〔韓作誌(Korean J. Crop Sci.) 37(2) : 155～165(1992)

Development of Vascular Bundles in the Peduncle of Different Tillers and its Relationship to Panicle Characteristics in Rice.

벼 이삭줄기의 維管束發育과 이삭特性과의 關係

李東珍*. 비 에스 벨가라**. 오 비 자모라***. 金鳳九****. 蔡濟天****

Dong Jin Lee*, Benito S. Vergara**, Oscar B. Zamora***, Bong Ku Kim****, and Je Cheon Chae****

ABSTRACT : Experiments were conducted to determined the development of the vascular bundles in the peduncle of different tillers on its development in order to improve the vascular system and possibly increase grain yield. The development of the vascular bundle in the leaf, stem and panicle is an important aspect of assimilate translocation and differentiation of panicle characters. Two cultivars were used in this study : IR58, an indica type, and Unbong 7, a japonica type.

The main culm(M) had more and bigger vascular bundles in the peduncle and those vascular bundle decreased with tiller order and tiller development. In the primary tillers, P1 had more large and small vascular bundles than P5 in both cultivars. IR58 developed more large vascular bundles compared to Unbong 7, but the small vascular bundle in unbong 7 was more than in IR58. The cross sectional area of phloem and xylem in large vascular bundle decreased with tiller order in both cultivar. Larger area of phloem and xylem in the early formed tillers more efficient transport of assimilates. The number of spikelets, the weight of panicle and grain yield per panicle were highest in the main culm followed by the order of their initiation or emergence. The number of primary and secondary branches to be positive associated with the number and area of vascular bundles. Furthermore, the number of vascular bundles in the peduncle was highly correlated with the peduncle thickness which in turn was correlated with the number of primary and secondary branches on the panicle.

These results showed tillers that are initiated early and have relatively longer growth duration usually have more vascular bundles, larger peduncle, more spikelets per panicle, better spikelet filling and ultimately higher yield.

* 湖南作物試驗場(Honam Crop Experiment Station, RDA, Iri 570-080, Korea)
** 國際 벼 硏究所(International Rice Research Institute, P. O. Box 933, Manila, Philippines)
*** 필리핀大學校(University of the Philippines at Los Banos, College, Laguna, Philippines)
**** 檀國大學校(College of Agriculture, Dankook University, Cheonan 330-714, Korea) 〈접수일자 92. 4. 16〉

Rice yields have increased rapidly during the past fourty years. The average rice yield in the world has increased from 1.6 t/ha in 1949 to 3.3 t/ha in 1988. Although some farmers has obtained yields of more than 10 t/ha, the theoretical calculated yield for a 130−140 day cultivar is much higher, around 36 t/ha[13]. To get near the theoretical yield, not only cultural management but cultivar improvement is necessary.

Recently, Vergara et al[14], suggested ideotype of rice plant for increasing yield potential by increase the number of high density grains. The proposed plant type should be low tillering, panicle weight type ; have panicles with more primary branches, spikelets with large pedicellar vascular bundle and thick culms. The top six or fewer tillers per plant, early formed, have been shown to be better morpho-anatomically and physiologically to the rest of the tillers[8].

Among the various parts of the rice plant, the panicle is the most important in relation to grain yield. In the development of large panicles with many primary branches[14], the vascular bundle (VB) play an important role. The number of VB is closely correlated with the number of primary branches[5,12], number of secondary branches and spikelets[2,3,12]. More and bigger VB in peduncle enhanced production of high density grain and increase grain yield potential[10].

This stμdy was undertaken to determine the vascular bundles development in the peduncle of different tillers and to investigate the relationship between number of VB and panicle characteristics of rice plant.

MATERLALS AND METHODS

The experiment was conducted in 1989-1990 at the greenhouse of the Agronomy, Plant physiology, and Agroecology Division, International Rice Research Institute(IRRI), Los Banos, Laguna, Philippines located at 14° N, 121° 15'E and at elevation of 21m.

Rice cultivars used were IR58 (IR28/Kwang Chang Ai/IR36, indica type) and Unbong 7 (Eunhabyeo/Akiyudaka, japonica type). IR58 was selected since this cultivar has been generally used in high density(HD) grain studies[1] while Unbong 7 was selected for adaptability to field condition at IRRI as observed by the Korean Seed Multiplication Team.

Seed were sterilized in 1.6% formalin solution for one minute and rinsed with water. They were soaked in water for 48 hours and incubated for another 24 hours. Germinated seeds were sown in seedling trays at 1 seed per cell of 1.0 by 1.0cm. Fourteen day-old seedlings in Dec. 9, 1989 were transplanted in 4-liter plastic pots containing 3.5kg of puddled Maahas clay soil mixed with 0.9g N, 0.4g P_2O_5 and 0.5g K_2O.

