Dehydration-avoidance responses of tepary bean lines differing in drought resistance

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Received August 31, 2000 · Accepted August 7, 2001

Summary

Four tepary bean (Phaseolus acutifolius) lines were studied for the responses of the dry matter accumulation and partitioning, the growth characteristics of the root and the shoot genotypes, and the potential seed yield to drought. Comparatively, two lines were high (NE # 8A and NE # 19) and two lines (NE # 5 and NE # 7) were low in the seed yield under well-watered conditions. The two high yielding lines remained higher in the seed yield than the two low yielding lines under drought conditions. NE # 19 is characterized by a deep root penetration and a balanced root : shoot growth pattern, along with the greatest mass of root in the deepest soil profile. Its leaves exhibited sensitive stomates in response to drought stress. Except for having less depth of its root penetration, NE # 8A was very similar to NE # 19. NE # 8A showed less reduction than NE # 19 in the potential seed yield as affected by the water deficit. It appeared to use less soil water, suggesting operating sensitive stomates. However, the RWC of NE # 8A leaves showed more reduction than NE # 19 in response to the drought. NE # 19 could cope with more severe water stress due to its deeply penetrating root along with the sensitive stomates of the leaf genotype.

Key words: Phaseolus acutifolius – chlorophyll fluorescence – drought – legumes – root growth – stomatal resistance – water stress

Abbreviations: C well-watered. – DS drought stress. – E transpiration. – F₀ minimal fluorescence of dark-adapted leaves. – Fₘ maximal fluorescence of dark-adapted leaves. – Fₚ/Fₘ optimal quantum yield of PSII. – gₛ stomatal conductance. – LA/R the ratio of leaf area to root dry mass. – PSII photosystem II. – R/S root-to-shoot ratio. – RWC relative water content

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Introduction

Tepary bean (Phaseolus acutifolius A. Gray), a legume for potential inclusion in the human diet (Idouraine et al. 1995, Miklas et al. 1994), is well-adapted to arid environments (Miklas et al. 1994). It has been grown in the southwestern USA, Central America, Mexico, and Africa (Federici et al. 1990). This Phaseolus species has long been suggested for domestication in arid areas with poor farming conditions (Morci and El-Murraba 1960), where its relative, common bean (P. vulgaris L.), yields poorly if at all. Tepary bean, in addition, could be used to enhance stress resistance of common bean through interspecific breeding (McElory 1985, Mohamed 1990, 1996). Therefore, there is a renewed interest in tepary bean among bean researchers (Federici et al. 1990, Mohamed 1991, 2000, Silbernagel 1986).

Reported studies of tepary bean responses to drought, however, focused either on its performance in yield trials (Federici et al. 1990, Mohamed 1996, Simon 1993) or on mechanisms underlying its ability to cope with water deficit (Markhart 1985, Yu and Berg 1994). Identification of dehydration-avoidance mechanisms were assessed using one or few tepary bean lines, and some of the studies focused on only a few shoot or root characteristics. Transfer of specific mechanisms of the dehydration-avoidance into common bean has been suggested in order to enhance its drought resistance (Markhart 1985, Mohamed 2000). However, information is needed on the responses of the traits related to dehydration-avoidance of tepary bean lines differing in seed yield under drought stress conditions. A high yielding line in the field may not have all the morphological and physiological traits developed by the species to cope with water-stress (Hassan 1995). On the other hand, different elite lines may have different combinations of the potential traits of drought resistance. When incorporating such trait(s), more durable and stable drought resistant lines may be obtained.

Understanding the physiological mechanisms of tepary bean to cope with water deficit in relation to its seed yield, therefore, would enable the development of the most precise procedures for screening potential germplasm to increase the yield of the domesticated lines of this species, and planning of the most efficient strategies for improving drought resistance of common bean. Our primary objective, therefore, was to assess the physiological and morphological responses of the shoot and root genotypes to water deficit in four tepary bean lines differing in seed yield under drought stress conditions.

