Diagnosis of Nutrition of Crop Plants by Their Leaf Colors

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Crop plants react very sensitively to the nutritional status such as deficiency or excess of essential nutrients or to nutritional disturbances due to some injurious elements, and change their leaf colors. This phenomenon can be used as a means of diagnosing their nutritional status. This is the reason why changes in leaf colors are closely observed in many studies on nutrition and physiology of crop plants. Leaf colors, however, can only be expressed by resorting to our senses, not by using objective numerical terms, and therefore cannot be reproduced.

Although some devices of determining leaf colors, for example chlorophyllo meter[1] or colorimetric standard solution method[2] have been recently developed, inaccuracy in expressing colors, complicated handling and high price of the apparatus must be further improved for their wider application to nutritional diagnosis. The use of the leaf color board[3], in which embroidery threads ranging from yellowish green to green are used, is also insufficient for the purpose, though practical, because it cannot give quantitative data and the threads used are easy to fade.

An ideal method of leaf color determination for the purpose of nutritional diagnosis of crop plants should be easy and practical, and in such method colors should be numerically expressed and reproduced. With these prerequisites in mind, the author developed a new method, in which color charts were compiled by selecting color chips that serve as standards. The possible extent of its application to the diagnosis was also investigated.

Preparation of standard leaf color charts

Among the color systems presently utilized, it is convenient to use the color appearance system for the purpose of visual determination of leaf colors. In the present work, Munsell Renotation System (JIS Z 8721), the most representative system of its kind, was adopted. This system intends to express the surface color of an object in terms of co-ordinates in the three-dimentional space (cylindrical co-ordinates) according to the three attributes of colors. The three axis in color co-ordinates represent hue (There are such basic hues as red, yellow, green, etc.), value (larger value indicates lighter color) and chroma (numerically larger chroma means increased vividness in a color). The method of color notation in the system is to write letters and figures in the order of hue, and value/chroma, for instance, as 5GY 4/6.

By using the above notation system and color difference meter, leaf colors of various crop plants, including common crop plants, horticultural crops, trees, and forage crops, 64 kinds in total, were determined under different environmental conditions. The result showed that under normal conditions the leaf color of rice plants was 5–7.5GY in hue and 4–6 in both value and chroma, and in vegetables the hue of their leaf color widely ranged from most common 7.5GY 3–5/3–5 to dark green of nearly 10GY in hue or dark reddish purple of 5RP. In the cases of fruit trees and other trees, their leaf color in May was 5GY 5–6/4–6 in many samples, but at the early stage of leaf emergence, hues of 2.5GY, 7.5YR, or 10R were observed. They became 7.5–10GY 3–5/3–5 in August, their most vigorous growing stage.

When a color difference meter was used, more accurate data obtained from the investigation indicated that the changes in leaf color are consecutive and that hue is an important factor in the determination of leaf color.

The present Standard Leaf Color Charts was completed after the minimum and necessary hues for the purpose were carefully selected to compile the Charts of 359 colors, consisted of 11 charts and 17 hues.[4] As the luster of the leaf varies depending on the kind of the plant, the color chips in the charts are all finished with solvent-type, semi-glossy ink. Table 1 shows the kinds of hue, range of value and chroma and number of color chips contained in the present system.

About the half of the color chips contained in the charts have hues of yellowish green (GY). The reason is that the difference in leaf colors comes from the difference in the relative contents of chlorophyll and carotenoid in the grana of chloroplasts in the leaf. A leaf of crop plants, however, contains various pigments and they give leaves of each plant a certain complex color which is characteristic to the plant. For this reason the charts include hues belonging to the groups of red (R), yellowish red (YR), yellow (Y), and red purple (RP). Such difference in leaf colors depends on the ratio of various pigments specific to the plant. At the same time, even in the same plant the color changes according to its growth stage, and conditions of nutritional supply. For instance, a plant often gives a completely different hue from the normal plant due to the occurrence of anthocyanin pigment in case of phosphorus deficiency.

Table 1. Contents of the Standard Leaf Color Charts

Hue		Value	Chroma	Number of color chips
2.5	R	4—6	6—10	7
5	R	4—6	4—10	11
7.5	R	4—6	6—10	9
10	R	3—6	3—10	12
2.5	YR	4—7	4—10	9
5	YR	4—7	4—10	14
7.5	YR	6—8	3—10	13
10	YR	5—9	2— 8	39
2.5	Y	3—8	3— 8	36
2.5	GY	4—9	4— 9	38
5	GY	3—8	1— 8	51
7.5	GY	3—7	2—10	55
10	GY	3—8	2— 5	24
2.5	RP	3—4	2— 8	8
5	RP	3—5	2—10	9
7.5	RP	3—5	2—10	12
10	RP	4—6	2—10	12

Leaf color of rice plants

The leaf color of rice plants changes with their growth stages as seen in Fig. 1. The data were obtained from the rice plants grown in the field of alluvial soils by applying conventionally accepted amount of fertilizer. The determination was made with a color difference meter on the third leaf from the top on the main culm. The hue until the middle of the ripening stage fluctuated between 5 to 7GY, then at later stages hues of yellowish green declined, followed by the changes to yellow (Y) or light yellowish red (YR), and finally the plant withered. Though the value and chroma at the vigorous stages were 4–5, which are comparatively dark color

