IMPROVING THE WATER USE EFFICIENCY OF CROP PLANTS BY APPLICATION OF MYCORRHIZAL FUNGI

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Summary
In 2008 the European Union obligated itself to increase the proportion of renewable energy to 20 % of the total energy consumption and to 10 % biofuel in transportation fuel by 2020. Besides forestry, field crops are necessary to achieve this goal (Rechberger & Lötjönen, 2009).
In Germany the production of biogas from energy crops is very popular, whereas research mainly focuses on technological solutions rather than farming systems. Since the largest contribution to biogas production of about 85%, comes from the agricultural sector in Germany, it is important to ensure a sustainable production of these energy crops (Gabauer & Dörrie 2009).

Sustainable and resource conserving management of agricultural production systems includes efficient management of soil microorganisms such as mycorrhizas (Jeffries et al. 2003, Selosse et al. 2004, Bunemann et al. 2006, Vosátka and Albrechtová 2009, Gianinazzi et al. 2010).

In a multi- year lysimeter experiment we investigated the influence of a commercial mycorrhiza inoculum on the water use efficiency and biomass production of the 'energy plants': Maize, Sunflower, Sweet clover, Sweet sorghum, *Silphium perfoliatum* and the Szarvazi-1" energy grass when exposed to high or low ground-water levels.

Results showed that independent from the species, plants benefited from the mycorrhiza symbiosis. Mycorrhizal plants were more effective in terms of dry matter production and water use than the non-mycorrhizal plants, independent of the fungal origin –introduced or autochthonous. However, different plant species responded differently to the application of mycorrhizal fungi.

The results indicate that inoculation with mycorrhiza and promotion of the natural abundant mycorrhiza in agricultural production systems can significantly contribute to a sustainable production of energy crops. Effects depend on plant species, cultivar, soil type, ground-water level and the mycotrophy of the individual energy crop species.

Introduction
Energy crops are plants with high contents of lignin and cellulose in their biomass. They are specifically grown to transform their biomass into fuel or heat. Energy crops can be grown in low-input systems and are still profitable for farmers (Wang et al 2013).

One ecological benefit expected from the production and use of energy crops is the substitution of fossil fuels as an important contribution to reduce anthropogenic CO_2 emissions (Schrama et al., 2014; Koçar & Civaş, 2013). Therefore energy crops are considered as sustainably produced biomass which preserves fossil resources. A whole range of different crop species are used as energy plants. To ensure a sufficient supply, a cost-effective and ecologically sustainable production, the cultivation system has to be highly efficient. The various energy crop species differ not only in their productivity and in the chemical and physical properties of their biomass, but also in the environmental requirements such as climate, soil and groundwater levels and crop management (Lewandowski, 2003). The choice of plant species needs to fit all these conditions.

Due to the long growing season and the deep rooting system energy crops often have a high water use. Therefore, aspects of energy crop water use and water availability can be crucial for the cultivation (Jørgensen & Schelde, 2001). North East Germany has an annual precipitation of 500 - 550 mm and dry springs. A high water use efficiency of the energy crops is crucial for cultivation and high crop yield.

Arbuscular mycorrhiza (AM) the symbiotic association between soil fungi and plant roots are known to protect host plants from the harmful effects of drought (Auge´, 2001; Ruiz-Lozano, 2003; Boomsma, 2008) and to improve the nutrient uptake and growth of plants under water stress conditions. Various experiments under controlled and field conditions have shown, that the mycorrhizal colonization of roots increased drought tolerance of different crops such as maize (Sylvia et al., 1993; Subramanian et al., 1995) wheat (Bryla and Duniway, 1997), soybean (Bethlenfalvay et al., 1988), onion (Azco´n and Tobar, 1998), lettuce (Tobar et al., 1994a,b; Azco´n et al., 1996; Ruiz-Lozano and Azco´n, 1996), or red clover (Fitter, 1988). One of the mechanisms of the mycorrhizal symbiosis on host plant water balance is the increased root biomass and subsequently plant size. In particular the mobilization and uptake of phosphorus is often related to an increase in plant size (Subramanian 2006).