Materials and Methods

Four tepary bean (Phaseolus acutifolius A. Gray) lines (NE # 5, NE # 7, NE # 8A, and NE # 19) were used in the present study. These TP lines were originally obtained from the Department of Horticulture, University of Nebraska, USA. They were evaluated for seed yield in a field experiment conducted for two years under typical semiarid conditions in southern Egypt (the Research Station of the Faculty of Agriculture, Assiut University, Assiut, Egypt). The experiment was arranged as a split-plots in a randomized complete-block design (RCBD). The whole plots contained drought and control treatments, while the four lines were in the sub-plots. The whole plots of the drought treatment were surrounded by belts of 2-m-wide ridges. Each sub-plot consisted of 4 rows (8.4 m²). Seeds were planted at 25 cm on the northern side of 0.7-m-wide and 3-m-long rows. The drought treatment started 10 days after planting (3–4 days after emergence). The soil moisture was determined gravimetrically after drying to constant weight at 105 °C. The soil samples were taken at 30–40 cm depth every 2–3 days. The control plants were irrigated, when 58% of the available soil water was depleted (Mohamed 1996). The plants in the drought treatment were irrigated when 72% of the available soil water was depleted. The average day temperature during the growing season (mid-May to mid-Sept.) ranged from 30–35 °C. Data were recorded on shoot dry weight for the flowering plants (5–6 weeks after planting, using plants of one of the 4 rows) and the seed yield at the end of the growing season. Shoot dry mass was determined after drying to constant weight at 80 °C. Subsequently, the four lines were used in a physiological assessment of root and shoot traits related to the dehydration avoidance in two different experiments conducted in 1999 and 2000 at the Department of Horticulture, University of Bonn, Germany. Each experiment was repeated twice. One experiment was carried out in a controlled environment chamber, while the other was undertaken in a temperature-controlled greenhouse.

Growth chamber experiment (leaf growth, conductance, and the water status)

To minimize the differences in the water status of the leaves, which could be due to the variable root growth and penetration, seeds were planted in a limited root medium using small pots with a diameter of 5 cm and a height of 7 cm. The pots were filled with 0.1 liter of a dry peat moss/sand mixture (1:1, v/v). One seed was sown per pot. The seedlings were grown at a 16/8 h light/dark period under 400 µmol m⁻² s⁻¹ PAR on the surface of the unfoliate leaves in a controlled environment chamber. The day/night temperature was 22 ± 2 °C/15 ± 2 °C and the relative humidity was about 60 %. The experiment was split-plot in a RCBD with six replicates. The two water treatments were in the main plots. The sub-plots contained the four lines.

After complete emergence (about 6 days after seed planting), all pots were watered with modified Hoagland nutrient solution (Chen et al. 1997) to the drip point. Subsequently, water was withheld from one set of plants. The other set was watered regularly when needed. Four to six plants were sampled at different (0–4) days after starting the water stress treatment. These plants were used to determine the chlorophyll fluorescence parameters Fv/Fm, F0 and Fm stomatal conductance (gs), leaf area, and the relative water content of the leaves. Chlorophyll fluorescence of the leaves was determined in vivo with a portable pulse amplitude modulation fluorometer (PAM 2000, Walz GmbH, Effeltrich, Germany) after dark adaptation for 30 min. Transpiration rate and stomatal conductance were measured in vivo on the same leaves used for chlorophyll fluorescence. These gas exchange characteristics were obtained using a CIRAS-1 portable infrared gas analyzer connected to a broad Parkinson leaf chamber (PP System, Hitchin, Herts., England).

