Growth Diagnosis of Rice Plants by Means of Leaf Color

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Introduction

Leaf color of rice plants has been regarded as important since old days, because it reflects best the nutritional status of the plants. Recently, as the preference for good quality rice caused increased cropping of varieties which have good quality but are less resistant to lodging, the leaf color comes to attract more attention from the viewpoint of preventing lodging. Therefore, if leaf color can be measured objectively and easily, and appropriate crop management is made based on the result of leaf color measurement, it will contribute a great deal to achieve stable and high yielding culture of rice.

With such background, research on methods of measuring leaf color has progressed, and it was made possible to measure leaf color easily in the field. There are two types of methods: use of machines or use of simple tools. The latter is more practical. Recently, a new tool named "Standard rice leaf color scale" (Fuji Film Co.) was developed. A series of studies on growth diagnosis by leaf color recently conducted are presented in this paper.

Method of measuring leaf color

1) *Features of "Standard rice leaf color scale"*

This scale is a plastic plate, 35.5 × 10 cm in size, composed of 7 cards, arranged from No. 1 card (light colored) to No. 7 card (dark colored) with the same size. The color is highly stable against solar radiation (light and heat) and rain (wetting). This scale can be used to measure leaf color of a single leaf or of plant community. The procedure of the measurement is as follows[8]:

(1) Leaf color of a single leaf

After the leaf position on the main stem of the leaves to be used for color measurement is decided, a single leaf of that position is placed on the scale, and the color of middle part of the leaf is measured (Fig. 1). The leaf color can be expressed by numerical values, i.e. from 1 to 7, with the minimum unit of 0.5. Generally, the second or third expanded leaf counted from the uppermost leaf is used. In the field, 5–10 leaves are used.

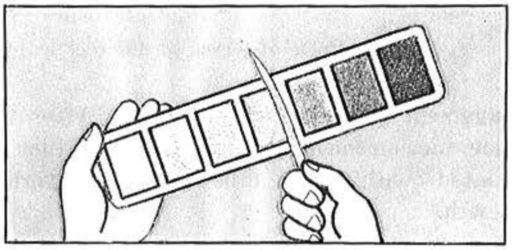

Fig. 1. Measuring leaf color of a single leaf with the standard rice leaf color scale The leaf is kept about 1 cm above the scale.

(2) Leaf color of plant community

After selecting a place representing the typical leaf color of the community, the scale is fixed with a supporting rod at the height of the middle part of the uppermost expanded leaves, and a person standing 3 m apart from the scale with his back facing the sun compares the leaf color with the color of the scale. The measurement is not done in early morning or evening, at around noon of fine days, and in strong wind, because proper

