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Case Studies on High Yields of Paddy Rice in Jiangsu Province, China

I. Characteristics of grain production*

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Abstract: Analysis of the characteristics of grain production of 965 gm^{-2} obtained by Shan You 63 (F_1 hybrid rice) in 1991 was carried out. Absorption of nitrogen reached 21 gm^{-2} up to the time of heading, and a large capacity of grain yield (50,360 spikelets per m^2) was obtained. Efficiency of increase in spikelet number per m^2 by absorbed nitrogen up to heading was essentially the same as in west Japan. Mean Leaf Area Index 10 days before heading became exceptionally large (10.18). A large amount of translocation of accumulated assimilation products before heading improved the percentage of ripened grain. Increase in translocation of assimilated products stored in the culm and leaf before heading may remarkably increase yield in China.
Key words: China, Grain production, High yield, Paddy rice, Shan You 63, Translocation.

中国江蘇省における水稲多収穫の事例解析　第1報　子実生産特性：天野高久・朱　慶森**・王　余龍**・井上直人***・田中英彦****（京都府立大学農学部・**中国江蘇農学院・***京都大学農学部・****北海道立上川農業試験場）

要　旨　江蘇省連雲港市において1991年にハイブリッドライス汕優63号によって得られた玄米収量965 gm^{-2}の子実生産特性を解析した．出穂期までに21 gm^{-2}の窒素を吸収し，m^2当たり50,360粒のもみを得た．吸収窒素のもみ数生産効率は西日本並みであった．出穂前10日間の葉面積指数は10.18に達した．出穂期前の蓄積同化産物の移行量の増加が登熟歩合の向上に働いていた．出穂期前に茎葉に蓄積された同化産物の穂への移行量の増加が中国の水稲栽培において著しい増収をもたらしていると考えられた．
キーワード：移行量，子実生産，水稲，汕優63号，多収穫，中国．

As examples of high yields of paddy rice in China, Kunihiro[2] reported on brown rice yield of 1120 gm^{-2} by Zhen Yu No. 1 in Dali, Yunnan Province, 1200 gm^{-2} by Guizhao No. 2 in Binchuan, Yunnan and 1350 gm^{-2} by Guizhao No. 2 in Hegin, Yunnan. Xu et al[14]. obtained as unhulled rice 1360-1440 gm^{-2} for three years continuously in the trial of Ganhua No. 2 (F_1 hybrid rice) in Ganyu County, Jiangsu Province. This means a 1050 to 1110 gm^{-2} brown rice yield. Even though examples of brown rice yield over 1000 gm^{-2} were quite frequent, the factors determinig yield have scarcely been studied[14]. In the three examples of Yunnan Province mentioned above, information on growth factors is not clear except on yield components.

Therefore, the authors tried to analyze the factors for high yields exceeding 1000 gm^{-2} of brown rice in China. In this paper, characteristics of grain production of 965 gm^{-2} of brown rice obtained by Shan You 63 (F_1 hybrid rice) in Lianyungang, Jiangsu Province, China in 1991 are analyzed.

Materials and Methods

Two experimental paddy fields of 1200 to 1500 m^2 were in each county: Ganyu and Donghai, in Lianyungang, Jiangsu Province. There was about 50 km in a straight line between both counties. Chinese F_1 hybrid rice and Japanese varieties were grown in the same way in each county. For reference, a Japanese veriety was cultivated in a paddy field of an experimental farm at Kyoto Prefectural University. An outline of each variety, planting areas, cultivation methods and soil conditions is shown in Table 1.

