Varietal Difference in Morphology and Photosynthetically Active Radiation Distribution in Spring Wheat Canopy*

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Abstract : It has been generally believed that the crop ideotype canopy has an erect small leaves to allow the photosynthetically active radiation (PAR) to penetrate deeply. In wheat, this might be not always applied to high-yielding varieties. We investigated the morphology and the PAR distribution in canopy ($400 \text{ plants m}^{-2}$) for three varieties with different canopy structures at early and late sowing times (April 13 and May 10, respectively). These three varieties, semi-dwarf early Norin 61 bred in Kyushu Japan, semi-dwarf early Haruyutaka bred in Hokkaido Japan, and tall late Selpek bred in Germany, differ from each other in canopy structure. Surface areas of ears and lower leaves were larger in early sowing than in late sowing for the three varieties, while those of flag leaves were larger in late sowing. Surface area of ears was larger for long-awned Haruyutaka than for short-awned Norin 61 and awnless Selpek, so that PAR penetration under the ears was lower for Haruyutaka. Surface area of flag leaves was larger for Haruyutaka and Selpek than for Norin 61, so that PAR penetration under flag leaves was lower for these varieties. However Haruyutaka and Selpek yielded their biomass higher than Norin 61. PAR penetration under lower leaves was higher in late sowing, and was especially high for Norin 61 and Selpek. On the other hand, there were significant negative relations between surface areas and PAR penetrations within layers of ears, flag leaves and lower leaves. Regression analysis showed that the horizontal flag leaf intercepted the PAR more effectively than the erect lower leaves. Culm surface areas seemed to intercept 27% of PAR within the flag leaf layer and 51% of PAR within the lower leaf layer.

Key words : Canopy structure, Crop ideotype, PAR penetration, Sowing time, Spring wheat variety, Surface area.

春播コムギ群落の形態と光合成有効放射透過分布の品種間差異 : 高橋 肇・中世古公男 (北海道大学農学部)

要 旨 : 一般に、作物群落では、小さく立ち型の葉をもち、光合成有効放射 (PAR) を内部まで深く透過させるような構造をもつ草型が理想型であると考えられてきた。しかしながら、コムギにおいては必ずしもすべての多収品種がこのような草型をもつとは限らないようである。本試験では、育成地が異なり、特に穂および止葉の形態が大きく異なる3品種 (九州で育成された半矮性・早生の農林61号、北海道で育成された半矮性・早生のハルユタカおよびドイツで育成された長稈・晩生の Selpek) を供試し、早播き (4月13日播種) および晩播き (5月10日播種) することで圃場条件において異なる6条件での群落構造および PAR の透過分布を調査した ($400 \text{ 個体} \cdot \text{m}^{-2}$)。穂および下位葉の表面積は3品種とも早播区が晩播区に比べて大きく、止葉の表面積はこれとは逆に晩播区が早播区に比べて大きかった。また、穂の表面積は芒の長いハルユタカが芒の短い農林61号および芒のない Selpek に比べて大きく、穂の下での PAR 透過率はハルユタカで低かった。一方、止葉の表面積はハルユタカと Selpek が農林61号に比べて大きく、止葉の下での PAR 透過率はハルユタカと Selpek で低かったが、バイオマス生産はハルユタカと Selpek で高かった。下位葉の下での PAR 透過率は晩播区で高く、特に農林61号と Selpek で高かった。さらに穂、止葉および下位葉の表面積とこれらの器官の位置する層での PAR 透過率との間には有意な負の相関関係が認められた。回帰式による分析の結果、表面積による遮光の効果は、葉身がほぼ水平に傾いていた止葉が立ち型の下位葉よりも高かった。また、稈の表面積による遮光は止葉の層で 27%、下位葉の層で 51% であると推定した。

キーワード : 群落構造, 播種期, 春播コムギ品種, 表面積, PAR 透過率, 理想草型。

Donald and Hamblin²⁾ showed that the criteria relating to plant form show promise in cereal breeding and that the “crop ideotype” is an erect sparsely tillered plant with small erect leaves. Many of the Japanese wheat varieties have plant forms resembling this

ideotype, but Haruyutaka, bred in Hokkaido, and Selpek, bred in Germany, do not.

Photosynthetically active radiation (PAR) penetrates deeply within the “ideotype” canopy. Wheat canopy is, however, senescing from lower organs. It is found that ear, leaf sheath and culm have photosynthetic activity as well as leaf blade^{1,3,4,5,11)}. Is that really the

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“ideotype”? Grain yield is reportedly related to assimilation by organs above the flag leaf within the canopy^{8,9,13}. We also found that the converted rate of the PAR to biomass production increased after heading than before heading under intensive PAR conditions¹⁰. Therefore, heading drastically improved the canopy structure in this case. Improvement in PAR distribution is one idea for improving productivity in the wheat canopy, although it is not clearly known whether the canopy into which PAR penetrates deeply can be called an “ideotype”.

In this experiment we found the variation in morphology and PAR distribution for three spring wheat varieties planted in April and May. Moreover their relationship to biomass and yield productivity was discussed.