Tiller production was monitored and sampling was by tiller order. For the anatomical characteristics of internodes, the section just below the node were collected. The materials were fixed in FAA solution(50mℓ ethyl alcohol, 10mℓ formaldehyde, 5mℓ acetic acid and 35mℓ distilled water). The free-hand transverse section were made. Hematoxylin and safranin were used for staining and the samples were mounted with canada balsam. The number and cross sectional area of small and large vascular bundles were determined from the internodes and peduncle using a microscope.

Number of primary and secondary branches and spikelets were counted. Peduncle thickness and panicle weight were measured from each sampled plant at harvest. Panicle number per pot, spikelet number per panicle, spikelet fertility and 1,000 grain weight were determined. Grain yield was at 14% moisture. Two factors (two cultivars and tiller position) in completely randomized design(CRD) with 3 replications were used. Data were analyzed by the ANOVA and the Least Significant Difference (LSD) or Duncan's Multiple Range Test

RESULTS AND DISCUSSION

1. Development of Vascular Bundles

The vascular bundle(VB) of the rice plant connects the leaf, stem, and panicle and thus facilitate transport among organs[6]. The development of the VB in the leaf and stem is an important aspect of assimilate translocation and differentiation of panicle characters.

The large vascular bundle (LVB) and small vascular bundle(SVB) are developed in the stem, leaf blade and leaf sheath of rice[15]. In the stem of the rice plant, the SVB are located near the epidermis and oftentimes referred to as outer VB while the LVB or inner VB are located towards the center.

At flowering, number of LVB and SVB in all the internodes were significantly different between the two cultivars (Fig. 1). IR58 had more LVB and SVB than Unbong 7 except in SVB at the 1st internode. The number of LVB was lowest at the 1st internode from the top. The results agree with report that indica cultivars develop more VB than japonica cultivars like Unbong 7[9].

Although the number of LVB in the 1st internode was significantly lower from the rest of the internodes, there were no marked differences among the internode positions from the 2nd internode. A similar pattern was found in SVB.

The cross sectional area of LVB and SVB in elongated internodes were generally bigger in the lower internodes compared to the upper internodes in both cultivars (Fig. 2). The VB is composed two kinds of conduction tissues : the phloem through which organic materials are transported, and the xylem which conducts water and soil-derived nutrients[4]. The cross sectional area of the phloem and xylem of LVB follows the same trend with the cross sectional area of LVB.

The cross sectional area of the VB, phloem and xylem of LVB were significantly different between the two cultivars, i.e. IR58 had larger

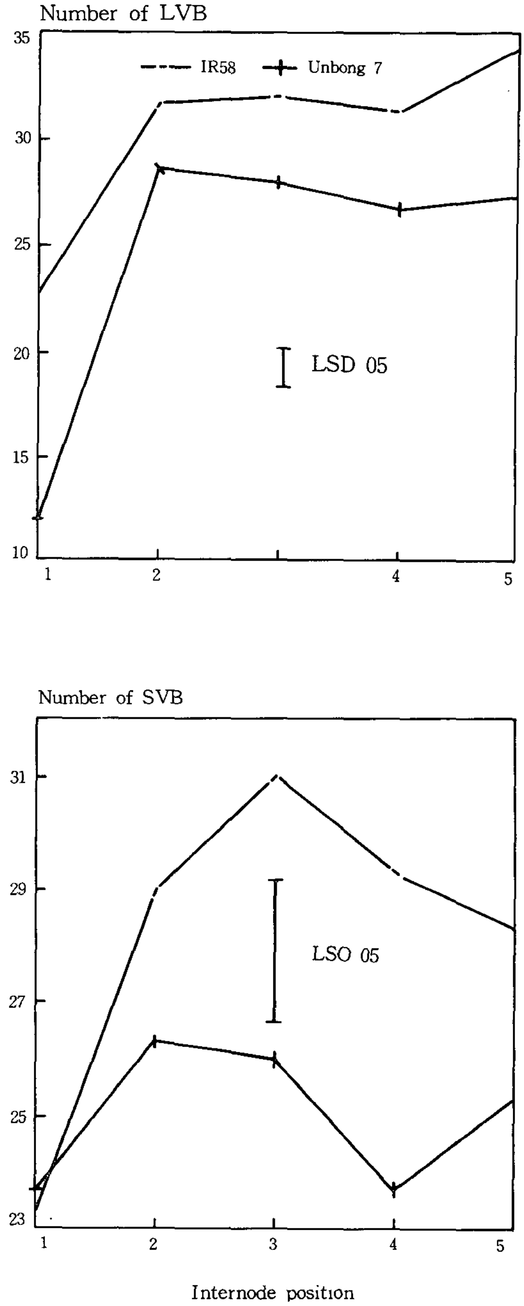

Fig 1. Number of large (LVB) and small (SVB) vascular bundles in elongated internodes of the main culm of IR58 and Unbong 7. Vertical bars indicate LSD at P.05 to compare all treatment means.

