EXPERIMENT IV.

Acclimatic Adaptation of Barley Seedlings to Hypoxic Pre-treatment and High Temperature

Objectives

This research work was conducted to determined the morphological and physiological responses dealing with the combination effect of hypoxic pre-treatment with high air temperature level at seedling stage. These responses of barley genotypes differing in waterlogged tolerance, were evaluated as the following;

(i) the morphological changes of the roots;

(ii) some enzymes associated with hypoxic-induced acclimation;

(iii) dry matter accumulation, total soluble sugar and total nitrogen content in the shoots and roots which related to photosynthetic efficiency.

Materials and Methods

Expermental conditions

Three barley genotypes selected from the first experiment; SMG1 (tolerant), FNBLS#140 (moderately tolerant) and BRBRF9629 (susceptible) were grown in the stagnant agar nutrient solution (as hypoxic condition) and the aerated nutrient solution (as control). Both of nutrient solution preparations in this experiment were done as described by Wiengweera *et al.* (1997). The oxygen concentration and temperature in each nutrient solutions represented in Appendix 10a.

When the first nodal root was emerged at least 5 cm long from the base of the shoots, the 150 vigor seedling plants of each barley genotypes plants were grown in 5.4 L pot, containing aerated full strength nutrient solution, with 240-270 ml min^{-1} air pump rate. The other 150 vigor seedling plants of barley genotypes were grown in the stagnant agar full strength nutrient solution. Both treatments were studied in the growth chamber throughout the experiment. This experiment was conducted in the growth chambers which had set the same diurnal light intensity, CO_2 ambient concentration and air humidity. The daily maximum air temperature levels were set as sub-experiments at 25, 30 and 40 $^{\circ}$C in the mid day and controlled 15 $^{\circ}$C during the night. Each sub -experiments was four replications. The climatic data of the sub-experiments in the growth chambers represented in Appendix 10b.

All data were determined at 0, 3, 5, 7 and 9 days of the 1st hypoxia in the plant growth chambers. Then the hypoxic barley plants were grown in full strength nutrient solution with aeration for 7 days in the same growth chambers (as recovery period). After that the 2nd hypoxic condition was imposed to these barley plants and the recordings data were repeated. For barley plants grown in the aerated nutrient solutions, the data were also recorded at the same time as hypoxic treatment.

Plant culture conditions

Seedlings of all barley genotypes were germinated and grown as described in the Experiment III. Both of the nutrient solutions were changed every 4 days throughout the end of this experiment for normal barley growth.

Plant measurements

1. Photosynthetic efficiency and leaf chlorophyll fluorescence of barley leaves were recorded as described in the Experiment I and II. These data were measured on the youngest fully expanded leaves at 10.00-12.00 a.m. Four leaf samples /barley genotype / time were used to investigate.

2. Total nodal root length / plant and the number of nodal roots / plant were measured from 7 plant sample plants of each barley genotypes. Each nodal root length was measured with the ruler and calculated as the total nodal root length / plant.

3. Shoot and root dry matter accumulation (unit: g / plants) were measured. Seven plant samples of each treatments were separated into shoots and roots, and dried at 75 $^{\circ}$C for 24 hours by the hot dry air oven.

4. Total nitrogen content in the shoots and roots (unit: % total nitrogen / g dry weight sample) were analysed by the methods of Supakhumnert (1998) and Janjalernsuk *et al.* (1998) which detected the color of the ammonium nitrogen (NH_4^+-N) of extracted solution by Kjeldahl method and was described in Appendix 14.

5. Alcohol dehydrogenase (ADH) activity (unit: nanomole ADH /g root fresh weight /min) in the nodal roots were measured. The nodal root length (more than 5 cm long) of each barley genotypes were taken and analysed for the enzyme activity by the bioassay method (Greenway,1993).

6. Nitrate reductase (NR) activity (unit: microgram $NaNO_2$ /g leaf fresh weight /hour) in the leaves were measured. The youngest fully expanded leaves were taken and analysed for NRA by the bioassay method (Jaworski,1971).

7. Total soluble sugar in the barley shoots (unit: mg glucose/ g shoot dry weight) were measured by the method of Yoshida *et al.*(1976).

Data of dry matter accumulation, total nitrogen content and total soluble sugar were taken from the same plant samples. And both of the enzyme activities were measured from the other plant samples at the same time.

Results and Discussion

Root growth and development

The production of the number of nodal roots / plant

All barley genotypes had different number of nodal roots / plants due to the time period of hypoxia and high temperature effect (Figure 8). The 1st hypoxia (0-7 days)induced higher nodal roots / plant as compared to under aerated condition and the 2nd hypoxia. Although all barley genotypes had closely the number of nodal roots / plant in the final, but varied on the rate of nodal roots formation. However, the mechanisms by which flooding promotes adventitious rooting are not clear and differ depended on plant species (Vartapetian and Jackson, 1997).

In consideration under the 1st hypoxia, all barley genotypes grown at 25-30/15 °C, especially BRBRF9629 rapidly increased the nodal roots /plant (Figure 8). However, it did not happened at 40/15 °C for BRBRF9629 genotype. It was observed that only SMG1 at 40/15 °C still produced a continuously nodal root formation under hypoxia. Although the tolerant species may be not associated with the morphological changes in the roots such as aerenchyma formation and high nodal roots / plant, but it has an adaptation for plant survival under the severe waterlogging with high temperature (Drew,1983). A similar observation has been reported (Jackson and Drew, 1984; Krizek, 1982; Vartapetian and Jackson, 1997).

Under the 2nd hypoxic condition, FNBLS#140 and BRBRF9629 did not produce new nodal root formation and some roots were death especially at 40/15 °C. However, FNBLS#140 grown at 30/15 °C could produce a few nodal root at the end of the 2nd hypoxia. For the tolerant genotype, SMG1 could have a few new nodal roots / plant at 40/15 °C (Figure 8). The lack of oxygen deficiency for root respiration markedly affected plant survival when temperature increased (Drew *et al.*1994; Drew, 1997; Krizek, 1982).

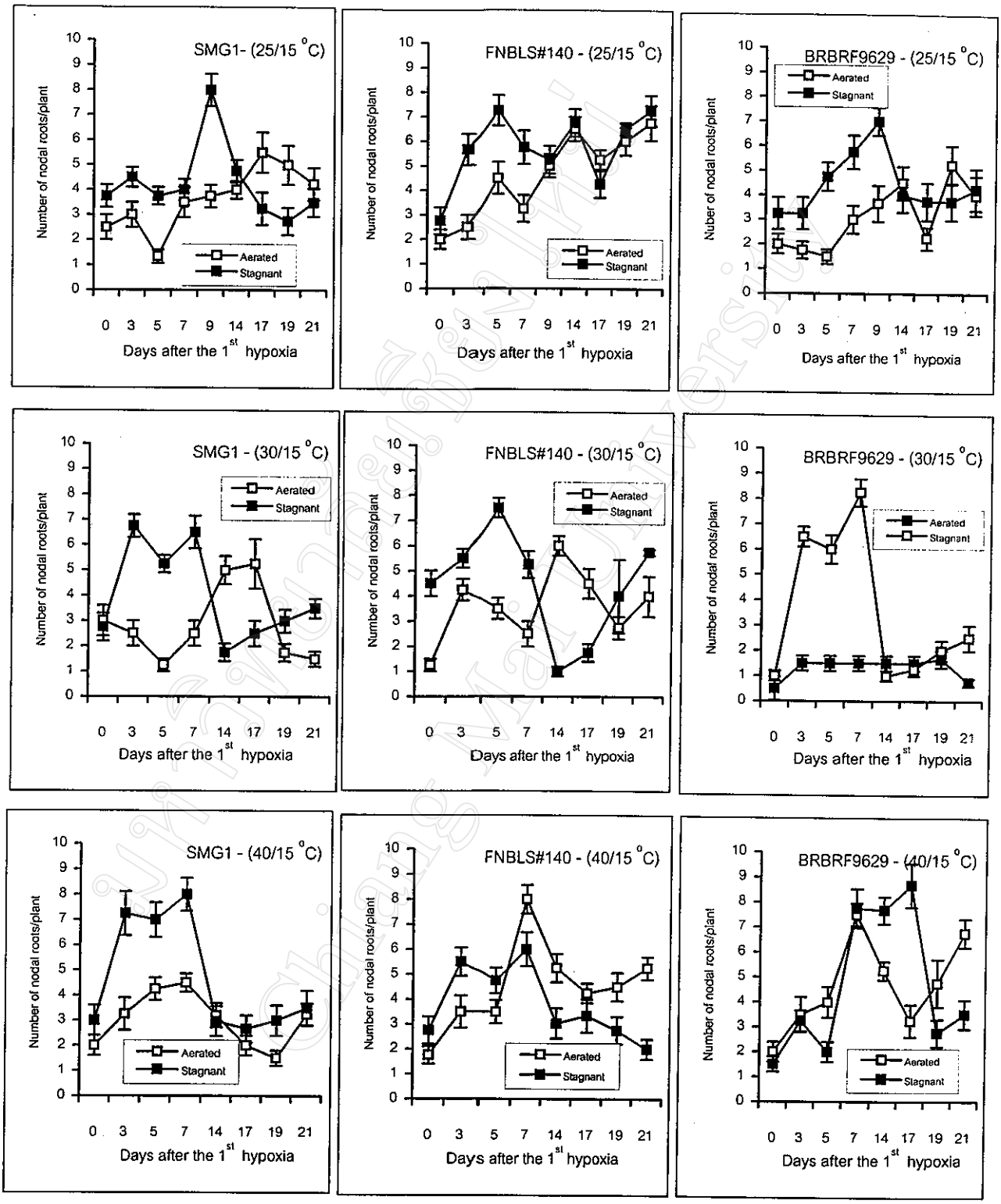

Figure 8 The number of nodal root per plant of barley genotypes grown in aerated and stagnant agar nutrient solution at 25/15, 30/15 and 40/15 °C (day /night temperature).