After transplanting, the culm number of

* The outline of this paper was presented at the 193th meeting of the Crop Science Society of Japan, April, 1992.

about 50 hills was measured in each test plot periodically. Ten hills with the mean culm number from each test plot were collected at the time of early tillering, booting, heading and maturity. After cutting the roots, the hills were separated into leaf blade, culm+leaf sheath and ear and were power dried for 2 days at 80 to 90°C before dry weight was determined. Leaf area was calculated from the total dry weight of the leaf blade and dry weight of the leaf blade per 100 cm^2. Mean Crop Growth Rate ($\overline{CGR}$), mean Leaf Area Index ($\overline{LAI}$) and mean Net Assimilation Rate ($\overline{NAR}$) were calculated by dry weight and leaf area in each growth stage. At maturity, 7 of 10 hills were used to determine the dry weight, leaf area, percentage of ripened grain (seed selection was made by salt solution of the specific gravity 1.06) and number of spikelets per one ear was counted with three culms remaining. Total nitrogen (N) of each part of the plants at heading and maturity was measured by Indophenol colorimetric analysis[5]. N was expressed as percentage of dry weight.

Yield survey was carrid out as follows: Winnowed unhulled rice weight was measured after reaping rice hills at 2 plots, each 10 m^2 (2 m×5 m), threshing and wind selection. Unhulled rice of 300 g were husked to make whole brown rice, and then put through a 1.7 mm sieve to remove any immature kernels. Weight of winnowed unhulled rice, whole brown rice and winnowed brown rice were converted into water content of 15% and these were expressed as the mean value of 2 plots. Straw weight was calculated from dry weight of the leaf blade and the culm+leaf sheath of 7 hills collected at maturity.

Table 1. Outline of cultivation methods.

Ganyu County (34° 80′ N, 119° 10′ E)	Donghai County (34° 60′ N, 118° 70′ E)
Variety and planted area (without replication)	
Shan You 63*, 100 m^2 (22 m×45.5 m)	Xu You 3-2*, 1300 m^2 (35 m×37.1 m)
Koganebare**, 100 m^2 (8 m×12.5 m),	Nipponbare**, 200 m^2 (12×16.7)
Transplanting date: June 15	June 25
Transplanting density: 52 hills m^{-2}, 1 plant/hill	42 hills m^{-2}, 1 plant/hill
Fertilizer application	
Basal dressing (June 14)	Basal dressing (June 25)
N: 26.9 gm^{-2}, P_2O_5: 18.8 gm^{-2},	N: 12.8 gm^{-2} (Ammonium carbonate)
K_2O: 18.8 gm^{-2} (Urea, Compound f.)	Top d. (July 2, 48 days before heading)
Top d. (June 20, 61 days before heading)	N: 9.6 gm^{-2}, P_2O_5: 6.9 gm^{-2}
N: 8.1 gm^{-2} (Urea)	(Urea, Ammonium Phosphate)
Top d. (June 28, 53 days before heading)	Top d. (July 25, 25 days before heading)
N: 1.6 gm^{-2}, P_2O_5: 4.1 gm^{-2}	N: 2.8 gm^{-2} (Urea)
(Ammonium Phosphate)	
Top d. (July 8, 43 days before heading)	Total N: 25.2 gm^{-2}, P_2O_5: 6.9 gm^{-2}, K_2O: 0
K_2O: 12.2 gm^{-2} (Potassium sulfate)	
Top d. (July 30, 21 days before heading)	
N: 3.4 gm^{-2}, P_2O_5: 6.1 gm^{-2} (Urea, Ammonium Phosphate)	
Total N: 40.0 gm^{-2}, P_2O_5: 29.0 gm^{-2}, K_2O: 31.0 gm^{-2}	
Disease and insect pest control	
July 8, July 28 (Insecticide)	July 28, August 20 (Insecticide)
August 4 (Insecticide, Fungicide)	August 25 (Insecticide, Fungicide)
Weed control: June 20 (Herbicide)	July 28 (Herbicide), August 5 (Hand weeding)
Cropping system: Wheat-rice double cropping	Wheat-rice double cropping
Soil condition: Loam	Clay loam

*F_1 hybrid rice, **Japanese variety, Top d.: Top dressing. Compound f.: Compound fertilizer.

