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Cultivar Differences in Leaf Photosynthesis and Grain Yield of Wheat under Soil Water Deficit Conditions*

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Abstract : Cultivar differences in leaf photosynthesis (LPS) and grain yield of wheat [*Triticum aestivum* L.] were examined under irrigated and non-irrigated conditions in Cerrados, a semi-arid region in Brazil. Twelve Brazilian, five Mexican and two Japanese cultivars were used in this project. The plants were grown under low planting density to elucidate the relationship between LPS and the potential yield of an individual plant. Brazilian cultivars ranked high in LPS, followed by Mexican and Japanese cultivars under non-irrigated conditions, although there were practically no differences in LPS among these three groups of cultivars in irrigated conditions. The LPS showed a significant positive correlation with grain yield (r=0.63**) and dry matter yield (r=0.73**) per plant in non-irrigated conditions. However, LPS showed neither correlation with grain yield nor dry matter yield per plant in irrigated conditions. The present results suggests that PLS could be a breeding criteria to increase the yield per plant under soil water deficit conditions.
Key words : Cultivar difference, Drought, Grain yield, Photosynthesis, Soil water deficit, *Triticum aestivum* L., Water use efficiency, Wheat.

土壌水分欠乏下におけるコムギ品種の光合成速度と収量との関係 : 和田道宏**・Luiz J.C.B. CARVALHO・Gustavo C. RODRIGUES・石井龍一*** (**農業研究センター・セラード農業研究センター・***東京大学農学部)

要　旨 : ブラジルの半乾燥地帯であるセラードにおいて，ブラジル，メキシコ，日本原産のコムギ，19品種を非潅漑条件と潅漑条件下で栽培し，個葉光合成速度と子実および乾物収量との関連性を調べた．非潅漑条件下ではブラジル品種が高い光合成速度を示し，メキシコ品種と日本品種がそれに続いていた．しかし，潅漑条件下では光合成速度に品種群間差が見られなかった．また，非潅漑条件下では光合成速度と水利用効率との間に高い正の相関関係が認められたが，潅漑条件下では認められなかった．これらより，非潅漑条件下ではブラジル品種は高い光合成速度と水利用効率を示し，逆に，メキシコや日本の品種では光合成速度も水利用効率もブラジル品種より低いことが判った．また，光合成速度と栽植密度の低い条件下での個体当り収量（一種の潜在的収量）との関係を調べたところ，非潅漑条件下では両者の間に有意な正の相関関係が認められたが，潅漑条件下では相関関係が認められなかった．これらのことから，土壌が乾燥した条件下では，光合成速度の品種間差は潜在的収量の品種間差に反映され，光合成速度の改善が収量の改善に結び付く可能性が示された．しかし土壌水分が好適に保たれている場合には，光合成速度の品種間差は収量の品種間差に関係しないと考えられた．
キーワード : コムギ，個葉光合成速度，収量，土壌水分欠乏，品種間差，水利用効率．

In order to raise the yield of crops, the improvement of source capacity as well as sink capacity is considered to be important. Photosynthetic rate per unit leaf area (Leaf photosynthesis, LPS) is one of the components of source capacity. Differences in LPS among cultivars were examined in wheat[4,10,14,16] and in other grain crops[1,2,5,12] in relation to grain yield. However, a definite conclusion for the interrelationship between LPS and grain yield in the cultivars has not been reached. One of the reasons for this could be that experimental conditions, such as soil water conditions, are different. Most of the investigations so far conducted were made under well-watered conditions in which LPS can demonstrate its potential ability. We have limited information

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about the relationship between LPS and grain yield under soil-water deficit conditions.

In this study, we examined the cultivar differences of LPS and grain yield under soil-water deficit conditions to discover whether LPS is limiting to the differences in grain yield and dry matter yield under drought conditions.

Materials and Methods

1. Plant materials

Twelve Brazilian, five Mexican and two Japanese cultivars of wheat (*Triticum aestivum* L.) were used in this study (Table 1). The Brazilian cultivars were bred from local cultivars. The Mexican cultivars included two types, one introduced from the International Research Center of Maize and Wheat (CIMMYT), and the other bred from CIMMYT cultivars in Brazil. The Japanese cultivars included in this experiment were cultivars adapted to humid conditions. Since it has been reported that there is a negative correlation between days to anthesis and grain yield in wheat under drought conditions[3,4], all cultivars were selected for similar heading times to exclude the direct effects of the length of growth duration on the grain yield. The seeds were hand-sown at the beginning of the dry season, June 7th in 1984, on the well-irrigated field (dark red Latosol) of Cerrados Agricultural Research Center of Brazil. Seedlings were thinned to a plant density of 31 plants/m^2 at a spacing of 65 cm × 5 cm, which was about a third of the usual density in this area. The yield per plant in this density, therefore, was considered to be nearly equal to the potential yield of an individual plant. In irrigated plots, the plants were watered every 3 to 4 days until the end of August, when the dry season ended. In non-irrigated plots, irrigation ceased on July 12th and was resumed again on August 13th. The amount of fertilizer applied was 130, 250, and 60 kg/ha of N, P_2O_5, and K_2O, respectively, with 3 t/ha of lime according to the soil test recommendations in the Cerrados area.

