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7. Leaf Color Chart: A Portable Tool for Nutrient Management

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Abstract:

Leaf color charts (LCCs) are vital tools in agriculture, providing a quick and cost-effective means of assessing plant nutrient status. They are widely used to diagnose nutrient deficiencies and guide fertilizer applications, particularly for nitrogen management. In rice cultivation, LCCs help optimize nitrogen use efficiency, reduce environmental impact, and enhance crop yields. Their development has evolved to include precise calibration and validation methods for various crops, ensuring accuracy and reliability. LCCs also play a crucial role in sustainable agriculture by minimizing nutrient runoff and greenhouse gas emissions. They offer significant benefits, including cost savings, increased productivity, and improved soil health. Additionally, integrating LCCs with modern technologies like remote sensing and data analytics can enhance precision in nutrient management, supporting both environmental sustainability and food security.

Keywords:

Nutrient Management, Agriculture Technologies, Leaf Color Charts, Rice Cultivation, Fertilizer Applications.

7.1 Introduction:

7.1.1 Importance of Nutrient Management in Agriculture:

Nutrient management is essential to achieve optimal crop yields, preserve soil health, and promote sustainable agricultural practices. Effective nutrient utilization guarantees that crops receive the necessary essential elements in appropriate quantities to support their growth and overall development. Effective nutrient management minimizes the risk of nutrient losses into environment, thereby reducing the environmental pollution and promoting the sustainability of agricultural systems. The aim is to optimize crop productivity while mitigating adverse environmental impacts. Among plant nutrients, Nitrogen (N) takes the major share, as it is essential for the synthesis of proteins, enzymes, and chlorophyll, and plays a crucial role in the overall growth and development of plants. Nitrogen (N) is the most widely used fertilizer in cereal crops, and its consumption has significantly increased in recent years. Global crop production has significantly increased due to the use of nitrogenous fertilizers (Peng, 2010). The main reason for low nitrogen uses efficiency is the improper application of split nitrogen doses in amounts exceeding the crop's needs. Inefficient use leads to a substantial amount of applied nitrogen being lost through leaching and denitrification. The nitrogen status of leaves can be indirectly evaluated by assessing the chlorophyll levels, as most of the nitrogen in leaves is incorporated into chlorophyll (Moran *et al*., 2000). The greenness of plants indicates the presence of nitrogen. The color of the leaves reflects the nitrogen content in the plants; thus, the N content of crop can be assessed through physical examination of its leaf color. Direct measure of leaf N status using laboratory techniques is more tedious and expensive. Nevertheless, farmers often apply nitrogen fertilizer inappropriately, hoping for exceptionally high yields. Evidently, the detrimental effects of improper nitrogen fertilization on soil have led to a significant decline in soil health and quality (Pahalvi *et al.,* 2021). Leaf Color Charts have been introduced for estimation of leaf nitrogen status and to schedule the fertilization, which emerged as a best solution for the above said issues.

7.2 Overview of Leaf Color Charts (LCCs):

Leaf Color Charts (LCCs) are simple, cost-effective tools that allow farmers to assess the nitrogen status of crops by comparing the color of leaves with standardized color strips (Figure.7.1). The LCC can feature four to six colors, depending on the manufacturer, ranging from yellowish to deep green, similar to the lush green color of foliage. The LCC is made from high-quality plastic and measures 8×3 inches in size (Singh, 2008). Each color is distinctly different from the others. These charts provide a visual representation of leaf color, which correlates with the nitrogen content in the plant. By using LCCs, farmers can make informed decisions about the timing and amount of fertilizer application, leading to better nutrient management. LCCs are particularly useful in regions where access to advanced diagnostic tools and technologies is limited.

Figure7.1: Leaf Color Chart

7.2.1 Evolution and Advancements of Leaf Color Charts:

The concept of using leaf color to assess nutrient status has been around for decades. Initially, visual observation was the primary method used by farmers and agronomists to estimate the nutrient status of crops. However, this method lacked standardization and could be highly subjective.

The development of LCCs provided a more reliable and reproducible approach. The Leaf Color Chart (LCC) was first introduced in the global agricultural sector by Japanese scientist, Furuya (1987). Chinese researchers at ZAU, Hangzhou developed an LCC with a scale of eight green color shades (3, 4, 5, 5.5, 6, 6.5, 7, and 8) tailored for rice varieties (Yang *et al.,* 2003). Similarly, scientists at UC Davis created an 8-panel LCC with shades ranging from 1 to 8. Recently, researchers at IRRI have refined the IRRI-LCC's color panels to align with the spectral reflectance of crop leaves and promoted a 4-panel IRRI-LCC with green shades from 2 to 5 since 2003 (Fairhurst *et al.,* 2007). This design helps evaluate chlorophyll development and content in crops. Over time, these charts have been refined to improve their accuracy and usability.

