

Design and Development of Colorimetry based Optical Soil pH Meter

Varsha Atul Shukre¹ and Supriya Santosh Patil²

¹Department of Computer Science & Applications, Dr. Vishwanath Karad MIT World Peace University, Pune, Maharashtra, India

Email: varsha.sontakke@mitwpu.edu.in

²Department of Electronic Science MES Abasaheb Garware College (Autonomous), Pune, Maharashtra, India

Email: patilss121@gmail.com

Abstract—Soil pH is a vital characteristic as it directly affects the accessibility of vital nutrients in the soil. Measuring and managing soil pH is fundamental for creating an environment that supports overall plant health. In this research work, different methods of measuring soil pH are discussed along with their pros and cons. This paper aims to develop a cost-effective and portable pH meter prototype based on the colorimetry principle using soil test kit reagents. TCS3472 color sensor is used for sensing RGB Color component of the solution under test which is interfaced with Node MCU (ESP8266). Trials are conducted to obtain the true color response of the reactants, which will be utilized as color benchmarks. The mathematical model is developed based on the analyzed data. The system is calibrated and validated using Prerana Laboratories Soil Test kit. The device is tested using 10 soil samples collected from different states of India with different pH levels. By using the standard deviation method system performance is analyzed. The system accuracy is found to be 99.30%. The values obtained from the sensors are displayed in a user-friendly embedded web server application without Internet as well as on system LCD. Based on the pH level system also classifies soil samples as acidic, neutral, and alkaline. To facilitate the measurement of Soil pH for farmers from rural areas where Soil testing labs are not easily available, this non-contact type portable pH meter will play an important role to periodically test soil pH to improve soil fertility where accuracy, speed, non-destructive testing and reduced maintenance are critical factors.

Index Terms— Colorimetry, Embedded Web Server, pH measurement, RGB. Soil Nutrients.

I. INTRODUCTION

India's economy has benefited greatly from agriculture, which provides a significant amount of the nation's people with one of their primary sources of income [1]. It contributes significantly to the country's revenue generation through dissemination of agricultural products like wheat, spices, rice, fruits etc. Moreover, it serves as the bedrock for rural development, fostering economic and social growth and thus providing employment opportunities in numerous sectors [2]. Hence, agriculture continues to be India's vital foundation remarking upon the nation's socio & economic stability and sustenance assurance. Soil pH is a critical parameter influencing nutrient availability and uptake by plants. The soil pH, indicating the alkalinity or acidity of the soil solution through the concentration of hydrogen ions (H^+), is a crucial soil attribute that significantly affects plant growth, microbial activity, and overall soil health.

The soil solution's acidity or alkalinity plays a direct role in the solubility and distribution of vital nutrients. The alkalinity or acidity of the soil solution directly influences the solubility and movement of essential nutrients. It is a well-established fact that different crops require different optimal pH ranges, and any deviations from these ranges can cause nutrient deficiencies or toxicities, thus impeding plant growth [13].

A. Overview of Traditional Methods of Measurement of Soil pH

Traditional methods for measuring soil pH typically involve laboratory-based techniques or field-based tests using chemical indicators [2]. Review of the following methods are as followed:

Laboratory pH Meter

The first step involves gathering soil samples and blending them with distilled water to produce a soil-water suspension. Next, the suspension is tested by immersing a pH electrode, and the pH content of the soil solution is gauged by a laboratory pH meter. This requires specialized equipment and trained personnel also it is Time-consuming and labor-intensive, as it involves sample collection, preparation, and analysis. It is not suitable for real-time monitoring of soil pH in the field.

pH Test Strips

The soil samples are mixed once more with a chemical indicator, and the ensuing change in color is subsequently matched against the color chart to establish the pH of the soil sample. The limitations are the subjective interpretation of color changes can lead to inaccuracies, limited accuracy and precision compared to laboratory methods, results may be influenced by properties of soil such as the texture, moisture levels and organic matter content.

Soil pH Probe

A soil pH probe with an electrode is inserted directly into the soil to measure pH in situ. This requires calibration and regular maintenance to ensure accuracy. Depth of measurement may be limited by probe length, potentially leading to variability in pH readings at different soil depths. Susceptible to interference from soil contaminants, air bubbles, or electrode fouling.