Data are means of four samples ± SE.

The changes of total nodal root length /plant

It was found that high temperature significantly caused total nodal root length / plant to decrease lower than the effect of hypoxia (Figure 9). This result might be related to high root respiration rate due to decreasing in root growth (Drew, 1983). Total nodal root length /plant under the 1st hypoxia was not significantly different from under aerated treatment (Figure 9). Moreover, this root length tended to decrease when the air temperature was 40/15 °C.

During the 2nd hypoxia, total nodal root length /plant of barley genotypes especially BRBRF9629 grown at 40/15 °C, markedly decreased (Figure 9). Drew (1997) commended that high temperature caused to be lower oxygen dissolution in nutrient solution and also affected root respiration rate. In consequence, it increased more fold oxygen stress in the hypoxic roots to reduce root growth. Total root length of barley genotypes especially SMG1 under aerated condition with 40/15 °C, were affected as severe as under hypoxia (Figure 9). High temperature, 40/15 °C might completely suppressed enzyme activities (Klamsomboon, 1983) which can be affected to this result.

The biochemical substances changes for barley root survival

Alcohol dehydrogenase (ADH) activity in the roots

The ADH activities of all barley genotypes grown under hypoxic conditions with high temperatures, were shown in Figure 10. It was also found the activity of ADH from the aerated root. This result might be the lack of oxygen in the core of root cells and caused to induce ADH activity for anaerobic respiration (Greenway, 1993; Vartapetian and Jackson, 1997). However, ADH activity of barley genotypes under hypoxia increased much more fold rate than under aerated condition.

All barley genotypes under the 1st hypoxia at 25-30/15 °C had the same activity of ADH enzyme, excepted at 40/15 °C which caused to increase this activity. ADH activities decreased during the recovery period and closed to the aerated

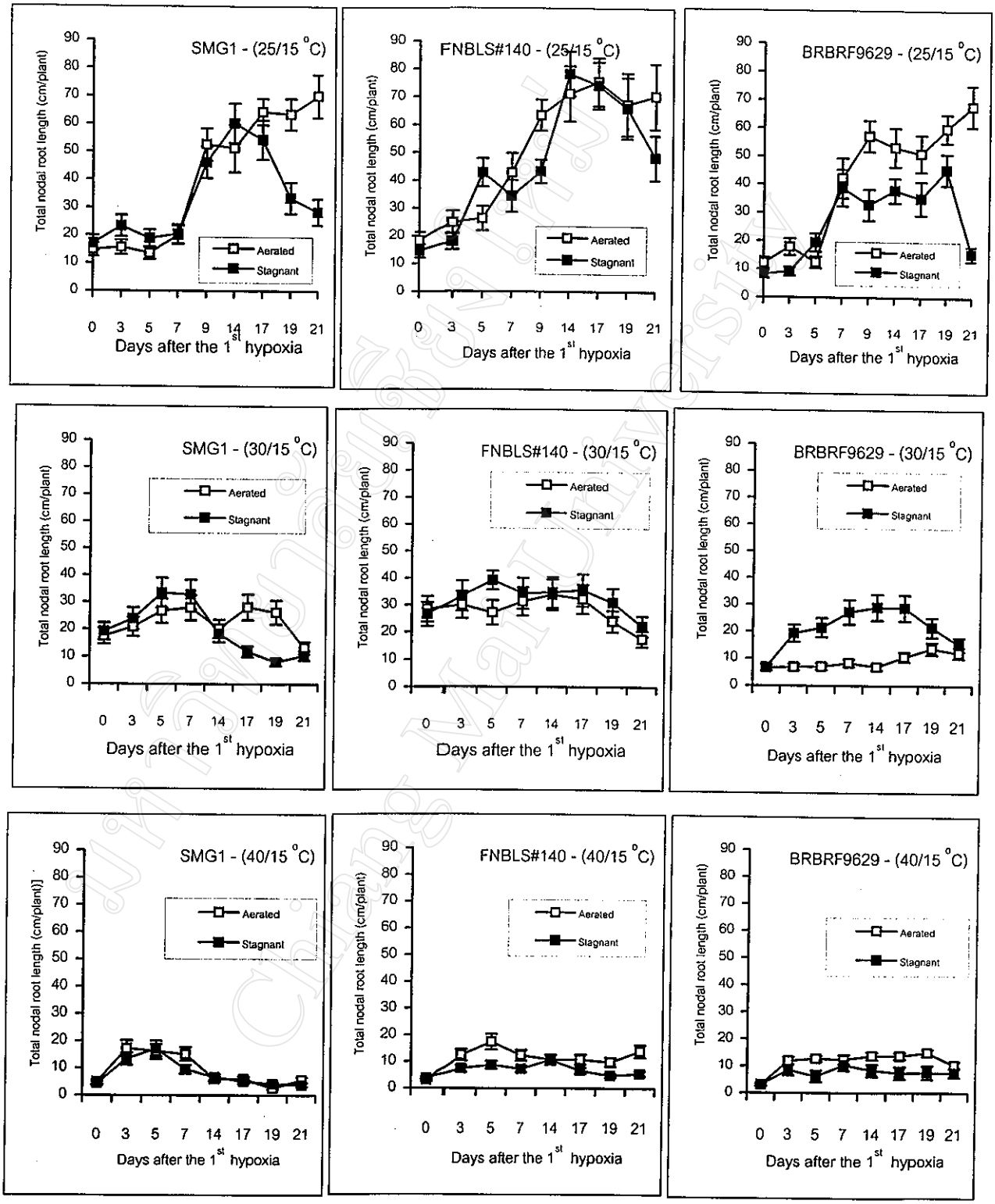

Figure 9 The nodal root length (cm) of barley genotypes grown in aerated and stagnant agar nutrient solution under different temperature levels; 25/15, 25/15, 30/15 and 40/15 °C (day /night temperature). Data are means of four samples ± SE.

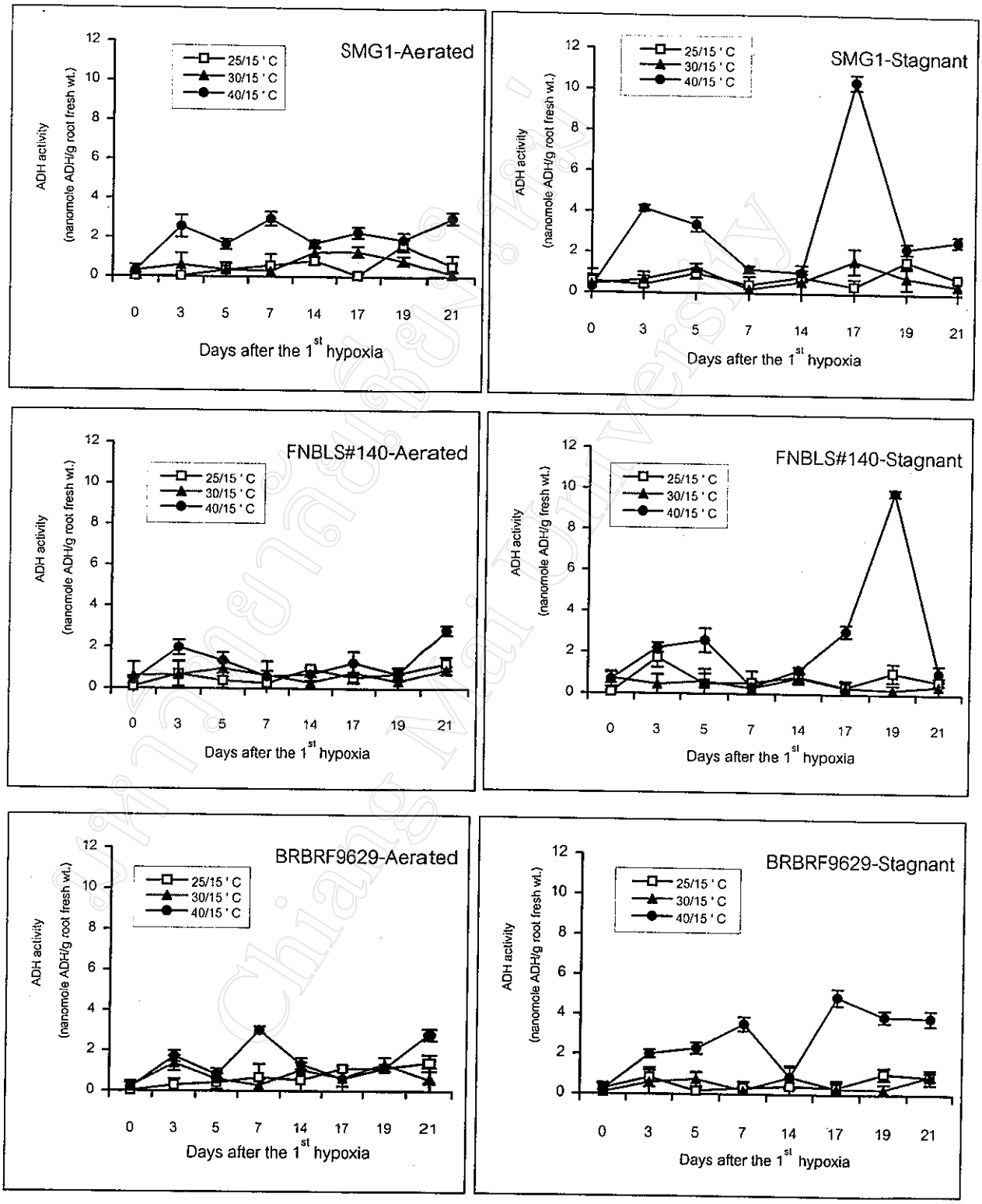

Figure 10 Alcohol dehydrogenase activity of nodal roots of barley genotypes grown in aerated and stagnant agar nutrient solution at 25/15,30/15 and 40/15 °C (day/night temperature).