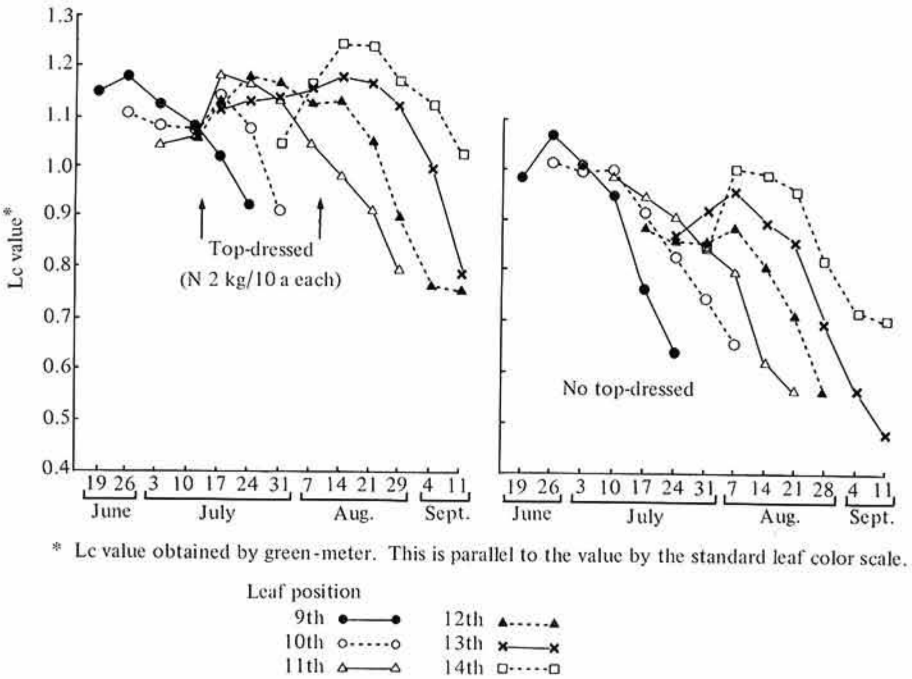

Fig. 2. Color of leaves of different leaf positions on the main stem (var. Koshijiwase, 1980)[5]

judgement is difficult to be made. After the color measurement, the number of tiller is counted with 5–10 hills showing average growth.

Relation between crop leaf color** and single leaf color

A single leaf at the time of its emergence showed lower leaf color value (Lc value) than lower leaves, but its Lc value increased to the maximum when the leaf fully expanded and became the most active leaf in the community, and then decreased with age. Naturally, N top dressing increased Lc value, and the increased value lasted for a long time. This tendency was more remarkable with the second and third leaves (Fig. 2).

Miyama et al.[8] examined the relation between crop leaf color and single leaf color. It was found that at around the maximum tiller number stage and the young panicle formation stage, the crop Lc value was lower than single leaf color, irrespective of the rate of N application, although the increase of Lc value by N application was greater in the former than in the latter. On the other hand, Lc value of the single leaf at the tillering stage showed no increase with increased N application, and it increased only slightly at the young panicle formation stage. However, at the heading stage, both crop Lc value and single leaf Lc value increased with increased N application. At this stage, the leaf color showed varietal differences. Lc value of single leaf was higher than crop Lc value in Koshihikari, a tall variety, whereas both are almost same in Hayahikari, a short straw variety. Based on these results, they[8] concluded that crop leaf color reflects more sensitively the N-nutritional status at any growth stage than single leaf color.

In addition, Tanno et al.[11] pointed out that the measurement of single leaf color incurs more personal differences than crop leaf color measurement. Thus, the latter seems to be

** Leaf color of plant community is referred to crop leaf color, and leaf color of single leaf to single leaf color. Leaf color value is abbreviated as Lc value.

more suitable than the former for judging in the field the N-nutritional status of rice plants.

Relation of crop leaf color to N-nutritional status of plants

Many reports[1,5,7,11] showed high correlations between crop leaf color and N content of leafblades (Fig. 3). As to the correlations

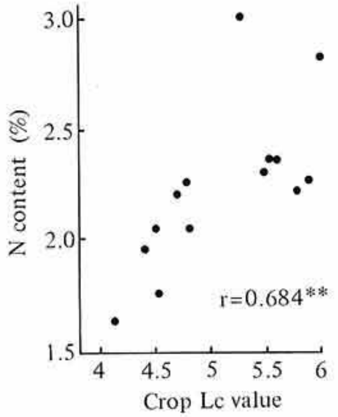

Fig. 3. Relation between leaf color and N content in leaf blade
(var. Koshijiwase at leaf number index 95, July 26, 1980)

at various growth stages, it was found that small differences in leaf color corresponded to large differences in leaf N content at the tillering stage, but this relation was reversed at the spikelet differentiation stage and the heading stage.[12] It was also reported with two varieties that Lc value increased with the progress of plant growth, but leaf N content did not increase so much. Leaf N contents of two varieties, Sasanishiki and Koshihikari, at the young panicle formation stage were 2.5 and 2.4% for Lc value of 3, 2.9 and 2.6% for Lc value 4, and 3.4 and 2.8%, respectively, for Lc value 5. The increase of leaf N content per Lc value increase by 1 was 0.4–0.5% in Sasanishiki, and 0.2% in Koshihikari.[11]

