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EFFECTS OF WATER DEFICIT ON PHYSIOLOGY AND MORPHOLOGY OF THREE VARIETIES OF NERICA RAINFED RICE (*Oryza sativa* L.)

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ABSTRACT

Water deficit is a major problem in rice grown under rainfed conditions. It affects plant growth and development and ultimately leads to a considerable yield reduction or crop failure. Although the rice crop is susceptible to water deficit, there is a marked genotypic variation in rooting pattern in rice in response to water deficit. Drought tolerant cultivars have deep and thick roots. The thick roots are positively correlated with xylem vessel area, which are vital to the conductance of water from soil to the upper parts of the plants to meet the evaporative demand. The objective of this experiment was to investigate the possibility that the three developed rainfed rice varieties referred to as, New Rice for Africa (NERICA) and coded as N_2, N_4 and N_{11} might reveal cultivars specific diversity in the regulatory mechanisms underlying their different responses to water deficit with a view of establishing the most drought tolerant rice variety that can be grown under rainfed conditions in Kenya. This study was carried out at the University Botanic Garden, Maseno, during 2005- 2006. Plants were subjected to water deficit treatments in the green house in a factorial set up. The seeds of the three NERICA cultivars of rice were planted in 20 Litre PVC pots in the greenhouse arranged in a randomized complete block design (RCBD) with four treatments and four replications. The treatments were irrigating once a day (control) and every 2, 4 and 6 days, respectively. The parameters measured included plant height, root length, plant biomass, transpiration and stomatal conductance rate. Plant height, plant biomass and root length reduced with a decrease in water content. The stressed plants had lower transpiration and stomatal conductance rates than the well watered plants in all the three varieties. In all the parameters measured N_2 was least affected by the water deficit as compared to N_4 and N_{11}. Results indicate that N_2 has superior physiological traits under water deficit hence may be recommended for growing under rainfed conditions in Kenya.

Keywords: NERICA rice, water deficit, plant biomass, root: shoot ratio, transpiration and stomatal conductance.

INTRODUCTION

Water deficit is one of the most environmental stresses affecting agricultural productivity around the world and may result in considerable yield reductions (Boyer, 1985). Drought affects nearly all the plant growth processes; however, the stress response depends upon the intensity, rate, and duration of exposure and the stage of crop growth. Inhibition of leaf growth by water stress can be considered to be an adaptive response. Thus it limits leaf area production, eventually plants rate of transpiration (Lu and Neumann, 1998). Reduced transpiration may then prolong plant survival by extending the period of availability of essential soil water reserves in the root zone (Passioura *et al*., 1993). However prolonging survival is not usually the main problem in intensive agricultural practice. A greater concern then is that moderate (non-lethal) water stress. The effect of drought stress on the plant growth process has been extensively reported (Hsiao, 1973; Lu and Neumann, 1998). Reduction in photosynthesis in water stressed leaves may be due to stomatal closure (Hsiao, 1973). Higher stomatal conductance increases CO_2 diffusion into the leaf and favours higher photosynthetic rates. Higher photosynthetic rates could in turn favour a higher biomass and higher crop yields. Evapotranspiration at the leaf surface lowers leaf temperature and higher stomatal conductance enhances this leaf cooling. Plants regulate their diurnal water status at a favorable level by the control of stomatal aperture. Stomatal closure helps to maintain high leaf water content and thereby a higher leaf water potential, which leads to a reduction in photosynthetic activity. Plant responses to water scarcity are complex, involving deleterious and/or adaptive changes. Some of the differences among species in growth and survival can be traced to different capacities for water acquisition and transport rather than to drastic differences in metabolism at a given water status. Nevertheless, carbon assimilation at the whole plant level always decreases as a consequence of limitations to CO_2 diffusion in the leaf, diversion of carbon allocation to non-photosynthetic organs and defence molecules, or changes in leaf biochemistry that result in the down-regulation of photosynthesis. Acclimatory changes in the root: shoot ratio or the temporary accumulation of reserves in the stem of rice (Rodrigues *et al*., 1998) under water deficit are accompanied by alterations in carbon and nitrogen metabolism, the fine regulation of which is still largely unknown (Pinheiro *et al*., 2001). Drought tolerant cultivars have deep and thick roots. The thick roots are positively correlated with xylem vessel area, which are vital to the conductance of water from soil to the upper parts of the plants to meet the evaporative demand. The specific aim of this experiment was to investigate the possibility that the three NERICA rainfed rice varieties might reveal cultivars specific diversity in the regulatory mechanisms underlying their different responses to water deficit. The seeds had been developed for rain-fed culture by African rice centre in West Africa.