Data are means of four samples ± SE.

treatment. This confirmed that the ADH enzyme was induced under the hypoxic occurrence in the roots (Drew *et al.*, 1994).

During the 2nd hypoxia with 40/15 °C, all barley genotypes especially SMG1 and FNBLS#140 increased ADH activity greater than under 1st hypoxia at the same temperature levels. It may be waterlogged response for tolerant genotypes especially SMG1 grown under this severe hypoxic stress. The increasing of nodal roots during the recovery possibly caused to be high anaerobic respiration rate under hypoxia (Drew *et al.*,1994). Andrews *et al.* (1993) confirmed that ADH activity induction depended on the severe levels of oxygen deficiency in the roots and the sequent of hypoxic condition.

ADH activities of SMG1 and FNBLS#140 immediately increased and then decreased under hypoxic conditions with 40/15 °C. There have another hypoxic mechanism to improve the efficiency of root respiration to prevent the radial oxygen loss from the root surface (Vartapetian and Jackson, 1997). Drew and Stolzy (1991) concluded that plant adaptation to hypoxia was associated with the efficiency of anaerobic respiration and the pasture effect in the roots, especially at high temperature. BRBRF9629 genotype had continuously low ADH activity under hypoxia and had a longer period of ADH activity as compared with the other genotypes. This result may be related to the large aerenchyma formation in the hypoxic roots which causes low ADH activity (Drew *et al.* 1994)

Nitrate reductase (NR) activity changes in the barley leaves

NR activities in the leaves of all barley genotypes under hypoxia with different air temperature levels are presented in Figure 11. This enzyme activity varied between the effect of hypoxia and high temperature. High temperature evidently affected the NR activity greater than the effect from hypoxic condition. Losada (1976) reported that plant species vary widely in their root ability to reduce incoming nitrate, a positive correlation of nitrate reductase in roots. In this experiment, NR activity of barley

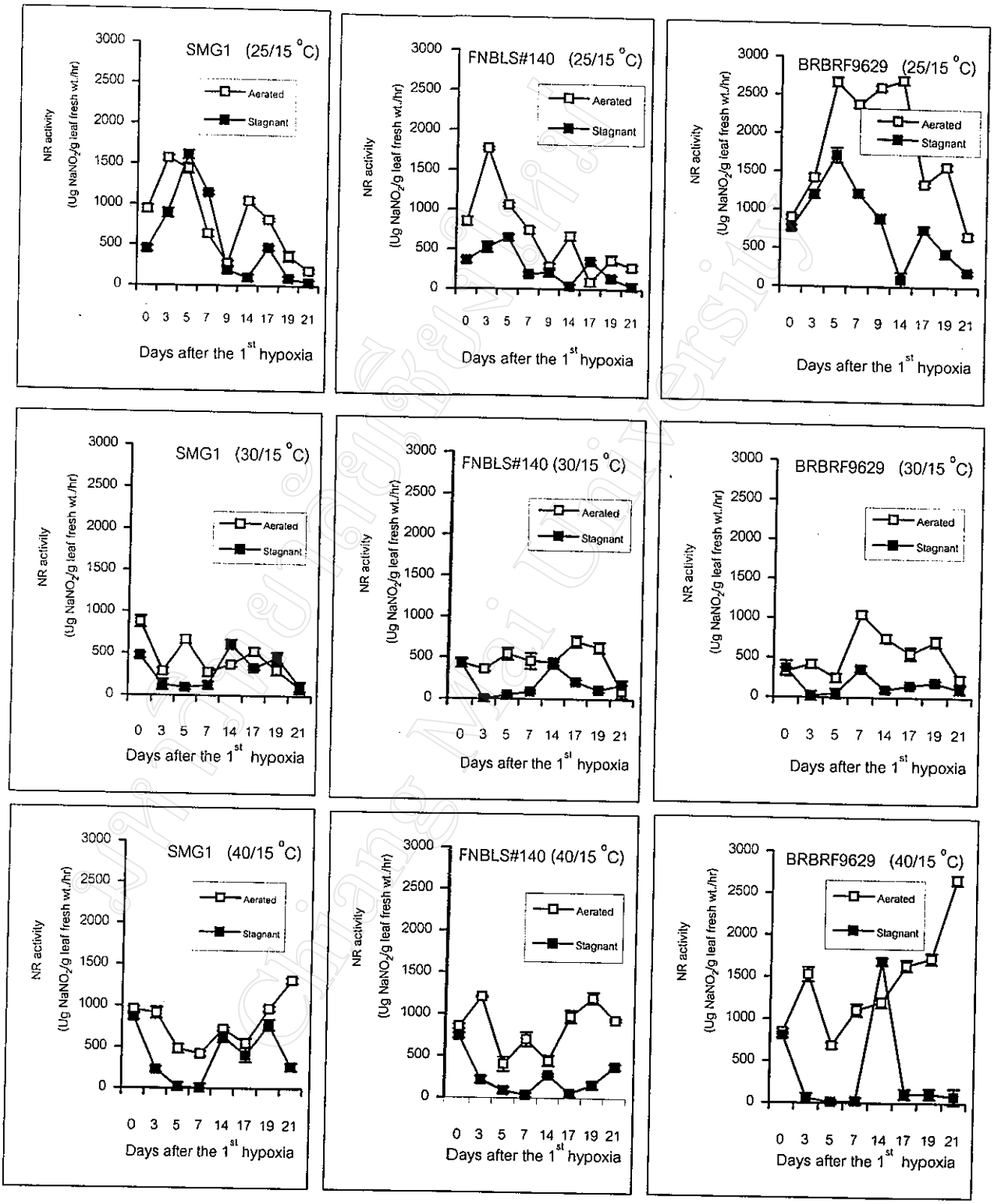

Figure 11 The nitrate reductase activity in the leaves of barley genotypes grown in aerated and stagnant nutrient solution at 25/15, 30/15 and 40/15 °C (day/night temperature).

Data are means of four samples ± SE.

genotypes rapidly increased when the hypoxic condition started. It was related to the synthesize particular protein for anaerobic respiration, such as ADH enzyme (Vartapetian and Jackson, 1997).

In aerated condition, NR activity decreased along with the time period at 25/15 $^{\circ}$C, consistently at 30/15 $^{\circ}$C, and increased at 40/15 $^{\circ}$C. The similar observations were made by Klamsomboon (1983) and Pressarkli (1994). BRBRF9629 grown under aerated condition had high NR activity as compared with the other genotypes, whereas the NR activity under hypoxia was the lowest.

NR activity of all barley genotypes under hypoxic conditions seemed to be similar at each air temperature levels. At 25/15 $^{\circ}$C condition, NR activity increased until the fifth days of the 1st hypoxia and then decreased. At high temperature (30-40/15 $^{\circ}$C), the enzyme activity decreased under the 1st hypoxia. It was indicated that high temperature might suppressed this enzyme (Klamsomboon, 1983). The NR activity of all genotypes decreased so much under the 2nd hypoxia with high temperature (30–40/15 $^{\circ}$C). Although NR activity of SMG1 decreased as the other genotypes under the 1st hypoxia with high temperature, but the activity increased under the 2nd hypoxia with high temperature as compared to the aerated condition. It may be the ability of waterlogged tolerant genotype to maintain the efficiency of root adsorption. This result evidently had high NR activity for nitrogen assimilation in the leaves. FNBLS#140 genotype had the same hypoxic adaptation as SMG1 but had lower NR activity under the severe hypoxic stress condition.

Photosynthetic efficiency

The rates of photosynthesis during stress conditions

In consideration during the 1st hypoxia with 25/15 $^{\circ}$C, the photosynthetic rates of barley genotypes, especially SMG1 increased and then decreased during recovery period (Figure 12). Jiang (1995) also found that strawberry plant under transient waterlogging had high photosynthetic rate and transpiration rate during the first 24