Chemical Titration

Soil samples are mixed with a chemical indicator and titrated with a standardized acid or base solution until a color change occurs, indicating the endpoint of the titration and the soil pH. It requires precise measurement of reagents and careful titration techniques to achieve accurate results. Time-consuming and requires multiple steps. Limited suitability for field-based measurements due to the need for laboratory equipment and controlled conditions.

Soil Test Kits

Method: Portable soil test kits containing reagents and instructions for performing colorimetric tests are used to assess soil pH in the field. In this, the reliability and accuracy may vary depending on the quality of the test kit and user proficiency. Limited range of pH values that can be accurately measurement, not suitable for high-throughput or large-scale soil testing.

The Soil test kits use color reagents which are mixed with Soil sample. The intensity of the color varies with respect to the concentration of pH present in a soil.

The solution is compared with the standard color charts provided by the Soil test kit.

As the human eye has limitations, particularly in differentiating between certain color shades and results depends on the Individual perceptions of color. Also, with the color comparator charts user gets the range of pH instead of its actual value. Therefore, to overcome these limitations of Soil Test Kit the efforts are made to develop a colorimetry-based optical soil pH meter which is simpler, more cost-effective, and field-friendly solution for exact measurement of soil pH, thereby empowering farmers with actionable information for better soil management and crop production outcomes.

B. Aim and Objectives

The objectives of the research on developing a colorimetry based optical soil pH meter are as given below:

- To find out the variation in RGB Values of given soil sample based on its pH
- To design and develop Colorimetry based Optical pH meter
- To interface color sensor with Microcontroller Unit (Node MCU)
- To calibrate Optical pH meter using Color comparator charts provided by Prerana Soil Test Kit
- To check the system performance using the Standard deviation method.

C. Literature Review

Several traditional and modern methods have been brought into use for measurement of soil pH which includes potentiometric methods (e.g., glass electrode, combination electrode), spectrophotometric methods (e.g., colorimetry, UV-Vis spectroscopy), and electrometric methods (e.g., ion-selective electrodes). Among these, colorimetry-based methods stand out for their simplicity and ease of use. Previous studies have extensively explored the application of colorimetry in soil pH measurement, demonstrating its reliability and practicality. In Paper [1], Three spectrophotometric methods, namely the separated three-indicator (STISM), one-indicator (OISM) and mixed three-indicator (MTISM) methods, are put forward. These methods have the potential to be influenced by changes in soil composition, which may result in interference from organic matter, minerals, or other contaminants. Therefore, the accuracy of pH measurements can be compromised. The costs associated with spectrophotometers can be prohibitive for smaller laboratories or research facilities, limiting accessibility to this method for soil pH analysis. Among the various soil sensing methods that are available, Cremer's glass electrode-based method, discovered in 1906 [3], remains a popular choice in many laboratories. This technique offers fast, accurate, and reliable readings. However, it does come with a few drawbacks, including the complexity involved in its construction, the use of brittle materials, and the need for periodic calibration. These limitations make glass electrodes less suitable for miniaturization. The influence of soil pH on nutrient availability has been extensively researched. Among the different methods available for soil sensing, the glass electrode-based technique, which was discovered by Cremer in 1906 [4], remains a popular choice in many laboratories. This technique offers fast, accurate, and reliable readings. However, it does come with a few drawbacks, including the complexity involved in its construction, the use of fragile materials, and the need for frequent calibration. These limitations make glass electrodes less suitable for miniaturization. Polymers are chemical compounds composed of repeated structural units that are produced through the process of polymerization, where monomer molecules react to create polymer chains. The key advantage of employing polymers in sensor applications is their cost-effectiveness and ease of production. Most sensing applications make use of polymers because these materials exhibit alterations in their physical properties (such as volume) or chemical properties (such as ion concentration and conductivity) upon interaction with external substances (such as nutrients, humidity, pH levels, soil moisture and temperature).[5] Considering the limitations in existing soil pH measurement methods there is a need to develop low cost, portable non-contact type optical soil pH meter to measure soil pH periodically.