As for meteological data, values at each meteorological observation in Ganyu and Donghai counties and those at the experimental farm at Kyoto Prefectural University were used.

In this paper, grain yield was indicated as a product of grain yield capacity and contents in grain yield[3], and the characteristics of grain production were analyzed. Since spikelet size, a component of grain yield capacity, was not measured, spikelet number per m^2 was regarded as grain yield capacity. Regarding contents of grain yield, the weight of whole brown rice ($\triangle E$) was divided into T and $\triangle W$ for analysis[7], with T as the amount of translocation of the assimilated products stored in the culm and leaf before heading into the ear, and $\triangle W$ as dry matter production from heading to maturity. Furthermore, each value was divided by spikelet number per m^2 and E, T, W (En, Tn, Wn) per spikelet were estimated.

Kyoto (35° 27′ N, 135° 12′ E)
Nipponbare**, 80 m^2 (20m×40 m)
May 23 35 hills m^{-2}, 3 plants/hill
Basal derssing (May 21) N : 2.7 gm^{-2}, P_2O : 2.7 gm^{-2}, K_2O : 2.7 gm^{-2} (LP compound f.) Top d. (July 15, 26 days before heading) N : 2 gm^{-2}, K_2O : 2 gm^{-2} (NK compound f.) Top d. (July 20, 21 days before heading) N : 2.5 gm^{-2}, K_2O : 2.5 gm^{-2} (NK compound f.) Top d. (August 3, 12 days before heading) N : 2 gm^{-2}, K_2O : 2 gm^{-2} (NK compound f.) Total N : 9.2 gm^{-2}, P_2O_5 : 2.7 gm^{-2}, K_2O : 9.2 gm^{-2}
May 25 (Herbicide) Rice single cropping Clay loam

LP : Slow-release fertilizer.

Results

1. Daily mean air temperature and sunshine hours

Daily mean air temperature and sunshine hours at each location during the growing season were shown in Fig. 1. Approximately the same daily mean air temperature was recorded in Ganyu and Donghai counties. Daily mean air temperature in both counties was 0.4 to 2.3°C higher in the first 10 days, and middle of May and in July, and 0.2 to 3.7°C lower in other seasons than in Kyoto.

Daily mean sunshine hours in Ganyu County were longer than those in Donghai County. Daily mean sunshine hours in both Ganyu and Donghai were approximately the same as in Kyoto in the last 10 days of May and first 10 days of June, and were 6 to 54 hours longer in the season after the middle of June than in Kyoto.

2. Yields

Winnowed unhulled rice weight, winnowed brown rice weight, straw weight and brown rice-straw ratio (winnowed brown rice weight/

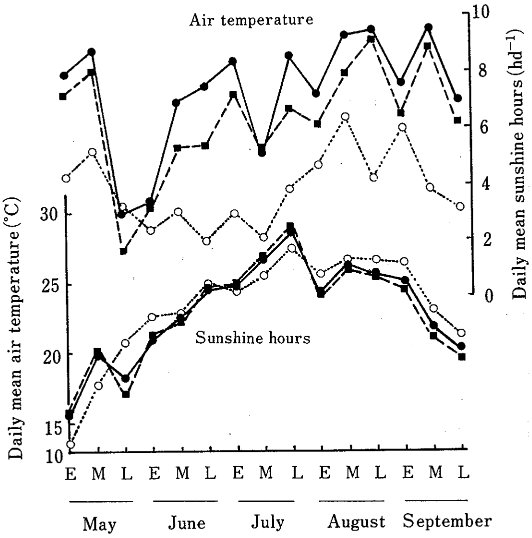

Fig. 1 Daily mean air temperature and daily mean sunshine hours at each location (1991).
—●— : Ganyu County, - - ■ - - : Donghai County, ---○--- : Kyoto.
E : First ten days, M : Middle ten days, Last ten days.