This study focused on the influence of a commercial mycorrhiza inoculum on the water use efficiency and biomass production of the ‘energy plants’: Maize, Sunflower, Sweet clover and Sweet sorghum, *Silphium perfoliatum* and the Szarvazi-1" energy grass when exposed to high or low ground-water levels in lysimeter experiments.

Site characteristics and experimental setup

The experiment was carried out in 24 lysimeters at the Lysimeter Station Paulinenaue in North East Germany with 515 mm precipitation/year (30 year average); 318 mm rainfall during the vegetation period, spring drought and an average annual temperature of 8.9 C°.

The lysimeter vessels are made of stainless steel and were filled in 1968 with undisturbed hydromorphic mineral soil monoliths of low-level moors, half-bogs, humus gley, sand gley as well as loamy substrates. The vessels have a surface area of 1 m^2 and are 1.5 m deep fully adjustable ground water levels at 40 cm, 70 cm, 100 cm and 120 cm. The last three groundwater levels simulated drought conditions.

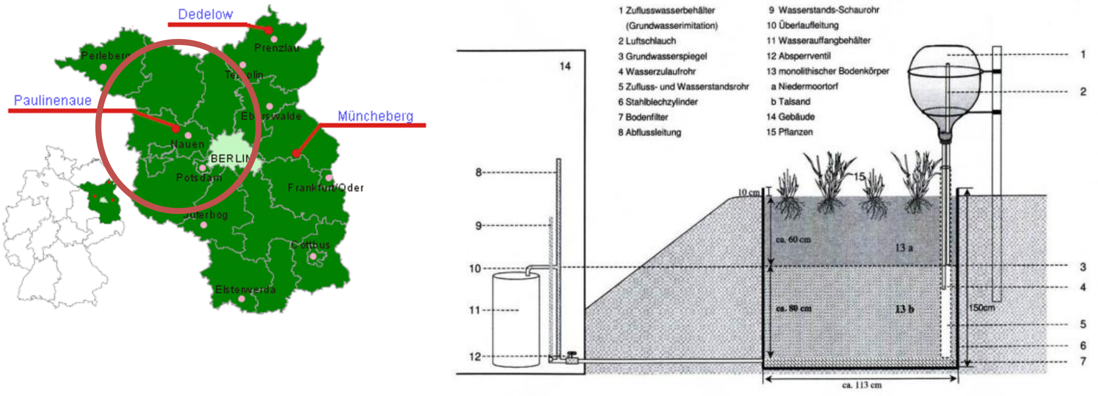

Fig.1 Experimental region in Germany and Lysimeter design

Maize “Nolween” (*Zea mayse*) (30kg/ha); Sunflower “Aloa”(*Helianthus annuus*) (7 seeds/m²); Sweet clover (*Melilotus officinalis*) (22kg/ha); Grain sorghum „Lussi“ (*Sorghum bicolor*) (30kg/ha); Sudan grass “Nutri Honey” (*Sorghum sudanense*) (30kg/ha); Cup plant (*Silphium perfoliatum) (*5 plants/m^2) and Szarvazi-1" energy grass (20kg/ha) were planted as energy crop species at least at two different ground water levels (40 cm below surface and low with 100 cm below surface). A commercial mycorrhiza product (Deutsche CUXIN Marketing GmbH) with two different species of mycorrhizal fungi *Rhizophagus interadices and Claroideoglomus etunicatum* was applied to each ground-water treatment according to the manufacturer’s instruction (75-100 g per m^2) in the upper 20 cm . Lysimeters without mycorrhiza application served as controls.

Fig.2 Experimental setup of the energy crop lysimeter experiment

Inoculation success

Root staining revealed that inoculated as well as control (non-inoculated) plants were colonized with mycorrhizal fungi. The mycorrhizal colonization of inoculated plants varied between 34% and 70% and was not significantly different from that of control plants over the entire monitoring period of five years. Because of the colonization potential of the natural abundant mycorrhizal fungi population, the mycorrhizal colonization of control plant roots was up to 68%, e.g. in maize in 2011 and *Silphie* control plants in 2013.