Leaf area was measured nondestructively with a portable leaf area meter (Model 100, LI-COR Inc. Lincoln, Nebraska, USA). From the
unifoliate leaf, disks were prepared and their fresh weight (Fw) was determined. Weight of fully turgent leaf disks (Tw) was obtained by keeping them at 10 °C in the dark on water-saturated filter papers in sealed Petri dishes until constant weight. Leaf disks were dried to a constant weight (Dw) at 80 °C. Relative water content (RWC) of the leaf disks was determined as follows: RWC = (Fw – Dw/Tw – Dw) × 100. The moisture of the root medium of the different lines in this experiment was determined gravimetrically.

Greenhouse experiment (responses of dry matter accumulation/partitioning and root and shoot growth characteristics to water stress)

Fifty-centimeter-deep cuboid acrylic 3.3-liter containers were used. The containers had a removable clear window on one of their sides, which was covered with black plastic-sheet. Each pot contained 3.1 kg of clean washed sand covered with a layer of pebbles, 1 to 2 cm in diameter, to prevent surface encrustation and to minimize evaporation. Two seeds were planted in each pot, which was then placed at an angle of about 60°. Seedlings were thinned to single plants 2 to 3 days after emergence. Growing plants were kept under natural daylight supplemented with artificial light providing, on average, 200 μmol m⁻² s⁻¹ PAR on the top of the plants. The average day/night temperature was 20 to 22/14 to 16 °C and the relative humidity ranged between 55 to 65 %. Seedlings were watered with either tap water or nutrient solution (the same as used in the growth chamber experiment) every other day until the first trifoliate was fully expanded (about 15 days after seed planting). Subsequently, the containers were watered with the nutrient solution to the drip point. Thereafter, the water was withheld 21 days. The experiment was a randomized complete-block design (RCB). The half number (6 plants) was harvested before the water withholding and the other at the end of the water stress period.

The depth of the deepest root was observed through the windows of the containers. The windows were then removed from the containers and the roots were divided into 10-cm-long parts. Soil samples were also taken from each 10 cm of the culture column. Subsequently, shoots were harvested and separated into leaves and stems. RWC was determined, as described in the growth chamber experiment, using leaf disks from the first trifoliate. The total leaf area of individual plants was measured. Leaves, stems, and root sections were dried to a constant weight at 80 °C. The moisture content of the soil samples was determined gravimetrically. Both the soil samples and plant organs were allowed to cool down for 2 to 3 h before determining the dry weight.

Statistical analyses

Data of all experiments were subjected to separate and combined analyses of variance (ANOVA) relevant to split-plot in RCB, as described by Gomez and Gomez (1984). The data of the two runs of each experiment were pooled based on the test of variance for the run and its interaction with the treatments. NE #19 was considered a reference line, since it was recommended for pulse legume production based on field trials in Egypt (Mohamed 1996; 2000). Therefore, the data of this line were presented to indicate the effect of drought stress on the different studied parameters. The differences between the means for the drought-stressed and non-stressed (control, in the field, and the growth chamber experiments) or for the performance before and after the drought stress (the greenhouse experiment) were compared with the Least Significant Difference Test (LSD) at 0.05 probability level. The data of the other three TP lines were presented in the form of ratios relative to NE #19 under control (C), drought stress (DS), and the difference between DS and C. The significance of the deviations for the relative means of the three TP lines from unity (NE #19, ratio = 1) was tested using Dunnett’s Test at 0.05 probability level.

Results

Growth chamber experiment (leaf growth, conductance, and the water status)

Seedlings of all TP lines were similar for all the studied parameters before starting the water withholding (day 0, data not shown). Five days after water withholding, RWC of NE #19 (reference line) fell significantly (10 %) in comparison with the well-watered (control) seedlings (Table 1 A). The leaf area of this line also fell significantly (23 %), and the changes in both the stomatal conductance (gₛ) and the transpiration rate (E) were significant in the response of NE #19 to the water stress. The moisture content in the root medium 4–5 days after the water withholding, as a percent of the control medium, was, on average, 27 ± 0.7. There were no differences in the moisture content in the root medium for the different lines (data not shown). Relative to NE #19, there were also no detectable differences in the RWC of the leaves of any of the lines, under either well-watered (C) (Fig. 1 A) or drought stress (DS) (Fig. 1B) conditions.