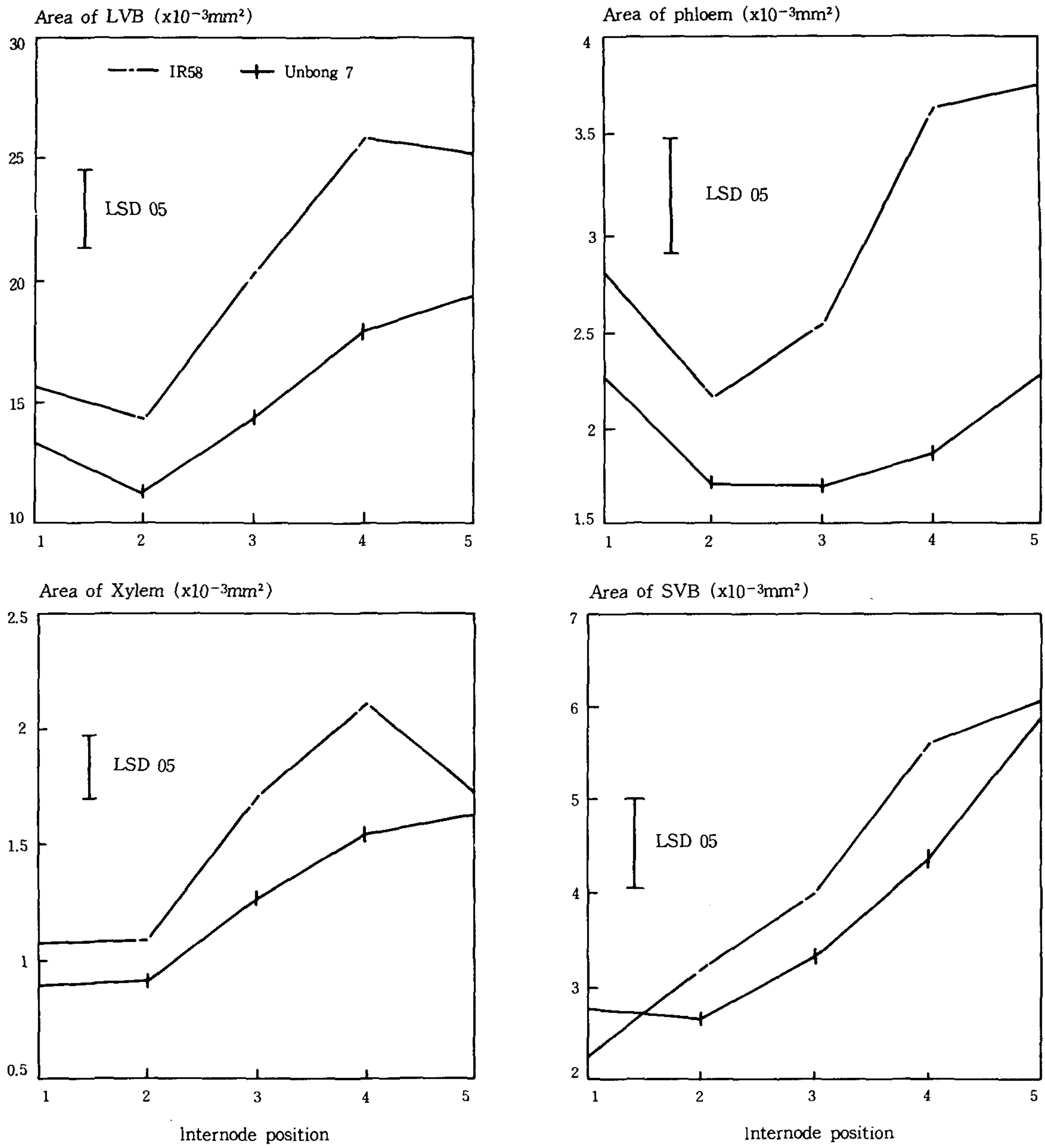

Fig 2. Cross sectional area of large (LVB) and small (SVB) vascular bundle in elongated internodes of the main culm of IR58 and Unbong 7. Vertical bars as in Fig. 1.

cross sectional area than Unbong 7. This findings implies that IR58 cultivar can be translocate more assimilate as compared with Unbong 7 cultivar.

The development of LVB and SVB in the peduncle of different tillers is presented in Table 1. The main culm(M) had more VB and these decreases with tiller order and tiller development. In the primary tillers, P1 had more LVB and SVB than P5 in both cultivars. In

Table 1. Number of large (LVB) and small (SVB) vascular bundles in the peduncle of different tillers in IR58 and Unbong 7.

