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Analysis of Productivity in Rice Plant

〔I〕 Potential Grain Yield

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벼의 생산력 분석

〔1〕 한계 수량

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요 약

수원 213, 수원 214, 진흥 및 팔달의 한계수량을 각엽위엽의 한계 수량으로부터 계산하였다. 한계수량의 패턴이 각엽의 백분율 기여도에 따라 IR 667 계통은 상위엽 의존형인 반면 진흥과 팔달은 하위엽 의존형으로 구분할 수 있었다. 이러한 패턴은 각기 조기노화 및 내음성과 관련될 것으로 추정되었다. 한계수량과 실수량을 비교한결과 초형이 비교적 불량한 진흥과 팔달은 보다더 한계수량에 미달하였다. 한계수량이 갖는 영양생리 및 육종에 있어서의 의의를 검토하였으며 한계수량 측정방법도 논의하였다.

Potential productivity could be defined, investigated and calculated at various levels i.e. community, individual plant or tiller, organ, cellular and further subcellular level such as chloroplast. Potential productivity of a crop generally tends to be determined under the community status considering light as limiting environmental factor since interacting assemblages among individual plants under the given environment display properties of community behavior not easily predicted from the known behavior of isolated plant[14]. It appears, however, that genetic selection generally has favored quality and quantity of economic yield, which often correlate poorly with primary community productivity[7]. Though apparent grain yield of a variety is the expression of its genetic potential through physiological processes it could not be considered as the full expression of its genetic capacity.

If we could estimate potential grain yield as the maximum expression of genetic ability we can find out genetic merits and defects, and also through these we can predict the way and the space of further improvement in breeding and cultivation. The function of leaves in different positions have been studied[1,2,3,16,17,18] but it was not considered in relation to potential grain yield, probably because no one has attempted to determine *potential grain yield at the organ level.* This study was attempted for the establishment of the estimation method of potential grain yield at the level of organ and for the physiological significance of potential grain yield.

Materials and Methods

Apparent and potential grain yield: Two lines (Suwon 213 and 214) from newly bred IR 667 and two commercial varieties(Jinheung and Paldal) were cultivated on the experimental field with 30 cm×15cm of spacing according to commercial method. Ten treatments by pruning leaves in different positions were given at random after 5 days from heading. A treatment had 15 to 20 replicates. Five tillers per hill were used for 5 treatment and extra tillers were eliminated. The grains below 1.06 of specific gravity were not included in yield. Potential grain yield of leaf sheath and head was defined as yield obtained by the elimination of all leaves. Potential grain yield of flag leaf was calculated by substracting grain yield of leaf sheath and head from grain yield of only flag leaf remained and so on for other leaves. Subsequently the sum of potential grain yield of each separate organ became potential grain yield per tiller of that variety. Apparent grain yield was defined as the yield of control in which all four leaves were remained and fifth leaf from top was eliminated.

Chemical analyses and leaf area: Plant samples were devided into each organ, dried at 70°C in a forced-draft oven for 24 hours and ground to 40 mesh with Wiley mill and then digested with H_2SO_4-$HClO_4$-H_2O mixture(1 : 18 : 1lv/v) by the method modified from Chat[4]. Nitrogen, phosphorus and potassium were determined by Kjeldahl distillation method, vanadomolybdate yellow color method and atomic absorption spectrophotometry, respectively. Leaf area was traced on light sensitive paper using infrared light bulb and the weight of paper was converted to area.

Ripened grain ratio and 1000-grain weight: Ripened grain ratio is the ratio of number of grains above 1.06 of S.G. to total number of grains. Grain weight was based on dry weight of grains above 1.06 of S.G. at 70°C for 24 hours.

Results and Discussion

Grain yields (total and above 1.06 of specific gravity),ripened grain ratio and 1000-grain weight when some leaves in various positions were eliminated at 5 days from heading were shown in Table 1. All four varieties showed similar trend according to the remained leaves in total grain yield, ripened grain yield, ripened grain ratio and 1000-grain weight. Grain weight was not much affected by leaf pruning but ripened grain ratio was severely affected and it determined yields. Since treatments were done at 5 days from heading ripened grain yield may well express the effect of treatments. Total yield of Jinhung supports it. Specific gravity(1.06) used for the separation of ripened grain may be higher than that of grains at the time of treatment and also it must not be the same to all four varieties. However the traditional 1.06 of S.G. was chosen for convenience. For the check of sampling size and growth status in this experimental field untreated ten hills were harvested at random and number of panicles per m^2 was investigated on 30 hills and yield were calculated(Table 2). Total grain yield of control in Table 1 were not greatly different from those of Table 2 indicating that sampling size was reasonable to eliminate sampling error and the growth status was normal considering high total yield.