Materials and Methods

The three spring wheat varieties, Norin 61, Haruyutaka and Selpek, were planted on April 13, 1990 (early sowing) and May 10, 1990 (late sowing) at the Experimental Farm of Hokkaido University. Both Norin 61 and Haruyutaka are semi-dwarf early varieties bred in Kyusyu and Hokkaido, respectively. Selpek is a tall late variety bred in Germany. Seeds were set up on seeder tapes (Nihon Plant Seeder), at intervals of 5 cm. The seeder tape was planted at a depth of 2 cm. Two tapes were set in each row and the plants were thinned to a single plant after two or three leaves expanded. The final plant density was an equidistant square pattern with 400 plants m^{-2} . The plot size was 2 m $\times$ 9 m with a 50 cm $\times$ 50 cm sampling area and three replications of each experiment were made. Fertilizer was applied prior to sowing: N, 90 kg ha^{-1} ; P_2O_5 , 150 kg; K_2O , 75 kg.

PAR distributions in canopy were measured at the milk ripe stage (14 days after anthesis; July 1: Norin 61, July 3: Haruyutaka and July 10: Selpek in early sowing, and July 16: Norin 61, July 14: Haruyutaka and July 23: Selpek in late sowing). Handmade PAR sensors were used in this measurement. Five photodiodes sensitive to wavelengths from 400 to 700 nm (Hamamatsu Photonics S1133) were attached at 2 cm intervals on a frosted acrylic plate (15 cm $\times$ 2 cm). They were sealed, then calibrated by a standard PAR sensor (Li-COR, Ltd. LI-190EB). To mea-

sure the PAR distribution in the canopy, sensors were placed under ears, flag leaves and lower green leaves. Five sets of these sensors were used and one sensor was placed on the tip of a 1.5 m height pole facing upward to measure incident PAR. Measurements were made every minute from 3 am to 8 pm (CHINO PROCOS VII). The data was integrated and recorded by a personal computer (NEC PC-8801). PAR penetrations under ears, flag leaves and lower leaves were calculated from PARs at these positions divided by incident PAR.

The areas of one side of the flag and lower leaves, and a cross section of the ear of twenty standard plants in the sampling areas were measured with a leaf area meter (Hayashi-Denko Corp. AAM-7). The area of cross section of the ear was multiplied by 3.14 to get the ear surface area. Plant figures were also drawn by a computer graphic system using the length, width and angle data for leaf blade, culm and ear.

Results

Figure 1 shows plant figures, ear numbers, surface areas of ears, flag leaves and lower leaves and PAR penetrations under these organs for the three varieties at early and late sowings. The number of ears was 160 m^{-2} higher in early sowing than in late sowing for Norin 61, while for Haruyutaka and Selpek the number was the same in the two sowings. The number of ears was greater for Haruyutaka than for Selpek on both occasions. However they did not show significant variance among varieties or between sowing times. Surface areas of ears were larger in early sowing than in late sowing for all three varieties (not significant). They were larger for Haruyutaka than for Norin 61 or Selpek in both sowing times ($P < 0.05$) because Haruyutaka has long awns; Norin 61 has shorter awns, and Selpek has no awns. On the contrary, surface areas of flag leaves were larger in late sowing than in early sowing for the three varieties, although they were not significant. They were significantly greater for Haruyutaka and Selpek than for Norin 61 in both sowing times ($P < 0.01$). The largest was in late sowing for Selpek (1.100 $m^2 m^{-2}$), and was smallest in early sowing for Norin 61 (0.497 $m^2 m^{-2}$). Norin 61 has the shortest flag leaves although it has the

Fig. 1
Plant figures, ear numbers, surface areas of ears, flag leaves and lower leaves, and PAR penetration % under these organs for three spring wheat varieties in early and late sowings. Figures in parenthesis are the PAR penetration % within the flag leaf and lower leaf layers alone.

most stem (657 m^{-2}). Surface areas of lower green leaves were larger in early than in late sowing for the three varieties ($P < 0.05$), because lower leaves were senescing faster in late sowing due to high temperature so that the plants had one more leaf in early sowing at the milk ripe stage. These were larger for Norin 61 and Haruyutaka than for Selpok in both sowing times, but not significant. Thus, surface area of lower leaves showed an opposite tendency to that of flag leaves for varieties and sowing times. Within lower leaf layer, surface areas of fruitless tiller leaves were 8% and 24% in early and late sowing times, respectively. On the other hand, PAR penetrations under ears were lower for Haruyutaka than for Norin 61 and Selpok in both sowing times, because Haruyutaka had a larger ear surface area. PAR penetrations under flag leaves were lower for Haruyutaka and Selpok than for Norin 61 because Norin 61 had smaller surface areas for ears and flag leaves. The values were particularly low in early sowing for Haruyutaka (32.0%) and in late sowing for Selpok (31.0%). PAR penetration within the flag leaf layer only, which was calculated as 100% under the ears, was the lowest in late sowing for Selpok (39.6%). Therefore, the higher interception by ears and leaves for Haruyutaka and Selpok, respectively, seemed to result in lower PAR penetration under flag leaves. PAR penetrations under lower leaves were lower in early sowing than in late sowing for the three varieties; they were highest in late sowing for Norin 61 and Selpok (13.3% and 11.2%, respectively). PAR pene-

trations within lower leaf layer alone, calculated as 100% under flag leaves, were higher in late sowing, especially highest for Selpok (36.1%), because lower leaves senesced rapidly and their surface areas were smaller.