II. METHODOLOGY

This section highlights the colorimetry-based soil pH meter along with the block diagram and flowcharts to explain the working principle. Beer-Lambert's Law explains the relationship between a solute's concentration in a solution and the amount of light absorption by that solution. In mathematical terms, Beer-Lambert's Law can be represented as follows:

$$A = \epsilon lc \quad (1)$$

Here, A stands for the solution's absorbance. The molar absorptivity, represented by the symbol ϵ , is a wavelength-specific constant that is peculiar to the absorbing material. The sample's path length, or the length of time light takes to pass through the solution, is represented by the variable l (usually measured in centimeters) and c stands for the solute concentration in the solution, which is often expressed in moles per litre.

This section uses a block diagram to describe the overall operation of the intended work. It can be further classified into two categories based on its functioning. The soil sample preparation comes first, followed by the pH testing system.

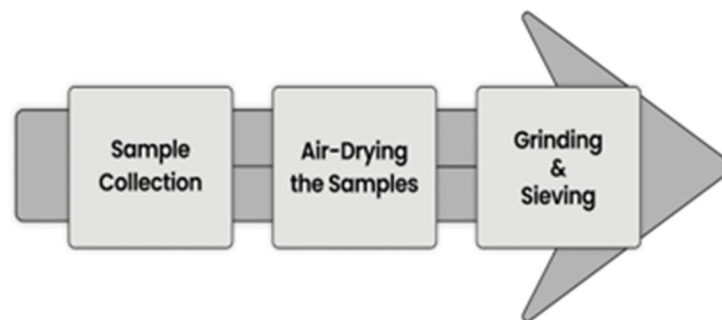


Figure 1. Soil Sample Preparation

The Soil samples are taken in a zigzag pattern at the depth of 20-30 cms. The samples are air dried in the shade. The dried samples are crushed gently using the pestle & mortar and sieved through 2 mm sieve.

Test Procedure

- 5 ml pH reagent is taken in a bottle.
- 2 gms of Soil is added with the help of funnel into bottle.
- The soil sample is mixed by gentle inversion for one minute and bottle is allowed to stand alone for 10 minutes to settle down the soil. The clear liquid layer is on the top.

The clear aqueous soil solution formed in this process is transferred into the cuvette. The corvette is placed in a pH meter cavity for further analysis.

A. Functional Block Diagram

The system's functional block diagram can be seen in the figure below. The white LED is used as a transmitter which is passed through the corvette.

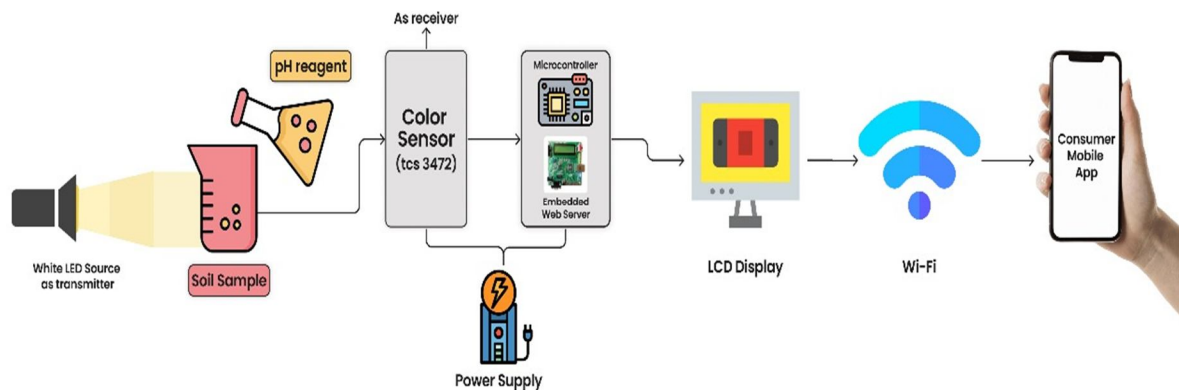


Figure 2. Functional Block diagram

According to Lambert's law light absorbed is directly proportional to the concentration of pH of solution under test. TCS 3472 Color Sensor is used to detect color of the solution under test. According to change in alkalinity or acidity of soil sample the RGB changes which is fed to Node MCU.

An embedded web server is web server software that is embedded within a hardware device or an application. Its primary function is to serve web pages and content to users over a network, typically a local area network (LAN) or the Internet.

Here's a simplified explanation of how an embedded web server works:

The Wi-Fi access point creates a wireless network by emitting radio signals at certain frequencies, often 2.4 GHz or 5 GHz. Each Wi-Fi access point is assigned a Service Set Identifier (SSID), which serves as the wireless network's name.