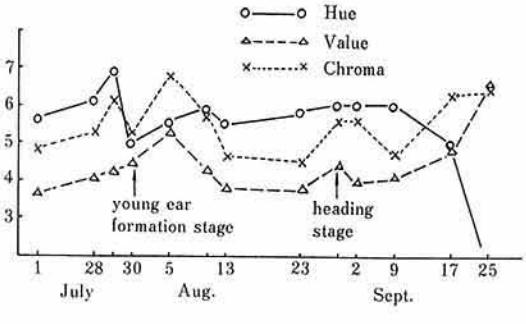

Fig. 1. Changes with growth stages of rice leaf color

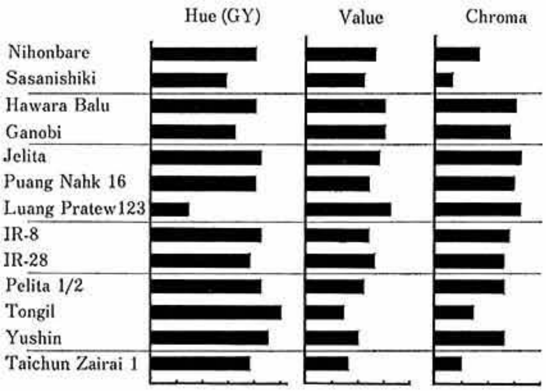

Fig. 2. Leaf color in different rice varieties

to our eyes, those at the time later than the middle of the ripening stage became 6–7 and lightness and vividness increased. A remarkable thing in the figure is a peculiar change in the leaf color at the young ear formation stage; that is, decline in hues, and increase in both value and chroma. This stage corresponds to the time suitable for top dressing, mainly of nitrogenous fertilizer, at the young ear formation stage.

Leaf color of rice, however, is recognized to vary according to the variety, soil condition, and cultural environment. Fig. 2 shows different leaf colors obtained from the experiment in which different varieties of japonica, subjaponica (Bulu), and indica rice were grown under the same cultural condition and the color of the second leaf from the top at the sixth leaf stage was measured. Differences in leaf color among the varieties are seen in the figure. Of all the 13 varieties, Tongil, the most productive high-yielding variety in Korea, has the leaves of the deepest yellowish green, whereas Luang Pratew 123 bore the lightest yellowish green leaves.

Kinds of soils are also a factor effecting leaf colors in rice. The experimental results indicate that content of humus and soil fertility are closely related to leaf colors.

It is a well-known fact that the kinds of nitrogen fertilizer affect leaf color of rice. Although urea and ammonium chloride give leaves lighter color than ammonium sulphate, they do not affect the yield. A tendency is observed that such difference is more distinct in the rice varieties which have leaves of comparatively darker colors.

Thus, when leaf colors are used for diagnostic purposes in rice, the name of the variety, the environmental conditions in and around the field must be clearly recorded for consideration of the result of color determination, because leaf colors differ depending on those factors.

Leaf color and assessment of the need for nitrogen top-dressing in rice plants

As there is a high correlation between colors and nitrogen concentration in rice leaves, the leaf color at the time when the nitrogen top-dressing is usually applied during the ear formation stage was investigated by using Standard Leaf Color Charts. The result suggests the need of additional color chips including those of hue of 6.25GY for the purpose of nutritional diagnosis of rice plant.[5] As seen in Table 2 color chips in 40 colors consisting of 5 kinds of GY hues were prepared.[6] By using these color chips made specially for rice plant diagnosis, the color of leaves at successive leaf positions was determined just before top-dressing at young ear formation stage in the fields of various sites. The results obtained at 352 samples were listed in Table 2. It shows that about 60% of the colors have the hues of 5GY, 27% have the hues of 6.25GY, whereas the colors of 7.5GY in hue are very few. The fact indicates that leaf colors during the time of top-dressing at the young ear formation stage lie between 5GY and 6.25GY in the hue, and their value and chroma range from those of color chips No. 13 to 24. When determination of colors is to be undertaken, it should be made on the third leaf blade from the top on the main culm, and on the spot between leaf veins at about 5 cm toward the leaf tip from the middle part of the leaf length. Although it is difficult to indicate nitrogen concentra-

Table 2. Contents of the color chips for the diagnosis of nutrition and distribution of rice leaf color at just before top-dressing during young ear formation stage