Percentage of ripened grain yield of each treatment to control (Figure 1) indicates clearly the difference between IR 667 lines and commercial varieties. The elimination of leaf decreased grain yield more in IR 667 lines.

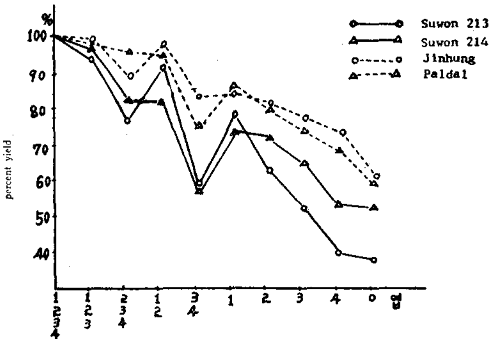

Figure 1. Percent yield of ripened grain(>1.06 S.G.) by leaf pruning.Number of leaf indicates remained leaf counted from top downwards.

Yield of treatment 0 is the product of non active photosynthetic organs, namely sheath and head. All other treatments include yield by sheath and head. Thus potential grain yields by leaves were calculated from Table 1 and shown in Table 3 with percentage contribution of each organ to total potential yield. The potential yield of sheath and head is strikingly large. It was highest in all three

Table 1. Grain yields by the elimination of leaves in different positions at 5 days from heading.

Treatment*	Suwon 213				Suwon 214			
	Total grain yield**	Grain yield	Ripened grain ratio	1000-grain weight	Total grain yield**	Grain yield	Ripened grain ratio	1000-grain weight
	(g/tiller)		(%)	(g)	(g/tiller)		(%)	(g)
Control	2.68	1.84	57.8	26.5	2.72	2.38	71.8	27.4
0	1.81	0.70	21.7	24.7	1.89	1.23	37.7	26.1
1	2.34	1.47	44.4	26.8	2.23	1.77	47.9	26.2
2	1.89	1.18	35.6	26.3	2.20	1.73	48.2	26.4
3	1.84	0.97	35.9	26.6	2.14	1.58	50.5	26.2
4	1.82	0.74	22.9	25.0	1.97	1.28	38.8	26.4
12	2.52	1.72	53.5	26.8	2.47	2.02	61.9	26.5
123	2.65	1.75	52.2	25.7	2.71	2.35	69.2	26.5
234	2.21	1.40	49.3	27.2	2.50	1.98	63.3	26.7
34	2.03	1.07	38.1	26.4	1.86	1.35	49.3	26.7

Treatment*	Jinhung				Paldal			
	Total grain yield**	Grain yield	Ripened grain ratio	1000-grain weight	Total grain yield**	Grain yield	Ripened grain ratio	1000-grain weight
	(g/tiller)		(%)	(g)	(g/tiller)		(%)	(g)
Control	2.15	2.92	84.0	29.7	1.84	1.66	84.6	28.1
0	1.64	1.20	51.5	26.0	1.41	0.96	49.7	26.5
1	1.93	1.72	71.4	27.3	1.73	1.45	71.6	26.7
2	1.84	1.61	59.7	28.2	1.70	1.35	76.0	27.6
3	1.88	1.60	68.4	26.3	1.69	1.27	57.5	27.9
4	1.84	1.52	64.1	27.5	1.55	1.16	65.4	27.0
12	2.09	1.77	68.5	26.8	1.75	1.59	83.0	26.4
123	2.12	2.00	86.6	27.8	1.78	1.65	82.5	27.7
234	2.03	1.81	84.4	27.0	1.77	1.62	80.1	26.4
34	1.88	1.73	75.8	27.3	1.58	1.24	63.3	27.5

*Number indicates remained leaf counted from top downwards.
**Before separation by specific gravity (1.06)

