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# Mycorrhizal fungi as biological components of integrated cucumber production (BIOMYC) - promising results for mycorrhizal technology transfer to horticultural practice

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**Abstract**

In a German-Chinese demonstration experiment the consideration of the mycorrhizal technology in horticultural practices of cucumber production (systems comparable to organic cucumber production in Germany, and organic and conventional production in China) resulted in commercially positive cost/benefit-relationships for the grower of cucumber in spite of severe nematode impact. Mycorrhizal fungi were one component among other biological components (e.g. hyperparasites) or biotechnical strategies (climate regulation) which led to an ecologically sound production system with socially adapted healthy growing conditions, i.e. zero input of chemical plant protection products.

## INTRODUCTION

Like other vegetables, cucumber (*Cucumis sativus*) can live in a symbiotic association with arbuscular mycorrhiza (AM). In the cucumber / AM symbiosis, the fungus takes up nutrient salts and water from the soil and makes them accessible for the plant partner (Cigsar et al., 2000; van Loon, 2007), while the plant supplies the fungus with essential carbohydrates produced during photosynthesis (Black et al., 2000). As the fine fungal hyphae can penetrate and exploit the soil to a much greater extent than the plant's own root hairs, mycorrhizal symbiosis increases both the ecological and the physiological fitness of the plant (Hao and Papadopoulos, 1999). This has a huge impact on the cultivation of cucumber by increasing plant growth, plant health and crop yield (Tullio et al., 2007; Bajorat et al., 1995). The absence of effective symbiotic fungi in commercial growth substrates is often limiting plant growth and yield.

In case of cucumber, benefits obtainable from optimal use of AMF can include: enhanced tolerance against soil-borne diseases (Li et al., 2007; Chandanie et al., 2006; Wang et al, 2005; Hao et al. 2005; Deokar and Sawant, 2001), pests (Schnitzler, 2004) and nematodes (Mendoza et al., 2008; Krishnaveni and Subramanian, 2004), increased drought tolerance and reduced water consumption (Valentine et al., 2002). The demonstration project BIOMYC summarized the existing knowledge about Good Agricultural Practice of cucumber production (Jianping et al., 2008) and applied it to greenhouse production of cucumbers in soil substrate. Soil was chosen as it represents the standard growth substrate in organic horticulture in Germany and also for most cucumber growers in China. Soil is, however, very suitable for nematode infestation (Echavez-Badel, 1989). In Germany, soil as growth substrate is of low importance except for organic horticulture.

Following the concept of Best Agricultural Practice (BAP, Feldmann 2007) AMF were first studied in preliminary experiments in 2003 and than more in depth over the next three years (2004-2006). The overall objective of mycorrhiza application was to increase marketable yield of cucumber under biotic stress conditions (nematode infestation). Furthermore, combining mycorrhizal fungi with other beneficial organisms and climate regulation should finally lead to an environmentally sound production of cucumber without the use of agrochemicals.

## MATERIAL AND METHODS

Between 2002 and 2007, the following steps have been realized within the BIOMYC project: the mycorrhizal technology at XAAS (Urumqi, China) was established, and biological control of biotic stressors (e.g. plant-parasitic nematodes, fungal pathogens, and pests) on cucumber (by beneficials and mycorrhizal fungi under greenhouse conditions) was studied. Also under greenhouse conditions, eco-physiological studies on mycorrhizal functioning in nematode-infested soils (e.g. influence of light, nutrition, population biology) were carried out.

*Experimental design*

A greenhouses site naturally infested with the root-knot nematode *Meloidogyne hapla* was chosen for the experiments. Attempts to control *M. hapla* on this site by resistant fodder radish cultivars and/or black fallow in the two previous years failed (Hallmann and Hommes, pers. com.). Therefore, we introduced mycorrhizal fungi to enhance the tolerance of cucumber towards nematode infestation and to produce fruits in co-existence with the pathogen.

The experiments were run in eight greenhouse cabins, each measuring 7.8 m x 5 m (= 39 $m^2$). In 2004 two cabins each were planted with either four rows of cucumber cv. ‘Tyria’, four rows of tomato cv ‘Harzfeuer’, three double-rows of bell pepper cv. Bendigo and a mixture with one row each of cucumber, tomato and bell pepper, repectively. Each row consisted of 16 plants

(1.6 plants / $m^2$). Of the two cabins per treatment, plants in one cabin were treated with mycorrhizal fungi.
For the experiment the cucumber variety 'Tyria' was chosen because it revealed intermediate tolerance to *M. hapla* in previous experiments and was responsive to mycorrhiza as well. After the initial analysis of nematode distribution, useful plants others than cucumber were used to modify the nematode numbers in the soil such as tomato (*Solanum lycopersicom* cv 'Harzfeuer') and bell pepper (*Capsicum annuum* cv. 'Bendigo'). Resulting heterogeneity of nematode distribution allowed to estimate the variability of cucumber response to mycorrhizal inoculation under variable nematode pressure.