Tiller	No. of LVB		No. of SVB	
position	IR58	Unbong 7	IR58	Unbong 7
M	22.7 a	12.0 a	21.0 a−c	24.7 a
P1	20.3 b−d	10.3 a−d	21.0 a−c	23.3 ab
P2	21.7 a−c	11.3 a−c	22.3 a	24.0 a
P3	20.0 b−d	11.0 a−d	20.0 a−c	23.7 a
P4	19.7 c−e	10.7 a−d	18.0 b−e	22.0 a−c
P5	19.7 c−e	9.0 cd	18.7 b−e	20.7 a−c
S1P1	20.3 b−d	9.3 b−d	20.3 a−c	19.3 bc
S2P1	19.0 d−e	9.7 b−d	17.3 c−e	21.3 c−c
S3P1	17.3 ef	9.0 cd	15.0 e	21.0 a−c
S4P1	16.3 f	9.3 b−d	14.7 e	18.0 c
S1P2	19.7 c−f	10.3 a−d	22.0 ab	23.0 ab
S2P2	19.7 c−f	11.0 a−b	19.3 a−d	21.7 a−c
S3P2	18.7 de	9.7 b−d	15.3 de	20.7 a−c
S1P3	18.3 d−f	8.7 d	17.0 c−e	19.3 bc
S2P3	18.7 de	10.3 a−d	15.7 de	20.7 a−c
S1P4	18.3 d−f	9.3 b−d	17.0 c−e	19.3 bc
F−value Cultivars	1,223.80**		46.29**	
Tiller position	5.92**		5.54**	
Interaction	1.44ns		0.99ns	

** means are siginificantly different at 1% level.
Means followed by common letter in a column are not significantly different at the 5% level by DMRT

the secondary tillers, number of LVB and SVB was less than that of the primary tillers. The tiller formed earlier(S1P1, S1P2) tend to have more LVB and SVB than S4P1. This results implied that the development of VB would be determined by tillering oreder and position.

Between the two cultivars, IR58 significantly developed more LVB compared to Unbong 7, but the SVB in Unbong 7 was significantly more than in IR58. Kim[7] reported similar reduction trend of n-2 in the number of LVB with tiller order. Unbong 7 had n-2 reduction from the main to the primary tillers but only n-1 from primary to secondary tillers. Table 2 showed that the cross sectional area of LVB and SVB in peduncle of different tillers followed the same trend with the number of LVB. Area of LVB ranged from 10.27 to 16.02 for IR58 and from 10.40 to 13.61($\times 10^{-3}mm^2$) for Unbong 7, respectively. The cross sectional area of LVB in peduncle was highest in the main culm(16.02 $\times 10^{-3}mm^2$ for IR58 and 13.60$\times 10^{-3}mm^2$ for Unbong 7) followed by that in the primary and secondary tillers in both cultivars.

The cross sectional area of phloem and xylem in LVB decreased with tiller order in both cultivars. IR58 had bigger LVB and SVB than Unbong 7.

This result agrees with earlier report of Lee et al[9]. that indica x japonica cultivars had larger LVB than japonica cultivars. The higher number and larger cross sectional area of the VB in the indica cultivars would underscore the more efficient transport of assimilates from the leaf and stem to the

Table 2. Cross sectional area of large (LVB) and small (SVB) vascular bundle in the peduncle of the different tillers IR58 and Unbong 7.

Tiller position	Area of LVB($\times 10^{-3}mm^2$)						Area of SVB ($\times 10^{-3}mm^2$)	
	VB		Phloem		Xylem			
	IR58	Unbong 7	IR58	Unbong 7	IR58	Unbong 7	IR58	Unbong 7
M	16.02 a	13.60 a	3.04 a	2.58 a	1.03 a	0.97 a	2.68 a	3.05 a
P1	15.42 ab	13.51 a	2.67 b	2.49 ab	1.01 ab	0.92 a−c	2.53 ab	3.01 a
P2	15.81 a	13.61 a	2.95 a	2.44 a−c	1.00 ab	0.94 ab	2.27 bc	2.60 bc
P3	14.76 bc	13.50 a	2.67 b	2.47 a−c	1.03 a	0.94 ab	2.61 ab	2.88 ab
P4	12.97 ef	13.21 a	2.35 d	2.33 b−d	0.85 c−f	0.88 a−d	2.10 cd	2.82 ab
P5	11.62 hi	10.59 e	2.03 fg	1.95 fg	0.82 d−f	0.84 b−d	1.91 d−g	1.97 fg
S1P1	13.61 de	11.95 b−d	2.25 de	2.00 fg	0.87 c−f	0.81 de	2.01 c−f	2.10 d−g
S2P1	12.28 f−h	12.29 bc	2.40 cd	2.28 b−f	0.88 c−e	0.84 b−d	2.06 c−e	2.56 bc
S3P1	11.75 g−i	12.13 bc	1.95 f−h	2.24 c−e	0.77 e−g	0.80 de	1.63 gh	2.33 c−e
S4P1	11.04 i	11.19 de	1.77 h	1.95 fg	0.76 fg	0.84 b−d	1.67 f−h	2.32 c−f
S1P2	14.09 cd	12.76 ab	2.41 cd	2.50 ab	0.92 b−d	0.86 b−d	2.33 bc	2.58 bc
S2P2	14.32 cd	11.64 cd	2.59 bc	2.36 a−d	0.94 a−d	0.86 b−d	2.10 cd	2.43 cd
S3P2	12.43 f−h	11.90 bd	2.05 e−g	2.16 d−f	0.81 d−g	0.78 de	1.73 e−g	2.07 e−g
S1P3	12.51 fg	11.88 cd	2.13 ef	2.08 ef	0.77 e−g	0.83 cd	1.87 d−g	2.20 d−g
S2P3	10.27 j	12.20 bc	1.48 i	2.08 ef	0.71 g	0.81 de	1.36 h	2.17 d−g
S1P4	12.43 f−h	10.40 e	1.86 gh	1.85 g	0.84 c−f	0.72 e	1.62 gh	1.84 g
F-value	Cultivar	96.40**	4.21*		1.97ns		106.63**	
	Tiller position	44.21**	38.72**		8.92**		20.50**	
	Interaction	11.49**	9.28**		3.89**		2.93**	