NE #5 and NE #7 developed a larger leaf area under the C conditions. However, their leaves had similar areas relative to NE #19 after 4–5 days of withholding the water. Contrary to NE #5 and NE #7, the leaves of NE #8A were similar in size to NE #19 in the control seedlings, but significantly larger in the DS seedlings. As indicated in Figure (1 C), the leaf expansion of NE #5 and NE #7 was more reduced in response to the water deficit than in NE #19. Therefore, in spite of the leaves larger than NE #19 under the well-watered conditions, they appeared smaller when the water was withheld. Such a relative change in NE #7 was less (P < 0.05) than in NE #5. On the other hand, the relative change in the leaf expansion for NE #8A due to the water deficit was significantly less than for NE #19. Thus, the leaves of NE #8A appeared significantly larger than NE #19 under water deficit conditions.

The stomatal conductance (gₛ) and the rate of transpiration (E) in NE #5 was similar to NE #19 in the C seedlings (Fig. 1 A). In contrast, high stomatal conductance was shown by NE #7 and NE #8A, and a high rate of transpiration was detected in NE #8A. All three studied lines were high in leaf conductance and the rate of transpiration relative to NE #19 under DS conditions. As indicated in Figure (1C) for NE #5 and NE #7, this was primarily due to the low changes for these parameters in response to drought conditions. However, NE #8A showed a reduction in the stomatal conduct-
Table 1. Effect of drought stress on the tepary bean line NE#19 grown in a controlled environment chamber (A), in the greenhouse (B), and in the field (C).1

(A) In a controlled environment chamber2

<table>
<thead>
<tr>
<th>Drought treatment</th>
<th>LA (cm²)</th>
<th>RWC (%)</th>
<th>E (mmol H₂O·m⁻²·s⁻¹)</th>
<th>gₛ (mmol H₂O·m⁻²·s⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-stressed (Control, C)</td>
<td>10.7</td>
<td>92.2</td>
<td>2.4</td>
<td>181</td>
</tr>
<tr>
<td>Drought-stressed (DS)</td>
<td>8.2</td>
<td>82.8</td>
<td>1.8</td>
<td>128</td>
</tr>
<tr>
<td>Difference</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
</tbody>
</table>

(B) In the greenhouse4

<table>
<thead>
<tr>
<th></th>
<th>PDM (g/plant)</th>
<th>SDM (g/plant)</th>
<th>STDM (g/plant)</th>
<th>LDM (g/plant)</th>
<th>LA (cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before stress (Control, C)</td>
<td>0.929</td>
<td>0.309</td>
<td>0.146</td>
<td>0.163</td>
<td>28.8</td>
</tr>
<tr>
<td>After Drought stress (DS)</td>
<td>4.384</td>
<td>0.820</td>
<td>0.415</td>
<td>0.405</td>
<td>86.2</td>
</tr>
<tr>
<td>Changes</td>
<td>3.455*</td>
<td>0.511*</td>
<td>0.269*</td>
<td>0.242*</td>
<td>57.4*</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>RM (g/plant)</th>
<th>R/S (Ratio)</th>
<th>LA/R (Ratio)</th>
<th>RD (cm)</th>
<th>RWC (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before stress (Control, C)</td>
<td>0.620</td>
<td>2.0</td>
<td>46.5</td>
<td>17.5</td>
<td>92.6</td>
</tr>
<tr>
<td>After Drought stress (DS)</td>
<td>3.580</td>
<td>4.4</td>
<td>24.1</td>
<td>45.7</td>
<td>85.4</td>
</tr>
<tr>
<td>Changes</td>
<td>2.960*</td>
<td>2.2*</td>
<td>-22.4</td>
<td>28.2*</td>
<td>-7.2*</td>
</tr>
</tbody>
</table>

