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EFFECT OF DROUGHT STRESS AND MYCORRHIZAL INOCULATION ON THE GROWTH, PHOTOSYNTHETIC ACTIVITY AND WATER USE EFFICIENCY OF LEEK (*ALLIUM PORRUM* L. 'GIGANTE SUIZO')

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Abstract

JEZDINSKÝ, A., PETŘÍKOVÁ, K., SLEZÁK, K., POKLUDA, R.: *Effect of drought stress and mycorrhizal inoculation on the growth, photosynthetic activity and water use efficiency of leek (Allium porrum L. 'Gigante Suizo').* Acta univ. agric. et silvic. Mendel. Brun., 2012, LX, No. 8, pp. 101–108

During the experiments it was examined two irrigation levels: 1. optimal water supply – the irrigation activation by available water capacity (AWC) < 65 %; 2. drought stress – irrigation activation by AWC < 45 %) and inoculation of plants by the vesicular-arbuscular mycorrhizal fungus *Glomus* in leek culture. The effect of treatments on the photosynthetic rate (A), transpiration rate (E), water use efficiency (WUE), biomass production (weight, dry matter content of different plant part), size of pseudostem, leaf area and specific leaf area (SLA) was observed. The drought stress had effect on all observed parameters: it decreased the photosynthetic and transpiration rate (A: from 5.04–5.37 to 3.33–3.43 µmol $CO_2.m^{-2}.\ s^{-1}$, E: from 1.78–1.91 to 0.99–1.03 mmol $H_2O.\ m^{-2}.\ s^{-1}$ in the average of 5 measuring date), the weight total fresh weight of plants: from 355–453 g to 152–255 g), and the leaf area, the length and diameter of pseudostem, too. The WUE, the dry matter content and the thickness of leaves increased under stress. In the most parameters, the water supply had stronger effect than the inoculation. The inoculation had positive effect mainly under drought stress: it improved the WUE at 3 measuring time (from 3.45 to 3.50 µmol CO_2.mmol H_2O^{-1}, in the average of 5 measuring date), increased the weight (total fresh weight of plants: from 152 g to 255 g) and the leaf area (from 0.16 to 0.12 m^2).

leek, *Glomus,* inoculation, morphology, photosynthetic rate, specific leaf area, water use efficiency (WUE)

Nowadays, there are many studies about the effect of inoculation of plants by microorganism. In the nature, one of the most important genus of the vesicular-arbuscular mycorrhizal fungus is *Glomus*. Many vegetable species have shown the positive effect of inoculation on the plant growth (Kim *et al.*, 2002; Sensoy *et al.*, 2007; Wang *et al.*, 2008), nutrient uptake (Smith, Read, 2008) and stress tolerance (Gianinazzi-Pearson, 1996). Literature sources demonstrated the effect of colonization on the plant physiological process (water use efficiency, photosynthetic rate, stomatal conductance) (Ruiz-Lozano and Gomez, 1995; Davies *et al.*, 2002; Nowak, 2004; Jezdinský *et al.*, 2012).

The leek (*Allium porrum* L.) is important crop in most each countries of European Union. It has moderate temperature demand; the optimum for growing is between 13–24 °C (Maynard, Hochmuth, 2007). The water demand of the leek in the vegetation period is 500–550 mm (Malý, 2006). It is sensitive to the drought stress (Sørensen, 1996). In the experiment of Gutezeit (2000) in sandy soil, the soil moisture levels between 40 and 70 vol% available water had no significant effect on the total mass at harvest, however, the lower (25%) moisture content was observable like strong drought stress. Comparing different water supply systems, Sørensen *et al.* (1995) observed the decreasing of yield of leek at a soil water potential of −0.09 MPa at 20 cm depth.

More than 20 years it is known the possibility of vesicular-arbuscular mycorrhizal relationships between leek and more *Glomus* species. The ability of different *Glomus* species is different (Hamel *et al.*, 1997; Hepper *et al.*, 1988).

Sorensen *et al.* (2003) examined the effect of the *Glomus intraradices* inoculation, and they observed favorable growth of leek, more intensive P and Zn uptake.

The aim of this work was to evaluate the effect of *Glomus* sp. on physiological parameters, biomass production and some morphological properties of leek, grown at two water supply levels.