MATERIALS AND METHODS

The study was carried out at the University Botanic Garden, Maseno in the green house and in the field. Maseno University is situated in Western Kenya. The area receives a mean annual precipitation of 1750 mm with a bimodal distribution. The mean temperature of Maseno is 28.7^{O}C and it is approximately 1500 m above sea level. Maseno lies at latitude 0^{o}1'N - 0'12'S and longitude 34^{o}25'E - 47'E. The soils at Maseno are classified as acrisol being well drained, deep reddish brown clay with pH ranging between 4.6 and 5.4 (Mwai, 2001). The potted plants were grown in a naturally illuminated green house where the light, CO_2 concentration and temperature conditions were uncontrolled. Day temperature ranged from 20-40^{O}C and relative humidity 45-90%. Maximum photosynthetic photon flux density (PPFD) or Photosynthetic active radiation (PAR) was 250-600 μmol $m^{-2}s^{-1}$, measured at the upper leaf surface. The natural light intensity was not supplemented. Air circulation in the green house was maintained by partially opening the windows. Seeds of three NERICA rice *(Oryza sativa* L.), varieties namely NERICA 2, 4 and 11 coded as N_2, N_4 and N_{11} were obtained from the NERICA adaptability trials in the University Botanic garden, Maseno. The soil was dug from the garden then solarized for one week after which the soil was filled into 20 litre PVC pots with perforated bottoms up to ¾ full. The seeds were soaked for a day prior to planting to facilitate germination. The pots were watered to field capacity before planting. Four seeds per hill were sown and there were 4 hills per pot with a spacing of 15 x 25 cm. Diamonium phosphate (DAP) fertilizer was applied in the pots during planting at recommended rate of 52 kg/ha. Top dressing was done using calcium ammonium nitrate (CAN) fertilizer in split application of 26 kg/ha at 21 days and 26 kg/ha at panicle initiation. The experimental design was a randomized complete block design (RCBD). The treatments were; irrigating once in a day (control), after every 2 days, after 4 days and after 6 days, respectively. For the first three weeks the plants were subjected to daily irrigation of one litter of water per pot. The pots were kept weed free by hand picking the weeds.

Plant height

Measurement commenced 21 days after planting and subsequent measurements were taken after every 14 days.

Whole plant fresh weight

This was determined immediately after harvesting using an electronic weighing balance (Denver instrument model XL -31000).

Whole plant dry weight

The harvested plants were partitioned into roots, shoots and leaves. The roots were washed in tap water to remove the soil particles before drying and then placed in paper bags and dried at 80^{O}C to constant weight in an oven, the plant parts were then weighed again.

Root, shoot and stem fresh weights and dry weights

At the end of the experimental period, the whole plants per hill were uprooted, soil particles were washed off the root system and the plant separated into leaves, stem and roots. The parts were put in a paper bag and the fresh weight taken, the samples were oven dried at 80^{O}C for 4 days until a constant dry weight was obtained. The weights of the samples were then determined.

Root length

The plants were uprooted and soaked in water to wash off soil particles. The length of the root was determined by using a meter rule. Measurements were taken from the stem base to the longest root tip of the tap root.

Gas exchange

Leaf transpiration and stomatal conductance measurements were carried out using a steady-state porometer (L1-1600, LICOR, Nebraska, USA). The measurements were conducted between 0900 and 1200 hours on fully sun exposed top leaf from an area of 0.7 cm^{2}. Measurements commenced when the plants were 30 days old and consecutive measurements were taken after every 14 days. The following were the adjustments or specifications during measurements; in the greenhouse, aperture set was 0.7 cm^{2}, cuvette air temperature varied from 26^{0} to 37^{0} C, relative humidity varied from 43% to 63%. In the field plots the aperture set was 0.7cm^{2}, cuvette temperature varied from 28^{0}C to 38^{0}C, relative humidity varied from 46% to 59%, pressure set was constant at 94.65.

Data analysis

Data was subjected to analysis of variance (ANOVA) using a statistical computer package SAS to determine whether the treatments effects were significant. The treatment and variety means were separated using the least significant differences (LSD) test.