2. Determination of leaf photosynthesis and transpiration

The rates of leaf photosynthesis (LPS) and transpiration (TR) were determined for each cultivar at heading time, which was at the beginning of August. The measurement was conducted on a flag leaf under full sunlight in the field, between 10 : 30 and 14 : 00 h. A exchange measuring system consisting of an infrared CO_2 analyzer (ZAL, Fuji Electronic Co. Ltd., Japan) and a humidity sensor (HMP23, Visara, Finland) was used, and was installed in a van. The leaf chamber was connected to the system by long teflon-tubing. Part of the flag leaf was mounted in the clip type leaf chamber (10×4×0.8 cm), into which air was introduced from a rubber balloon (1 m^3) to avoid fluctuation of CO_2 concentration in the air. Air temperature in the leaf chamber was maintained constant at about 30°C by circulating temperature-controlled water through a heat-exchange jacket mounted on the upper side of the chamber. The measurements were done on eight leaves of each cultivar, taking about two minutes for each measurement.

3. Determination of total dry weight and grain yield

Twenty plants from each cultivar were harvested at maturity, and grain yield (GY) and dry matter yield (DY) per plant were determined.

Results

1. Leaf photosynthesis (LPS)

The LPS of 19 cultivars are listed in the order of LPS in the non-irrigated plot (Table 1). Cultivar difference of LPS in the non-irrigated plot was large, compared with that in the irrigated plot, as judged from the magnitude of coefficients of variation (CV) of LPS. This indicates that the cultivar difference of LPS increases in soil moisture deficit conditions. Brazilian cultivars ranked higher in their LPS than Mexican or Japanese cultivars in non-irrigated conditions (Table 1). If we compare the mean values of LPS among three groups of the cultivars, the Brazilian plants showed the highest LPS, followed by Mexican, and then Japanese cultivars in the non-irrigated plots, while no significant difference in LPS was observed in the irrigated plots (Table 2). This indicates that Brazilian cultivars are tolerant to drought conditons with respect to leaf photosynthesis, compared to Mexican or Japanese cultivars.

2. Transpiration (TR) and water use efficiency (WUE)

The TR changed in correlation with LPS in

Table 1. Leaf photosynthesis (LPS) and transpiration (TR) of wheat cultivars under non-irrigated and irrigated conditions.

Cultivars		Non-irrigated		Irrigated	
		LPS (μmol $CO_2m^{-2}s^{-1}$)	TR (mmol $H_2Om^{-2}s^{-1}$)	LPS (μmol $CO_2m^{-2}s^{-1}$)	TR (mmol $H_2Om^{-2}s^{-1}$)
BR 8	(B)	14.3±4.4	5.9±1.0	24.7±4.7	8.5±0.9
BUTUI	(B)	13.5±3.0	5.9±1.4	20.8±2.8	8.6±0.9
BH 1146	(B)	13.3±2.8	6.8±1.2	20.4±3.5	8.1±0.8
BR 9	(B)	12.6±3.5	6.9±0.6	19.2±1.6	7.3±0.5
IAC 24	(B)	12.4±4.8	6.3±1.7	25.7±3.7	8.4±1.2
IAC 21	(B)	12.3±3.1	5.8±1.3	21.1±2.7	7.8±0.6
IAC 5	(B)	12.1±4.4	6.6±0.8	20.1±2.5	7.5±0.3
IAC 18	(B)	11.9±4.1	7.7±0.9	24.8±2.2	9.1±0.7
CANDEIAS	(B)	11.7±3.2	6.1±1.0	28.5±1.8	9.9±0.5
MINUANO 82	(B)	11.3±4.5	6.4±1.3	21.9±2.2	6.5±0.8
BUCKBUCK	(M)	10.7±6.2	5.2±1.5	24.2±3.2	9.0±0.4
SANTIAGO	(B)	10.3±3.0	5.7±1.0	28.9±4.7	10.8±1.4
ALONDRA 4546	(M)	9.2±4.3	6.1±1.5	19.2±5.2	6.3±1.4
NAMBU	(M)	8.0±3.7	4.9±1.1	22.7±3.0	8.8±0.6
BR 10	(M)	7.6±3.8	5.4±2.3	23.2±3.2	8.1±0.8
ASAKAZE	(J)	6.0±3.5	4.1±1.1	18.7±3.6	7.2±1.1
PELADINHO	(B)	5.2±2.1	4.5±0.6	18.0±4.0	7.7±1.3
CHIKUSHI	(J)	3.8±3.1	4.3±0.7	21.3±3.3	7.4±0.4
ANAHUAC	(M)	3.2±1.3	3.5±0.5	25.1±1.8	8.5±0.3
Mean		10.0±3.6	5.7±1.1	22.6±3.2	8.2±0.8
C.V. %		34.0	18.8	14.1	13.5