MATERIALS AND METHODS

The experiment was conducted in plastic tunnel in Lednice at the Faculty of Horticulture of Mendel University in Brno, in 2011. The tested plant material was *Allium porrum* L. 'Gigante Suizo'. The evaluation was conducted in four replications, at two different irrigation levels and with / without inoculation treatment.

The experiment was based on two different levels of irrigation being activated automatically by moisture sensors VIRRIB, which triggered the irrigation when it goes below the set value. The water supply level was:

- optimal water supply: the irrigation was activated when available water capacity (AWC) decreased below 65 %;
- drought stress: the irrigation was activated when AWC decreased below 45 %.

Inoculation was done by mycorrhizal product Symbivit® (Symbiom Ltd., CZ). The product contains natural clay carriers and six mycorrhizal fungi (*Glomus intraradices* BEG140, *Glomus mosseae* 95, *Glomus. etunicatum* BEG92, *Glomus claroideum* BEG96, *Glomus. microaggregatum* BEG56, *Glomus geosporum* BEG199). This product was applied at 100 ml per 1 L of substrate Klassman TS 3. The variants consist of control and by plants treated with the product Symbivit® (referred to *Glomus* sp. in the experiment).

The seeds were sown into the trays on March 28th. Planting took place on May 25th. The spacing was 0.5 × 0.1 m. The date of the harvest was October 20th.

The main climate characteristic of the vegetation period was: average temperature: 18.3 °C, amount of rainfall: 238.9 mm, number of sunny hours: 1237.

It was measured the photosynthetic activity and the transpiration of leaves of 80 % of their final development, five times during the vegetation. Methods of measurement of physiological parameters: The portable photosynthetic system LCpro+ with an infrared gas analyzer and leaf chamber was used to measure the rate of transpiration (E [mmol. H_2O m^{-2}. s^{-1}]) and the rate of photosynthesis (A [µmol CO_2. m^{-2}. s^{-1}]). The conditions of chamber: 25 °C (based on results Doran *et al.*, 2004), light irradiance 650 µmol m^{-2}s^{-1}. The water use efficiency was calculated based on the following formula: WUE = A / E [µmol CO_2 × mmol H_2O^{-1}]. Values were measured in the upper leaf surface – determined from the tip of sheet. The 3 plants were measured at each repetition. Measuring dates (Optimal water supply / Drought stress treatment): 29. 6. / 30. 6., 12. 7. / 13. 7., 2. 8. / 3. 8., 17. 8. / 18. 8., 31. 8. / 1. 9. (5th, 7th, 10th, 12th and 14th weeks after planting). In case of the stress treatment the plots were not irrigated at least for 1 week. The soil temperature and moisture data in the measuring days are presented in Tab. I.

At the harvest, it was measured morphological parameters and biomass production of plants. The measuring were conducted based on 20 plants per treatments. The examined parameters were:

- fresh weight (FW) and dry weight (DW) of all plants and plant parts (root system, pseudostem – main edible part –, green leaves [gram],
- dry matter content (DM) of main plant parts [%],
- length [LW, mm] and diameter [DW, mm] of pseudostem,
- total (green) leaf area [LA, m^2],
- specific leaf area (ratio of total leaf area and dry weight of leaves) [SLA,m^2. kg^{-1}].

RESULTS AND DISCUSSIOS

The effect of treatments on the photosynthetic activity and water use efficiency is presented on Fig. 1–2.

I: *Soil temperature and soil moisture conditions of the measuring dates*

Measuring period (weeks after planting)	Optimal water supply		Drought stress	
	Soil temperature [°C]	Available Water Content [%]	Soil temperature [°C]	Available Water Content [%]
5th	26.7	78.6	23.2	31.6
7th	24.6	70.8	24.1	14.3
10th	20.7	100.0*	21.5	38.9
12th	22.9	65.3	24.1	6.5
14th	20.8	97.2	19.3	5.3

*saturated

Under drought stress condition, the **photosynthetic rate** (A) was observed lower than in the optimal water supply. The decrease was stronger in the second part of the measuring period. Examined the effect of *Glomus* sp. inoculation, it was observed – statistically confirmed – positive effect of it at 2 measuring date (7th and 12th week). During this two measuring date was the soil moisture level low and the soil temperature was relatively high. The values of these environmental conditions are out of the threshold of the optimal range of the leek (Gutezeit, 2000; Maynard, Hochmuth, 2007).