No.	Hue (GY)	Value	Chroma	Number of leaves	No.	Hue (GY)	Value	Chroma	Number of leaves
1	2.5	6	8	0	19	6.25	5.5	6	7
2	2.5	6	7	0	20	6.25	5.5	5.5	0
3	2.5	6	6	0	21	6.25	5.5	5	0
					22	6.25	5	6	28
					23	6.25	5	5.5	1
4	3.75	6	8	0	24	6.25	5	5	2
5	3.75	6	7	0	25	6.25	4.5	6	43
6	3.75	6	6	0	26	6.25	4.5	5.5	2
					27	6.25	4.5	5	5
					28	6.25	4	6	2
7	5	6	9	0	29	6.25	4	5.5	3
8	5	6	8	1	30	6.25	4	5	1
9	5	6	7	2					
10	5	6	6	5	31	7.5	5	6	3
11	5	6	5	1	32	7.5	4.5	6	30
12	5	5.5	7	7	33	7.5	4.5	5.5	1
13	5	5.5	6	52	34	7.5	4.5	5	0
14	5	5.5	5	1	35	7.5	4.5	4.5	0
15	5	5	6	88	36	7.5	4	6	7
16	5	5	5	6	37	7.5	4	5.5	3
17	5	4.5	6	44	38	7.5	4	5	0
18	5	4.5	5	3	39	7.5	4	4.5	0
					40	7.5	4	4	0

Table 3. Effect of nitrogen top-dressing on leaf color and contents of nitrogen and chlorophyll in the leaf blade of rice plant

Plot	Position of leaf blade	Color of leaf blade			Nitrogen (%)	Chlorophyll (μg/F·Wt·g)
		Hue (GY)	Value	Chroma		
no top-dressing	Top leaf	5.0	4.9	5.5	2.02	2.15
	2nd leaf	5.0	5.3	5.5	1.74	2.01
	3rd leaf	5.0	5.7	6.2	1.53	1.24
top-dressing	Top leaf	7.5	4.1	5.0	2.64	3.24
	2nd leaf	7.5	4.7	6.0	2.27	2.78
	3rd leaf	5.0	4.9	5.9	2.14	2.37

tion in the leaf with each color chip, one example is shown in Table 3, in which the effect of top-dressing is clearly seen in the darker leaf color and higher concentration of nitrogen and chlorophyll in the leaves. Photosynthetic activity in leaf is generally said to be normal when the nitrogen concentration in the leaf is higher than 2%. If diagnosed with leaf colors, leaves of 5–6.25GY in hue, 4.5–5 in value, and of 5.5–6 in chroma usually contain nitrogen of 2% in concentration.

Further, it was confirmed that detailed observation with leaves at different leaf positions can indicate more clearly the nutritional status of the rice plant, giving useful data for the rice blast forecasting.

Rice plants, lacking slightly in phosphorus and potash, are characterized by the leaves of lower color value and chroma in comparison to normal rice leaves.

Application of the leaf color charts to other crop plants

Feeds containing a large amount of nitrate are toxic to farm animals. In order to avoid the toxicity, the Standard Leaf Color Charts have been utilized as an easy assessment of the NO_3-N concentration in Italian ryegrass.[7] The close investigation of the leaves revealed the phenomena that, when leaves get darker in color with the value and chroma decreasing lower than 7.5GY 4/4, the concentration of NO_3-N is high and careful measures must be taken against poisoning. Thus, the relation of color chips and NO_3-N concentration in the leaves of forage crops was clarified and the knowledge was widely spread among the farmers to be utilized for the prevention of damage on their livestock.

In answer to the recent need for the standard method of expressing basic leaf colors of soybean plants, the usefulness of the Standard Leaf Color Charts was examined. As the result standard colors of 5 kinds of green, namely 7.5GY 3/2 (dark green), 7.5GY 3.5/3 (deep green), 7.5GY 4/4 (green), 5GY 4.5/5 (light green), and 5GY 6/7 (yellowish green), were selected and are being utilized as a basis for soybean plant survey.

In several kinds of vegetables, if the relation of leaf color to nitrogen and chlorophyll content is clarified, it is said possible to know the optimum amount of fertilizer to be applied on them by observing their leaf colors under moderate fertilizing conditions.

With two varieties of apple trees also, an easy method for diagnosing their nutritional conditions can be widely applied on the basis of the study made by comparison between the leaf colors of a normal tree and those of less vigorous trees.

Also usefulness of leaf color determination was evidenced as a means of judgement of rice plants injured by air pollution. Investigation on leaves damaged by the pollution to such a slight degree as visual observation fails to find any symptom of the injury, revealed that the chroma of the damaged leaves increases first, then at the next stage the value increases, and hue changes into lighter yellowish green declining to lower hues.

Conclusion

Based on the fact that leaf colors of crop plants directly reflect their nutritional status, the need for the leaf color measurement by scientific, reproducible and quantitative methods was recognized. With this view in mind, leaf colors of many kinds of plants were determined by applying Munsell Renotation System and a color difference meter. As the outcome of the investigation, the Standard Leaf Color Charts and Color Chips for Plant Diagnostic Purposes were published.

These charts and chips are practical and effective for knowing the optimum time for nitrogen top-dressing to rice and also for diagnosing nutrition in other crop plants.

It is further desired to develop a method for an early diagnosis of plant nutrition by gaining knowledge of characteristics of nutritional disturbance found in the leaves and by examining the possible usefulness of leaf color charts for such purposes.

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