When a user wants to connect to a network, they choose an SSID from the list of accessible networks on their device. The Wi-Fi is secured with a password. This password is often referred to as the Wi-Fi password or network key. By entering the correct password, the device can access the Wi-Fi Network. In the present system embedded web servers use Static IP addresses.

Node MCU acts as an Embedded Web Server. Once the device is connected to a web server the Webpage can be accessed by any web browser by hitting the Embedded server's static IP address Via Wi-Fi.

Based on measured pH scale soil is classified as Acidic, Alkaline, or neutral and displayed on LCD as well as on the Embedded Web Server in real time.

III. CALIBRATION OF OPTICAL SOIL PH METER

By using pH color comparator chart, we found the RGB values for different pH levels. The acquired data is analysed.

As we found better response for green component which is shown in below graph 2.

To mitigate the non-linearity in Green component multipoint calibration technique is used as shown in graph 3 and 4. The mathematical equation is developed for the same which is implemented in the firmware.

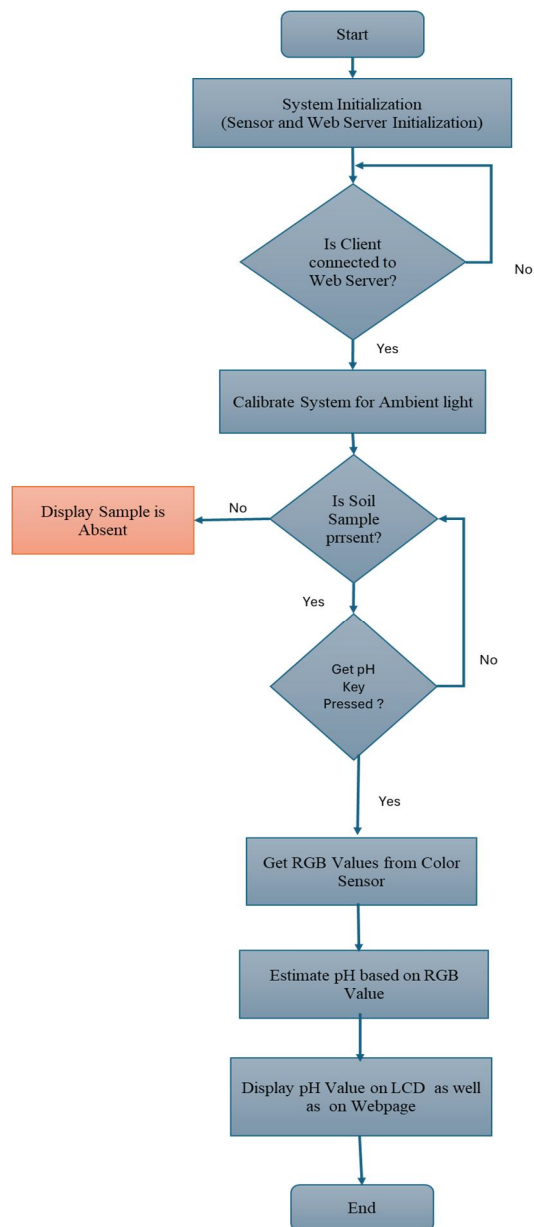


Figure 3. Flowchart

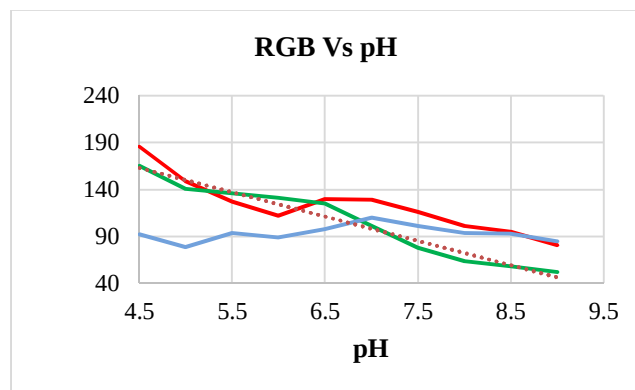


Figure 4.RGB Vs pH response

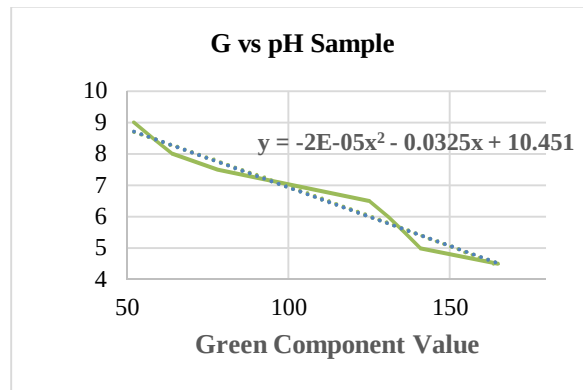


Figure 5. pH Vs Green Component response

IV. VALIDATION OF THE OPTICAL SOIL pH METER

Table 1 below describes the results obtained by Optical Soil pH meter and as per the soil test kit for different pH values. The average error is 0.69% hence the accuracy was found to be 99.31%.

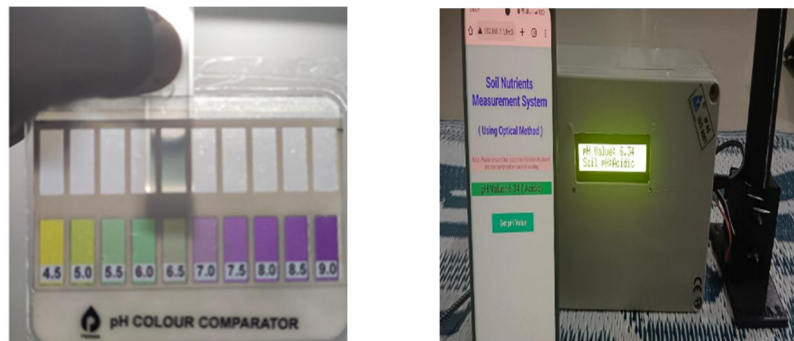


Fig 8. Developed Optical Soil pH meter with Embedded web server application

TABLE 1. VALIDATION OF OPTICAL SOIL pH METER USING DIFFERENT SOIL SAMPLES

Sample No.	According to Prerana Comparator Chart	According to Optical pH meter	Remarks
1	4.5	4.4	Highly acidic
2	5	5	Medium high acidic
3	5.5	5.6	Medium acidic
4	6	6	Slightly acidic
5	6.5	6.47	Very slightly acidic
6	7	7.02	Neutral
7	7.5	7.56	Slightly alkaline
8	8	8.07	Medium alkaline
9	8.5	8.51	Medium high alkaline
10	9	8.97	Highly alkaline

V. RESULTS AND DISCUSSIONS