Table 2. Weight of winnowed-unhulled rice, weight of winnowed-brown rice, straw weight and brown rice-straw ratio.

Location	Variety used	Weight of Winnowed-unhulled rice (gm^{-2})	Weight of Winnowed-brown rice (gm^{-2})	Straw weight (gm^{-2})	Brown rice-straw ratio*
Ganyu County	Shan You 63	1241	965	956	1.01
	Koganebare	798	662	932	0.71
Donghai County	Xu You 3-2	938	788	781	1.01
	Nipponbare	773	638	861	0.74
Kyoto	Nipponbare	897	691	889	0.78

*Brown rice-straw ratio : Weight of winnowed-brown rice/straw weight.

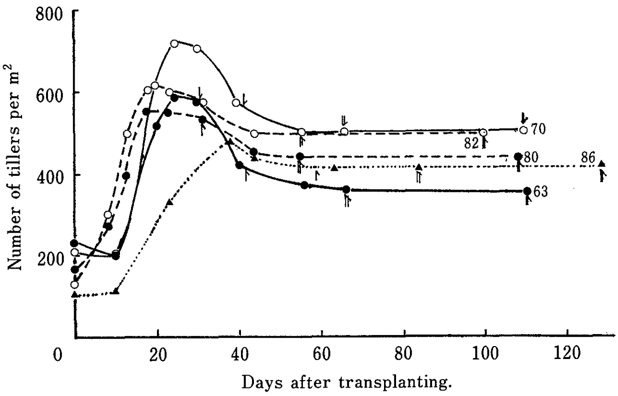

Fig. 2 Tillering patterns and growth stages. Numerals in the figure indicate percentage of porductive culm. Arrows indicate growth stages.
—●— : Shan You 63, —○— : Koganebare (Ganyu County),
--●-- : Xu You 3-2, ---○--- : Nippnbare (Donghai County),
···▲··· : Nippnbare (Kyoto).
↓ : Spikelet differentiation, ↓ : Heading, ↓ : Maturity.

straw weight) are shown in Table 2. Winnowed unhulled rice weight was heighest in 1241 gm^{-2} of Shan You 63, and decreased in the order of Xu You 3-2, Nipponbare of Kyoto, Koganebare, Nipponbare of Donghai County. For winnowed brown rice weight, Shan You 63 was 965 gm^{-2} and Xu You 3-2, was 788 gm^{-2}, and this order was the same as winnowed unhulled rice weight. Japanese varieties were within 638 to 691 gm^{-2}. Straw weight of Shan You 63 was a maximum 956 gm^{-2} and Xu You 3-2, a minimum 781 gm^{-2}. These yields were not the same as the order of winnowed brown rice yield. The brown rice-straw ratio was 1.01 for both Shan You 63 and Xu You 3-2, clearly indicating a high value compared to Japanese varieties.

3. Tillering patterns and growth stages

Tillering patterns and growth stage are shown in Fig. 2. In Shan You 63 and Koganebare, about 10 days after transplanting, the number of culms did not increase but thereafter, rapidly increased to a maximum tiller number stage 25 days after transplanting. The percentage of productive culm of Shan You 63 was 63% and lower than other varieties. Ear number per m^2 of Shan You 63 was the smallest. Xu You 3-2 or Nipponbare of Donghai County showed no delayed growth, reaching a maximum tiller number stage 18 days after transplanting. The percentage of productive culm of Xu You 3-2 was approximately the same as that of Nipponbare in Donghai County. Increase in the number of culms of Nipponbare in Kyoto was slow. However, many more ears were recognized because of the much higher percentage of productive culm. The number of days from transplanting to each growth stage was 17 to 19 days shorter in Ganyu County and 26 to 30 days shorter in Donghai County than in Kyoto.