A detailed study[8] was made on the relation between leaf color and N-nutritional status of plants at the young panicle formation stage, at which the leaf color assessment is most required to decide whether N top dressing is necessary or not. Significant correlations were found between crop Lc value and average N content of all live leaves, and the amount of N contained in plants in most varieties examined. On the other hand, single leaf color showed significant correlations with the average N contents with many varieties, but low correlations with the N amounts, showing less applicability of leaf color to nutritional diagnosis. Furthermore, crop Lc value $\times$ no. of tillers/m^2 gave much higher correlations with the average N content of all live leaves and the amount of N in plants, than crop Lc value alone. Thus, it was made clear that leaf N content and the amount of N in plants can accurately be estimated by crop Lc value $\times$ no. tillers/m^2.

It must be noted that when plant growth is abnormally retarded or plant metabolism is disturbed by adverse climate, etc., leaf color becomes dark in spite of low N content, and also the quantitative relation between leaf crop Lc value $\times$ no. tillers/m^2.
with years.

Growth diagnosis of rice plants by means of leaf color

Studies on actual diagnosis by leaf color have been made mainly with Koshihikari[3,4,8-11] and Sasanishiki.[1,11]

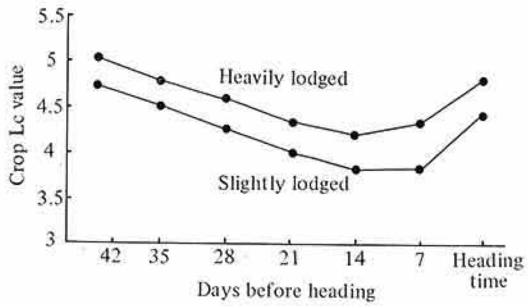

Fig. 4. Difference in leaf color between two groups of rice plants in farmer's fields
(var. Koshihikari, 1985)
One group lodged heavily and the other group slightly lodged. (Lodging occurred 30 days after heading)

Table 1. Correlation coefficient between leaf color or leaf color × no. of tillers, etc. and culm length or degree of lodging (var. Koshihikari, 1984)

Survey date	Days before heading	Leaf color	Leaf color	Lerf color × no. of tillers/m^2	Leaf color × plant length	Leaf color × no. of tillers/m^2 × plant length	Leaf color	Leaf color × no. of tillers/m^2	Leaf color × plant length	Leaf color × no. of tillers/m^2 × plant length
		plant length	Culm length				Degree of lodging (20 days after heading)			
June 18	53		0.409*				0.515*			
25	46		0.375*				0.460*			
July 2	39	0.777***	0.534**	0.427*	0.756***	0.629***	0.657***	0.549***	0.737***	0.710***
9	32		0.665**				0.694***			
16	25	0.629***	0.646***	0.462*	0.806***	0.633***	0.631***	0.601***	0.783***	0.742***
23	18		0.723***				0.817***			
30	11	0.777***	0.807***	0.677***	0.910***	0.813***	0.796***	0.743***	0.862***	0.855***

*, **, *** show the significant level of 5, 1 and 0.1 %, respectively.

1) *Relation of leaf color to lodging*

In a survey conducted in 1984 and 1985 on 30 pieces of farmers' field, transition of leaf color, plant growth, and lodging were examined. In 1985, crop Lc value of the group which lodged heavily (heavier than medium degree) on the 30th day after heading was compared with that of the group with slight lodging. The former was higher than 4 at the stage from young panicle formation to meiosis, while the latter was 3.5–4 (Fig. 4). Besides leaf color, number of tillers, and plant height are related to lodging. Severe lodging occurred when no. of tillers/m^2 on the 39th day and 25th day before heading was 680 and 550, respectively, and plant height was more than 73 cm on the 25th day before heading.