The values are expressed as mean±SD
(B), (M), and (J), are Brazilian, Mexican and Japanese cultivars, respectively.
The order of cultivars is by the rank of LPS in non-irrigated conditions.

Table 2. Mean values of leaf photosynthesis (LPS), transpiration (TR) and water use efficiency (WUE) in each group of cultivars.

Cultivar groups	Non-irrigated			Irrigated		
	LPS	TR	WUE	LPS	TR	WUE
F value	**	*	**	NS	NS	NS
Brazilian c.	11.7a	6.21a	1.88a	22.8	8.36	2.74
Mexican c.	7.8b	5.04b	1.50b	22.9	8.15	2.83
Japanese c.	4.9b	4.19b	1.17b	20.0	7.28	2.75

LPS : $\mu molCO_2m^{-2}s^{-1}$, TR : $mmolH_2Om^{-2}s^{-1}$, WUE : $\mu molCO_2/mmolH_2O$,
*, ** : significant at the 5% and 1% level, respectively. NS : not significant.
Different alphabetical letters mean significant difference at the 5% probability level[9].

both soil water conditions, showing high correlation coefficients with LPS in the irrigated (r=0.82**), and in the non-irrigated (r=0.84**) plots. However, when plotting WUE instead of TR against LPS in a graph, no correlation was observed in the irrigated cnditions, while they showed a significantly high correlation coefficient (r=0.92**) in the non

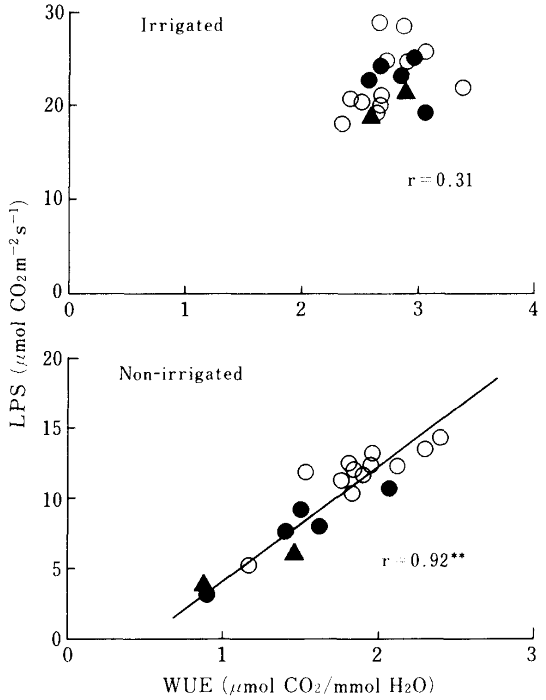

Fig. 1. Relationship between water use efficiency (WUE) and leaf photosynthesis (LPS) under irrigated and non-irrigated conditions.
○ Brazilian ; ● Mexican ; ▲ Japanese cultivar.

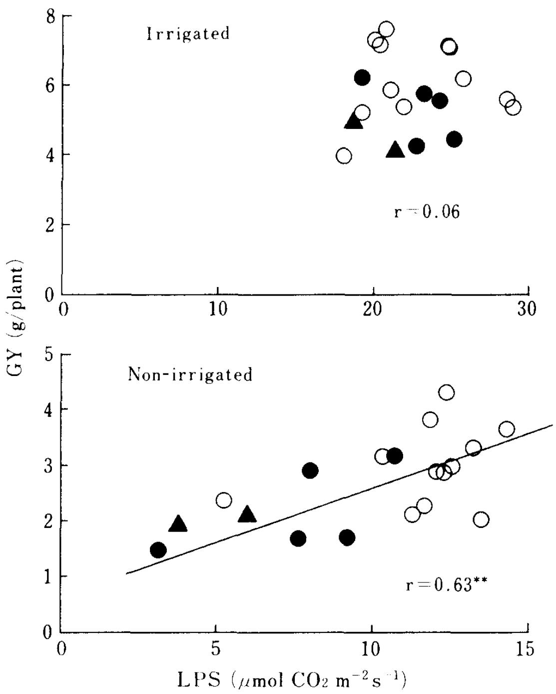

Fig. 2. Relationship between leaf photosynthesis (LPS) and grain yield (GY) under irrigated and non-irrigated conditions.
○ Brazilian ; ● Mexican ; ▲ Japanese cultivar.