4. Growth parameters at different growth stages

In Table 3, $\overline{CGR}$, $\overline{LAI}$ and $\overline{NAR}$ were shown. Shan You 63 showed the greatest $\overline{CGR}$

Table 3. Mean Crop Growth Rate ($\overline{\text{CGR}}$), mean Leaf Area Index ($\overline{\text{LAI}}$) and mean Net Assimilation Rate ($\overline{\text{NAR}}$).

Location	Variety used	From early tillering to booting[a)]			From booting to heading[b)]			From heading to maturity[c)*]		
		$\overline{\text{CGR}}$ ($gm^{-2}d^{-1}$)	$\overline{\text{LAI}}$	$\overline{\text{NAR}}$ ($gm^{-2}d^{-1}$)	$\overline{\text{CGR}}$ ($gm^{-2}d^{-1}$)	$\overline{\text{LAI}}$	$\overline{\text{NAR}}$ ($gm^{-2}d^{-1}$)	$\overline{\text{CGR}}$ ($gm^{-2}d^{-1}$)	$\overline{\text{LAI}}$	$\overline{\text{NAR}}$ ($gm^{-2}d^{-1}$)
Ganyu Couty	Shan You 63	23.76	3.71	6.40	39.46	10.18	3.88	14.27	6.17	2.31
	Koganebare	17.06	3.06	5.58	30.40	6.34	4.79	13.23	5.06	2.61
Donghai County	Xu You 3-2	16.51	3.49	4.73	27.96	8.24	3.39	15.75	5.70	2.76
	Nipponbare	14.71	2.83	5.20	32.01	7.65	4.18	14.17	4.44	3.19
Kyoto	Nipponbare	12.25	2.01	6.09	27.65	5.94	4.65	15.42	4.62	3.34

Period Ganyu County; a: June 25 to Aug. 10 (46 days), b: Aug. 10 to Aug. 20 (10 days), c: Aug. 20 to Oct. 3 (44 days), Donghai County; a: June 25 to Aug. 10 (46 days), b: Aug. 10 to Aug. 19 (9 days), c: Aug. 19 to Oct. 2 (44 days), Kyoto; a: June 2 to Aug. 5 (64 days), b: Aug. 5 to Aug. 15 (10 days), c: Aug. 15 to Sep. 29 (45 days).

* Xu you 3-2 of Donghai County shows from heading to late ripening.

Table 4. Number of spikelets.

Location	Variety used	Spikelet number per panicle	Spikelet number per m^2
Ganyu County	Shan You 63	139.5±27.1	50,360
	Koganebare	76.8±20.2	38,400
Donghai County	Xu You 3-2	124.1±25.0	55,100
	Nipponbare	82.8±23.3	40,700
Kyoto	Nipponbare	89.4±21.8	37,300

from the early tillering stage to the booting stage. $\overline{\text{CGR}}$ of Xu You 3-2 was lower than Koganebare, because $\overline{\text{NAR}}$ was lower. From the booting time to heading, $\overline{\text{CGR}}$ of Shan You 63 reached 39.5 and $\overline{\text{LAI}}$ was especially high at 10.18. $\overline{\text{NAR}}$ was lower than Japanese varieties. $\overline{\text{CGR}}$ of Xu You 3-2 of this time was lower than Japanese varieties. From heading to maturity, $\overline{\text{CGR}}$ of Shan You 63 was higher than Koganebare, but it was the same as Nippnbare of Donghai County. $\overline{\text{LAI}}$ of Shan You 63 was also greatest at the time and $\overline{\text{NAR}}$ was lowest. $\overline{\text{CGR}}$ was maximum in Xu You 3-2.

5. Capacity of grain yield

In Table 4, spikelet number was shown. Spikelet number per m^2 of Shan You 63 and Xu You 3-2 were much larger than Japanese varieties, reaching 50,360 in Shan You 63 and 55,100 in Xu You 3-2. Spikelet number per

Table 5. Efficiency of increase in spikelet number per m^2 by absorbed nitrogen until heading.