Correlations of leaf color with plant height, culm length, and lodging degree obtained at different growth stages are shown in Table 1. Very high, positive correlations were observed between leaf color and plant height 11, 25, and 39 days before heading. Positive correlations were also observed with culm length and lodging degree after the 53rd day prior to heading, particularly the correlations were high after the 39th day before heading. Leaf color × plant height and leaf color × plant height × no. of tillers gave higher correlations than above (leaf color alone) with culm length and lodging degree, while leaf color × no. tillers showed slightly lower correlations than leaf color alone.

Miyama et al.[8] also reported that Lc value alone is difficult to predict lodging degree, although lodging increases, in general, when Lc value increases, while Lc value × no. of tillers is more closely related to lodging degree. Lc value × no. of tillers shown at the young panicle formation stage of Koshihikari plants which showed later the lodging degree higher than 3 (severer than medium degree) was 1,900, and no. of tillers/m^2 was more than 550.

The similar survey was carried out by Tanaka et al.[10] with Koshihikari. High correlations were observed between Lc value × no. tillers at the middle growth stage and culm length, lodging degree, and no. spikelets/m^2 in a given year and a given cropping season, although the degree of these correlations markedly lowered when data of different years and cropping seasons were used in mixture. However, Lc value × no. tillers × plant length gave markedly higher correlations with lodging degree and no. spikelets/m^2, because plant length, closely correlated with temperature was taken into account. When the upper limit of lodging degree was taken as 3 (medium degree), and lower limit of no. spikelets/m^2 as 30,000, the value for Lc value × plant length × no. tillers was $(95-80) \times 10^3$, $(165-140) \times 10^3$ and $(200-160) \times 10^3$ at the stage of plants in terms of leaf number index of 70, 80, and 90, respectively (Fig. 5).

It was also found with Sasanishiki at the

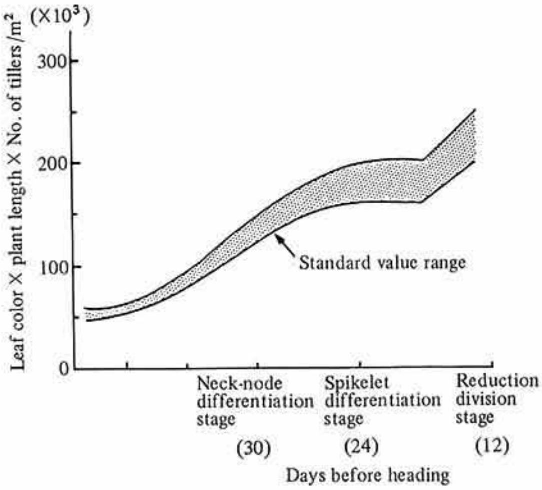

Fig. 5. Standard values of leaf color × plant-length × no. of tillers which are required for achieving stable high-yielding culture of var. Koshihikari,[10] irrespective of different cropping seasons

stage of around 90 of leaf number index that Lc value × no. tillers or Lc value × plant length is closely correlated (positively) with lodging degree.[2] Both values for the lodging less than medium degree were less than 3,000 and 320, respectively. At this stage, no. tillers/m² of 750, plant height 80 cm, and Lc value 4–4.2 were regarded upper limits for safety.[2]

As shown above, lodging can be predicted fairly well from leaf color, starting from about 40 days before heading, and the accuracy of prediction can be increased by using Lc value × no. tillers, Lc value × plant length, or Lc value × plant length × no. tillers. Thus, the values which can be used to predict the degree of lodging in advance are known with the above two varieties. With other varieties, studies are needed.

2) Leaf color and yield components

Correlation of Lc value of Koshihikari with no. tillers was high on the 39th day before heading, but it was not observed 11 and 25 days before heading. Correlation of Lc value with no. ears was not apparent, and that with no. spikelets/ear was not recognized at all.

Correlation of Lc value to no. spikelets/m² was significant after the 25th day prior to heading, but as a whole it was low, except somewhat high correlation found 11 days before heading. Correlation between Lc value × no. tillers and no. spikelets/m² was recognized only 11 days before heading, and it was higher than the correlation with Lc value alone (Table 2).