(C) In the field5

<table>
<thead>
<tr>
<th></th>
<th>SDM (g/plant)</th>
<th>TSY (g/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-stressed (Control, C)</td>
<td>72.9</td>
<td>246.1</td>
</tr>
<tr>
<td>Drought-stressed (DS)</td>
<td>39.0</td>
<td>143.2</td>
</tr>
<tr>
<td>Difference</td>
<td>*</td>
<td>*</td>
</tr>
</tbody>
</table>

1 LA = leaf area; RWC = relative water content of the leaf; E = transpiration rate; gₛ = stomatal conductance; PDM = plant dry mass; SDM = shoot dry mass; STDM = stem dry mass; LDM = leaf dry mass; RM = root dry mass; R/S = root-to-shoot ratio; LA/R = the ratio of the leaf area to the root mass; RD = root depth; TSY = total seed yield.
2 Nine-day-old seedlings either grown under well-watered conditions or water withheld for 4–5 days.
3 Significant at 0.05 level of probability.
4 Plants were watered when needed for 2 weeks and then the water was withheld for 3 weeks.
5 Non-stressed and drought-stressed plants were irrigated when 58% and 72% of the available soil water was depleted, respectively.

ance and the rate of transpiration similar to NE # 19. These parameters in NE # 8A under drought conditions, therefore, were mainly affected by their high initial values under C conditions. The differences in RWC between DS and C leaves were higher for NE # 8A and lower for NE # 5 and NE # 7 than for the check line NE # 19. There were no detectable changes in the chlorophyll fluorescence parameters F₇/F₅, F₀ and F₅ (data not shown).

Greenhouse experiment (responses of dry matter accumulation/partitioning and root and shoot growth characteristics to water stress)

Relative to NE # 19 (Table 1B), there were no detectable differences in any of the studied parameters of the three TP lines (Fig. 2A) before the water withholding, except for the high R/S ratio of NE # 5. Three weeks after the water withholding (Fig. 2B), NE # 7 showed a significant decrease in the plant dry mass compared to NE # 19. This line also showed reduced stem and root dry masses, a low R/S ratio, and a high ratio of the leaf surface area to the root dry mass (LA/R). NE # 5 was similar to NE # 19 in plant and shoot dry masses. However, it produced significantly less root dry mass and larger leaves. Therefore, its R/S ratio appeared low, while the LA/R ratio was high. NE # 8A developed large leaves, but also allocated great dry mass into the root. In contrast to NE # 5 and NE # 7, its R/S and LA/R ratios were not significantly different from NE # 19.

In spite of its root elongation (Fig. 2B), NE # 5 had a smaller root mass than NE # 19, especially in the deepest levels (>40) of the soil profile (Fig. 3A). NE # 7 and NE # 8A showed
Dehydration avoidance of tepary bean

Figure 1. The leaf relative water content (RWC), leaf area (LA), transpiration rate (E), and stomatal conductance (gs) of three tepary bean lines grown under 400 µmol m⁻² s⁻¹ PAR in a controlled environment chamber: A) non-stressed (control), B) four to five days after withholding the water, and C) the difference between A and B. Stars denote significant deviation from NE #19 (the cross line at the ratio 1) using Dunnett’s test at 0.05 probability level.

Field trial (shoot growth and the seed yield)

The relative dry weight of shoot from NE # 5, NE # 7, and NE # 8A at the flowering stage under well irrigated conditions did not differ from those of NE # 19 (Fig. 4 A). However, these lines varied in the seed yield. While NE # 8A was very similar to NE 19 in the potential seed yield, both NE # 7 and NE # 5 were significantly lower (40 %) relative to NE # 19. Under DS conditions, the shoot dry weight of NE # 19 decreased significantly (46 %) as compared with the control plants (Table 1C). The reduction in the seed yield was 42 % in this line. Except for the greater shoot dry weight in NE # 8A relative to NE # 19, the figure under the DS conditions (Fig. 4 B) was the same as under C conditions (Fig. 4 A). The relative changes (Fig. 4 C), however, indicated that the reduction in the shoot dry weight