The experimental design was modified in 2005. Four cabins were planted with three rows of cucumber cv. 'Tyria', two cabins with two rows of cucumber cv. 'Tyria' and two cabins with three double-rows of bell pepper cv. 'Bendigo'. In each cabin half the plants within a row were treated with AMF whereas the other half remained untreated.

In 2006 a comparison of other cucumber varieties besides 'Tyria' was carried out to estimate whether the data collected in the two previous years could be transferred to other promising varieties for German horticulture (cv. 'Euphorbia', 'Balance', 'Phoenix', 'Ladner', and 'Aviance'). Here, 3-6 plants per cultivar were planted in each cabin, homogenously distributed over the rows.

*Growing conditions*
Greenhouse cucumber plants have very large leaves, grow vigorously, and require large amounts of sunlight. In our experiment, the greenhouse cabins revealed a slight light gradient from the most southern to the northern cabin. The light gradient was sufficient to slow the ripening of fruits but not the final yield. Nevertheless, no additional light was necessary throughout the experiment.

Cucumber plants were trained on a vertical cordon system. Besides, all lateral branches produced before the main stem reached the overhead wire in 2.5 m height were pruned. The growing point of the main stem was removed when one or two leaves had developed above the wire. Two lateral branches near the top of the plant were allowed to grow and were trained over the overhead wire resulting in these two branches growing downward. The growing point of each lateral was removed when nearly to the ground. Fruits were let to develop at the node of each leaf. Fruit set on the bottom 1 m of the main stem was pruned off as soon as it appeared. This allowed the plant to vigorously produce early vegetative growth as a prerequisite for maximum fruit production. Fruits developed above 1 m from ground level were then allowed to develop.

Up to two fruits were allowed to develop at the same node. Any distorted fruit was removed immediately. The greatest fruit growth occurred between day 8 and 16 after the bloom opened. Maximum fruit length was reached at day 16 and was followed by increase in diameter. A marketable fruit size was usually reached at day 13 after the bloom opened.

Greenhouse cucumbers have a high nutrient requirement and grow very rapidly when supplied with sufficient nutrients. As a result of preliminary experiments we established an optimum nutrient programme where adjustments were made corresponding to changes in the crop demand. The greatest demand for nutrients is during the peak fruit production period. Nitrogen and potassium are required in the greatest amounts; however, a complete nutrition program including essential minor elements is required. Here, pot grown seedlings were fertilized with 66 g / $m^2$ Compo Blaukorn® (12-12-17-2) after planting and the developing plants monthly with 50 g / $m^2$. During fruit production this value was doubled.

Substrate moisture was kept below field capacity by irrigating 1-3 times per week automatically by drip irrigation.

The climate was regulated automatically by opening or closing the windows and regulating the heating system. The temperature was 24° C $\pm$ 3°C, the relative air humidity 60-70% in order to guarantee optimal stomata opening for photosynthesis. Direct sunlight during summer was reduced up to 40% by shading.

*Disease and pest regulation*
The use of cucumber varieties with low susceptibility to fungal diseases in combination with the cited climate regulation avoided outbreak of Powdery mildew (*Erysiphe cichoracearum* and *Sphaeroteca fuliginea*) and Downy mildew (*Pseudoperonospora cubensis*) over the entire experiment. *Sclerotinia sclerotiorum* and *Botrytis cinerea* were eliminated immediately after discovery by extracting the whole plant. Doing so, the development of the diseases was stopped before the economic threshold level was reached.

To control the outbreak of pests beneficials were used. *Amblyseius cucumers/barkeri* (50.000 / 100 m²) against *Thrips* was introduced one time in May, *Phytoseiulus persimilis* (1000 /200 m²) against spider mites three times (May, September, and October), and *Encarsia formosa* (500 / 100 m²) against aphids four times (May, June, September, and October). No synthetic plant protection agents were necessary over the whole experimental period of four years.

*Mycorrhizal application and analysis*
Before the experiment, the initial density of arbuscular mycorrhizal fungi in the soil substrate was measured following the spore count method described by Schenck and Perez (1983). Average densities were 1 $\pm$ 1 spores / $cm^3$ soil which caused some mycorrhization of control plants during the experiment. As a consequence, the amount of AMF inoculated was 5 spores / $cm^3$ substrate ("overwhelming strategy") in order to suppress the autochthones mycorrhiza and to support the introduced mycorrhiza with known characteristics.

