose (14th January) | 5th dose (28th February) | Total amount (g) |
| R1 | 20.5 | 25.3 | 31.6 | 21.4 | 32.5 | 131.3 |
| R2 | 21.5 | 20.8 | 24.8 | 26.3 | 23.9 | 117.3 |
| R3 | 24.3 | 21.7 | 28.5 | 31.4 | 25.3 | 131.2 |
| R4 | 19.8 | 27.1 | 24.5 | 21.7 | 31.8 | 124.9 |
| R5 | 23.4 | 22.6 | 27.4 | 30.2 | 32.7 | 136.3 |
| SEM |  |  |  |  |  | 1.735836 |
| CD 0.05 |  |  |  |  |  | 5.066794 |

Fig.4: Nitrogen application in T1 and T2

**Phosphorus fertilizer**

The soil contained high level of phosphorus (>90kg ha-1). The 25% recommended dose was decreased for each plot. The average amount phosphorus was 367.28 g per plant in T1 whereas it was 120.32 g. Two times of application of fertilizer in T1 added more chemical inputs in soil which were not required by the plant. This excess fertilizer was jeopardizing the environment. The P sensor saved 67.24% phosphorous fertilizer (Fig. 5) and suggested the efficient use of phosphatic fertilizers for better crop productivity and healthy nature.

Table -6: Phosphorus Fertilizers Application for Treatment T1 (g per plant)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Replication | 1st Dose (2nd October) | 2nd dose (2nd January) | Total Fertilizers (g) | Average application (g) |
| R1 | 182.7 | 182.7 | 365.5 | 367.28 |
| R2 | 178.8 | 178.8 | 357.6 |
| R3 | 183.2 | 183.2 | 366.4 |
| R4 | 187.5 | 187.5 | 375.0 |
| R5 | 186.0 | 186.0 | 371.9 |

Table -7: Phosphorus Fertilizers Application for Treatment T2 (g per plant)

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Replication | 1st Dose (2nd October) | 2nd dose (15th November) | 3rd dose (10th December) | 4th dose (14th January) | 5th dose (28th February) | Total amount (g) |
| R1 | 28.1 | 24.3 | 27.5 | 20.5 | 21.7 | 122.1 |
| R2 | 20.4 | 28.5 | 26.2 | 21.8 | 23.9 | 120.8 |
| R3 | 23.8 | 22.6 | 29.1 | 21.5 | 23.8 | 120.8 |
| R4 | 21.4 | 21.8 | 25.7 | 22.3 | 28.4 | 119.6 |
| R5 | 24.1 | 19.2 | 28.2 | 18.5 | 28.3 | 118.3 |
| SEM |  |  |  |  |  | 1.448072 |
| CD 0.05 |  |  |  |  |  | 4.226831 |

Fig.5: Phosphorus application in T1 and T2

**Potassium fertilizer**

The soil contained medium level of potassium (150-340 kg ha-1). The recommended dose @ 250g was applied for the plot having higher potassic content in soil and proportionately the doses were decreased with nutrient status (Table-8,9). Average potassium fertilizer applied for T1 without NPK sensor, was 508.62 g per plant whereas it was only 122.7g for T2 where NPK sensors were used to detect nutrient content at real time. It was found that sensor resisted the excess use of potassic fertilizers and saved 75.87 % (Fig.6).

Table -8: Potassium Fertilizers Application for T1 (g per plant)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Replication | 1st Dose (2nd October) | 2nd dose  (2nd January) | Total Fertilizers (g) | Average fertilizer (g) |
| R1 | 253.7 | 253.7 | 507.3 | 508.62 |
| R2 | 250.0 | 250.0 | 500.0 |
| R3 | 256.1 | 256.1 | 512.2 |
| R4 | 258.1 | 258.1 | 516.3 |
| R5 | 253.7 | 253.7 | 507.3 |

Table -9: Potassium Fertilizers Application for T2 (g per plant)

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Replication | 1st Dose (2nd October) | 2nd dose (15th November) | 3rd dose (10th December) | 4th dose (14th January) | 5th dose (28th February) | Total amount (g) |
| R1 | 27.3 | 25.4 | 28.1 | 22.9 | 20.8 | 124.5 |
| R2 | 21.8 | 27.9 | 25.4 | 26.1 | 27.2 | 128.4 |
| R3 | 22.5 | 21.7 | 27.3 | 20.8 | 26.8 | 119.1 |
| R4 | 22.9 | 28.1 | 22.5 | 19.9 | 27.8 | 121.2 |
| R5 | 22.7 | 21.4 | 24.5 | 26.1 | 25.6 | 120.3 |
| SEM |  |  |  |  |  | 1.454347 |
| CD 0.05 |  |  |  |  |  | 4.245147 |

Fig.6: Potassium application in T1 and T2

**Yield and cost estimation**

The yield was increased by 99.69 % in T2 (23.012) compared to T1(11.524) because of overdose fertilizer applied for very short time and plant absorbed more luxury nutrients which induced vegetative growth and indulged pest infestation (Table -10). After the exhaust of fertilizers plant started to starve and yield declined at great level. T2 was enjoying the balanced nutrients while fertilizers sensors depicted the real time nutrient status in soil which guided the application schedule and quantity of fertilizers for the concerned plant nutrient. Overall total of fertilizers decreased (72.37%) when it utilized the NPK sensors for soil health monitoring.