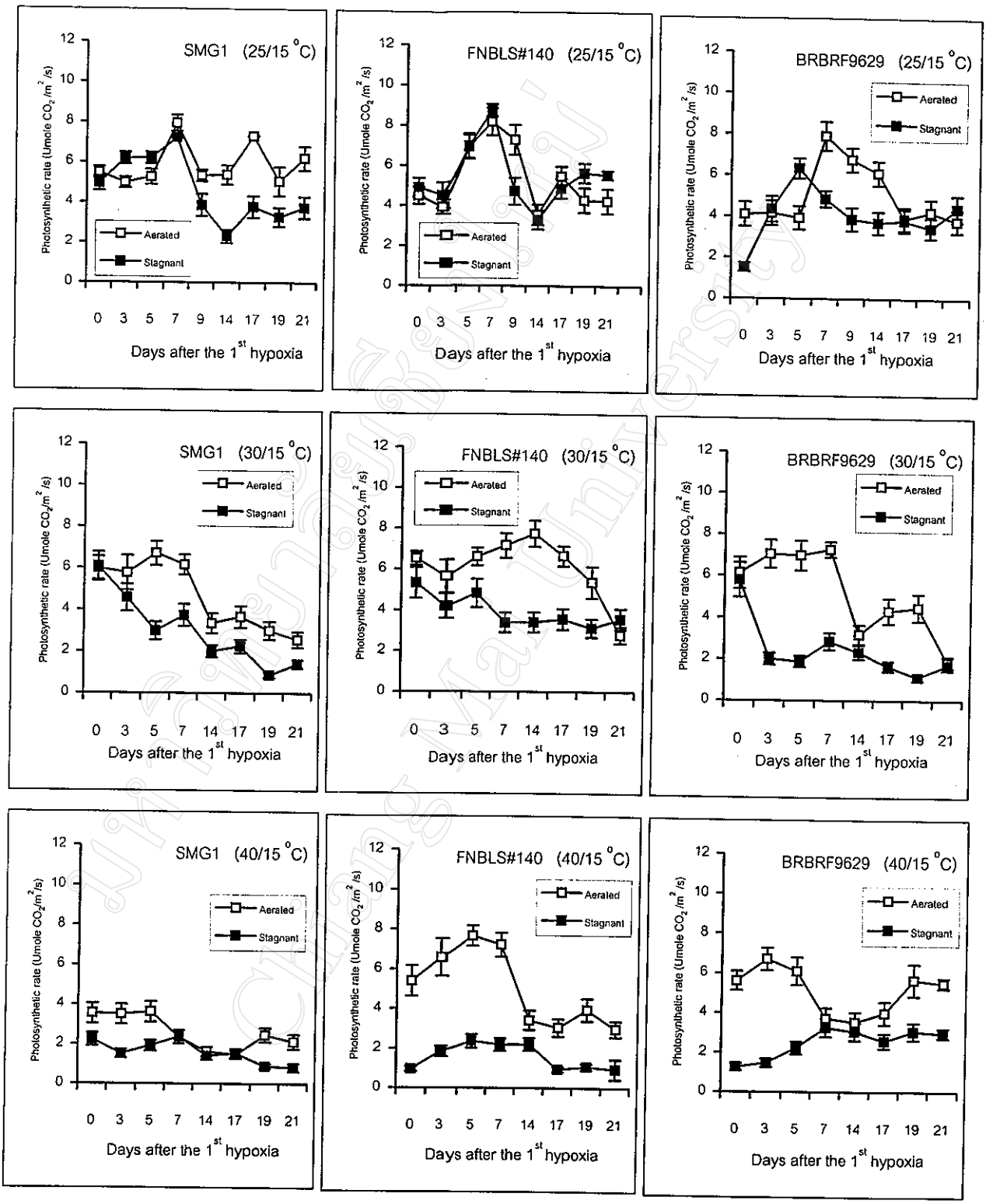

Figure 12 Photosynthetic rate of barley genotypes grown in aerated and stagnant agar nutrient solution at 25/15, 30/15 and 40/15 °C (day /night temperature).

Data are means of four samples ± SE.

hours after that the rates decreased. For high temperature (30-40/15 °C), the photosynthetic rates markedly decreased lower than under aerated condition, especially FNBLS#140 and BRBRF9629 genotypes (Figure 12). It was suggested that increasing temperature caused to be high respiration rate and less root absorption of water and nutrient. These results consequently affect net photosynthetic rate (Drew and Stolzy, 1991).

During the 2nd hypoxia, all barley genotypes could not maintain the photosynthetic rates at high temperature as compared to under aerated condition. The decreasing of photosynthetic rates of FNBLS#140 and BRBRF9629 genotypes were greater than the decreasing rate of SMG1 (Figure 12). It was observed that the photosynthetic rates at 25/15 °C did not affected and were closely the same rates as under aerated condition at the last period of hypoxia. condition. At 40/15 °C, only SMG1 genotype had consistently photosynthetic rate under the 2nd hypoxic and aerated condition (Figure 12).

The transpiration rate during stress condition

All barley genotypes had consistently transpiration rates at 25/15 °C even though they were exposed to double hypoxic stress (Figure 13). SMG1 genotype had lower transpiration rate under the 1st hypoxia and decreased sharply under the 2nd hypoxia with high temperature above 30/15 °C. FNBLS#140 genotype was affected by hypoxia with high temperature more than SMG1. Whereas BRBRF9629 was the most sensitive and had the lowest rate of transpiration when air temperature increase.

The stomatal resistance in barley leaves during stress condition.

The stomatal resistance of all barley genotypes under hypoxia increased especially imposing to the 2nd hypoxia at high temperature (Figure 14). This result may related to abscisic acid production during oxygen deficiency at high temperature which caused the stomata closed (Zhang and Davies, 1987; Hwang and VanToai,

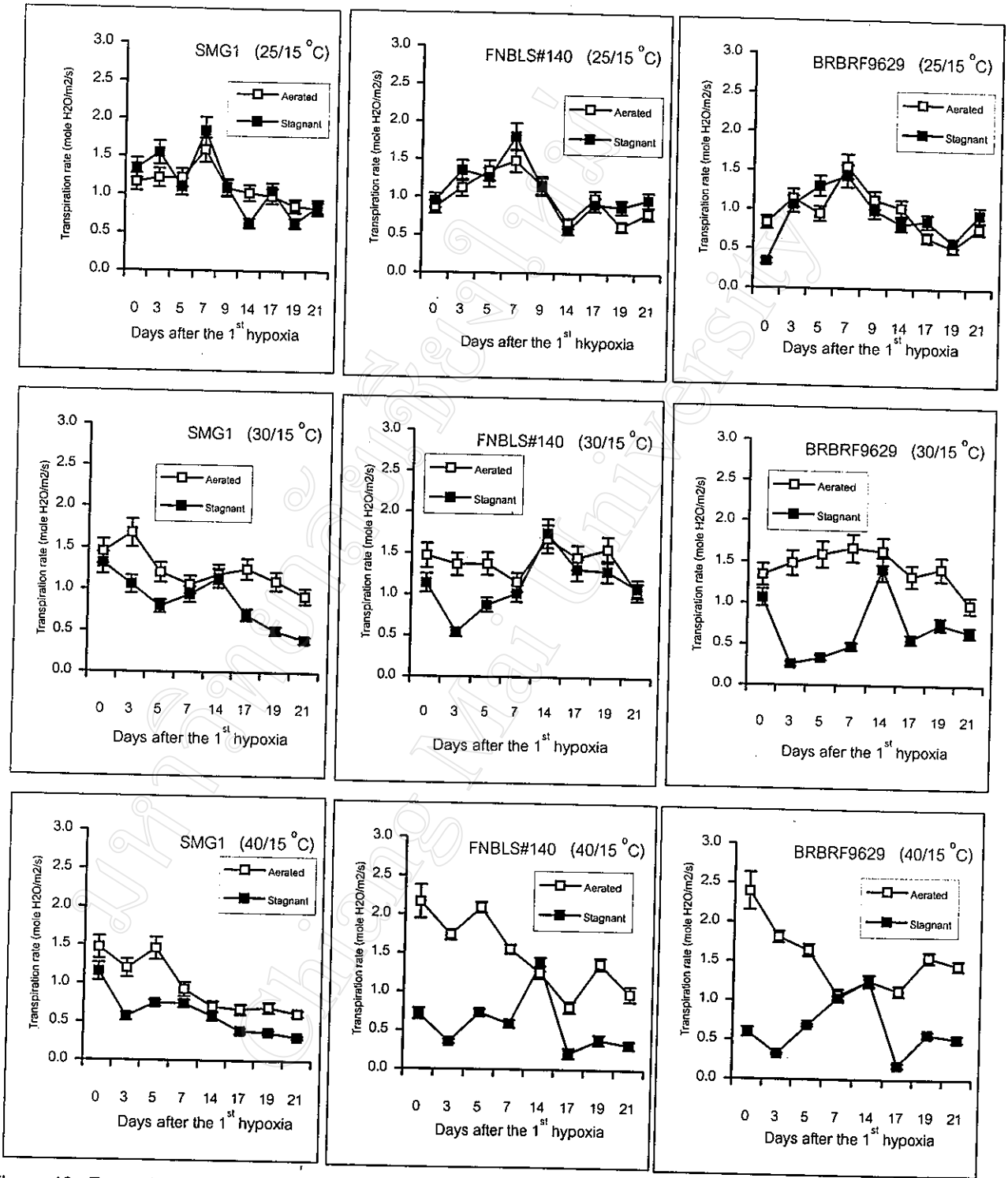

Figure 13 Transpiration rate of barley genotypes grown in aerated and stagnant agar nutrient solution at 25/15, 30/15 and 40/15 °C (day /night temperature).

Data are means of four samples ± SE.