Arbuscular mycorrhizal inoculum was produced following the Directed Inoculum Production Process (DIPP, Feldmann and Grotkass, 2002; Feldmann and Schneider, 2008) with "rapid

colonization" and "broad ecological niche" as selection criteria. Preliminary tests showed that the inoculum produced was able to successfully establish in the soil substrate of the experimental greenhouse, colonize the plant, spread within the plant and sporulate.

Vermiculate was used as carrier for the mycorrhiza. The mycorrhiza inoculum was mixed at 5 % (Vol./Vol.) with standard potting soil to reach a final concentration of 5 infection units per milliliter substrate. Pots of 14 cm diameter were filled with the mixture and received one cucumber seed. When reaching the four leaf stadium the seedlings were planted together with the potting mixture into the greenhouse soil. Before planting ten plants were checked for root colonization.

Mycorrhiza root colonization was evaluated three times during plant development: before the flower opened, during harvest and at the end of harvest. As cucumber roots grew more than two meters vertically and one meter horizontally they could n ot be assigned to an individual plant. Therefore colonization data reflect more the situation at one specific location within the greenhouse than for a specific plant.

Root colonization was made following the gridline/intersect method (Norris et al., 1992) after clearing and staining the roots as described by Philipps and Hayman (1976) substituting the stain by Trypan blue.

*Nematode analysis*

Soil samples for nematode analysis were always taken immediately before planting (= initial population density, Pi) and 4 weeks after harvest (final population density, Pf). Number of cores per sample was 30 for probing an entire cabin in 2004 and 20 for probing subplots within a cabin in 2005 and 2006. Sampling depth was in all cases 20 cm. The soil of one sample was mixed thoroughly and an aliquot of 500 ml were stored in plastic bags at 5°C until further processing. Nematode were extracted from 250 ml soil following the centrifugal flotation method described in Hooper et al. (2005) using a solution of $MgSO_4$ with specific gravity of 1.16. The number of *M. hapla* juveniles was counted under the microscope at 400x.

*Statistical analysis*

The statistical analysis based on values collected on single plant individuals and related biomass measures, nematode numbers or mycorrhiza colonization data. Due to the heterogenic distribution of nematodes and the intermingled growth of cucumber roots, root colonization and nematode numbers were clustered (joint collection of soil samples of five neighbored plants) while growth parameters and yield were evaluated for each single plant and later correlated to the nematode number counted for the specific soil sample cluster. If average values were compared it had been made sure that the nematode pressure at the single sites had been comparable.

The subsequent experiments are statistically no valid repetitions because every year the pre-conditions for the cucumber production changed because of the treatments of the previous years:

for instance, introduced mycorrhizal inoculum survived over years, nematode numbers in the soil changed depending on the susceptibility of plants grown before and so on. Nevertheless, individual evaluations allow relative yield comparisons between treatments or years and give valid information about the variability of the variants tested. On that background a grower should be able to estimate the expectations he can have using the technology in practice. For the statistical analysis SigmaStat for Windows 3.0 was used.

## RESULTS

In the experimental greenhouse a development plant diseases caused by fungal pathogens could be avoided by use of hyperparasitic organisms, phyto-hygienic procedures and climate regulation. Only root-knot nematodes had severe influence on plant growth and yield (Table 1). The fruit yield varied between years, depending on the greenhouse cabin and the crop rotation system. For cucumber, mycorrhizal inoculation with adapted AMF had a positive effect on yield in spite of autochthonous mycorrhizal fungi colonizing the roots of control plants. In contrast, tomato and bell pepper did not react to AMF inoculation under the given conditions. In fact, tomato and bell pepper grown before cucumbers reduced yield of the subsequent cucumber crop.

Table 1. Fruit yield [kg / $m^2$] of vegetables (Cuc: Cucumber cv. 'Tyria'; Pep: Bell pepper cv. 'Bendigo'; Tom: tomato cv. 'Harzfeuer' under the influence of nematodes between 2004-2006; Values of two table rows (M+/M-) are significantly different if they are marked with different letters. Plant number was n=36, 1.6 plants / $m^2$ in cabin A-G, planted in three rows. In cabin D and H one row of each vegetable specie was planted (n=12; 1.6 plants / $m^2$)