With advancements in material science and agricultural research, modern LCCs have become more durable, accurate, and user-friendly. Researchers have developed improved calibration techniques to ensure that LCCs provide precise readings for different crops and varieties. Modern LCCs are made from high-quality materials that resist fading and damage, making them suitable for use in various field conditions. Additionally, advancements in digital technology have led to the development of electronic LCCs and mobile applications that further enhance their utility.

7.3 Principles and Methodologies:

7.3.1 Theoretical Foundations:

LCCs operate on the principle that the color of plant leaves reflects their nitrogen content. Chlorophyll, the pigment that responsible for green color of leaves, contains nitrogen. Therefore, the intensity of green color in leaves directly relates with the plant's nitrogen levels. By comparing the color of the leaves with the standardized strips on the LCC, farmers can assess the nitrogen status of their crops and decide if additional fertilization is needed.

7.3.2 Calibration and Validation:

Calibrating LCCs involves extensive field trials and laboratory analyses to ensure accuracy. Different crops and varieties have specific nitrogen requirements and exhibit different shades of green based on their nitrogen content. Calibration involves determining the precise color shades that correspond to different nitrogen levels for each crop. Validation is an ongoing process that involves testing the LCCs under various field conditions to ensure their reliability and accuracy. This ensures that farmers can confidently use LCCs for nutrient management in diverse agro-ecological contexts.

7.4 Practical Utility in Nutrient Management:

7.4.1 Diagnosing Nutrient Deficiencies:

LCCs enable farmers to quickly diagnose nitrogen deficiencies by comparing leaf colors with the chart. When leaves appear lighter green or yellow, it indicates a nitrogen deficiency.

This immediate feedback allows farmers to take corrective actions, such as applying the appropriate amount of nitrogen fertilizer, to address the deficiency and prevent yield losses. The ability to diagnose nutrient deficiencies on-site without the need for laboratory testing makes LCCs a valuable tool for timely and efficient nutrient management (Figure.7.2).

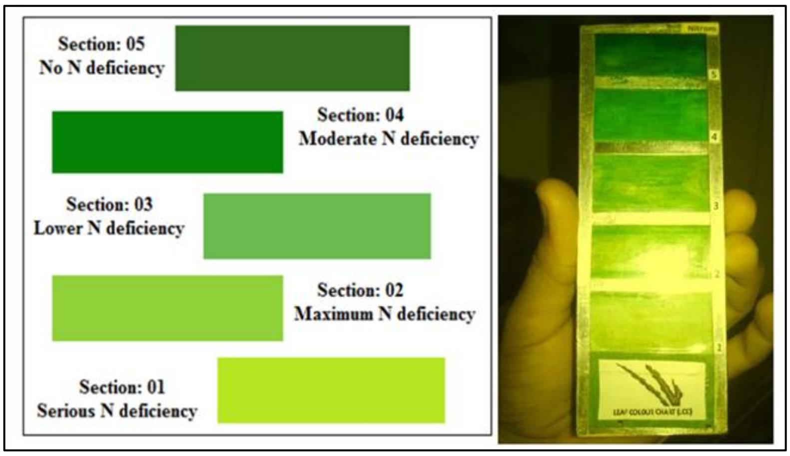

Figure 7.2: Different colours of LCC are well indicator of nitrogen deficiency in plant Leghari *et al.*, 2016

7.4.2 Guiding Fertilizer Applications:

Using LCCs, farmers can determine the precise amount of fertilizer needed, avoiding over- or under-application. Over-application of fertilizers can lead to nutrient runoff, pollution of water bodies, and increased production costs, while under-application can result in poor crop growth and reduced yields. LCCs help farmers apply the right amount of fertilizer at the right time, optimizing nutrient use efficiency and reducing costs (Figure 7.3). This targeted approach to fertilizer application enhances crop productivity and contributes to sustainable farming practices.