RESULTS

Plant height: There was a general decline in plant height with increasing water deficit (Figure-1). There was a significant difference ($P \leq 0.05$) in plant height among the watering regimes. The first two watering regimes had the tallest plants. The reduction in plant height with increased water deficit was more pronounced in N_{11} and N_4 as shown in Figure-1.

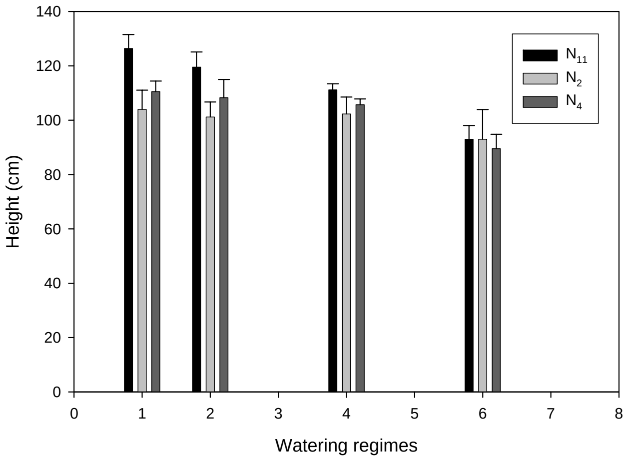

Figure-1. Effects of different watering regimes on the plant height of three NERICA rice varieties at DAS 82. Values are means of four replications ± STD DEV.

Plant biomass

There was a reduction in whole plant dry weight with the increase in water deficit (Figure-2). Plants of that were watered daily (control) had higher biomass accumulation than plants of the other watering regimes. There was a significant difference ($P \leq 0.05$) among the varieties in whole plant dry weight as shown in Figure-2a. N_{11} had the highest plant dry weight in all the watering regimes followed by N_2 and lastly N_4. There was a general increase in percentage change from the control in plant biomass with increased water deficit. N_2 had the least percentage biomass reduction from the control in all the watering regimes as shown in Figure-2b.

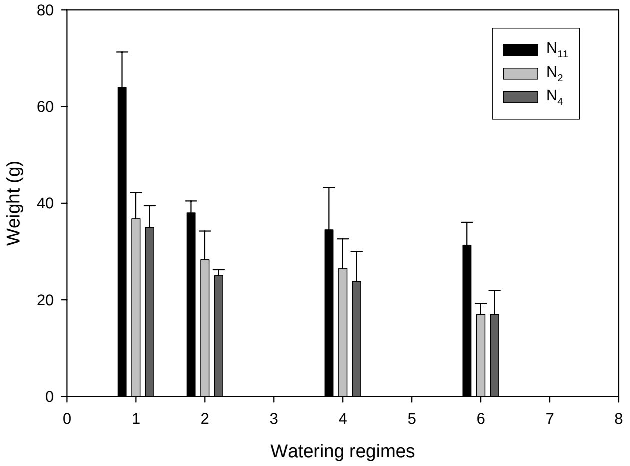

Figure-2a. Effects of different watering regimes on the whole plant dry weight of three NERICA rice varieties. Values are means of four replications ± STD DEV.

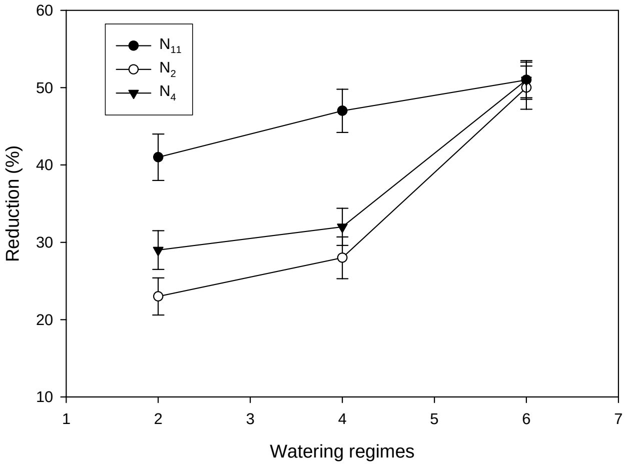

Figure-2b. Percentage change in biomass from the control of three NERICA rice varieties. Values are means of four replications ± STD DEV.