Table 3. Correlation coefficients of leaf photosynthesis (LPS) with grain and dry matter yield, under non-irrigated and irrigated conditions.

	Correlation coefficients	
	Non-irrigated	Irrigated
Grain yield	0.63**	0.06
Dry matter yield	0.73**	0.10

** : significant at the 1% level.

Table 4. Correlation coefficients of leaf photosynthesis (LPS) with Plant height under non-irrigated and irrigated conditions.

Correlation coefficients	
Non-irrigated	Irrigated
0.58*	−0.14

* : significant at the 5% level.

-irrigated conditions (Fig. 1).

In the graph for non-irrigated conditions, Brazilian cultivars were located in the area of high WUE and high LPS, while Mexican and Japanese cultivars were located in the low WUE area of the graph. This indicates that the drought tolerant cultivars, such as Brazilian cultivars, can demonstrate high LPS and high WUE in soil water deficit conditions.

3. Relationship between leaf photosynthesis and yield

Figure 2 and Table 3 show the correlation coefficients of LPS with grain yield (GY) and dry matter yield (DY). The LPS showed significant positive correlations with GY (r=0.63**) and with DY (r=0.73**) in the non-irrigated plots. But LPS showed no significant correlation with them in the irrigated plots (r=0.06 for GY, and r=0.10 for DY).

4. Relationship between plant height and leaf photosynthesis

It was found in Figure 3 and Table 4, that LPS was positively correlated with plant height under non-irrigated conditions (r=0.58*), although it was not correlated under irrigated conditions (r=−0.14). This suggests

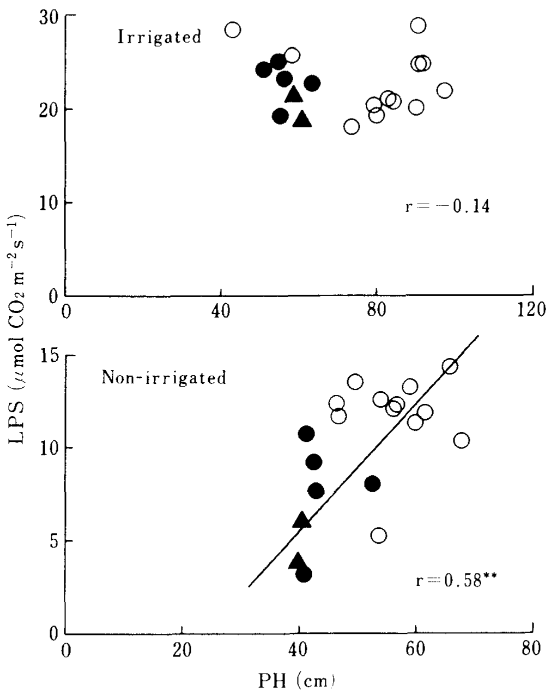

Fig. 3. Relationship between leaf photosynthesis (LPS) and plant height (PH) under irrigated and non-irrigated conditions.
○ Brazilian ; ● Mexican ; ▲ Japanese cultivar.

that the cultivars with large plant height are resistant to drought conditions in respect to LPS.

Discussion

Many experimental data on grain crops has indicated that interspecific or intraspecific difference of GY is not necessarily related to differences in LPS[2,6,7,8]. But it should be noted that most of the previous studies were conducted under favorable soil water conditions. So, it is not clear, at the present time, whether cultivar differences of LPS are related to those of grain yield under water-stressed conditions. In this paper, we found a positive correlation in wheat between LPS and grain yield only in non-irrigated condition. However, grain yield in this study was obrained from an individual plant in a low density population. For this reason, GY can be considered as a kind of potential grain yield for an individual plant. In semi-arid regions like Cerrados, the planting density of wheat is low compared with humid regions, to avoid the transpiratory water loss. In such low planting density conditions, the yield of individual plants corresponds to that of land area. Therefore, the relationship between LPS and GY obtained in this paper could be applied to actual planting density conditions in the Cerrados region, and hence, LPS could be a breeding criteria for high -yielding cultivars in semi-arid regions.

It is said that drought tolerant cultivars in wheat can maintain a good water blance within the leaf, and that they have extensively developed root systems[11,13,14,15,17]. This study demonstrated that LPS showed a significant positive correlation with plant height under non-irrigated conditions. The findings suggest that tall local cultivars, such as Brazilian ones, have good root systems and/or strong water absorbing ability to maintain favourable leaf water relations under non-irrigated conditions.

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