*, ** means are siginificantly different at 5% and 1% level, respectively.
Means followed by common letter in a column are not significantly different at the 5% level by DMRT

developing reproductive organs such as spikelets. Optimum levels of substrate would be transpoted for the formation and development of the well-filled spikelets.

2. Panicle Characteristics

The growth and development of panicle differed from one tiller to the other. Generally, the panicle weight of the *main tiller* was highest followed by the primary and secondary tillers(Fig. 3). In both cultivars, P5 was initiated much later and had lower panicle weight than the secondary tillers. Kim[7] reported that the earlier initiation of the tillers were the longer growing period, the bigger the panicle and the greater grain weight.

Between the two cultivars, IR58 had heavier panicles than Unbong 7. In this experiment, the panicle weight of IR58 in the top 9 tillers had minimal change but in the succeeding tillers was drastically reduced to as low as 1.2g per panicle. Kim[7] reported six top tillers in IR58 and the variation between Kim's data and the present experiment may be the result of differences in cultural management.

The number of primary and secondary branches were significantly different among

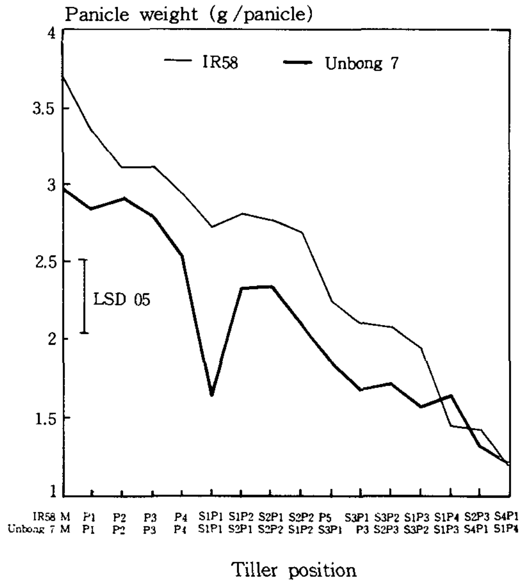

Fig 3. Variation in panicle weight in different tillers (arranged in development order) of IR58 and Unbong 7. Vertical bar as in Fig. 1.

tiller positions and between the two cultivars (Fig. 4). In the main culm, more primary(11.3) and secondary branches(29.0) were produced in IR58 and also in Unbong 7(9.7 and 24.3) for the primary and secondary branches, respectively. The primary and secondary tillers produced less number of branches than the main culm. Between the two cultivars, IR58 gave higher number of branches in all tillers than Unbong 7.

3. Grain Yield and Yield Components

The grain yield and yield components at various tiller positions in IR58 and Unbong 7 are shown in Fig. 5. The number of spikelets were highest in the main culm of both cultivars. The number of spikelets decreased significantly form the main culm to the last formed tiller in IR58 and Unbong 7 (Fig. 5). Early tillers produced more spikelets per panicle than the late tillers[11]. The decrease was

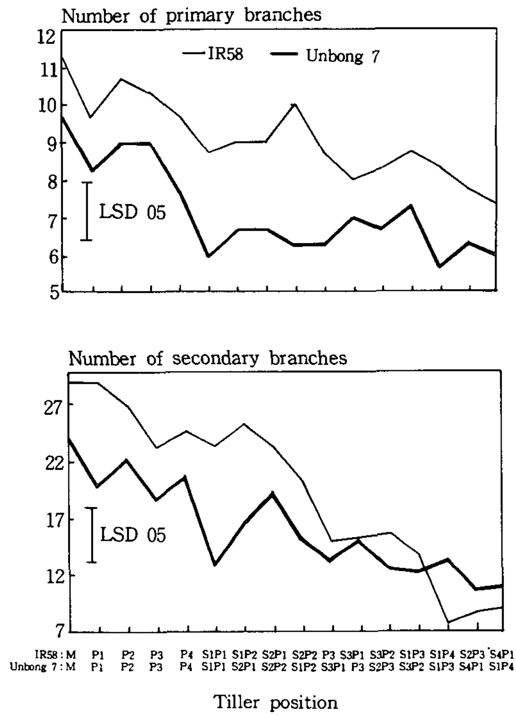

Fig 4. Number of primary and secondary branches in a panicle of different tillers (arranged in development order) in IR58 and Unbong 7. Vertical bars as in Fig. 1.