Root: shoot ratio

There was an increase in root to shoot ratio in the three varieties as water deficit increased (Figure-3). The lowest root: shoot ratio was recorded in N_{11} while N_4 had the highest root: shoot ratio in three watering regimes namely 2, 4 and 6, respectively.

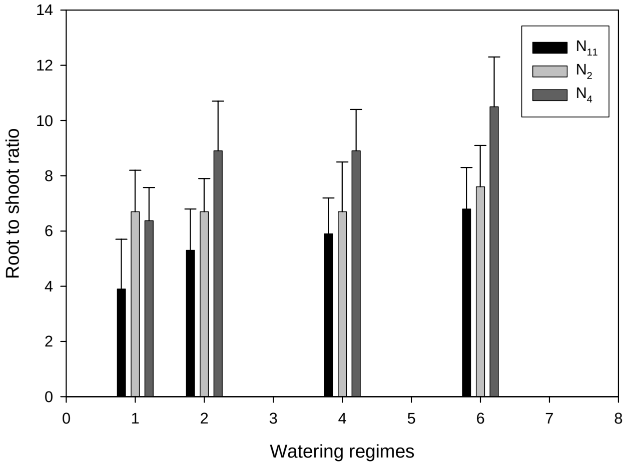

Figure-3. Effects of different watering regimes on the root: shoot ratio dry weight of three NERICA rice varieties. Values are means of four replications ± STD DEV.

Root length

There was a general reduction in root length with increase in water deficit (Figure-4). Plants of treatment 1(control) recorded higher root lengths than plants of treatments 2, 4 and 6, respectively. The most pronounced reduction occurred in N_{11}.

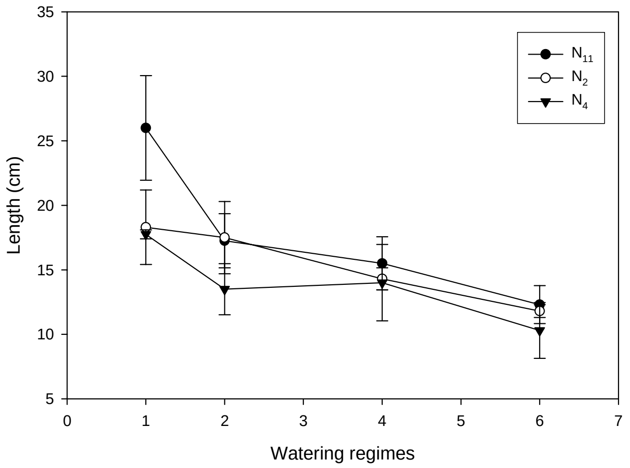

Figure-4. Effects of different watering regimes on root length of three NERICA rice varieties. Values are means of four replications ± STD DEV.

Gas exchange

There was a general decline in transpiration rate as water deficit increased (Figure-5a). The decline was most pronounced for NERICA11 and least pronounced for NERICA2. There was a significant difference ($P \leq 0.05$) among the treatments in transpiration rate. The stomatal conductance reduced remarkably among the treatments with increase in water deficit as shown in Figure-5b. There was a significant difference in stomatal conductance ($P \leq 0.05$) among the treatments. $N_{11}$was the most affected by water deficit and recorded the highest drop in stomatal conductance with increase in water deficit. The effect of water deficit was similar on N_2 and N_4 except at the plants which were watered after every four days where N_2 was more affected than N_4.

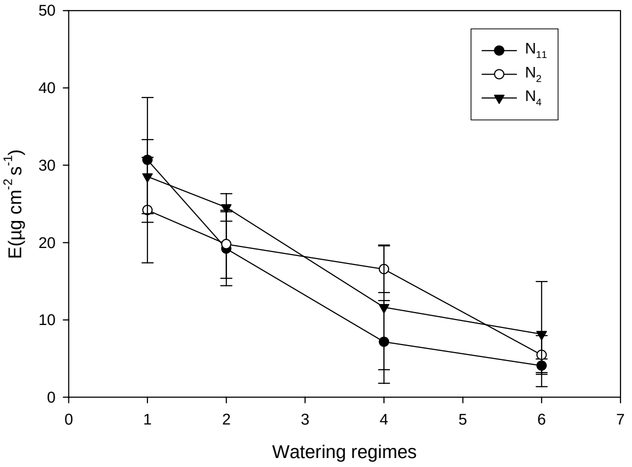

Figure-5a. Effects of different watering regimes on the transpiration rate of three NERICA rice varieties at DAS 70. Values are means of four replications ± STD DEV.