| Cabin | Inoculation | 2004 | 2005 | 2006 |
|---|---|---|---|---|
| **A** | M+ | 16.7a (Cuc) | 4.6a (Pep) | 10.8a (Cuc) |
| **E** | M- | 13.8b (Cuc) | 4.6a (Pep) | 7.2 b(Cuc) |
| **B** | M+ | 4.9a (Tom) | 3.1a (Cuc) | 12.8a (Cuc) |
| **F** | M- | 4.6a (Tom) | 4.2b (Cuc) | 9.9 b(Cuc) |
| **C** | M+ | 4.6a (Pep) | 3.0a (Cuc) | 10.6 (Cuc) |
| **G** | M- | 4.1a (Pep) | 2.4a (Cuc) | 10.2 (Cuc) |
| **D, row 1** | M+ | 12.0a (Cuc) | 13.0a (Cuc) | 15.9a (Cuc) |
| **H, row 1** | M- | 10.7b (Cuc) | 7.9b (Cuc) | 12.4b (Cuc) |
| **D, row 2** | M+ | 5.0a(Tom) | 14.7 (Cuc) | 13.8a (Cuc) |
| **H, row 2** | M- | 4.8a(Tom) | 9.2 (Cuc) | 3.5b (Cuc) |
| **D, row 3** | M+ | 5.3a(Pep) | 11.2 (Cuc) | 14.4a (Cuc) |
| **H, row 3** | M- | 3.7b(Pep) | 6.5 (Cuc) | 8.6b (Cuc) |

The variability in yield corresponded to changes in nematode densities in the soil and interactions between *M. hapla* and the cultivated plant species (Figure 1). Cucumber whether inoculated with AMF or not did not enhance the number of *M. hapla* juveniles found in soil during cropping but afterwards when hatched juveniles migrated from rotting roots into the soil substrate. During tomato production, an increase in *M. hapla* density was observed for plants that have been pre-

inoculated with mycorrhizal fungi. In contrast to cucumber, juveniles did not further increase during fallow after tomato production. Bell pepper production drastically increased the nematode numbers during crop production and also during the subsequent fallow. Cucumber following bell pepper or tomato reduced nematode numbers during growth but not during fallow.

Table 2. Root colonization (DRC [%]) of vegetables over three years.
(Cuc: Cucumber cv. 'Tyria'; Pep: Bell pepper cv. 'Bendigo'; Tom: tomato cv. 'Harzfeuer' under the influence of nematodes between 2004 and 2006; Plant number was n=36, 1.6 plants / $m^2$ in cabin A-C and E-G, planted in three rows. In cabin D and H one row of each vegetable specie was planted (n=12; 1.6 plants / $m^2$)

| Cabin | Inoculation | 2004 | 2005 | 2006 |
|---|---|---|---|---|
| **A** | M+ | 86 (Cuc) | 33(Pep) | 50 (Cuc) |
| **E** | M- | 74 (Cuc) | 28(Pep) | 25 (Cuc) |
| **B** | M+ | 32 (Tom) | 65 (Cuc) | 55 (Cuc) |
| **F** | M- | 27 (Tom) | 45 (Cuc) | 35 (Cuc) |
| **C** | M+ | 25 (Pep) | 42 (Cuc) | 45 (Cuc) |
| **G** | M- | 28 (Pep) | 21 (Cuc) | 29 (Cuc) |
| **D, row 1** | M+ | 54 (Cuc) | 62 (Cuc) | 52 (Cuc) |
| **H, row 1** | M- | 37 (Cuc) | 43 (Cuc) | 50 (Cuc) |
| **D, row 2** | M+ | 42 (Tom) | 52 (Cuc) | 66 (Cuc) |
| **H, row 2** | M- | 24 (Tom) | 32 (Cuc) | 39 (Cuc) |
| **D, row 3** | M+ | 31 (Pep) | 56 (Cuc) | 72 (Cuc) |
| **H, row 3** | M- | 18 (Pep) | 30 (Cuc) | 48 (Cuc) |

The mixed cropping of the three vegetable species resulted in high nematode numbers. There were indications of a reduction effect of cucumber to nematodes in root contact with bell pepper roots during the growth period and of tomato after it (in a way a “protective” effect of cucumber). From individual yield/nematode density analyses we learned that already low nematode numbers (> 4 juveniles / 100 ml soil) resulted in yield reductions of cucumber up to 25%. Under maximum nematode pressure (> 8,000 juveniles/100 ml soil) yield reduction was 86% less than in relation to the best value (Figure 2). Mycorrhizal effectiveness was highest in presence of low nematode numbers (< 4 / 100 ml soil, MEI 25%) and intermediate infestation (40 to 100 juveniles / 100 ml soil, MEI 20-60%). Under high numbers of nematodes (>100 / 100 ml soil) no positive effect of mycorrhizal inoculation has been detected.