The tendency of **transpiration rate** (E) was similar to the photosynthetic rate (A).

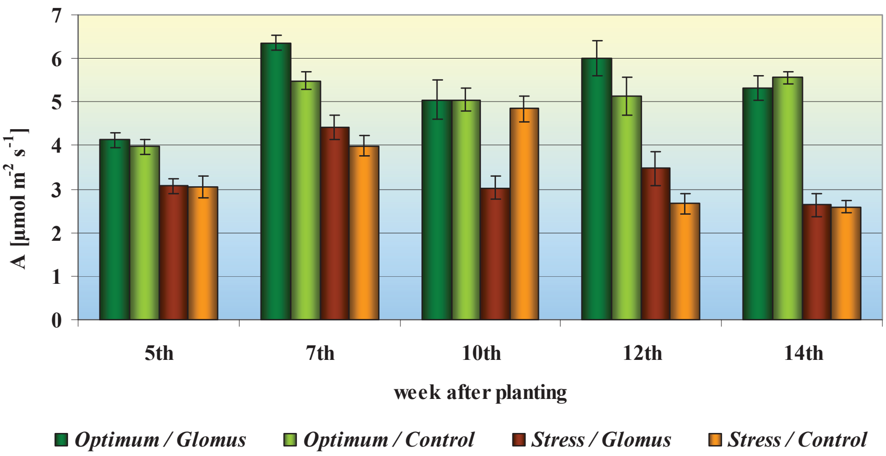
The decrease of the photosynthetic and transpiration rate confirms the sensitivity of leek to the drought stress (Sørensen, 1996), and also the sensitivity of these processes to the water deficit (Blum, 2005; Chaves *et al.*, 2009; Jezdinský *et al.*, 2012).

The **water use efficiency** of the plants (A to E ratio) were higher in the case of stressed plants at all measuring dates. This is in accordance with experience of Blum (2005) and Thiagarajan *et al.* (2008). The inoculation showed the significant effect only in the stress, but the direction of such effect was not clear. At the 7th, 12th and 14th week it was observed positive effect of *Glomus* sp., while at the 10th was found significantly negative effect to WUE.

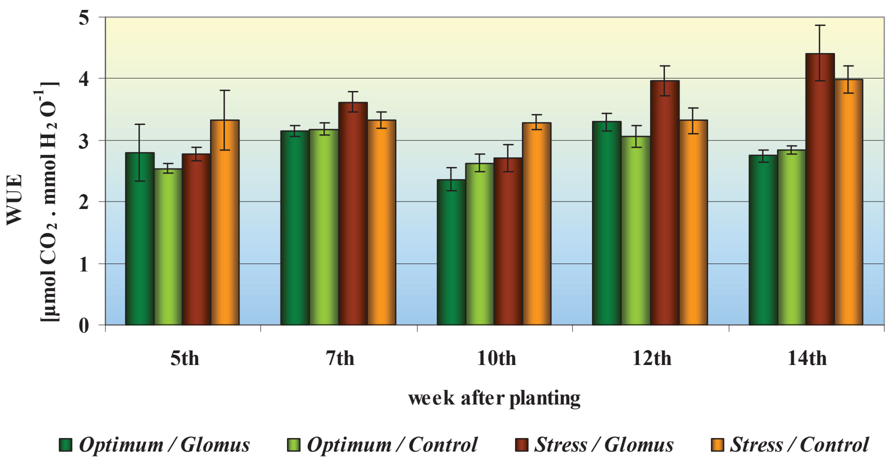
Based on the comparing of the tendency to the soil moisture values, it can be seen that the positive effect of *Glomus* sp. inoculation is confirmed in case of very low soil moisture content (5.3–14.3 AWC %).

The **weight** of the plants and different plant parts are summarized in Tab. II. and III. According to the results of measuring of the total biomass production (whole plant weight), the most favourable treatment was the *Glomus* sp. inoculation with optimal irrigation. The result confirmed the examination of Sorensen *et al.* (2003). In drought stress, the positive effect of inoculation was confirmed in case of all plant part weight. Under stress condition, the inoculation resulted by similar weight like the control plants grown under optimal water supply condition, in the most case.