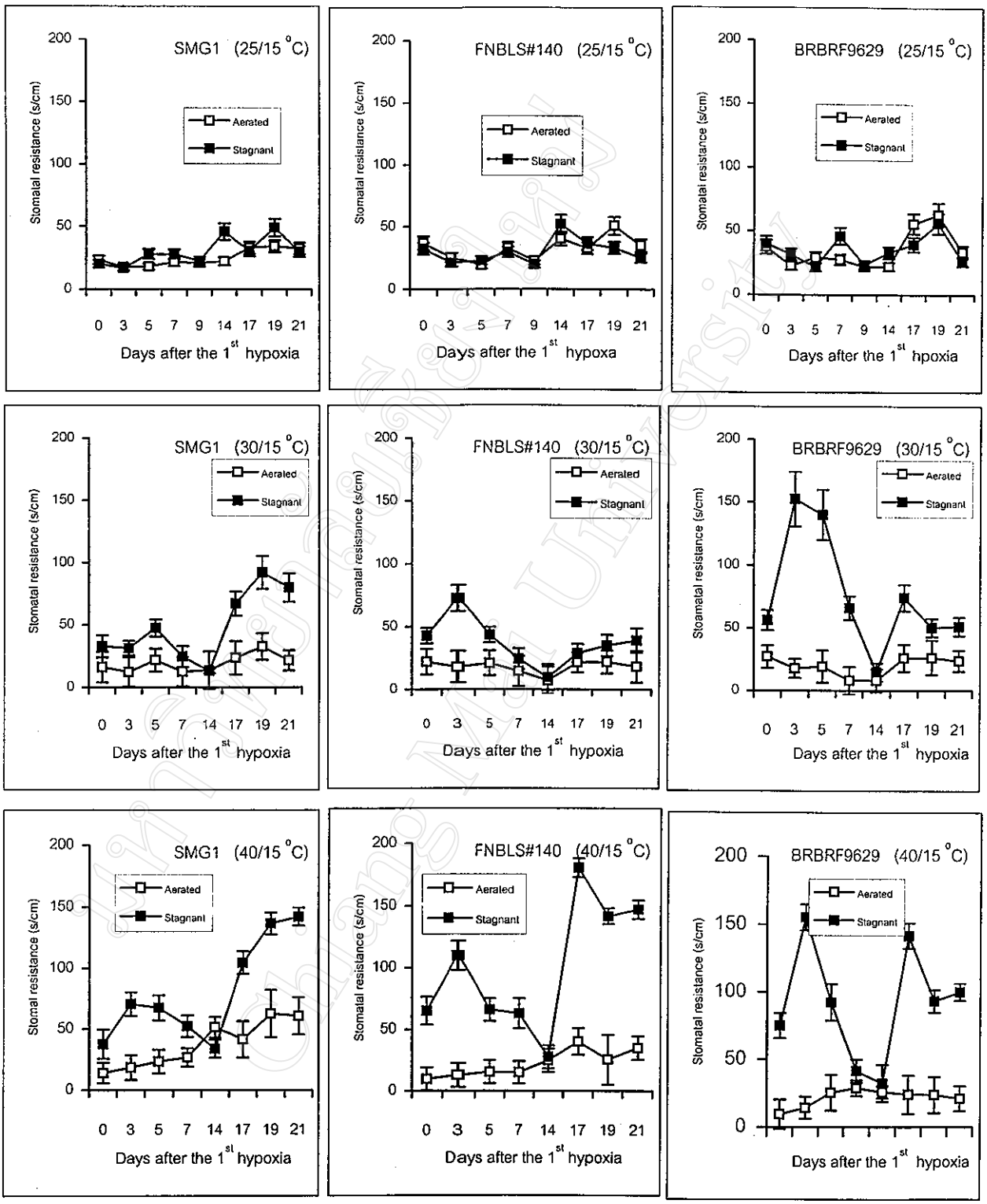

Figure 14 Stomatal resistance (s/cm) of barley genotypes grown in aerated and stagnant agar nutrient solution at 25/15, 30/15 and 40/15 °C (day /night temperature).

Data are means of four samples ± SD.

1991). However, all barley genotypes had lower stomatal resistance during the recovery period.

During the 2nd hypoxic condition with 25/15 °C, the stomatal resistance had the same value as under the aerated condition. SMG1 could maintain the stomatal resistance better than the other genotypes. BRBRF9629 genotype had the highest stomatal resistance under this stress condition (Figure 14). These results possibly depended on the efficiency of root adsorption and photosynthetic rate of barley genotypes differing in waterlogged tolerant. Therefore, the hypoxic tolerant could maintain water potential in the guard cells better than the susceptible varieties (Drew and Stolzy, 1991).

The leaf chlorophyll fluorescence (LCF) during stress condition

In general, high temperature as 30-40/15 °C affected LCF more than the hypoxia condition. However, the LCF was affected so much when exposed to the hypoxia with high temperature (Figure 14). SMG1 genotype had higher LCF under the 1st hypoxia with 25/15 °C as compared to the aerated condition, followed by FNBLS#140 and BRBRF9629 genotypes, respectively (Figure 15). Jiang (1995) reported that the effect of hypoxia might induce high leaf chlorophyll fluorescence for increasing photosynthetic rate and dry matter compensation. During the 2nd hypoxia, SMG1, tolerant genotype still had high LCF at 30 /15 °C and was lower LCF at 40/15 °C as compared to the aerated condition. The LCF of FNBLS#140 and BRBRF9629 genotypes decreased when air temperature increased. It was found that BRBRF9629, susceptible genotype had the lowest LCF at 40/15 °C, as compared with the other genotypes (Figure 15).

It was indicated that hypoxia affected the acceleration of LCF only grown under the 1st hypoxia with 25/15 °C. In consequence, all barley genotypes had high photosynthetic and transpiration rate greater than under the aerated condition.

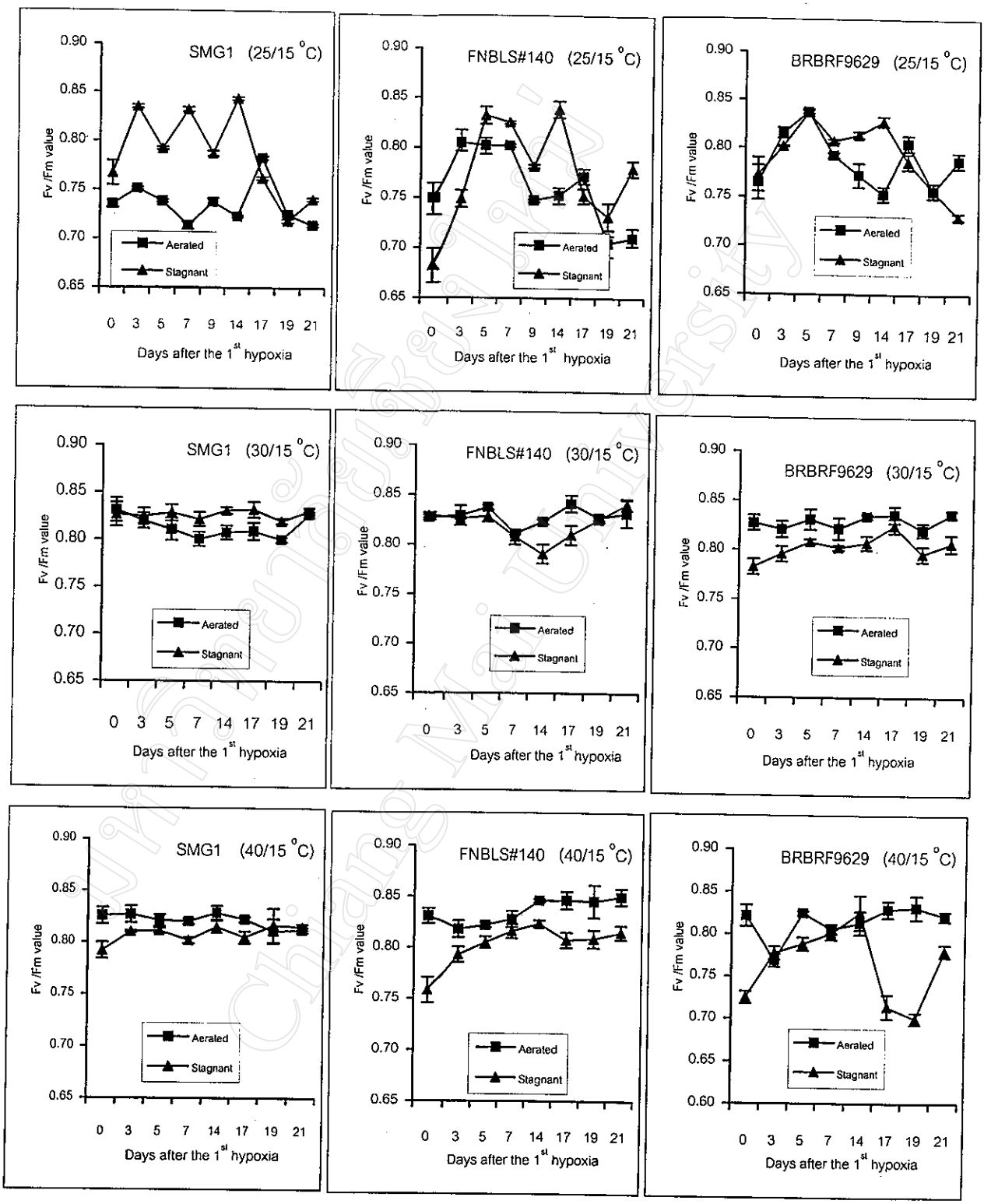

Figure 15 The leaf chlorophyll fluorescence of barley genotypes grown in aerated and stagnant agar nutrient solution at 25/15, 30/15 and 40/15 °C (day/night temperature).

Data are means of four samples ± SE.

Moreover, the higher air temperature increases, the more LCF decreased (Figure 12, 13 and 14).

This experiment found the necrosis symptom was found on the leaf tip especially for the SMG1 genotype under hypoxic conditions with 25/15 $^{\circ}$C. This result may be associated with the damage of free radicles in the leaves, and may be affected by hypoxia (Blokhina *et al.* 1999). Liu (1996) stated that the effect of low superoxide dismutase and catalase in maize leaves under waterlogging condition, caused leaf injury and related to lipid peroxidation. However this result was not found at higher temperature which caused to reduce LCF in the leaves (Figure 15).

Total soluble sugar and nitrogen accumulation in the shoots

Total soluble sugar accumulation in the barley shoots

In general, the hypoxic condition affected total soluble sugar accumulation in the shoots rather than the effect of high temperature. However, the hypoxic condition with high temperature was the severe effect which cause so much severe stress to total soluble sugar in the leaves. Only SMG1 genotype accumulated consistent total soluble sugar in the shoots under the 1st hypoxia with 25-30/15 $^{\circ}$C (Figure 16). This may be the advantage of the roots which had sufficient sugar for anaerobic root respiration. Thus it was not necessary to transport sugar to the roots (Drews and Stolzy, 1991; Waters *et al.* 1991). Whereas the other genotypes had high total soluble sugar in the shoots (Figure 16). It might be either suppressed the sugar transportation to the roots or improved the efficiency of root adsorption. All barley genotypes under the 1st hypoxia at 40/15 $^{\circ}$C had low total soluble sugar accumulation in the shoots.