Table 2. Yield and number of tillers in the experimental field

	Suwon 213	Suwon 214	Jinhung	Paldal
No. of tiller/m^2	259.4	272.5	276.9	294.3
grain g/tiller	2.76	2.76	2.28	1.80
grain yield kg/10a	716	753	631	529
No. of tiller/hill	12.6	10.9	10.8	13.1

varieties except in Suwon 213. If the contribution of head was assumed to account for about 20% (14), the contribution of sheath will be almost same as head. The lowest contribution of sheath in Suwon 213 seems to contradict to its greatest percentage of sheath weight (Table 4). Allometry of Suwon 213 is quite similar to Suwon 214. Both lines of IR 667 have greater sheath weight while the commercial varieties have greater culm weight. The contribution of sheath depends not only photosynthetic ability but much on the already stored carbohydrates in it and probably in culm. The role of sheath as a storage organ may be reconsidered together with respiratory consumption esp-

Table 3. Apparent and potential grain yield

Treatment*	Suwon 213		Suwon 214		Jinhung		Paldal	
	Yield (g)	Percent yield (%)	Yield (g)	Percent yield (%)	Yield (g)	Percent yield (%)	yield (g)	Percent yield (%)
0	0.70	30.9	1.23	46.1	1.20	42.1	0.96	40.5
1	0.77	34.1	0.54	20.2	0.52	18.3	0.49	20.7
2	0.48	21.2	0.50	18.7	0.41	14.4	0.39	16.4
3	0.27	12.0	0.35	13.1	0.40	14.0	0.33	13.9
4	0.04	1.8	0.05	1.9	0.32	11.2	0.20	8.5
Total								
Potential yield	2.26	100.0	2.67	100.0	2.85	100.0	2.37	100.0
Apparent yield	1.84	81.4	2.38	89.1	2.02	70.8	1.66	70.0

*Number indicates remained leaf counted from top downwards.

Table 4. Allometry of organ in rice plant at 5 days from heading

(% fresh weight)

	Suwon 213	Suwon 214	Jinhung	Paldal
Head	12.3	10.4	8.9	9.4
Blade	24.1	32.7	22.9	22.7
Sheath	38.5	33.8	29.9	29.2
Culm	25.1	23.1	38.3	38.7

Table 5. Leaf area of each leaf position at 20 days from heading

Leaf*	Suwon 213		Suwon 214		Jinhung		Paldal	
	cm^2/leaf	%	cm^2/leaf	%	cm^2/leaf	%	cm^2/leaf	%
1	28.1	20.6	25.5	19.6	24.4	19.7	27.5	23.4
2	42.2	31.0	39.5	30.4	33.0	26.6	29.2	24.8
3	35.1	25.8	39.8	30.6	35.1	20.3	33.3	28.3
4**	30.8	22.6	25.2	19.4	31.4	25.4	27.7	23.5
Total	136.2	100.0	130.0	100.0	123.9	100.0	117.7	100.0

*leaf counted from top to downwards.
**the discolored portions were not included.

ecially in the case of Suwon 213.

The potential yields of leaves and their percentage contribution to total potential yield were clearly different between IR 667 and commercial varieties (Table 3) especially in the 4th leaf. IR 667 (IR8 ×Taichung Native. 1×Yukara) lines have quite diffe rent potential yield pattern from commercial variety(Figure 2) as they did in allometry (Table 4). Potential yields of flag and 2nd leaf were greater in IR 667 lines while those of 3rd and 4th leaf were greater in commercial varieties. Potential grain productivity of IR 667 lines depends much on the upper leaves. Thus we may group IR 667 lines into the upper leaf-dependent type and the commercial varieties into the lower leaf-dependent type.

Potential grain yield of a leaf depends directly on two factors, leaf area as capacity factor and photosynthetic activity as intensity factor. The leaf area at 20 days from heading(Table 5) showed

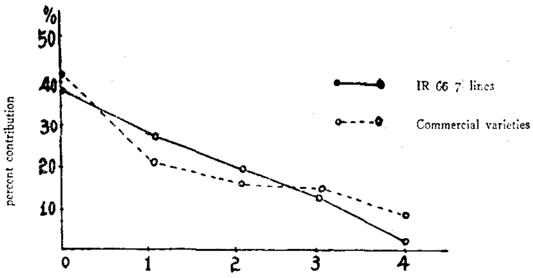

Figure 2. Percentage contribution of each leaf in different positions to potential grain yield. Zero indicates no leaf and numbers indicate leaf counted from top downwards.

greater leaf area in upper two leaves in Suwon 213 which showed greatest contribution and also greater percentage of leaf area in lower two leaves in the commercial varieties which grouped into the lower leaf-dependent type. Flag leaf contributed about 20 percent of total leaf area in IR 667 lines and it was much greater than that of IR 5 (11). Photosynthetic activities of each leaf in different position were reported (19) but the investigation of varietal difference in each leaf position seems to be remained yet.