The **dry matter content** was highest in the control treatment in stressed treatment. According to the results of two-factor analysis of variance, the water supply had stronger effect on the dry matter content of each part, and on the fresh weight of root system,



1: *Photosynthetic rate (A) of leek leaves*



2: *Water use efficiency (WUE) of leek leaves*

II: *Weight of the plants and different plant parts [grams, %]*

Parameter		Optimal irrigation				Drought stress			
		Glomus		Control		Glomus		Control	
Whole plant	**FW**	453.26	a	334.28	b	255.85	b	152.14	c
	DW	60.05	a	44.43	b	39.24	b	26.51	c
	DM	13.25	c	13.29	c	15.34	b	17.42	a
Root system	**FW**	31.92	a	29.59	ab	21.64	b	16.89	c
	DW	4.32	a	3.89	ab	3.03	ab	2.77	b
	DM	12.45	bc	12.30	bc	13.66	b	14.85	a
Pseudostem	**FW**	151.22	a	122.91	ab	96.74	b	53.87	c
	DW	25.23	a	18.30	b	16.72	b	11.13	c
	DM	14.94	b	14.20	b	17.38	a	18.52	a
All leaves	**FW**	270.13	a	181.78	b	137.46	b	81.38	c
	DW	30.50	a	22.24	b	19.50	b	12.62	c
	DM	10.39	b	11.13	b	13.81	a	14.33	a

DM: dry matter content [%], FW: fresh weight [g] DW: dry weight [g]. Note: different letters placed beside the averages designate (by rows) the treatments that are statistically different at a $p < 0.05$ level

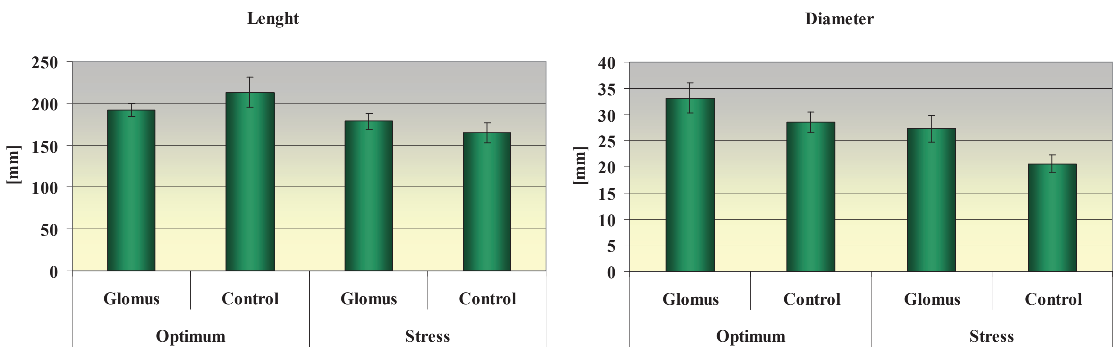
III: *Effect of different conditions on the fresh weight and dry matter content of plant parts*

Conditions	Root system		Pseudostem		Green leaves	
	FW [g]	DM [g]	FW [g]	DM [g]	FW [g]	DM [g]
Water supply (*Glomus and Control treatments together*)						
Optimal	30.75	12.37	137.07	14.57	225.95	26.37
Stress	19.27	14.26	75.31	17.95	109.42	16.06
Treatments (*Optimal water supply and stress conditions together*)						
Glomus	26.78	13.05	123.98	16.16	203.79	25.00
Control	23.24	13.57	88.39	16.36	131.58	17.43
Statistical effect of conditions (p-values and level of significance)						
Water supply	0.0000*	0.0001*	0.0000*	0.0000*	0.0000*	0.0000*
Treatment	0.1483	0.2632	0.0000*	0.7435	0.0000*	0.1441
Water supply x Treatment	0.6188	0.1504	0.3724	0.1163	0.2414	0.7995

*The statistical analyses confirmed differences on the level at a $p < 0.05$

than the inoculation. However, the inoculation and water supply had equally strong effect on the fresh weight of aboveground parts.