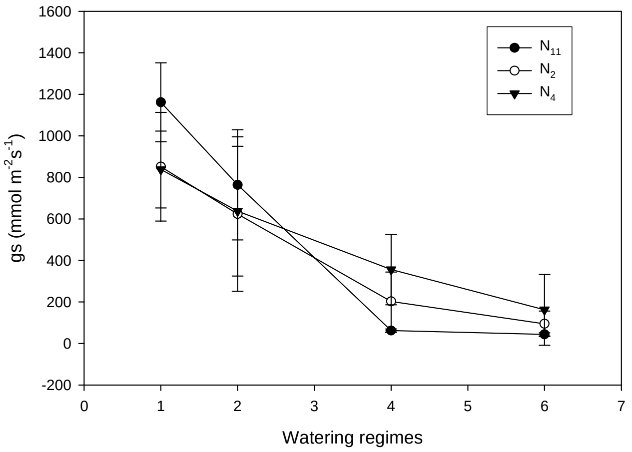

Figure-5b. Effects of different watering regimes on stomatal conductance of three NERICA rice varieties at DAS 84. Values are means of four replications ± STD DEV.

DISCUSSIONS

The general reduction in plant height with increase in water deficit (Figure-1) in rice agrees with results of Siddique *et al.* (2000) in wheat. Growth involves both cell growth and development which is a process consisting of cell division, cell enlargement and differentiation and these processes are very sensitive to water deficit because of their dependence upon turgor (Jones and Lazenby, 1988). The inhibition of cell expansion is usually followed closely by a reduction in cell wall synthesis (Salisbury and Ross, 1992).This may have affected plant height of the rice. This study has shown that NERICA 2 were generally taller than NERICA 4 and 11 at severe moisture deficit conditions. This implies that N_2 can withstand higher levels of dehydration. In terms of plant height, N_2 is the most tolerant variety among the three NERICA varieties.The shoot, leaf, root and whole plant dry weights decreased with increased water deficit. Similar results were obtained by Willumsen (1993). Large and vigorous root system and the continued production of new root hairs are required for maximum response to nutrients supply and optimum environmental conditions and that this positively correlates with the dry matter accumulation within the shoot (Willumsen, 1993). The reduction in shoot dry weight could be associated with reduced rate of leaf production hence low number of leaves. Reduction in leaf growth may also have been contributed by lower rates of cell division and cell extension in the leaves. Reduction in leaf growth leads to less photosynthesis hence retarded overall plant growth as the resources required for growth processes become limited in supply (Mwai, 2002). Decline in root and shoot dry weight under water deficit may be attributed to root damage and death thereby reducing the sink activity of the roots leading to the built up of carbohydrates (Munns and Termaat, 1986). There was inhibition of root growth which may be attributed to reduced extensibility of the root tip tissue due to hardening of the expanding cell walls. Reduced root growth would impact negatively on plant growth owing to the fact that available surface area for absorption of water and mineral salts is reduced (Neumann *et al*., 1994). In the present study, among the three NERICA varieties, N_2 recorded the least percentage biomass reduction from the control in all the treatments (Figure-2b). This implies that N_2 is tolerant to water deficit and accumulates biomass even under soil moisture deficit conditions.