Photosynthetic activity potential of leaves may be predicted through nutritional status especially nitrogen and potassium. Nitrogen, phosphorus, and potassium content in the leaves at 5 days from heading (Table 6) showed higher nitrogen content in the upper leaves of IR 667 lines but also higher in the lower leaves indicating that persistency of photosynthetic activity is more important than that of heading time. More dead leaves are found in the tropics than in temperate regions (8) and the optimum harvesting of tropical varieties from heading is 30 days (9) while that for japonica varieties is 45 days. These facts indicate probable fast senescence of leaf in tropical varieties. When the rate of senescence was measured by the number of dead leaves in each positions from heading to harvest in this experiment there was no clear difference between IR 667 and commercial varieties though IR 667 have tropical blood and they appeare to senesce fast. It indicates that the rate of senescence must be measured by the active leaf area rather than number of dead leaves. The senescing rate may be expected from the nutritional status at harvesting stage. Nitrogen contents were higher but phosphorus and potassium contents were lower in Suwon 214 than that in Jinhung (Table 7) in control. However in the case of leaf pruning nitrogen, phosphorus, especially potassium in the lower leaves were higher in Jinhung than in Suwon 214 (Table 7). It may indicate that Jinhung persists photo-synthetic activity longer than Suwon 214 does. Thus it appears to be reasonable that the upper leaf dependency in yield is related to fast senescence. The peristency of photosynethetic activity in lower leaf seems to depend much on nutritional status especially in potassium (Table 7) considering that photosynthetic rate and cyclic photophosphorylation were lowest in low potassium than in any other nutrient (10). When the lower leaves were pruned potassium absorption was greatly decreased and consequently ripening was mainly affected (1, 2) due to the poor supply of food to root(17) resulting in weak root activity (15). Potential grain yield thus appears to depend on root activity during the grain formation. The lower root activity of IR 667 than that of the commercial varieties(unpublished data) seems to be consistent to the lower potential yield of lower leaves in IR 667. The increase of nutrient content especially remarkable in Jinhung (Table 7) indicating that abundant supply of nutrient into the remained leaf. Such phenomena appeared in the sheaths and culms even in the heads (Table 8). Phosphorus content in sheath is higher than that in culm in Suwon 214, but it is quite reverse in Jinhung. It indicates possible quantitative difference in phosphorus metabolism.

Whether the contribution of each leaf to apparent grain yield is the same as in the potential grain yield is still questionable. If it follows the same pattern photosynthetic activity of lower leaves of commercial varieties must be greater than IR 667. It indicates that the commercial varieties are more shade resistant than IR 667 and it may be harmonious combination with leaf angle

Table 6. Nitrogen phosphorus and potassium in leaf (at 5 days from heading, % dry weight)

Leaf*	Suwon 213			Suwon 214			Jinhung			Paldal		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
1	1.96	0.41	0.85	1.89	0.32	0.71	1.82	0.34	0.85	1.82	0.26	0.48
2	1.75	0.33	0.86	1.75	0.28	0.74	1.73	0.35	0.93	1.63	0.30	0.60
3	1.53	0.28	0.96	1.48	0.26	0.44	1.54	0.28	0.71	1.41	0.33	0.85
4	1.45	0.25	0.85	1.39	0.24	0.29	1.31	0.25	0.69	1.26	0.29	0.66

* leaf counted from top.