The percentage of colonized root was not affected by the addition of the commercial inoculum (Fig. 3).

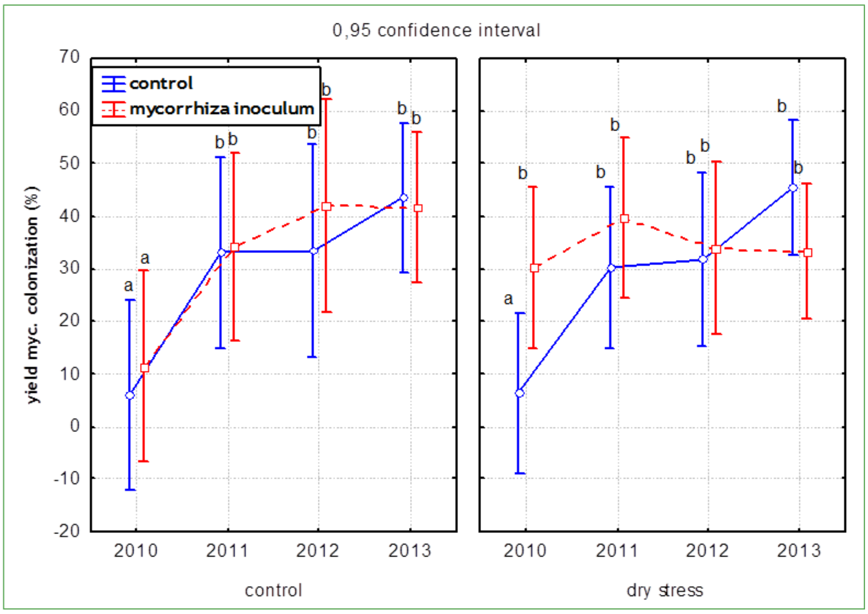

Fig. 3 Mycorrhizal colonization of control plants and inoculated plants across all analysed plant species

However, in maize the colonisation of roots was significantly increased after inoculation with the commercial inoculum in almost all treatments (Fig. 4).

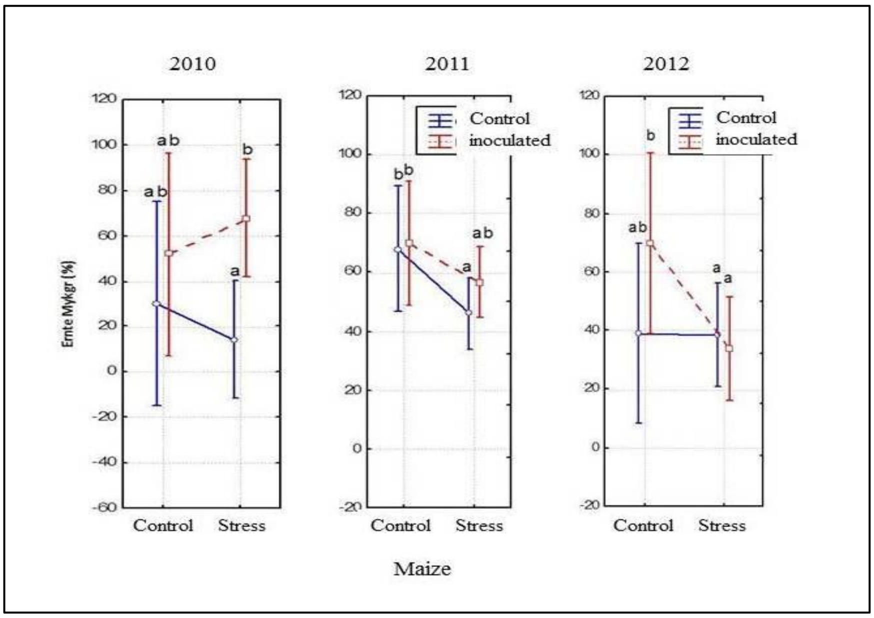

Fig.4 Mycorrhizal colonisation of maize plants

Dry matter

Although for most plant species there was no additional colonisation after application of the commercial inoculum, the effect of colonisation by autochthonous populations and applied mycorrhiza on plant development could be shown.