The **size of the consumed part** plant (pseudostem) was more favourable in the optimal irrigation (Fig. 3). The diameter of inoculated plants grown under drought stress was statistically same like the plants grown under optimal irrigation, without inoculation. In the optimal irrigation, the inoculated plants were characterized by shorter, and thicker pseudostem than the control plants. Based on the results of two-factor analysis of variance



3: *Size of the leek pseudostem*

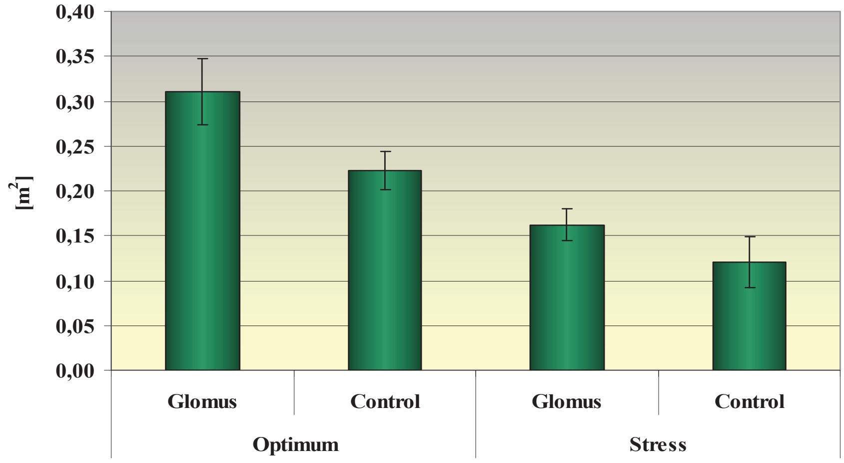
IV: *Effect of different conditions on the size of pseudostem, leaf area (LA) and specific leaf area [SLA]*

Conditions	Pseudostem		Leaf area (LA) [m²]	Specific leaf area (SLA) [m².kg⁻¹]
	Lenght [mm]	Diameter [mm]		
Water supply (*Glomus and Control treatments together*)				
Optimal	202.85	30.80	0.2666	10.22
Stress	171.75	23.93	0.1416	9.00
Treatments (*Optimal water supply and stress conditions together*)				
Glomus	185.60	30.18	0.2365	9.35
Control	189.03	24.55	0.1716	9.87
Statistical effect of conditions (p-values and level of significance)				
Water supply	0.0000*	0.0000*	0.0000*	0.0024*
Treatment	0.5750	0.0000*	0.0000*	0.1860
Water supply x Treatment	0.0054*	0.3557	0.0680	0.1091

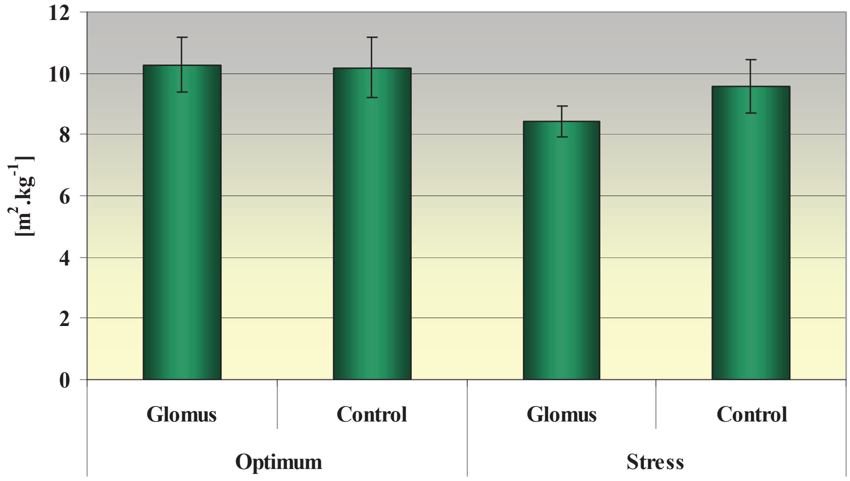
*The statistical analyses confirmed differences on the level at a $p < 0.05$

(Tab. IV), the optimal water supply and inoculation has equally strong positive effect on the diameter.

The inoculated plants grown under optimal irrigation developed significantly bigger **leaf area** (LA) than in the other plots (Fig. 4). In this parameter the water supply and inoculation has equally positive effect: the drought stress decreased the leaf area, while the *Glomus* sp. inoculation increased it, in



4: *Leaf area (LA) of plants*



5: *Specific leaf area (SLA)*

both water supply level (Tab. IV). This observation is in accordance to the result of Aguilera-Gomez *et al.* (1999) in sweet pepper test plants.