Location	Variety used	Nitrogen content at heading (%)	Total dry weight at heading (gm^{-2})	Amount of absorbed nitrogen until heading (gm^{-2})	Efficiency of increase in spikelet number*
Ganyu County	Shan You 63	1.37	1532	20.99	2399
	Koganebare	1.44	1150	16.56	2319
Donghai County	Xu You 3-2	1.96	1048	20.54	2683
	Nipponbare	1.63	990	16.13	2523
Kyoto	Nipponbare	1.51	1062	16.03	2327

* Spikelet number per m^2/amount of absorbed nitrogen until heading.

Table 6. Analysis of contents of grain yield (ΔE).

Location	Variety used	Weight of whole brown rice (gm^{-2}) ΔE	Total dry weight at maturity (gm^{-2})	Dry weight incureased after heading (gm^{-2}) ΔW*	Amount of translo-cation (gm^{-2}) T**	Contri-bution ratio $T/\Delta E$
Ganyu County	Shan You 63	1007	2160	628	379	0.38
	Kohanebare	670	1732	582	88	0.13
Donghai County	Xu You 3-2	792	1848	800	−8	−0.01
	Nipponbare	643	1614	624	19	0.03
Kyoto	Nipponbare	717	1756	694	23	0.03

* Total dry weight at heading was shown in Table 5. **Amount of translocation of assimilated products stored in the culm and leaf before heading ($\Delta E - \Delta W$).

ear in both varieties was remarkably high.

In Table 5, N% of the rice plant at heading, the amount of absorbed N until heading and efficiency of increase in spikelet number (spikelet number per m^2/the amount of absorbed N until heading) are shown. The amount of absorbed N until heading in Shan You 63 and Xu You 3-2 was exceptinally higher than Japanese varieties and both varieties exceeded 20 gm^{-2}. Shan You 63 was high in the total weight and Xu You 3-2 was high in N%. Efficiency of increase in spikelet number of Xu You 3-2 was somewhat higher than the Japanese varieties and that of Shan You 63 was approximately the same as that of Japanese varieties.

6. Contents of grain yield

$\triangle E$, T and $\triangle W$ are shown in Table 6. $\triangle E$ was maximum in Shan You 63, follwed by Xu You 3-2. $\triangle W$ of Shan You 63 was somewhat higher than Koganebare, but approximately the same as Nipponbare in Donghai County and Kyoto. $\triangle W$ of Xu You 3-2 was maximum. T of Shan You 63 was very high and that of Xu You 3-2 was a minus. Contribution ratio of T to $\triangle E$ ($T/\triangle E$) in Shan You 63 was 0.38. That of Xu You 3-2 was a minus and Japanese varieties were 0.03 to 0.13.

In Table 7, $\triangle En$, $\triangle Wn$, Tn and percentage of ripened grain are shown. $\triangle En$ of Shan You 63 was highest and Xu You 3-2 was minimum. $\triangle Wn$ of Shan You 63 was lowest and $\triangle Wn$ of Xu You 3-2, less than Japanese varieties. Tn of Shan You 63 was exceptionally large and Xu You 3-2 showed a minus. Tn of Japanese varieties was 0.4 to 2.2. The percentage of ripened grain of Shan You 63 followed that of Nipponbare of Kyoto. That of Xu You 3-2 was lowest.

Table 7. Contents per 1 grain(ΔEn) and percentage of ripened grain.

Location	Variety used	Weight of whole brown rice (mg) ΔEn*	Dry weight increased after heading (mg) ΔWn**	Amount of translo-cation (mg) Tn***	Percentage of ripened grain (%)
Ganyu County	Shan You 63	20.0	12.5	7.5	78.3
	Koganebare	17.4	15.2	2.2	75.3
Donghai County	Xu You 3-2	14.4	14.5	−0.1	64.2
	Nipponbare	15.8	15.4	0.4	72.2
Kyoto	Nipponbare	19.2	18.6	0.6	87.4

* ΔEn : ΔE/number of spikelets per m^2, ** ΔWn : ΔW/number of spikelets per m^2.
*** $Tn = \Delta En - \Delta Wn$.