Under the site specific conditions of North East Germany mycorrhizal plants had a higher biomass/dry matter than non-mycorrhizal plants across all years. The degree of mycorrhizal colonisation of the different plant species is directly correlated (significant at r = 0.71) to the produced dry matter per m^2 in the lysimeter. Plants with a mycorrhizal root colonisation of 60% formed 30% more dry matter than plants with only 30% of mycorrhiza colonisation (Fig. 5).

Moreover the P and N content of the dry matter was significantly correlated with the mycorrhizal colonization of the roots with r = 0.68, and r = 0.66, respectively.

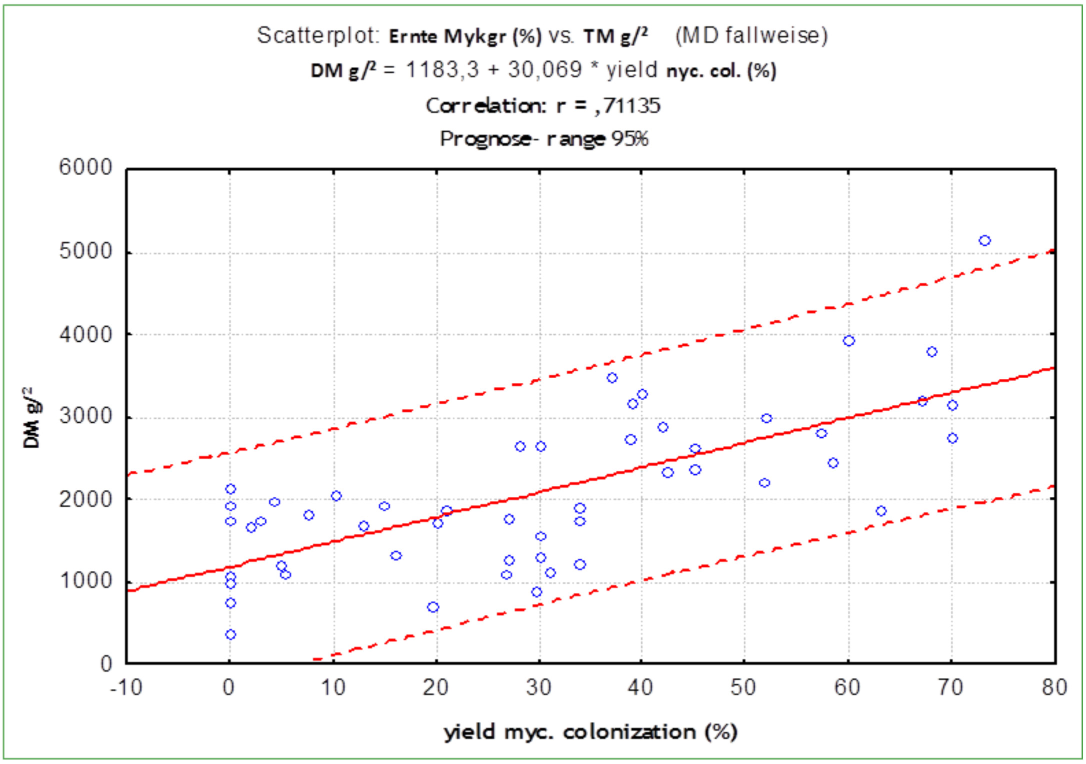

Fig. 5 Correlation of mycorrhizal colonisation with plant dry matter, the N_t (r = 0.68) and P_t (r = 0.66) in all plants across all years.

Water use efficiency

Except for Grain Sorghum the specific water use efficiency was improved for all plants with a high percentage in mycorrhizal colonisation. The mycorrhizal effect was apparent in the control (r = 0.44) as well as under drought stress conditions (r = 0.46).