Under the 2nd hypoxia condition, total soluble sugar in the shoots of all barley genotypes decreased at early period and then increased at the end of treatment especially SMG1 genotype (Figure 16). Total soluble sugar under severe stress might be transported to the roots for dry matter compensation dealing with anaerobic root respiration (Ella, 1996). Wiengweera *et al.*(1997) stated that root dry matter

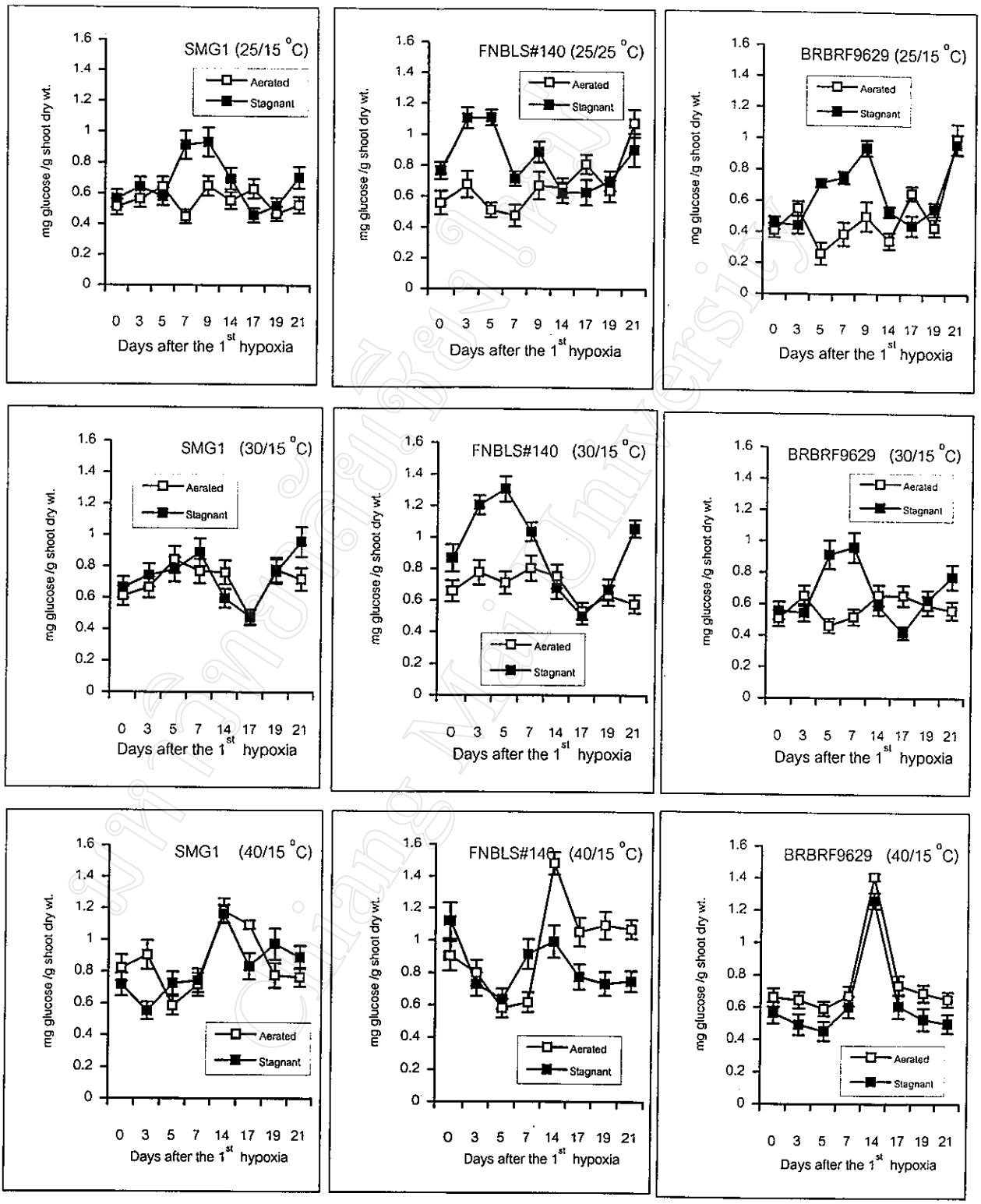

Figure 16 Total soluble sugar in the shoots of barley genotypes grown in aerated and stagnant nutrient solution at 25/15, 30/15 and 40/15 °C (day /night temperature).

Data are means of four samples ± SE.

accumulation increased under hypoxia greater than under aerated condition. The amount of total sugar supply for root survival under the severe stress might be due to the pasture effect in the roots (Vartapetian and Jackson, 1997).

Total nitrogen accumulation in the shoots

Total nitrogen content in the shoots of barley genotypes varied under hypoxia with high temperature (Figure 17). During the 1st hypoxia with 25/15 °C, SMG1 had high total nitrogen in the shoots more than under aerated condition whereas the other genotypes had low amount especially BRBRF9629. This indicated that the tolerant genotype had high NR activity (Figure 11) for producing high particular protein under hypoxia (Vartapetian and Jackson, 1997).

Under the 2nd hypoxia with 25/15 °C, all barley genotypes could obtain total nitrogen in the shoots at the same amount as the aerated condition (Figure 17) due to the low activity of NR for protein synthesis in the shoots (Figure 11). At 30/15 °C, total nitrogen content in the shoots of FNBLS#140 and BRBRF9629 decreased under the 2nd hypoxia more than under the 1st hypoxia, especially BRBRF9629 (Figure 17). Total nitrogen in the shoots of FNBLS#140 and BRBRF9629 at 40/15 °C significantly decreased. Whereas total nitrogen in the shoots of SMG1 also decreased, but was lesser than the other genotypes (Figure 17). These results indicated that high temperature under hypoxia especially under the 2nd hypoxia affected the NR enzyme synthesis and caused to be low total nitrogen content in the shoots (Figure 11 and 17). This may be possibly associated with the efficiency of leaf photosynthetic rate of the plant, the increasing of carbon and nitrogen in dry matter of the plant parts, and the determination of C:N weight ratios (Pate, 1980; Yoshida,1981).

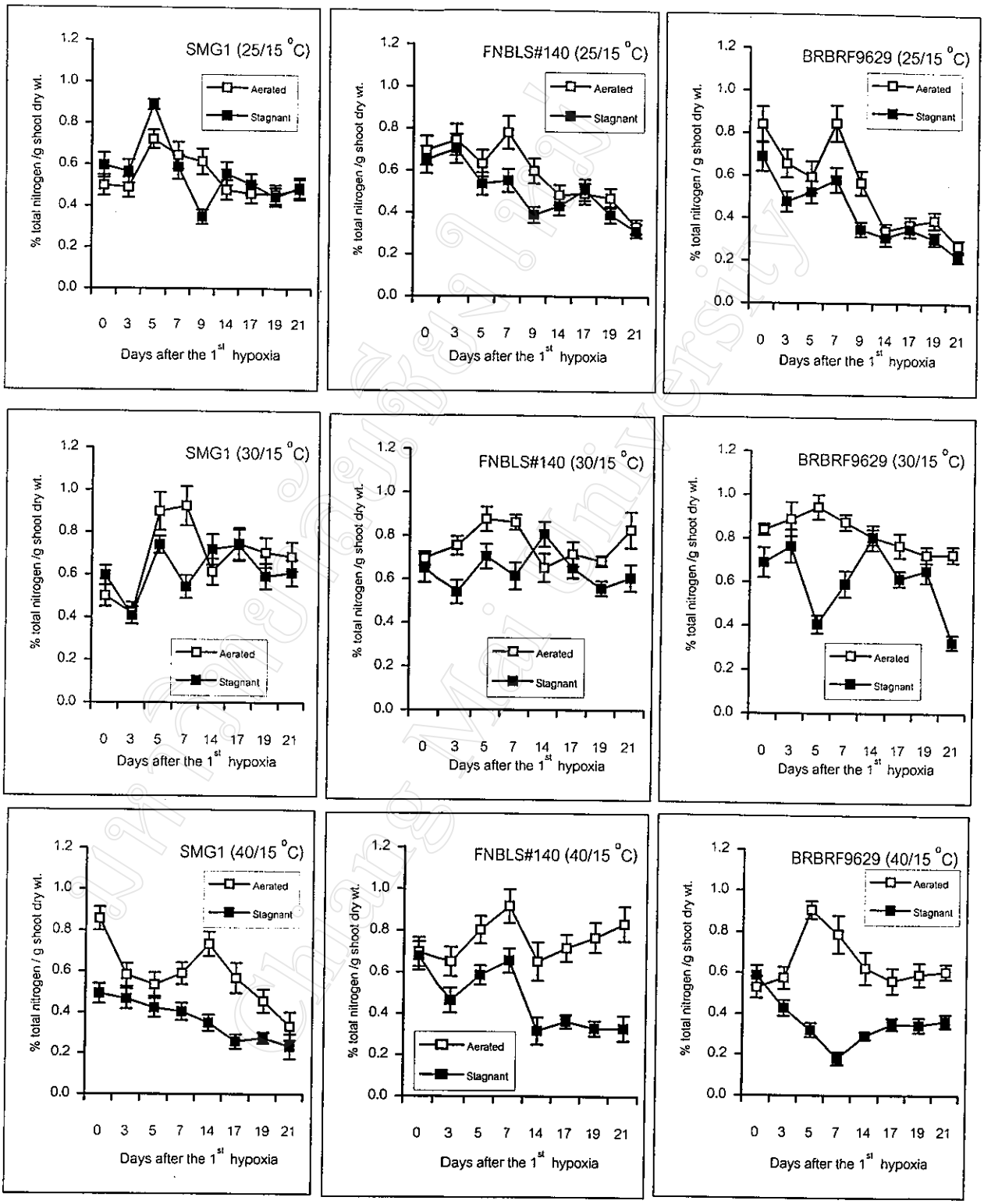

Figure 17 Total nitrogen of the shoots of barley genotypes grown in aerated and stagnant agar nutrient solution at 25/15, 30/15 and 40/15 °C (day /night temperature).

Data are means of four samples.± SE.