less root elongation in response to the water deficit (Fig. 2 C) and developed shorter roots than NE # 19 (Fig. 2 B). The TP NE # 7 had less root mass in all depths of the soil profile, except in the top 10 cm. However, the soil moisture around the roots of NE # 5 and NE # 7 was similar to NE # 19 (Fig. 3 B). These lines, therefore, used similar amounts of water from the top 40 cm of the soil profile. NE # 8A developed great root mass in the top 10 cm and in the depth of 20–30 cm, but an apparently small root mass in the depth of 30–40 cm. Nevertheless, the soil moisture content was higher than NE # 19 in the levels of the soil profile deeper than 20 cm. It seemed, therefore, to use less water than NE # 19. In spite of lack of differences in RWC relative to NE # 19 under DS conditions, RWC significantly decreased for the three lines due to the effects of the water deficit (Fig. 2 C). Distinctly, NE # 7 was characterized by a higher RWC reduction than NE # 5 and NE # 8A (P<0.05).

Figure 2. The leaf relative water content (RWC), the dry mass of the plant (PDM), shoots (SDM), stem (STDM), leaves (LDM) and root (RDM), the root-to-shoot ratio (R/S), the root depth in the soil profile (RD), the leaf area (LA), and the ratio of the leaf area to the root mass (LA/R) of the three tepary bean lines grown in 50-cm deep containers in the greenhouse before (A) and after (B) 3 weeks of withholding water. In (C) the differences between (A) and (B) are shown. Stars denote significant deviation from NE #19 (the cross line at the ratio 1) using Dunnett’s test at 0.05 probability level.
of all lines was relatively less than in NE # 19. The lines NE # 5 and NE # 7 had a similar reduction to NE # 19 in the potential seed yield. Nevertheless, NE # 8A showed significantly less relative reduction of its potential seed yield.

Discussion

Tepary bean is considered a dehydration postponing species. One of its main dehydration-avoidance mechanisms is stomata sensitivity (Markhart 1985). As indicated in our study in a controlled environment chamber, the four tested tepary bean lines exhibited comparatively differential leaf reactions in response to the water deficit in the limited root medium (Fig. 1C). NE # 19 and NE # 8A (high yielding lines) showed an appreciable reduction in the stomatal conductance. NE # 19, in addition, reduced its leaf expansion (23 %). NE # 8A exhibited relatively less reduction in the leaf area. Relative to NE # 19, NE # 5 (low yielding line) apparently had a great reduction in the leaf expansion but negligible change in stomatal conductance. The leaf genotype of the other low yielding line (NE # 7) responded to the water deficit in terms of reducing leaf expansion and increasing the stomatal resistance. Relatively, however the reduced leaf expansion was less than in NE # 5 and the stomatal resistance lower than in NE # 19. Considering the relative changes in the RWC, the reduction of the transpiration surface (leaf area) seemed to be more effective than increasing the stomatal resistance.

In our investigation, RWC of the leaves 4–5 days after withholding water from the small pots (growth chamber experiment) was roughly comparable (Tables 1A and B, Figs. 1B and 2B) to the 3 weeks of drought stress in containers with the 50 cm deep soil profile (greenhouse experiment). The relative changes of the RWC (Fig. 2C) suggested that transpiration started exceeding the absorption and all lines suffered more water reduction than NE # 19 in the leaf tissues. In the two low yielding lines (NE # 5 and NE # 7), this was not due to less extracted water from the upper 40 cm of the soil profile (Fig. 3B), but could be attributed to less root mass in the depth > 40 cm. The two low yielding lines accumulated less dry matter in the root. Therefore, their relative root-to-shoot ratios were lower, while the ratios of the transpiration surface to the absorption surface were higher than in NE # 19.