significantly large between S1P1 and P5 of IR58 resulting in nine top tillers with not only a large number of spikelets but also heavy panicles. IR58 had more of spikelets in IR58 than that of Unbong 7 due to higher VB development in peduncle.

Spikelet fertility showed no significant difference among tiller orders in IR58 and tended to be higher in the early formed tillers of Unbong 7, except the orders although the main and primary tillers tended to have heavier grains. The grain yield per panicle, similar to panicle weight, was highest in the main culm followed by the order of their initiation or emergence. The number of spikelets and grain yield per panicle had the same trend reported result mainly of more spikelets per

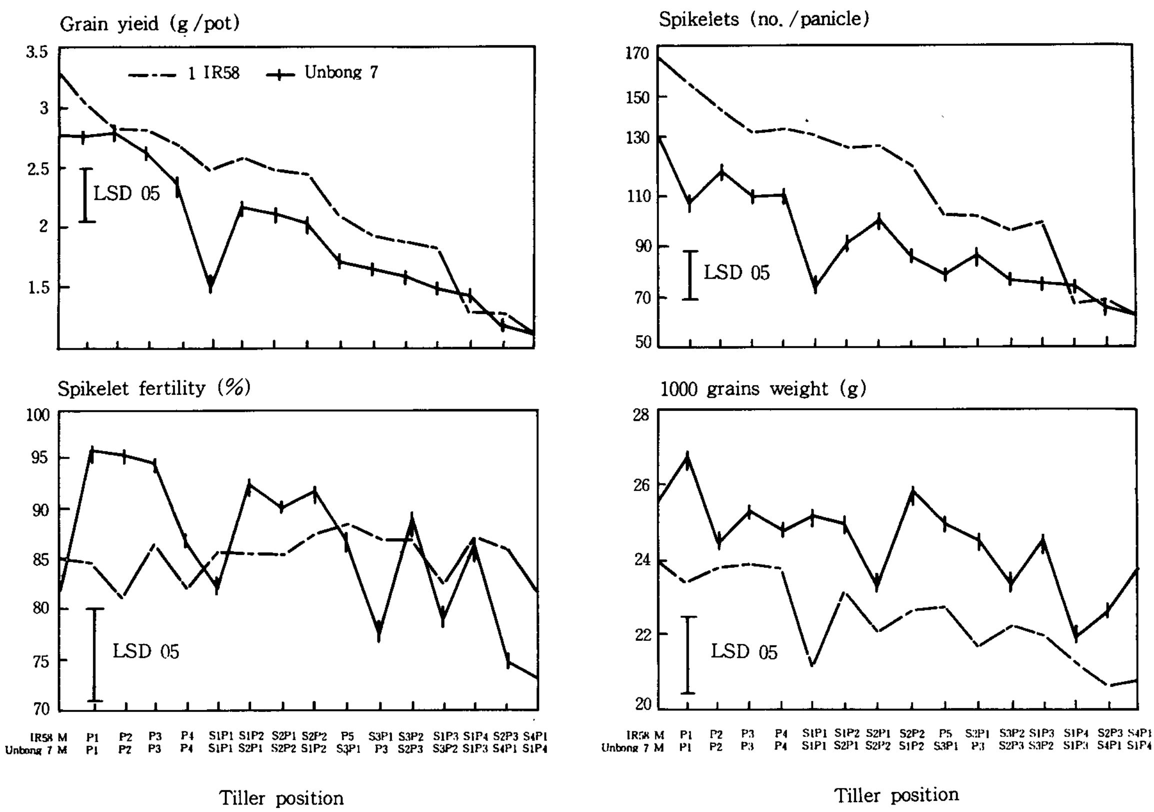

Fig 5. Yield and yield components in different tillers (arranged in development order) in IR58 and Unbong 7. Vertical bars as in Fig. 1.

panicle. Early formed tillers may have an advantage to accumulate more carbohydrates through better utilization of solar energy for photosynthesis than that of the rest tillers.