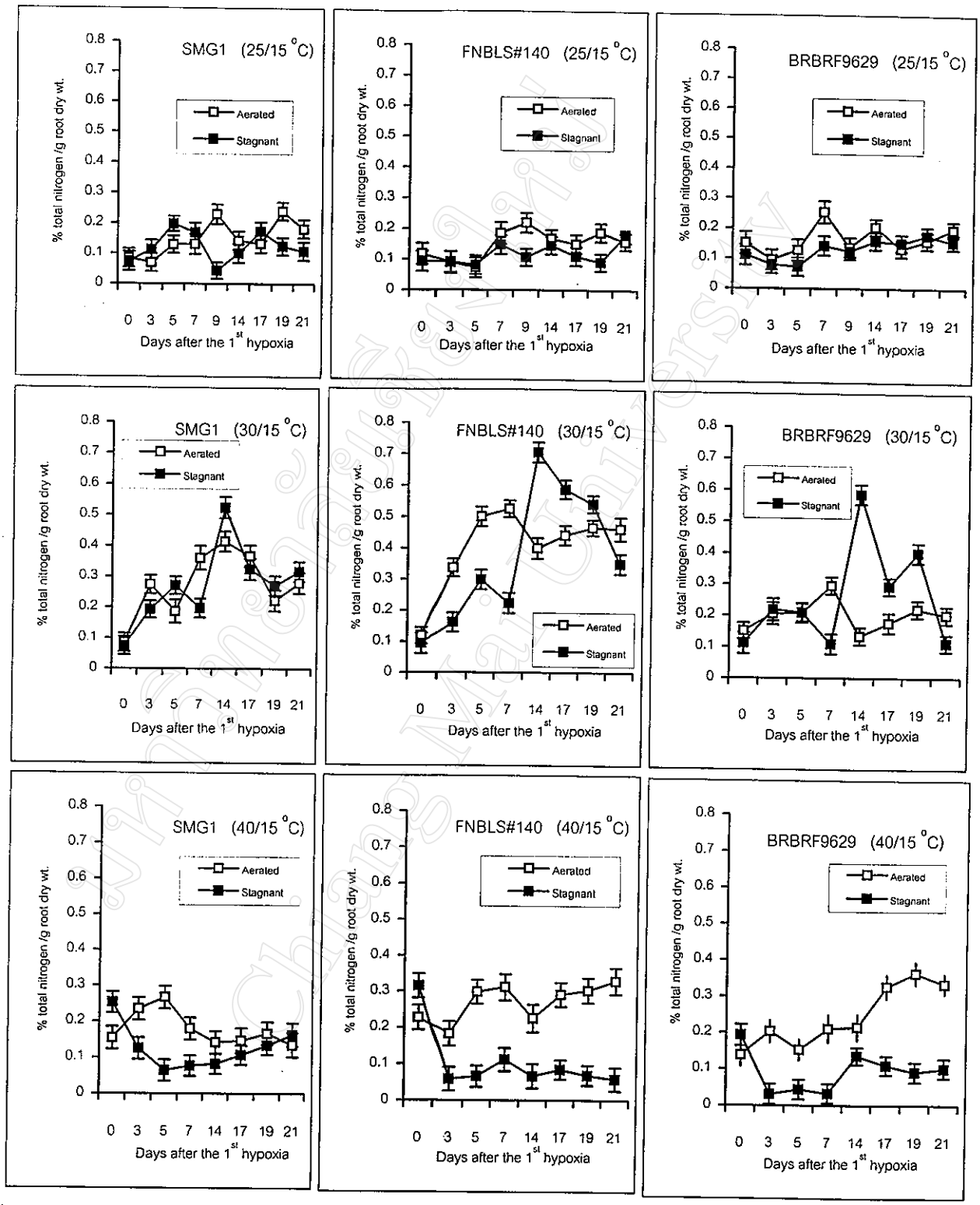

Figure 18 Total nitrogen of the roots of barley genotypes grown in aerated and stagnant agar nutrient solution at 25/15, 30/15 and 40/15 C (day/night temperature).

Data are means of four samples ± SE.

The changes of total nitrogen accumulation between the shoots and roots

The total nitrogen content of the shoots of barley genotypes under hypoxia with high temperature decreased greater than the result of the roots. It was found that total nitrogen content of barley genotypes markedly decreased under the 2nd hypoxia with 30-40/15 °C (Figure 17 and 18). Among barley genotypes, SMG1, tolerant genotype under the 2nd hypoxia with 25-30/15 °C had lesser total nitrogen content in the roots than the other genotypes. However, the sugar content of SMG1 significantly increased at 40/15 °C. It was indicated that SMG1 needs more some enzymes and particular protein for root survival only under the severe stress (the 2nd hypoxia with 40/15 °C). A similar result was reported by Losada (1976).

Acclimatic adaptation associated with total soluble sugar and nitrogen accumulation of each barley genotypes

SMG1 (tolerant genotype):

During the 1st hypoxia with 25/15 °C, total soluble sugar and nitrogen in the SMG1 shoots was slightly consistent (Figure 16 and 17). This might be the waterlogged adaptation of tolerant genotypes to decrease the dry matter loss under hypoxia by increasing the leaf chlorophyll fluorescence (LCF) and maintaining the consistently photosynthetic and transpiration rates (Figure 12-15). After re-transferring to the 2nd hypoxia, the photosynthetic efficiency and the NR activity of SMG1 decreased (Figure 11), but did not affected the total soluble sugar and nitrogen accumulation in the shoots. This may be related to the increase of root adsorption (Drew and Stolzy, 1991). In the other hand, the dry matter accumulation during the recovery period could compensate the growth damage under repeating hypoxic condition (Ella, 1996). Moreover, there have a consistence of total nitrogen in the shoots during the 2nd hypoxia (Figure 11) whereas NR activity significantly decreased (Figure 11). The chlorophyll degradation may be related to this result (Jackson and Drew, 1984; Thomson *et al.*, 1992). When air temperature increased at 30-40/15 °C,

total soluble sugar in the shoots under the 1st hypoxia slightly increased at 30/15 °C and decreased at 40/15 °C (Figure 16). This result was related to the effect of leaf chlorophyll fluorescence by increasing the photosynthetic efficiency (Figure 12 and 15). It was also associated with the NR activity for a particular protein production under hypoxia at high temperature (Figure 11). Krizek (1982) supported that flood-tolerant species markedly increases in NR activity in the roots and leaves during waterlogging and also have a greater ability to synthesize amino acids than do intolerant species. In this experiment, NR activity of SMG1 decreased under the 1st hypoxia (Figure 11) and caused to be low total nitrogen in the shoots under the 1st hypoxia with 40/15 °C (Figure 17). Champigny and Foyer (1992) reported that the changes of total soluble sugar and nitrogen in the shoots during hypoxia, were associated considerably with the reducing power and photosynthate substance for the particular protein synthesis.

After re-growing under the 2nd hypoxia with 30-40/15 °C, the NR activity of SMG1 increased the same level as under the aerated condition (Figure 11). Total nitrogen in the shoots decreased much more than under the aerated condition while the total soluble sugar in the shoots and the photosynthetic efficiency had similar results to the aerated condition (Figure 12-15 and 17). This was indicated that the changes of biochemical substances of tolerant genotype were the same responses as under the 1st hypoxia (Figure 12-15). Under the 2nd hypoxia with 40/15 °C, the NR activity of SMG1 still increased (Figure 18). Increasing of NR activity under hypoxia might be associated with the production of the particular protein substances for anaerobic root respiration (Krizek,1982). For the total nitrogen in the roots under hypoxia, it increased at high temperature (Figure 18) and caused to be high photosynthetic efficiency by increasing the nitrate adsorption along with the increase of NR activity (Figure 11). It was also indicated that the plant roots was the most sensitive to hypoxia which affected the shoot and root growth in final (Huang *et al.*,1994b). However, total soluble sugar in the SMG1 shoots was transported to the

roots for survival (Figure 16) due to the increasing of dry matter accumulation roots especially at 40/15 $^{\circ}$ C (Figure 19).

FNBLS#140 (moderate tolerant genotype)

During the 1st hypoxia with high temperature, NR activity and total nitrogen accumulation of this genotype decreased lower than under the aerated condition. The decreasing rate was greater than SMG1 genotype (Figure 11 and 17). The photosynthetic efficiency of FNBLS#140 also decreased at 30-40/15 $^{\circ}$ C (Figure 12-15). However, high total soluble sugar in the shoots was found only at 30/15 $^{\circ}$ C, but have a consistency at 40/15 $^{\circ}$ C (Figure 16). This result may be associated with the high respiration rate of the shoots (Drew and Stolzy, 1991).

After re-transferring to the 2nd hypoxia, total soluble sugar and nitrogen in the shoots decreased at 30-40/15 $^{\circ}$ C (Figure 16 and 17) and were transported to the root under the severe stress whereas the photosynthetic rate decreased (Figure 12). Smirnof *et al.* (1985) suggested that the NR activity and total nitrogen accumulation under stress condition could be used for maintaining the photosynthetic rate.

BRBRF9629 (susceptible genotype)

BRBRF9629 genotype seemed to have a similar adaptation to hypoxia with high temperature as FNBLS#140 genotype, but had a lower adaptability for survival. NR activity and total soluble sugar of BRBRF9629 increased only during the recovery period at 40/15 $^{\circ}$ C. Under the 2nd hypoxia with high temperature, the photosynthetic efficiency and total nitrogen in the shoots decreased much more than under the aerated condition as compared to the other genotypes (Figure 11-17).

Dry matter accumulation and Partitioning

All barley genotypes accumulated the dry matter in the shoots by 80-90%, much more than in the roots and significantly decreased especially under the 2nd hypoxia with 30-40/15 °C (Figure 19). A similar observation was also made by Vartapetian and Jackson (1997). For root growth with high temperature, dry matter accumulation in the roots increased only 1-2% under the 1st hypoxia and increased by 6-9% under the 2nd hypoxia as compared to the aerated condition (Figure 19).