The importance of the deeply penetrating roots as a dehydration-avoidance mechanism has been noticed in tepary bean by several researchers (Markhart 1985, Mohamed 2000, Thomas and Waines 1982). NE # 5 and NE # 19 had a comparable root depth. However, the difference was in the
mass in the soil profile deeper >40 cm. While the deeply penetrating roots could explore water in deep soil, the greater mass in the deeper zones could enable the extraction of water from a greater volume of soil. It is noticeable, here, that the mechanism of leaf reduction was not potentially useful in NE # 5 and NE # 7 sustaining a better water status comparable to NE # 19. This is because of the slower and more gradual decrease of the moisture in the 50-cm deep containers (3.1 liter) than in the 7-cm deep pots (0.1 liter). In the former case, substantial leaf expansion occurred before the root could develop a recognizable drought signal to the leaf directing it to reduce its expansion (Loveys 1984).

The two high yielding lines (NE # 8A and NE # 19) were different in both their root depth (Fig. 2 B) and root growth patterns (Fig. 3 A). However, they had similar ratios for root-to-shoot and transpiration surface-to-water absorption mass. In spite of their comparable growth, NE # 8A seemed to use less water (Fig. 3 B). This suggests that the sensitive stomates in NE # 8A were operating towards the end of the drought period in the greenhouse experiment. Although the root of NE # 8A was not as deeply penetrating as NE # 19, its large mass could enable the extraction of water from a large volume of soil in the field. In view of the shoot growth, there was a good agreement between the greenhouse (Fig. 2 C) and the field (Fig. 4 C) experiments, where the plant samples were harvested at about the same age and with roughly comparable soil moisture in the 30–40 cm depth soil profile. All lines could use the available soil water to develop shoot growth similar to or greater than NE # 19 under these field conditions. However, the potential seed yields of NE # 8A and NE # 19 (two high yielding lines) suffered only less or similar depressions (Fig. 4 C) compared with the two low yielding lines (NE # 5 and NE # 7). Therefore, these lines remained higher in seed yield than the two low yielding lines under drought stress (Fig. 4 B). This observation suggests that the water availability during seed development was the crucial factor affecting the potential seed yield depression (Kimball and Idos 1983). In this context have the potential traits of the leaf and the root to face the increasing needs for water during seed development, and thus, NE # 19 could sustain high seed yield under drought conditions in the field. NE # 8A showed even less seed yield depression than NE # 19. Bunce (1977) suggested that rapid stomata closure of soybean [Glycine max (L.) Merr.] in response to water stress reduces transpiration more than photosynthesis. Thus, stomata sensitivity could improve photosynthetic water use efficiency. It has been well documented that increasing stomatal resistance is affected by regulating signal(s) from the partially drying roots (Loveys et al. 2000). The root of NE # 19, in contrast to the root of NE # 8A, may not develop such a recognizable drought signal since it could elongate in the field and penetrate deeply into soil profiles with high moisture contents.

In conclusion, our study indicates that the root of greater mass and deeper penetration as well as the sensitive stomates clearly differentiate between the low and the high yielding lines of tepary bean. It has been shown that the two high yielding lines may rely on different strategies of resistance to drought in the field. In particular, increasing stomatal resistance seemed to play an important role in NE # 8A, while developing a great mass for a deeply penetrating root characterized NE # 19. NE # 8A would be efficient in rationalizing water use under irrigated cultivation with a prolonged schedule. However, NE # 19 may perform better than NE # 8A for seed crops under non-irrigated cultivation, when a more severe drought is expected and the soil profile is deep.

Acknowledgements. This study is part of project # IV-1-7108-AGY/1065519 of the AvH-foundation, Germany. Their financial support is highly appreciated. We thank Assiut University, Egypt, for their support in starting this project and conducting the initial field experiments at the Agricultural Research Station of the Assiut University. Thanks are due to Dr. C. Lankes, Dr. F. Lippert, and Dr. M. Schmitz-Eiberger for their helpful discussions and assistance.

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