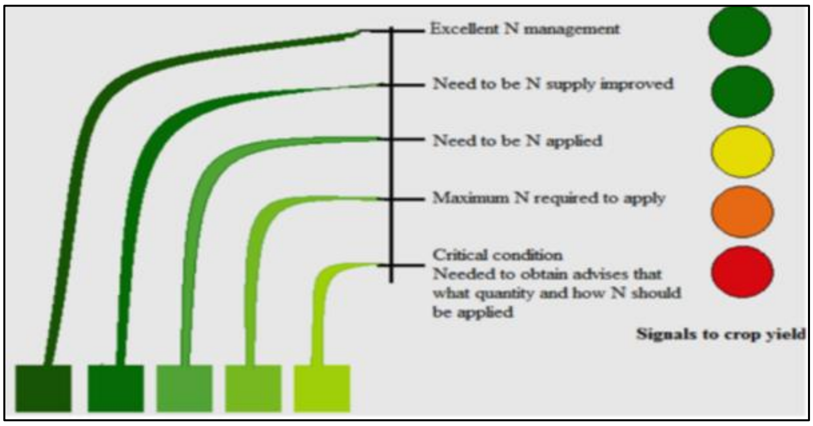

Figure.7.3: LCC colours are Guiding for Nitrogen Application Leghari *et al.*, 2016

7.4.3 Precautions to Be Taken While Using LCC In the Field:

1. Select at least 7-10 disease-free plants randomly from a field with uniform plant distribution until flowering.
2. Collect the readings mostly during morning or afternoon hours.
3. Choose the top-most fully expanded leaf. Position the central section of the leaf on a chart and compare its color with the panels on the LCC.
4. Readings can be affected b direct sunshine, therefore take the readings from observer's shadow.
5. Avoid breaking or cutting the leaf during the color comparison process with the LCC.
6. Whenever possible, ensure that the same person takes LCC readings at the same time of day consistently.
7. Calculate the average LCC reading for the selected leaves and adjust nitrogen fertilizer application accordingly.
8. Apply nitrogen alternately if the mean value is less than the critical value, if six out of ten LCC readings fall below this critical value, then nitrogen should be applied.

7.5 LCC Under Field Use:

7.5.1 LCCs in Rice Cultivation:

Rice farmers have extensively adopted LCCs to manage nitrogen applications. Studies in various rice-growing regions have shown significant yield improvements and cost savings through optimized fertilizer use. Singh and Khind (2015) investigated the response of irrigated rice for application of N using LCC ad SPAD meter in comparison with Recommended dose of fertilizer application.

They have observed significantly higher nitrogen recovery (59.7 and 65 %) and agronomic efficiencies (31.8 and 32.4 kg grain/kg N applied) when N was applied using the SPAD-based sufficiency index approach at 80 kg N/ha and the LCC at a score of 4 with 100 kg N/ha respectively. Thus, the study indicates that to prevent N over-application and achieve high yields and nitrogen-use efficiency in irrigated rice, fertilizer application should be guided by either the sufficiency index approach using SPAD or an LCC score of 4. Hence, LCCs have proven particularly effective in managing nitrogen in high-yielding and hybrid rice varieties, contributing to enhanced food security and therefore LCC can be considered as principle and inexpensive tool to improve utilization of N in paddy.

7.5.2 LCCs in Other Crops:

LCCs are also effective in managing nitrogen for other crops like wheat, maize, cotton, sugarcane and vegetables (Fig.4). Each crop has specific nitrogen requirements and exhibits different shades of green based on its nitrogen content. By calibrating LCCs for these crops, farmers can accurately assess their nitrogen status and optimize fertilizer applications. Punjab Agricultural University has recommended LCC for different crops *viz.*, rice, wheat, basmati rice and cotton for effective N utilization. (Figure.7.5). Role of LCC in overall land productivity and N-fertilizers consumption in various crops and regisons are mentioned in Table 7.1.