Mycorrhizal plants required less water than non-colonised plants to produce 1kg of dry matter. Plants with 60% of root colonisation required about 25% less water to produce 30% more dry matter than plants with 30% colonisation (Fig.6). They were more effective. Regardless of the degree of mycotrophy in the analysed plant species this correlation was not affected and more pronounced under drought stress.

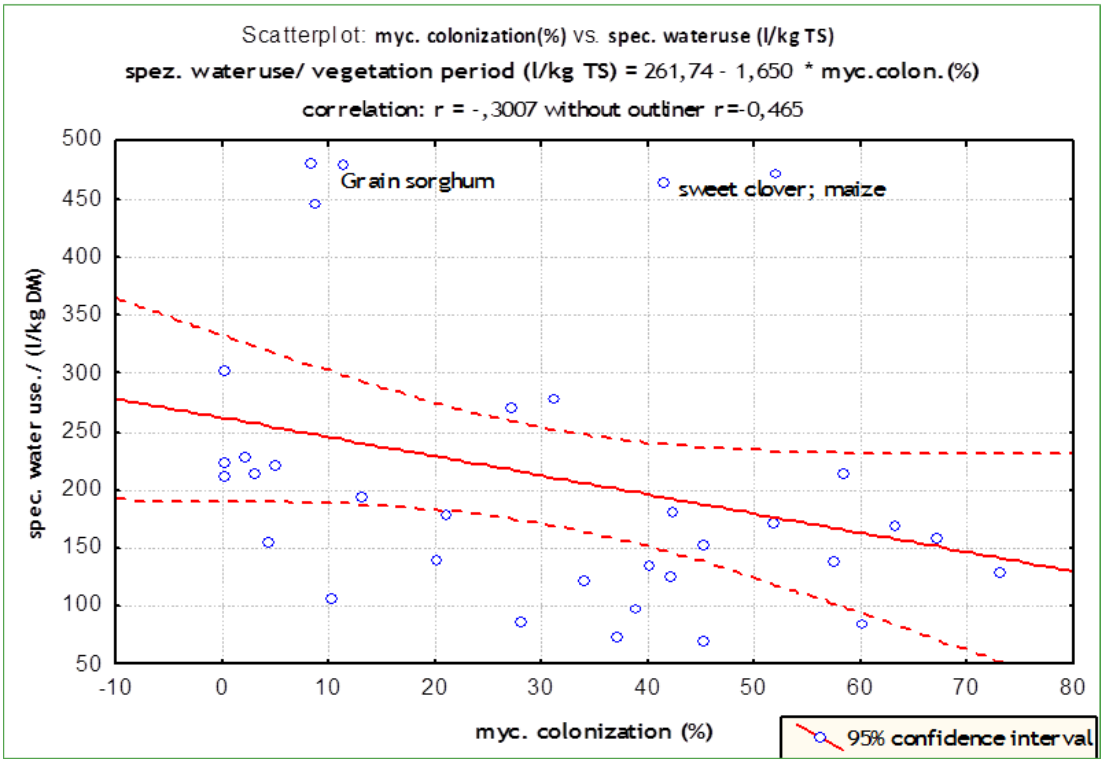

Fig.6 Correlation of root mycorrhizal colonization and water use efficiency

Conclusion

In our experiments all analysed energy crop species benefited from the mycorrhiza symbiosis. Colonised plants of all tested species were more effective in terms of dry matter production and water use than the non-mycorrhizal plants, independent of the fungal origin –applieded or autochthonous. The different species varied in the degree of their reaction to the mycorrhiza but the effect was more pronounced under drought stress conditions.

Results showed that mycorrhiza can not only improve the growth of high productive energy crops, but also promote their adaptation to different environmental conditions such as deep groundwater levels. To make the application of mycorrhizal inocula more effective a continuous monitoring of the natural abundant mycorrhiza population and possible changes in the population structure and function by introduced fungi is necessary.

Acknowledgements

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