The effect of water supply had effect also on the **thickness of the leaves**. The inoculation has effect on it only under drought stress. The lowest specific leaf area (SLA) – the thickest leaves – was developed by the plants grown in the drought stress with inoculation (Fig. 5, Tab. IV).

CONCLUSIONS

The evaluation of physiological processes change, the biomass production and the morphological parameters, confirmed the sensitivity of the leek to the drought stress.

The water supply had stronger effect on observed parameters, than the inoculation by *Glomus*. The inoculation by *Glomus* sp. promotes the growth of the plants, mainly under drought stress. However, the values of fresh weight of aboveground parts, the diameter of pseudostem and the leaf area are higher as effect of *Glomus* symbiosis, under optimal or low water supply conditions. The *Glomus* sp. inoculation at the stress conditions positively influenced the plants to reach almost same favourable results, like the plants grown with optimal irrigation, without inoculation.

SUMMARY

The aim of the experiment was to evaluate the effect of inoculation *Glomus* sp. on some physiological parameters, biomass production and some morphological properties of leek grown at two water supply levels (optimal water supply and drought stress; irrigation activation by AWC < 65 % and < 45 %, respectively). It was measured the photosynthetic activity (A) and the transpiration (E) of leaves of 80 % of their final development, five times during the vegetation, by the portable photosynthetic system LCpro+. At the harvest, it was measured morphological parameters and biomass production of plants: fresh weight and dry weight of all plants and plant parts (root system, pseudostem of leaves – main edible part –, green leaves; dry matter content of main plant parts, length and diameter of pseudostem of leaves, total (green) leaf area, specific leaf area (ratio of total leaf area and dry weight of leaves). The drought stress decreased the photosynthetic and transpiration rate (A: from 5.04–5.37 to 3.33–3.43 µmol CO_2. m^{-2}. s^{-1}, E: from 1.78–1.91 to 0.99–1.03 mmol $H_2O.m^{-2}$. s^{-1} in the average of 5 measuring date), the weight total fresh weight of plants: from 355–453 g to 152–255 g), and the leaf area, the length and diameter of pseudostem, too. The WUE, the dry matter content and the thickness of leaves increased under stress. In the most parameters, the water supply had stronger effect than the inoculation. The inoculation had positive effect mainly under drought stress: it improved the WUE at 3 measuring time (from 3.45 to 3.50 µmol CO_2. mmol H_2O^{-1}, in the average of 5 measuring date) and increased the weight (total fresh weight of plants: from 152 g to 255 g). In case of more examined parameter, the inoculated plants reached almost same results under stress, like the plants in optimal irrigation, without inoculation.

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REFERENCES

AGUILERA-GOMEZ, L., DAVIES, F. T., OLALDE-PORTUGAL, V., DURAY, S. A. and PHAVAPHUTANON, L., 1999: Influence of phosphorus and endomycorrhiza (*Glomus intraradiens*) on gas exchange and plant growth of chile ancho pepper (*Capsicum annuum* L. cv. San Luis). *Photosynthetica*, 36, 3: 441–449.

BLUM, A., 2005: Drought resistance, water-use efficiency, and yield potential – are they compatible, dissonant, or mutually exclusive? *Australian Journal of Agricultural Research*, 56: 1159–1168.

CHAVES, M. M., FLEXAS, J. and PINHEIRO, C., 2009: Photosynthesis under drought and salt stress: regulation mechanisms from whole plant to cell. *Annals of Botany*, 103: 551–560.

DAVIES JR., F. T., OLALDE-PORTUGAL, V., AGUILERA-GOMEZ, L., ALVARADO, M. J., FERRERA-CERRATO, R. C. and BOUTTON, T. W., 2002: Alleviation of drought stress of Chile ancho pepper (*Capsicum annuum* L. cv. San Luis) with arbuscular mycorrhiza indigenous to Mexico. *Scientia Horticulturae*, 92, 3–4: 347–359.

DORAN, J., LAIRSON, L., GRODZINSKI, B. and MCDONALD, M. R., 2004: Leaf photosynthesis and transpiration of two leek cultivars with differing pseudostem pungency levels. *Acta Horticulturae*, 633, pp. 51–57.

GIANINAZZI-PEARSON, V., 1996: Plant Cell Responses to Arbuscular Mycorrhizal Fungi: Getting to the Roots of the Symbiosis. *Plant Cell*, 8, 10: 1871–1883.