Table 7. Nitrogen, phosphorus and potassium in leaf at harvest (% dry weight)

	Leaf*	N		P_2O_5		K_2O	
		Control	Pruning	Control	Pruning	Control	Pruning
Suwon 214	1	0.67	0.65	0.21	0.23	0.93	0.99
	2	0.72	0.65	0.23	0.24	0.86	1.11
	3	0.65	0.50	0.15	0.20	0.91	1.00
	4	0.13	0.44	0.08	0.16	0.54	0.66
Jinhung	1	0.80	0.96	0.23	0.35	1.45	1.17
	2	0.54	0.68	0.23	0.24	1.08	1.22
	3	0.43	0.62	0.14	0.24	0.94	1.22
	4	0.11	0.31	0.08	0.17	0.36	1.02

* leaf counted from top.

Table 8. Nitrogen, phosphorus and potassium content at harvest (% dry weight)

	Treatment*	N			P_2O_5			K_2O		
		Head**	Sheath	Culm	Head	Sheath	Culm	Head	Sheath	Culm
Suwon 214	Control	0.41	0.34	0.27	0.21	0.34	0.15	1.86	1.39	3.23
	0	0.38	0.21	0.27	0.30	0.38	0.30	1.97	1.43	4.02
	1	0.47	0.27	0.22	0.28	0.35	0.26	1.73	1.39	3.49
	2	0.42	0.31	0.21	0.26	0.41	0.18	1.50	1.40	3.67
	3	0.42	0.33	0.26	0.36	0.37	0.23	1.69	1.56	3.97
	4	0.40	0.26	0.29	0.30	0.44	0.28	2.25	1.51	3.62
Jinhung	Control	0.35	0.21	0.24	0.15	0.15	0.15	1.34	1.02	2.39
	0	0.36	0.21	0.28	0.24	0.21	0.38	1.37	1.02	3.49
	1	0.37	0.20	0.20	0.23	0.18	0.30	1.29	1.00	3.49
	2	0.41	0.21	0.23	0.15	0.15	0.24	1.36	1.14	3.40
	3	0.32	0.25	0.24	0.21	0.14	0.30	1.53	1.05	3.18
	4	0.18	0.15	0.24	0.21	0.26	0.29	1.28	1.19	3.67

* Remained leaf counted from top downwards. 0: Indicates no leaf
** Head except grain.

in the evolutionary process considering that IR 667 is more erect type. Shade resistance is very important to withstand long cloudy monsoon climate in summer. The information on photosynthetic activity of different leaf position in intact condition may give some answer to the question of each leaf contribution to grain yield. The investigation on the anatomycal difference of leaf tissue [5,6] between varieties also can give strong evidence on different leaf contribution to grain yield.

The differences between potential yield and apparent yield (Table 3) indicate that apparent yield of commercial varieties reached to 70% of potential yield while IR 667 reached to above 80%. Thus there remains more rooms to improve in the commercial varieties through breeding or cultural practices. Considering that IR 667 lines have more productive canopy structure (unpublished data) than the commercial varieties the closer approach to potential yield of IR 667 lines is easily expectable.

There seems to be many ways for measuring potential yield. For example potential yield of flag leaf can be calculated from the difference between control and 2, 3, 4 plot in Table 1. In this case potential yield of leaf could not fully detected because leaf is not most favorable condition. The values calculated from Araki's data(3) are 17.7% for flag leaf 10.4% for second leaf, 8.7% for 3rd leaf and 14.9% for other three lower leaves and those are less than 18.3, 14.4, 14.0 in Jinhung (Table 3) as expected. When single leaf is remained assimilate repression of photosynthesis can be eliminated by the decrease of the source to the sink[13], light difficiency will not occur, and nutrient supply will be in the most efficient condition. Consequently potential grain productivity must be maximized. Still there is another problem on the interaction among tillers. It may be minimized by eliminating the untreated tillers and it seems not too great to give significant error[12]. However the varietial difference in the interrelationship among tillers which was not investigated in this study should be considered.

Summary

Potential grain yield of rice plant was calculated from potential grain yield of each leaf for two lines of IR 667 and two commercial varieties(Jinhung and Paldal). According to the percentage contribution of each leaf the pattern of potential grain yield of IR 667 lines could be grouped into the upper leaf-dependent type indicating fast senescence while that of commercial varieties could be grouped into the lower leaf-dependent type indicating shade resistance. The comparisons between potential grain yields and apparent grain yields indicate that the commercial varieties having a comparably unfavorable plant type thus remained much behind the potential yield. The significance of potential grain yield was discussed in relation to nutrio-physiology and breeding. Methods for potential yield determination were also discussed.

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