Figure 7.4: LCC Use in Different Crops

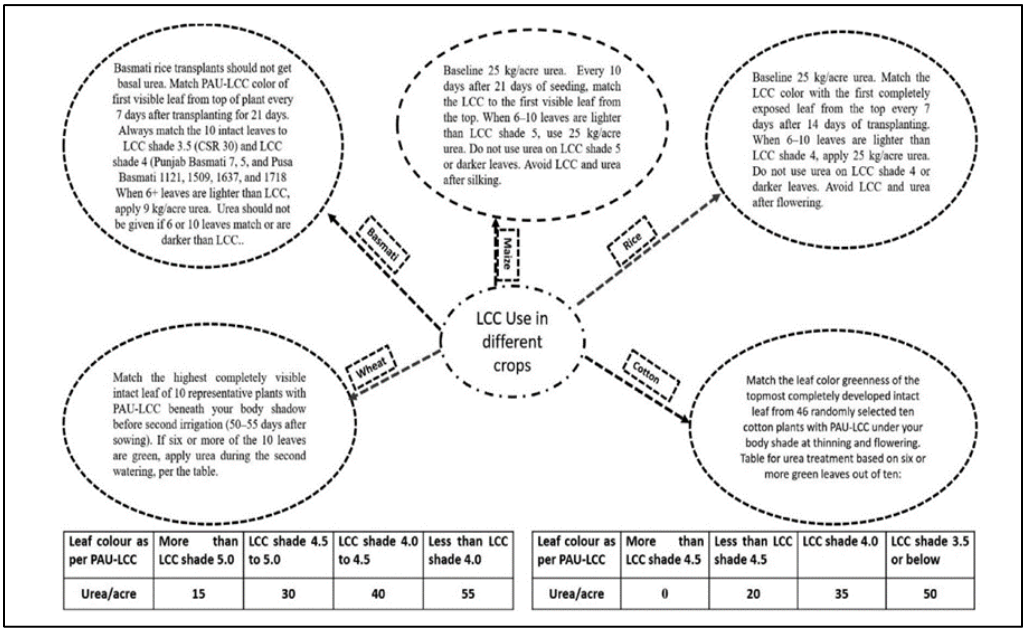

Figure 7.5: Recommendations of Punjab Agricultural University for LCC in Different Crops (PAU 2023a, 2023b).

Table 7.1: Role of LCC in overall land productivity and N-fertilizers consumption

Region/Crop	Salient Findings	Reference
Asian Subcontinent	Helps in assessing the relative greenness representing the N status	Hussain et al. (2000)
Indian Subcontinent	With precision N management increases crop yield	Bhat et al. (2017)
Maize crop/Kashmir, India	Use of LCC-enhanced NUE and yield.	Bhat et al. (2022); Fayaz et al. (2022)
Paddy/Kashmir, India	LCC-based N management may be the best option for farmers who want to conserve fertilizer N while also preserving soil fertility and better yield.	Bhat et al. (2017)

Region/Crop	Salient Findings	Reference
Mingora, Swat	The N fertilizer responded favorably to LCC management practices on the crop and optimum fertilizer management with better productivity.	Ahmad et al. 2016
Sialkot, Punjab-Pakistan	The LCC technique recorded a higher BC ratio (1.51) compared to conventional farmer practice (1.31) and saved more urea (approximately 40%) without reducing production.	Iqbal et al. (2016)
Bangladesh	Comparing the use of LCC for N management to farmers' fertilizer practices in Bangladesh, both grain output and profit have consistently increased.	Alam et al. (2005); Alam et al. (2009); Baksh, et al. (2009)
Bangladesh	N application based on LCC showed non-significantly higher yield as that of farmer's practice with higher NUE.	Haque et al. (2003)
Paddy/Bangladesh	Higher yield response was observed with BMP (24.6%) in Aman and (8.6%) in Boro season (BMP + LCC).	Alam et al. (2013)
Pakistan	The interaction between rice genotypes and LCC based crop practices was found to be best(significant) for all the recorded crop growth parameters including yield.	Ahmad et al. (2016)
Maize/Dharwad, India	Higher growth parameters were obtained in fodder maize by application of 150 kg N ha^{-1} (40% N basal) + remaining based on LCC 5 or SPAD 50 as compared to recommended dose and method of N application.	Sangalad et al. (2022)
Rice/Nepal	Application of LCC increased the yield and NUE by 25% and 75%, respectively, over the control and recommended practice.	Bohara et al. (2021)

Bhatt and Kunal (2024)

7.6 Integration with Precision Agriculture Technologies:

The integration of the Leaf Color Chart (LCC) with precision agriculture technologies represents a significant advancement in optimizing nitrogen management for crop production.

7.6.1 IoT-Based Framework for LCC:

A novel IoT-based framework has been proposed that integrates the LCC with advanced sensor technology and cloud computing. This system utilizes specialized sensors to capture leaf color data, which is then analyzed using computer vision techniques.

The framework allows for real-time monitoring and precise assessment of nitrogen levels in crops, enabling farmers to apply fertilizers more accurately and reduce waste. This integration not only streamlines data collection but also enhances decision-making processes in nitrogen management, contributing to sustainable agricultural practices.

7.6.2 Remote Sensing and LCCs:

Combining LCCs with remote sensing technologies enhances nutrient management. Remote sensing tools, such as drones and satellites, can provide broader field assessments and complement the localized data from LCCs. These technologies capture images and spectral data that can be analyzed to assess crop health, nutrient status, and variability within fields. Integrating remote sensing data with LCC readings allows for more precise and targeted nutrient management, improving overall efficiency and effectiveness.