The prototype that was created underwent testing using ten samples sourced from various locations. Variations in soil pH absorption were observed and analysed. To validate the results, comparisons were made with data from standard laboratories and the developed sensor. Over a month-long period, pH levels were continuously

monitored, and variations noted, with RGB values analysed. The Standard Deviation method was applied, involving 30 trials for each sample to ensure repeatability. The coefficient of standard deviation for each value was found to be 0.012, indicating satisfactory system performance, with an accuracy rate of 99.30%.

Currently, within the agricultural sector, there is no completely non-contact method available for monitoring soil pH. The proposed system offers real-time measurement of soil pH values on the spot. It is designed as a handheld, portable device that is user-friendly. Moreover, the embedded web server operates locally on Wi-Fi, eliminating the need for an internet connection. With just one deployment needed, this Soil nutrient measurement system is incredibly economical.

VI. CONCLUSION

In conclusion, the Optical Soil pH meter is developed based on calorimetry principle. The sensor was calibrated using Prerana soil test kit with 10 different soil samples and the mathematical relationship is developed between RGB component and soil pH. The system is validated for different types of soils using soil color comparator chart provided in test kit.

Analysis of the system's performance using standard deviation further validates its reliability and accuracy. Additionally, a user-friendly embedded web server application is developed to get real time soil pH to inform the soil status as alkaline, acidic, or neutral which can be used for further process.

Future goals for this project are to include soil macronutrients (NPK) and micronutrients details. Also, AI/ML based advisor for crop recommendation/Fertilizer recommendation can be developed thereby facilitating informed decision-making and improving soil fertility management practices. The existing system takes 12-15 days for sample analysis whereas optical soil nutrient detector provides results in less than 1 minute and gives more accurate results when compared with existing soil test kits. Also, with kits we get results in range instead of precise value of the nutrient.