Plants show increased root: shoot ratio during soil moisture deficit (Boyer, 1985). The present study on rice is in agreement with this finding. Similar results have also been obtained in mango rootstock seedlings (Luvaha, 2005). The differential sensitivity of roots and shoots (with root growth being less sensitive to water deficits) leads to large increases in the root to shoot ratio in drought (Sharp and Davies, 1985). This may be an adaptation of NERICA rice varieties for survival under drought conditions since increased root surface area allows more water to be absorbed from the soil. A reduction in shoot growth coupled with continued root growth would result in an improved plant water status under extreme water deficit conditions. In maize seedlings, root growth continues at very low water potentials which are completely inhibitory to shoot growth (Boyer, 1985). The three NERICA varieties may posses' mechanisms of biomass accumulation under moisture deficit conditions. In this study N_2 exhibits superior tolerance to water deficit in terms of biomass accumulation. Transpiration rates in the NERICA rice varieties generally decreased with increase in soil water deficit (Figure-5a). Similar results have been observed in beans (Ohashi *et al*., 2004). Decrease in transpiration may be due to increased hydraulic resistance to the movement of water at the leaf and root surfaces (Kingsbury *et al*., 1983). Transpiration is controlled by the closing and opening of the stomata. Guard cells loose their turgidity under soil moisture deficit conditions causing stomatal closure. This limits the rate of CO_2 diffusion through the stomates causing a decline in the photosynthetic rates (Luvaha, 2005). The transpiration rate in NERICA 4 and 11 reduced with increasing water deficit but N_2 maintained a relatively high transpiration rate up to treatment 4. This shows that N_2 is fairly more tolerant to moisture deficit than NERICA 4 and 11 and can photosynthesize under certain levels of soil moisture deficit. There was a significant difference among the varieties in the stomatal conductance ($P \leq 0.05$). The stomatal conductance of NERICA 2, 4 and 11 declined with increase in water deficit (Figure-5b). Luvaha (2005) had similar results with the mango root stock seedlings. The reduction in soil moisture may have led to lower water content in the leaves causing guard cells to loose turgor and hence the stomatal pores to reduce (Tezera *et al*., 2002). In addition, increased stomatal resistance may have led to reduced water transport in the leaves further causing a decrease in stomatal conductance. Reduction in stomatal conductance decreases transpiration and limits photosynthesis (Tezera *et al.,* 2002).

CONCLUSIONS

The present study has shown that water deficit leads to a reduction in plant growth and biomass accumulation. In terms of plant growth NERICA 2 is the most tolerant among the three varieties and is able to accumulate higher biomass under soil moisture deficit conditions.

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REFERENCES

Boyer J. S. 1985. Water transport. Ann. Rev. Plant Physiol. 36: 473-516.

Jones B.M. and Lazenby A. 1988. The grass crop, the physiological basis of production. Chapman and Hall, London. pp. 226-240.

Kingsbury R.W., Epstein E., Pearly R.W. 1983. Physiological responses to salinity in selected lines of wheat. Plant Physiol. 74: 417-423.

Luvaha Elizabeth. 2005. The effects of water deficit on the growth of mango (*Mangifera indica*) rootstock seedlings. M.Sc Thesis. Maseno University, Kenya.

Munns R. and Termaat A. 1986. Whole plant responses to salinity. Aust. J. Plant Physiol. 13: 143-166.

Mwai G.N. 2001. Growth response of spider plant (*Cleome gynandra* L.) to salinity. M.Sc.Thesis. Maseno University, Kenya.

Neumann P.M., Azaizen H. and Leon D. 1994. Hardening of root cell walls: A growth inhibitory response to salinity stress. Plant Cell Envt. 17: 303-309.

Ohashi Y., Nakayana N., Hirofumi S. and Kounosuke F. 2004. Changes in photosynthetic gas exchange, chlorophyll fluorescence and stem diameter of soybean plants under drought stress conditions. 4th international crop science congress Brisbane, Australia.

Pinheiro C., Chaves M.M., Ricardo C.P.P. 2001. Alterations in carbon and nitrogen metabolism induced by water deficit in the stem and leaves of *Lupinus albus* L. Journal of Experimental Botany. 52: 1063-1070.

Salisbury B. and Ross W. 1992. Plant physiology. 4th edition, Wadsworth, Belmont, California. pp. 580-585.

Schulze E.D. 1986. Carbon dioxide and water vapor exchange in response to drought in the atmosphere and in the soil. Annual Revelation Plant Physiol. 37: 247-274.

Sharp R.E. and Davies W.J. 1985. Root growth and water uptake by maize plants in drying soil. Expt. Bot. 36: 1441-1456.
Siddique M.R., Hamid A., Islam M. 2000. Drought stress effects on water relations of wheat. Bot. Bull. Acad. 41: 35-39.

Rodrigues ML, Pacheco CA. Chaves MM. 1995. Soil-plant relations, root distribution and biomass partitioning in *Lupinus albus* L. under drought conditions. Journal of Experimental Botany. 46: 947-956.

Tezara W., Mitchel V., Driscul S.P. and Lawlor D.W. 2002. Effects of water deficit and its interaction with CO_2 supply on the biochemistry and physiology of photosynthesis in sunflower. Exp. Bot. 53: 1781-1791.

Willumsen J. 1993. Assessment of fluctuations in water and air content of pot substrates during plant growth. Acta. Hort. 295: 249-259.