High temperature affected dry matter accumulation in the shoots more than the effect of hypoxia. At 25/15 °C, barley genotypes, especially SMG1 could compensate for dry matter loss during the 1st hypoxia by increasing the photosynthetic efficiency (Figure 12-15). During the 2nd hypoxia, dry matter accumulation in the shoots decreased and then slightly increased as compared to the 1st hypoxic condition (Figure 19). This result was due to the efficiency of photosynthetic rate during hypoxic condition especially BRBRF9629 genotype (Figure 12). BRBRF9629, susceptible genotype was the lowest dry matter accumulation during the 1st hypoxia and could not maintain the photosynthetic rate during the recovery period (Figure 12). It was stated that plant with more initial carbohydrates can survive under the anaerobic stress (Vartapetian and Jackson,1997). Colmer (1996) also reported that the starch content is probably an important factor for waterlogging resistance.

Total dry matter accumulation in the shoots of barley genotypes at 30/15 °C decreased under the 1st hypoxia after that the total dry matter of SMG1 and FNBLS#140 slightly increased. However, during the 2nd hypoxia, all barley genotypes especially BRBRF9629 were low dry matter accumulation at 40 /15 °C (Figure 19). Drew and Stolzy (1991) suggested that the dry matter accumulation served as the energy for survival under hypoxia and depended on the air temperature level which associated with the respiration rate and the amount of photosynthate.

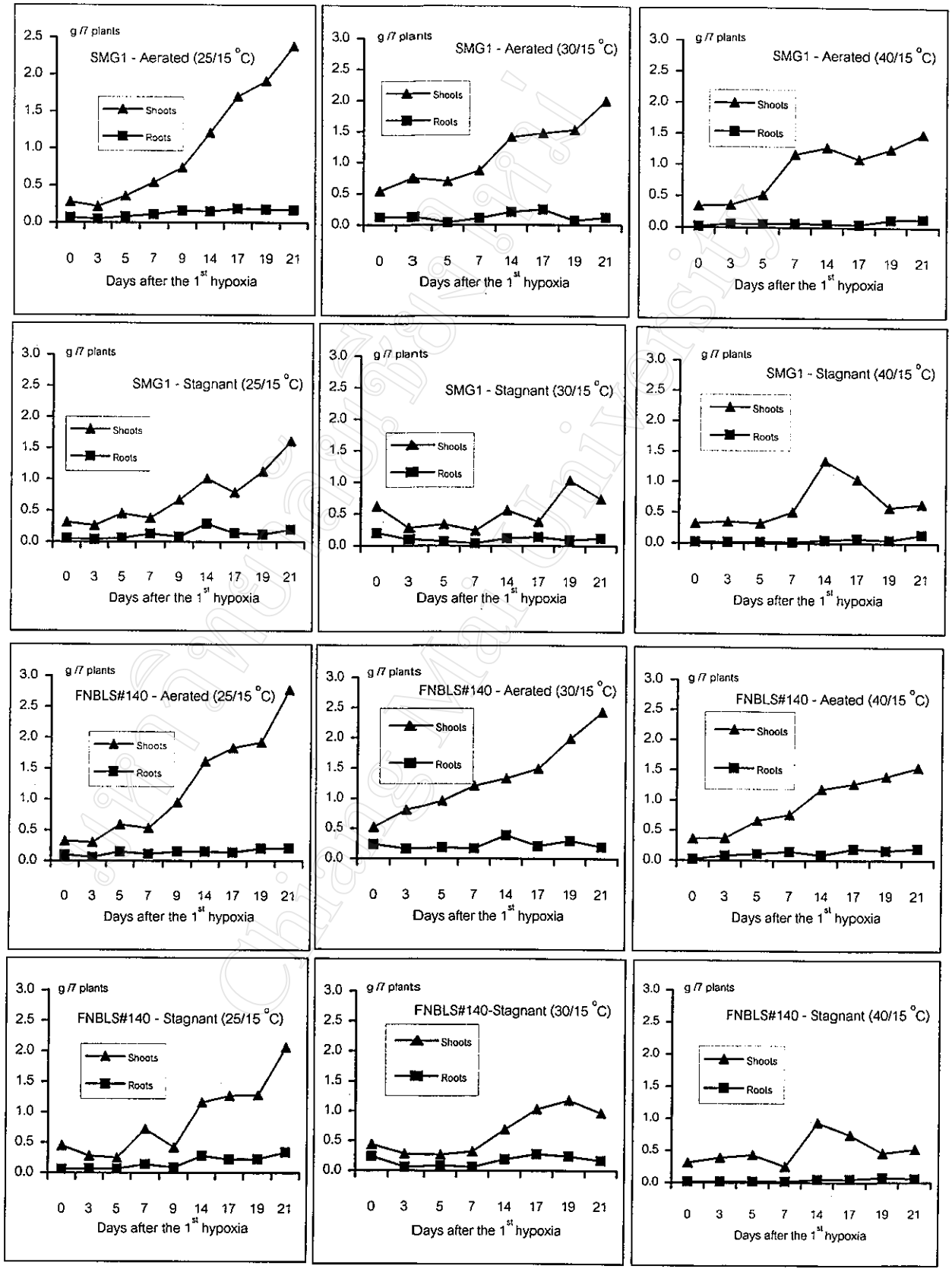

Figure 19 Dry matter accumulation and partitioning of barley genotypes grown in aerated and stagnant agar solution at 25/15, 30/15 and 40/15 °C (day/night temperature).

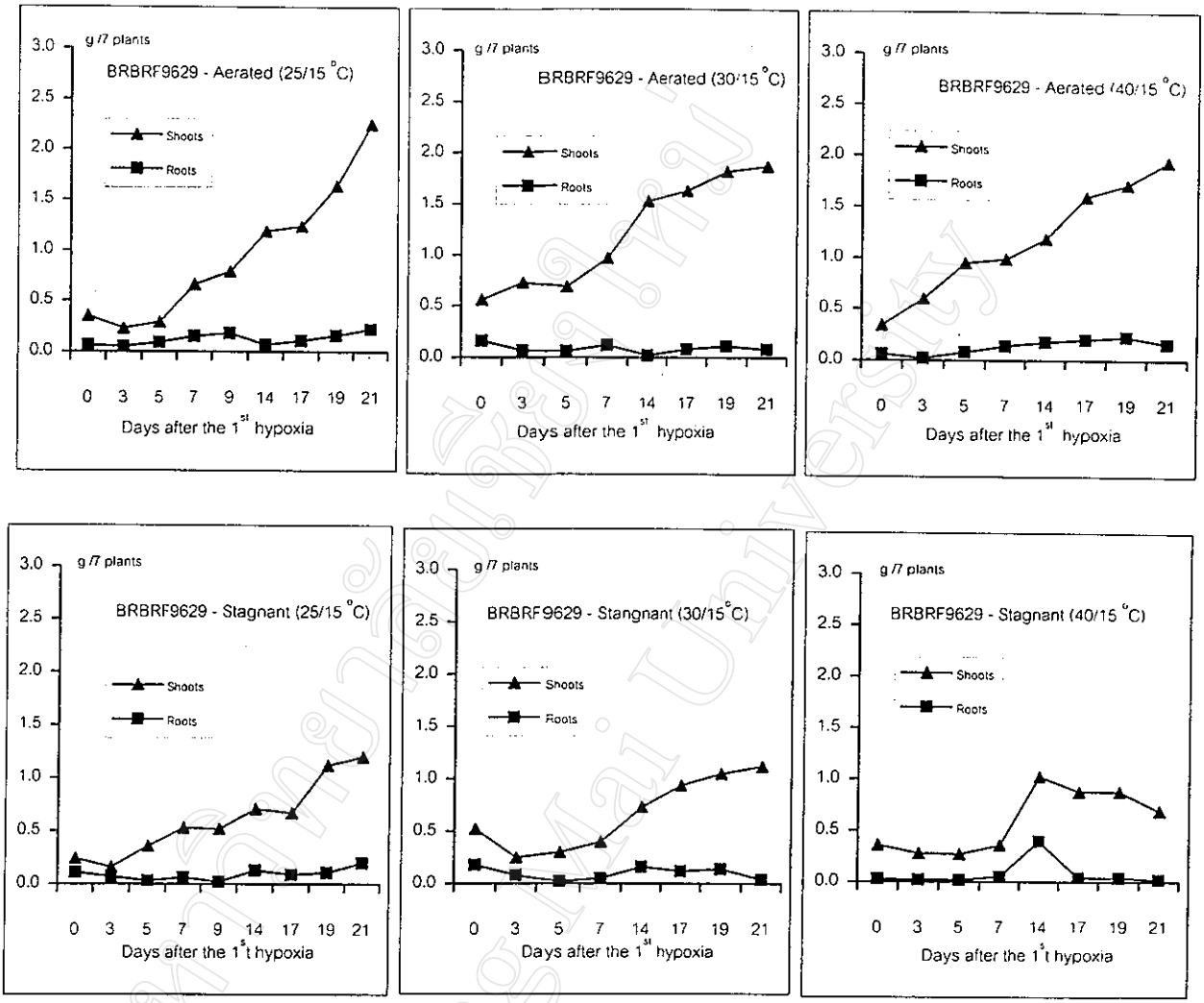

Figure 19 (continued)

Dry matter accumulation and partitioning of barley genotypes grown in aerated and stagnant agar solution at 25/15, 30/15 and 40/15 °C (day/night temperature).

Note : Aerated = to grow in the aerated nutrient solution; Stagnant = to grow in the stagnant agar nutrient solution.

This experiment could explain the physiological adaptation of barley for root survival under hypoxia with high temperature. So, it should be considered to the partitioning of photosynthate between the shoots and the roots under areated and hypoxic condition. In consequence, it should be more realizable about the effect of barley growth under hypoxic condition with high temperature by constructing the mechanistic model for education.