Therefore, it is different from the systems in use in the industry today. As a result, the recommended strategy saves time.

ACKNOWLEDGMENT

We would like to thank Mr. Ravindra Sudhakar Wadkar Soil Testing Officer Pune Department of Agriculture Government of Maharashtra and Ministry of Agriculture Government of India for providing information of soil properties and its chemical analysis. We would also like to thank Prerana laboratories for providing reagents for measuring Soil pH. We would also like to thank Prof.A.D.Shaligram Sir, CEO of SPPU Research Park Foundation, for providing valuable guidance for this research work.

REFERENCES

- [1] Fornasier, E., Fornasier, F., & Di Marco, V. (2018). Spectrophotometric methods for the measurement of soil pH: A reappraisal. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*, 204, 113-118. Thomas, G. W. (1996). Soil pH and soil acidity. *Methods of soil analysis: part 3 chemical methods*, 5, 475-490.
- [2] Kumar, S., & Thakur, R. (2015). Soil pH Sensing Techniques and Technologies. *International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering*, 4(5), 1-3
- [3] J. D. R. Thomas, "Devices for Ion Sensing and pH Measurements", *Pure Applied Chemistry*, Vol.Vol73, No1,2001, pp.31-38.
- [4] P. Bergveld, "Development of an Ion-Sensitive Solid- State Device for Neurophysiological Measurements", *Ieee Transactions on Biomedical Engineering*, Vol. BM17, No. 1, 1970, pp. 70
- [5] Vinay S. Palaparthi, Maryam S. Baghini, Devendra N. Singh "Review of polymer-based sensors for agriculture-related applications", *Emerging Materials Research Volume 2 Issue EMR4*, Published online 23/07/2013
- [6] Masrie, M., Rosli, A. Z. M., Sam, R., Janin, Z., & Nordin, M. K. (2018, November). Integrated optical sensor for NPK Nutrient of Soil detection. In *2018 IEEE 5th international conference on smart instrumentation, measurement and application (ICSIMA)* (pp. 1-4). IEEE
- [7] Tasneem, N., Hasan, M. A., Akther, S. B., & Khan, M. M. (2021,May). An automatic soil testing machine for accurate fertilization. In *2021 IEEE World AI IoT Congress (AIIoT)* (pp. 0325-0331). IEEE.
- [8] Mahadevaswamy, U. B., Pavan Nayak, R., Darshan, M. N., Kumar, T. V., & Gautham Gopi, S. (2021). Automation of Soil Nutrient Measurement System and Irrigation Control. In *Proceedings of International Conference on Communication, Circuits, and Systems: IC3S 2020* (pp. 117-125). Springer Singapore.
- [9] Masrie, M., Rosman, M. S. A., Sam, R., & Janin, Z. (2017, November). Detection of nitrogen, phosphorus, and potassium (NPK) nutrients of soil using optical transducer. In *2017 IEEE 4th international conference on smart instrumentation, measurement and application (ICSIMA)* (pp. 1-4). IEEE.

- [10] Khairnar, H. M., & Kulkarni, S. S. (2018, August). Automated soil macro-nutrient analyzer using embedded systems. In 2018 Fourth International Conference on Computing Communication Control and Automation (ICCUBE) (pp. 1-3). IEEE.
- [11] Yokota, M., Okada, T., & Yamaguchi, I. (2007). An optical sensor for analysis of soil nutrients by using LED light sources. *Measurement Science and Technology*, 18(7), 2197.
- [12] Lalitha, R. S., Srinivas, R., Raghavendran, C. V., Kavitha, K., Kumar, P. S., & Sravanthi, P. S. L. (2022). Real Time Nitrogen, Phosphorus, Potassium (NPK) Detection in Soil Using IoT. In *Advanced Techniques for IoT Applications: Proceedings of EAIT 2020* (pp. 408-416). Springer Singapore.[Conference on Computational Science and Technology (ICCST).IEEE,2022.
- [13] M. E. (1994). Measurement of soil pH: problems and solutions. *Communications in Soil Science and Plant Analysis*, 25(7-8), 859-879.