Discussion

It is clear that meteorologcal conditions of longer sunshine hours in Ganyu County brought about high yields of Shan You 63[3]. However, higher yields of Nipponbare in Kyoto than Japanese varieties in China indicate the high yields of Shan You 63 depend not only on meteorological conditions but the characteristics of grain production of Shan You 63 as well.

For high-yield cultures, overluxuriant growth during ripening should be avoided. For this reason, it is important to efficiently obtain the spikelet number per m^2 [4,11]. Efficiency of increase in spikelet number per m^2 by absorbed N until heading differed with area[4]. In Japan, it is high in the north and low in the south[4]. In west Japan, the relationship between spikelet number per m^2 and the amount absorbed N until heading can be represented by Shimizu's equation as follows: $N = 0.039765\,m - 0.876$ where N is the amount of absorbed N until heading (gm^{-2}), and m is spikelet number per m^2 ($\times 10^2$)[4]. All varieties in this study were essentially on this regression line. Efficiency of increase in spikelet number of Shan You 63 is considered to be the same as the west area of Japan. Since N% of Shan You 63 at heading was lower than in other varieties, an increase in the amount of absorbed N was due mainly to that in dry weight. The period of dry matter production from transplanting to heading of Shan You 63 was considerably short compared with the period in Japan[3,9]. Therefore, the large capacity of grain yield in Shan You 63 is considered to be due to extremely high $\overline{CGR}$ up to heading. The reason for high $\overline{CGR}$ is high $\overline{LAI}$, rather than $\overline{NAR}$.

Spikelet number per one ear of Shan You 63 was clearly large compared with Japanese varieties and this tendency was the same in the other high yielding rice varieties[1,6,7,10,14]. However, the percentage of productive culm was very low in Shan You 63. Xu et al.[14] pointed out that the percentage of productive culm in Ganhua No. 2, yielded 1360 to 1440 gm^{-2} of unhulled rice, was lower than 45%. High yields and a high value of brown rice-straw ratio in Shan You 63 can not be fully explained by efficiency of increase in spikelet number.

As to contents of grain yield ($\triangle E$), increase in $\triangle E$ of Shan You 63 was based on $\triangle W$ equal to Nipponbare of Donghai County, and remarkably high T. T of Shan You 63, 371 gm^{-2}, this being approximately the amount equivalent to dry matter production, 395 gm^{-2}, from booting time to heading. The prcentage of ripened grain was related to the amount of contents of grain yield per one spikelet ($\triangle En$)[12,13]. Wn of Shan You 63 was minimum, but $\triangle En$ highest, because Tn of Shan You 63 was three times as much as other varieties. Weng et al.[13] reported that high Tn makes the rate of translocation of carbohydrate into the ear high. The remarkablely high T of Shan You 63 may cause high Tn, thereby improving the percentage of ripened grain.

Song et al.[7] pointed out that in breeding high yielding rice variety, large sink size was important, and increase in the contribution rate of T for △E as well. Weng et al.[13] and Song et al.[8] recognized that the more the accumulated carbohydrate at heading, the higher was the yield, in a range of 276 to 746 gm^{-2} of ear weight by weng et al., and a range of 415 to 809 gm^{-2} of brown rice weight by Song et al. However, it was not clear whether this tendency was continued effectively or not beyond those yields. In this study, T of Shan You 63 increased by about 24% compared with 809 gm^{-2} by Song et al.[7], and the high percentage of ripened grain could be obtained. The contribution ratio of T for △E was the same, Increase in translocation of the assimilated products stored in culm and leaf before heading is considered to remarkably increase yield in China.

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* In Japanese with English summary.
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*** In Chinese with English summary.
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