GUTEZEIT, B., 2000: Using a non-destructive growth measurement tehcnique to estimate the critical soil moisture level for leek. *Acta Horticulturae*, 537, pp. 805–812.

HAMEL, C., DALPÉ, Y., FURLAN, V. and PARENT, S., 1997: Indigenous populations of arbuscular mycorrhizal fungi and soil aggregate stability are major determinants of leek (*Allium porrum* L.) response to inoculation with *Glomus intraradices* Schenck & Smith or *Glomus versiforme* (Karsten) Berch. *Mycorrhiza*, 7, 4: 187–196.

HEPPER, C. M., AZCON-AGUILAR, C., ROSENDAHL, S. and SEN, R., 1988: Competition between three species of *Glomus* used as spatially separated introduced and indigenous mycorrhizal inocula for leek (*Allium porrum* L.). *New Phytologist*, 110, pp. 207–215.

JEZDINSKÝ, A., VOJTÍŠKOVÁ, J. SLEZÁK, K., PETŘÍKOVÁ, K. and POKLUDA, R., 2012: Effect of drought stress and *Glomus* inoculation on some physiological process of sweet pepper (*Capsicum annuum* L. cv. 'Slávy'). *Acta Universitatis Agriulturae et silviculturae Mendelianae Brunensis*, 60, 3: 69–76. ISSN 1211-8516.

KIM, K. Y., CHO, Y. S., SOHN, B. K., PARK, R. D., SHIM, J. H., JUNG, S. J., KIM, Y. W. and SEONG, K. Y., 2002: Cold-storage of mixed inoculum of *Glomus intraradices* enhances root colonization, phosphorus status and growth of hot pepper. *Plant and Soil*, 238, pp. 267–272.

MALÝ, I., 2006: Pór. In: K. Petříková et al. (eds.) Zelenina pěstování ekonomika prodej. Profi Press s.r.o., Praha. pp. 116–118. ISBN 80-86726-20-7.

MAYNARD, D. N. and HOCHMUTH, G. J., 2007: Knott's Handbook for vegetable growers. 5th edition. John Wiley & Sons Inc., Hoboken. ISBN 978-0-471-73828-2.

NOWAK, J., 2004: Effects of arbuscular mycorrhizal fungi and organic fertilization on growth, flowering, nutrient uptake, photosynthesis and transpiration of geranium (*Pelargonium hortorum* L. H. Bailey 'Tango Orange'). *Symbiosis*, 37, pp. 259–266.

RUIZ-LOZANO, J. M. and GOMEZ, M., 1995: Effects of arbuscular-mycorrhizal *Glomus* species on drought tolerance: Psychological and nutritional plant responses. *Applied and Environmental Microbiology*, 61, pp. 456–460.

SENSOY, S., DEMIR, S., TURKMEN, O., ERDINC, C. and SAVUR, O. B., 2007: Responses of some different pepper (*Capsicum annuum* L.) genotypes to inoculation with two different arbuscular mycorrhizal fungi. *Scientia Horticulturae*, 113, pp. 92–95.

SMITH, S. E. and READ, D. M., 2008: *Mycorrhizal Symbiosis* (3rd ed.), Academic Press, London. 605. p. ISBN 9780123705266.

SØRENSEN, J. 1996: Improved efficiency in vegetable production by fertilizer placement and irrigation. *Acta Horticulturae*, 428, pp. 131–140.

SØRENSEN, J. N., JOHANSEN, A. S. and KAACK, K., 1995: Marketable and nutritional quality of leeks as affected by water and nitrogen supply and plant age at harvest. *Journal of the Science of Food and Agriculture*, 68, pp. 367–373.

SORENSEN, J. N., LARSEN, J. and JAKOBSEN, I., 2003: Management strategies for capturing the benefits of mycorrhizas in the production of field-grown vegetables. *Acta Horticulturae*, 627, pp. 65–71.

THIAGARAJAN, A., LADA, R. R. and ADAMS, A., 2008: Optimizing photosynthetically active radiation and moisture regimes can enhance water efficiency in carrots. *Acta Horticulturae*, 767, pp. 53–58.

WANG, C., LI, X., ZHOU, J., WANG, G. and DONG, Y., 2008: Effects of Arbuscular Mycorrhizal Fungi on Growth and Yield of Cucumber Plants. *Communications in Soil Science and Plant Analysis*, 39, 3–4: 499–509.

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