Table -10**: yield of guava in** T1 andT2

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Treatment | Yield  (kg / plant) | Cost of N Fertilizers | for Cost of P Fertilizers | Cost of K Fertilizers | Total Cost |
| T1 | 11.524 | 14.00 | 32.00 | 30.00 | 76.00 |
| T2 | 23.012 | 3.00 | 11.00 | 7.00 | 21.00 |
| Increase / Decrease (%) | 99.69 | -78.57 | -65.625 | -76.67 | -72.37 |

**Conclusion**

Fertilizers are essential for crop production. Soil was also having different nutrient holding capacity. NPK sensors helped to detect the exact point of nutrient deficiency which was crucial for better crop production. These sensors reduced the quantity of fertilizers which are polluting the environment and crippling the human health. The cost of fertilizers as well as cost of total cultivation decreased. This NPK sensor improved the soil health through the smart agriculture.

**Reference**

1. Ada˜o, T., Hrusˇka, J., Pa´dua, L., Bessa, J., Peres, E. ,Morais, R., Ahmed, N., Ullah, S., & Saleem, S. (2020). IoT-based NPK monitoring system for optimized fertilizer application. Computers and Electronics in Agriculture, 174, 105465.
2. Ahmad, M. and Khan, R. (2015). Sensor network based automatic irrigation management system for agricultural crops, in Smart agriculture: An approach towards better agriculture management. World Applied Sciences Journal. 24(8).
3. Ahmad, Y. A., Surya Gunawan, T., Mansor, H., Hamida, B. A. , Fikri Hishamudin, A. and Arifin, F. (2021). On the Evaluation of DHT22 Temperature Sensor for IoT Application,in 2021 8th International Conference on Computer and Communication Engineering (ICCCE).
4. Bray, R. H., and L. T. Kurtz. 1945. Determination of total, organic, and available forms of phosphorus in soils. Soil Science 59:39–45.
5. Eli-Chukwu, N.C. 2019. Applications of Artificial Intelligence in Agriculture: A Review. Engineering, Technology & Applied Science Research, 9(4). 4377–4383
6. Hafsi, C., Debez, A., & Abdelly, C. (2014). Potassium deficiency in plants: Effects and signaling cascades. Acta Physiologiae Plantarum, 36(5), 1055–1070.
7. Jackson, M. L. (1976). Soil Chemical Analysis. Prentice-Hall of India Private limited, New Delhi.
8. Lee, S., Choi, J., & Kim, Y. (2021). Soil fertility management through real-time data. Precision Agriculture, 22(1), 113–129.
9. Leghari, S. J., Wahocho, N. A., Laghari, G. M. (2016). Role of nitrogen for plant growth and development: A review. Advances in Environmental Biology, 10, 209.
10. Kulkarni, Y., . Warhade , K. K, and . Bahekar. (2014), Primary nutrients determination in the soil using UV spectroscopy: International Journal of Emerging Engineering Research and Tecnology, vol. 2, pp. 198-204, 2014.
11. Mohanty, S.R., Pal, A.R., & Das, M. (2020). Application of sensors in precision agriculture: Impact on productivity. Agronomy Journal, 112(4), 2338– 2350.
12. Olsen, S. R., C. V. Cole, F. S. Watanabe, and L. A. Dean. 1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. Washington, D.C.: U.S. Government Printing.
13. Park, S. Y., Oh, J. K., & Kim, S. H. (2017). Sensor-based nutrient management in paddy fields. Journal of Environmental Management, 204, 456–465.
14. Pooniya, V., Bhatia, R., Rana, K. S., & Kumawat, N. (2018). Optimizing nitrogen and water use efficiency. Agricultural Water Management, 207, 38–45
15. Potdar, R. P., Shirolkar, M. M., Verma, A. J., More, P.S., & Kulkarni, A. (2021). Determination of soil nutrients (NPK) using optical methods. Journal of Plant Nutrition, 44(12), 1826-1839
16. Ramane, Deepa V., Patil, Supriya S., Shaligram, A, D. (Feb 2015). Detection of NPK nutrients of soil using Fiber Optic Sensor, International Journal of Research in Advent Technology
17. Sangwan, S., Singh, J., & Malhotra, R. (2022). IoT- driven soil nutrient monitoring. Smart Agriculture Technologies, 12, 203–212.
18. Subbiah, B.V. and Asijia, G.L. (1956). A rapid procedure for the determination of nitrogen in soils. Current Science, 25, 259-260.
19. Yohannes, Z., Yoseph, T., Kiflu, A., Ayalew, T., &Haile, A. (2024). Liquid bio-slurry enhances the productivity of N-fertilized maize under field conditions in Ethiopia. International Journal of Experimental Research and Review, 43(Spl Vol), 13–31.
20. Zhang, Z., Liu, D., Wu, M., Xia, Y., Zhang, F., & Fan, X. (2021). Long-term straw returning improves soil K balance and potassium-supplying ability. Scientific Reports, 11(1), 1–15.