Figure 2 shows the relations between PAR penetrations within the ear, flag leaf and lower leaf layers and surface areas of ears, flag leaves and lower leaves, respectively. The PAR penetration within the ear layer alone was the same as that under the ears; the penetration within the flag leaf layer alone was calculated from the penetration under the flag leaves divided by that under the ears; the penetration within the lower leaf layer alone was calculated from the penetration under the lower leaves divided by that under the flag leaves. These three relations showed negative correlations which were all 5% levels of significance. Thus PAR penetration within each single organ decreased as surface area of that organ increased. The inclination of linear relation was the highest for the flag leaf layer (31.2), the ears layer (23.4) and the lower leaf layer (14.8) in that order. Therefore the flag leaf surface most effectively intercepted PAR. The flag leaf blade showed horizontal inclination, whose angle was -6° for an average among varieties and sowing times, while horizon is 0° . Contrary to this, those in the lower second and third leaves were 30° and 50° , respectively. The effective interception in flag leaf might be attributed to the horizontal inclination. The constant of linear relation, which is a cross point of the Y axis, is the same as the PAR penetration intercepted by only the culm sur-

Fig. 2 Relationships between surface areas and PAR penetrations within the ear, flag leaf and lower leaf layers in spring wheat canopies.

○: early sown Norin 61, ●: late sown Norin 61, △: early sown Haruyutaka, ▲: late sown Haruyutaka, □: early sown Selpok, ■: late sown Selpok.

Table 1. Biomass and grain yield for three spring wheat varieties in early and late sowings.

	Biomass yield (g•m ⁻²)	Grain yield (g•m ⁻²)
Early		
Norin 61	953	461
Haruyutaka	1073	465
Selpek	1069	391
Late		
Norin 61	673	288
Haruyutaka	829	355
Selpek	818	248
Significance		
Sowing time	*	*
Variety	*	*
Interaction	NS	NS

* : 5% level of significance.

NS : non significant.

face within each layer. The constant was 100% within the ear layer which had no culm ; 73% within the flag leaf layer, and 49% within the lower leaf layer. Thus, we concluded that culm surfaces within the flag leaf and the lower leaf layers intercepted 27% and 51% of PAR, respectively.

Table 1 shows biomass and grain yield for three varieties in early and late sowings. Both biomass and grain yield were significantly different between sowing times ($P < 0.05$) and among varieties ($P < 0.05$). Biomass yield was lower for Norin 61 than for Haruyutaka and Selpek in early and late sowings. It was higher in early sowing than in late sowing for three varieties. Grain yield was higher for Norin 61 and Haruyutaka in early sowing and for Haruyutaka in late sowing. However these yields did not attribute only to the morphologies or PAR distributions.

Discussion

Varieties and sowing times caused different PAR distributions in canopy because the surface areas of ears, flag leaves and lower leaves differed in both amount and proportion. There are few papers which show the distribution of PAR penetration or proportion of PAR interception by plant organs, so that the rela-

tion between PAR distribution and dry matter production in canopy has not been known. For wheat, ear has significant photosynthetic activity, and leaf sheath and culm also have activity^{1,3,4,5,11}). Productivity in canopy, therefore, cannot be assessed only with characteristics of leaf blades. Moreover, there is reportedly close correlation between grain yield and photosynthesis above the flag leaf node^{8,9,13}), thus the canopy structure in which PAR penetrates deeply may not be good for dry matter production. Trenbath and Angus¹²) reported the relationship between leaf inclination and crop production though they did not argue for varietal difference. Saini and Nanda⁶) evaluated light-utilization efficiency for four wheat varieties, but they did not determine whether preferable efficiency was attributable to high assimilation activity or to effective PAR distribution. Siddique et al.⁷), on the other hand, compared 10 cultivars representing old and modern wheats to identify any morphological and physiological characteristics which might be associated with higher grain yield of modern wheat. They found the green area index and ground cover higher in old than in modern cultivars ; however, the efficiency of conversion of PAR to dry matter was slightly greater for modern cultivars. In our experiment, three varieties were characterized by PAR distribution in canopy as follows : Haruyutaka intercepts much PAR with its large ears ; Selpek intercepts much PAR with its large flag leaves, and Norin 61 intercepts much PAR with its large lower leaves. The proportion of the lower leaf area was higher in early sowing and that of the flag leaf area was higher in late sowing. In addition, the fruitless tiller leaves were 24% of lower leaves in late sowing. Norin 61 penetrated a lot of PAR into the lower leaves, and showed lower biomass yield than Haruyutaka and Selpek. However, we can not conclude easily that deep penetration is not good for wheat crop production, because other factors should also influence the biomass yield. The involvement between PAR distribution in canopy and crop production was not found definitively here. The effects of the morphological characters we did determine, however, should be assessed for their impact on crop production.

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