4. Relationship between the Morpho-anatomical Characteristics and Yield Components

The number of LVB was highly correlated with the thickness of the peduncle in IR58 and Unbong 7(Fig. 6). This agrees with the results of Chae et al[2]. and Lee et al[9]. in which they reported that the number of LVB were correlated with internodal diameter in rice cultivars. Increasing the peduncle thickness increased the number of LVB which in turn was correlated with number of primary and secondary branches on the panicle and number of spikelets (Table 3). Grain yield was highly correlated with peduncle thickness, panicls weight and spikelet number (Table 4). Hayashi[5] found high and positive correlation coefficients between the number of large VB in the first (highest) internode and the number of primary branches in the panicle, the number of grains per panicle, and the weight of a panicle. Chae et al[2]. reported that the number of VB were positively correlated with panicle length, the number of rachis branches, and the number of spikelets in rice cultivars. The number and site of VB and the thickness of internodes had significant correlation with the panicle length, number of primary and sec-

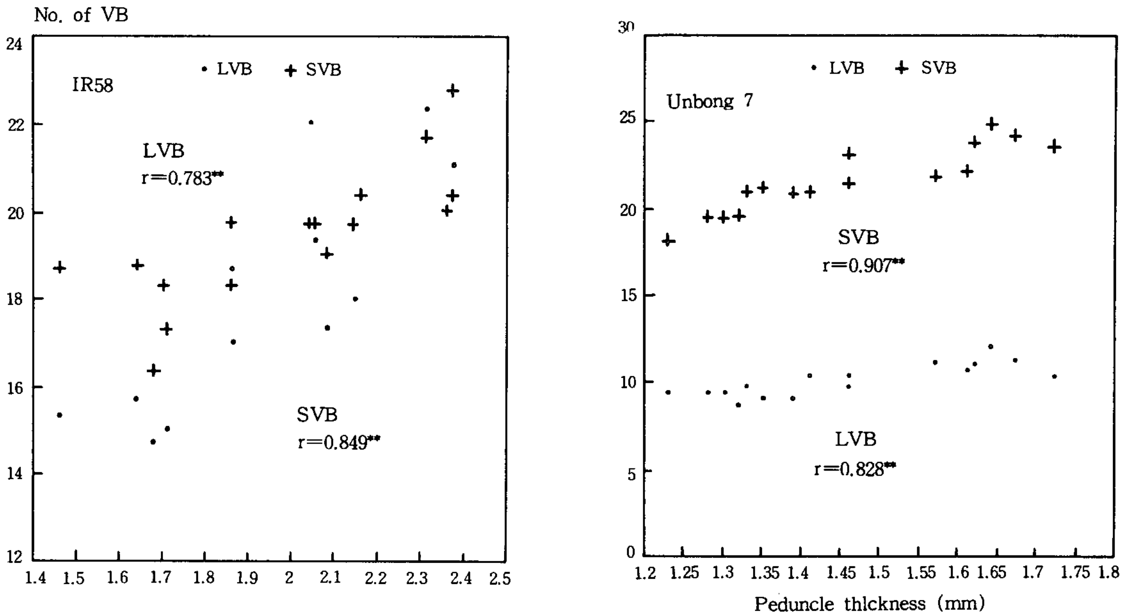

Fig 6. Relationship between the number of large (LVB) and small (SVB) vascular bundles in the peduncle and thickness of the peduncle in IR58 and Unbong 7.

Table 3. Correlation coefficients between thickness and number of large vascular bundles (LVB) in the peduncle and panicle characteristics in IR58 and Unbong 7.

Characters	Cultivars	No. of primary branches	No. of secondary branches	No. of spikelets
LVB /peduncle	IR58	0.524**	0.553**	0.573**
	Unbong 7	0.645**	0.520**	0.604**
Peduncle thickness	IR58	0.654**	0.788**	0.814**
	Unbong 7	0.689**	0.707**	0.790**

Table 4. Correlation coefficients between grain yield and peduncle thickness, panicle weight and number of spikelets in IR58 and Unbong 7.

Characters	Grain yield	
	IR58	Unbong 7
Peduncle thickness	0.893**	0.909**
Panicle weight	0.999**	0.996**
Number of spikelets	0.991**	0.950**

ondary branches and number of spikelets per panicle[9].

Dana et al[3]. concluded that a fairly reliable prediction can be made on the number of spikelets from the number of VB in the culm. The increase in large and small VB in the rachis were accompanied by increase of primary branches, and the increase of small VB in primary branches were considered to be followed by that of secondary branches and peduncles[12].

Cultural management that can increased the thickness of the peduncle, can increase the number of spikelets and resulting grain yield. By selecting cultivars with large peduncle or changing the cultural management to produce only tillers with large peduncle, grain yield potential can be increased. The results from the present study supports the assumption that only an optimum number of tillers should be produced. Those tillers that are initiated early and have relatively longer growth duration, usually have more LVB, large peduncle, more spikelets per panicle, better spikelet filling and ultimately higher yield.

摘　要

本 實驗은 水稻이삭줄기의 維管束 發育을 增進시켜 收量을 增加시킬 수 있는 方案을 摸索하기 爲하여 1989－1990年에 國際벼硏究所(IRRI)에서 印度型인 IR58과 日本型인 Unbong 7을 供試하여 實施하였다.