With Koshijiwase, significant correlation was recognized between Lc value × no. tillers and no. panicles and spikelets/m² at the stage after 81 of the leaf number index. The correlation became higher with plant age, particularly after 96 of the leaf number index.[6] With several varieties, almost similar results as above were obtained.[7]

Thus, it can be said that only low correlation was observed between Lc value and no. ears, or no. spikelets/m² about 25 days before heading. Correlation of Lc value × no.

Table 2. Correlation coefficient between leaf color or leaf color × no. of tillers and no. of ears or no. of spikelets (Koshihikari, 1984)

Survey date	Days before heading	Leaf color				Leaf color × no. tillers/m²
		No. tillers/m²	No. ears/m²	No. spk/ear	No. spk/m²	No. spk/m²
June 18	53		0.403*			
25	46		0.345			
July 2	39	0.589***	0.455*	−0.051	0.357	0.324
9	32		0.303	0.015	0.308	
16	25	0.338	0.474**	0.014	0.432*	0.363
23	18		0.124	0.320	0.382*	
30	11	0.243	0.290		0.553**	0.658***

spk: spikelets

Table 3. Standard values of leaf color at successive dates before heading of rice plants[8)]

Variety	Days before heading				
	40	30	25	20	Heading time
Koshihikari	4-4.5	3.5-4		3.5(3.3-3.8)	4.5-5
Todorokiwase	4.5-5	3.5-4	3.5-4		5-5.5
Hatsuboshi	4.5-5	4		3.5-4	5-5.5
Hayahikari	5-5.5	4-4.5	4-4.5		5.5-6

tillers to no. spikelets/m² was higher than that of Lc value alone, particularly after the leaf number index of 95. Relation between Lc value and grain ripening is a future problem.

Practical examples of growth diagnosis

Miyama et al.[8)] made clear the leaf color which is regarded as normal and standard at successive growth stages (Table 3), and the desirable range of the value of Lc value × no. tillers at the young panicle formation stage for major varieties in Chiba Prefecture. When the yield target is 550 kg/10 a with Koshihikari, crop Lc value at the young panicle formation stage should be 3.3–3.8, and Lc value × no. tillers be 1,700–2,000.

In Niigata Prefecture, Lc value and Lc value × no. tillers at successive growth stages were made clear for Koshihikari, aiming at suppressing the lodging at maturity to lower than the medium degree, and to get the ripening degree (1,000-grain weight × percentage of ripening grains) higher than 1,700 (Table 4). The Lc value and Lc value × no. tillers are almost similar to those in Chiba Prefecture.

Table 4. Standard values of leaf color, and leaf color × no. of tillers at successive dates before heading of var. Koshihikari[4)]

Days before heading	Leaf color × no. of tillers/m²	Leaf color
40	2,300	4.0-4.5
30	1,900	3.5
20	1,400	3.0-3.5

As shown above, Lc value and Lc value × no. tillers which can be regarded as standard were determined for successive growth stages of Koshihikari. When a crop shows higher values than the standard, intensive mid-summer drainage is practised to avoid lodging. On the other hand, when crop Lc value is less than 3.5, N top dressing is made at the rate of 0.7–0.8 kg/10 a. When Lc value is higher than the standard at the time when Hogoe* is to be applied, the rate of application has to be reduced.

As shown by these examples, growth diagnosis by means of leaf color is useful in achieving stable rice culture with high yields. However, studies on this problem have been done mainly with the two varieties liable to lodge. Further studies have to be done with other varieties, and at the same time more studies are needed to know how to regulate plant growth when measured leaf color is deviated from the standard leaf color. As rice plants which showed the standard leaf color at each growth stage were recognized to express high resistance not only to lodging but also to diseases and insect pests, and good ripening under adverse climatic conditions, it is desirable to establish comprehensive standard leaf color adaptable to different edaphic and climatic conditions for each growth stage of each variety. This will lead stabilization and saving cost of rice production.

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* N top dressing at the young panicle formation stage

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