7.6.3 Mobile Applications and Data Analytics:

Mobile applications are being created to digitalize LCC readings, offering real-time data analysis and recommendations. Farmers can use these smartphone apps to take pictures of leaves and compare them with digital LCCs.

The apps analyze the images, deliver immediate feedback on nitrogen levels, and suggest suitable fertilizer applications. By combining LCCs with mobile technology, nutrient management becomes more accurate and accessible, particularly for smallholder farmers. Data analytics can further enhance decision-making by aggregating data from multiple fields and seasons to identify trends and optimize practices.

7.6.4 Precision Nitrogen Management:

Studies have demonstrated that LCC-based nitrogen management can significantly impact crop yield and nutrient uptake. For instance, research focusing on hybrid maize genotypes has shown that using LCC for nitrogen assessment leads to improved phenological development and sustainable yield outcomes. This approach allows for tailored nitrogen applications that align with the specific needs of crops at different growth stages, thereby maximizing efficiency and minimizing environmental impacts.

7.6.5 Benefits of Integration:

The combination of LCC and precision agriculture technologies offers several benefits:

- Enhanced Accuracy: The integration improves the precision of nitrogen assessments, allowing for more effective fertilizer application.
- Resource Optimization: By using IoT technologies, farmers can monitor various agricultural parameters, leading to better resource management and reduced input costs.
- Sustainability: This approach promotes environmentally friendly practices by minimizing nutrient runoff and optimizing nitrogen use efficiency, which is crucial for sustainable farming.

7.7 Merits of LCC:

- The LCC is a simple and user-friendly tool for farmers to assess the nitrogen status of leaves and determine the appropriate timing for applying additional nitrogen to paddy crops.
- It is cost-effective and portable, making it convenient to transport to the field for on-site nitrogen status evaluation.
- The method is non-destructive and does not require any laboratory analysis, making it more accessible and practical for field use.
- Using the LCC does not require specialized knowledge or skills; it relies on comparing the leaf color to a standard chart and interpreting the scale, which is straightforward for most users.
- The LCC can help optimize nitrogen use efficiency, reduce unnecessary fertilizer application, and contribute to better crop management and environmental sustainability.
- It allows for timely and precise nitrogen management, potentially improving crop yields and quality by ensuring that nitrogen is applied only when needed.
- The LCC is adaptable to different crop types and can be used across various farming systems, enhancing its versatility and utility in diverse agricultural contexts.
- It aids in minimizing the environmental impact of nitrogen fertilizers by reducing the risk of over-application and subsequent leaching or runoff.
- The LCC can contribute to more informed decision-making and better resource management, ultimately supporting more sustainable agricultural practices.

7.8 Demerits of LCC:

- The accuracy of the LCC in assessing leaf nitrogen status can only be validated when compared with chlorophyll meter readings and appropriately calibrated for different plant species and varieties.
- LCC operates within the range of color shades, it may not detect minor variations in leaf nitrogen status.
- The LCC is primarily used for adjusting top-dressing nitrogen but does not address the application of basal nitrogen, limiting its scope.
- It is most effective within a site-specific nutrient management approach for N fertilizer and may not be as reliable if other essential nutrients are limiting.
- Deficiencies in phosphorus (P) or potassium (K) can cause a decrease in leaf color intensity, leading to potential inaccuracies in LCC readings and nitrogen status interpretation.

7.9 Future Prospects:

Ongoing research aims to expand the use of LCCs to a wider range of crops and agro-ecological conditions. Scientists are working on developing calibration protocols for additional crops, including legumes, oilseeds, and horticultural plants. This will increase the utility of LCCs and allow more farmers to benefit from their use. Expanding the applicability of LCCs to different regions and farming systems will enhance their impact on global agriculture.

Future innovations may include enhanced LCC materials, better integration with digital tools, and more comprehensive calibration datasets. Researchers are exploring the use of advanced materials that improve the durability and accuracy of LCCs. Digital tools, such as artificial intelligence and machine learning algorithms, can enhance the precision of LCC readings and provide more detailed nutrient management recommendations. Comprehensive calibration datasets will ensure that LCCs remain reliable and effective across diverse agricultural contexts.

7.10 Conclusion:

Leaf Color Charts represent a vital tool for modern agriculture, providing an effective means of managing nutrient applications. Their evolution and integration with precision agriculture technologies promise continued benefits for both productivity and sustainability. Continued research and innovation will expand their applicability, ensuring that LCCs remain a cornerstone of nutrient management strategies worldwide. By enhancing nutrient use efficiency, reducing environmental impacts, and improving socio-economic outcomes, LCCs contribute to the advancement of sustainable agricultural practices and global food security.

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