1. 主稈의 節間位置別 維管束數는 上位로부터 第1節間(穗首節間)은 第 2,3,4,5節間에 比해 顯著하게 적었으며, 品種別로는 IR58이 Unbong 7 보다 많이 發育되었다.
2. 穗首節間의 維管束數 및 *橫斷面積은 主稈이 1,2*次 分蘖莖보다 많고 컸으며, 分蘖의 發育順序에 따라 低下되는 傾向이었고, IR58은 Unbong 7보다 大維管束의 數와 橫斷面積이 많고 컸으나 小維管束은 적고 작았다.
3. 養分의 移動通路인 篩部와 水分의 移動通路인 木部의 橫斷面積도 分蘖의 出現이 빠른것이 늦은것보다 크게 發育되어 있어서 出現이 빠른 分蘖莖이 養水分吸收 및 同化物質의 轉流에 有利한 特性을 가지고 있는 것을 思料되었다.
4. 이삭當 穗重 및 收量은 主稈에서 가장 높았고, 1次分蘖 및 2次分蘖의 順序로 낮아지는 傾向으로 分蘖莖의 出現順序와 密接한 關聯性을 가지고 있었다.
5. 穗首節間의 大維管束數는 이삭形質인 1,2次 枝莖數와 有意한 正의 相關關係를 나타냈으며, 이는 大維管束이 枝莖數 및 穎花數 分化에 直接的인 影響을 준 것으로 解析되었다.
6. 일찍 出現된 分蘖莖은 늦게 出現된 分蘖莖에 比해 比較的 긴 生育期間을 가지고 있었으며, 良好한 維管束의 發育, 굵은 穗首直徑, 穎花數 分化 및 登熟率을 向上시키고 나아가서 收量이 많아지는 特性을 나타냈다.

LITERATURE CITED

1. Ahn, J. K. 1986. Physiological factors affecting grain filling in rice. Ph. D. thesis, University of the Philippines at Los Banos. 127 p.
2. Chae, J. C., B. K. Kim and D. J. Lee. 1984. A study on the development of internodal vascular bundles and air spaces, and its relationships to panicle characteristics of rice varieties. Korean J. Crop Sci. Soc. 29 (4) : 356－361.
3. Dana, S., B. B. Chaudhari and S. L. Basak. 1969. Correlation between vascular bundles and panicle characters in rice. International Rice Commission Newsletter 18(1) : 36－38.
4. Esau, K. 1977. Anatomy of seed plants. John Wiley and Sons, New York. 550 p.
5. Hayashi, H. 1976. Studies on large vascular bundles in paddy rice plant and panicle formation. 1. Relationships between the number of large vascular bundles in the culm and the plant types. Proc. Crop Sci. Soc. *Japan 45(2) : 322－327.*
6. Inosaka, M. 1958. On the connection between the branches on the first order and upper leaves of rice plant. Proc. Crop Sci. Soc. Japan 26(3) : 197－198.
7. Kim, J. K. 1988. Physiological studies on low-tillering rice ; an ideotype for increasing grain yield potential. Ph. D. thesis, University of the Philippines at Los Banos. 187. p.
8. Kim, J. K. and B. S. Vergara. 1991. A low tillering ideotype of rice plant for increasing grain yield potential. Korean J. Crop Sci. 36(2) : 134－142.
9. Lee, D. J., K. J. Kim, J. H. Lee, B. K. Kim and J. C. Chae. 1985. The effect of nitrogen fertilization on vascular bundles and air space development in the internodes of several rice varieties and the relationship between the histological structure and panicle characteristics. Korean J. Crop Sci. Soc. 30 : 107－115.
10. Lee, D. J. 1990. Effect of nitrogen and grain density on the development of vascu-

lar bundles in rice(Oryza sativa L.) Ph. D. Thesis, University of the Philippines at Los Banos. 175 p.
11. Majumdar, D. K. 1976. Emergence of tillers, yield and components of mother, primary, secondary and tertiary tillers of rice variety Taichung native-1 and effects of fertilizer combinations thereon. J. Res. Visra-bharati 1 : 37－41.
12. Shimizu, M and Y. Takeoka. 1966. Effects of gibberellin on the morphogenesis in rice plants. 6. Effects of gibberellin on the development of vascular bundles in panicles. Proc. Crop Sci. Soc. Japan. 35(1-2) : 105－112.
13. Togari, Y. 1972. Photosynthesis and dry matter production of crops. Yokendo Tokyo. 420 p.
14. Vergara, B.S., B. Venkateswarlu, M. Janoria, J.K. Ahn, J.K. Kim and R.M. Visperas. 1990. Rationale for a low tillering rice plant type with high density grains. Paper presented at the International Rice Research Conference, Seoul, Korea, August 27－31.
15. Yoshida, S. 1981. Fundamentals of rice crop science. IRRI, Los Banos, Laguna, Philippines 269 p.