The inoculation of cucumber, tomato and bell pepper resulted in higher root colonization by AMF only in cucumber (difference between M+/M-, Table 2). The other plant species were similarly colonized in the inoculated variant and the non-inoculated variant. Probably, the general positive effectiveness of the tomato and bell pepper plants still surviving highest nematode numbers might have been masked through the effect of colonization by autochthonous AMF. In cucumber, AMF colonization (measured as degree of root colonization, DRC) and nematode numbers during the experiment were negatively correlated.

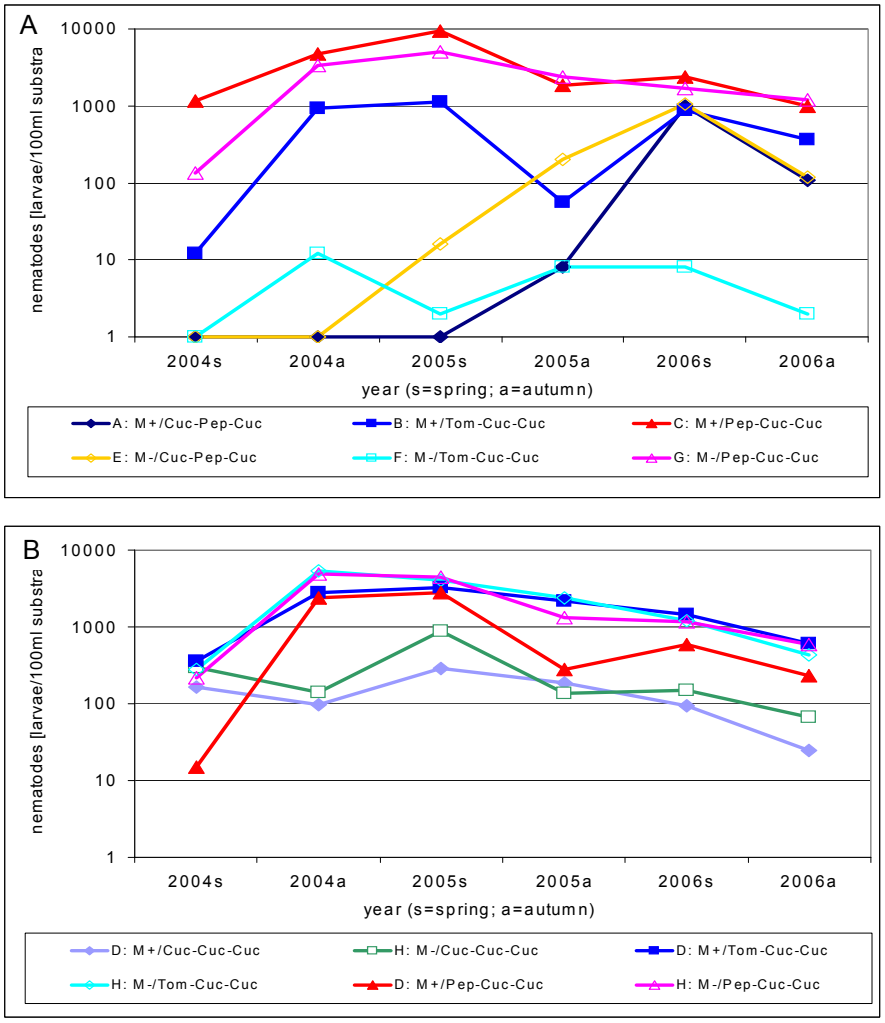


Figure 1. Nematode numbers over three years in greenhouses with different cultivation systems (Cuc: cucumber; Tom: tomato; Pep: bell pepper; greenhouses cabins A-C, E-G: n=36, above; greenhouse cabins D, H: n=12; below)

Figure 2. Development of cucumber plants under high nematode pressure with (in front) and without (behind) mycorrhizal inoculation (left: May 2005, right: June 2005)

The complex interrelationships between the main important variables can be elucidated by multifactor analysis of a matrix containing all individual sets of data at the same time (Figure 3). In that figure, factors showing the same direction are with some probability more correlated than those positioned rectangularly. Opposite directions indicate negative correlations. Without mycorrhizal inoculation the yield of cucumber plants were related to some extent to biomass and leaf area development of the cucumber plants. The relatively low correlation between these factors can easily be understood if the trimming by the gardener is taken into consideration. Light intensity and quantity, like temperature was regulated in the greenhouses and therefore, consequently, seem not to have an important impact to variability of cucumber yield. The most important factor, of course, was the negative effect by nematode infestation (compare results cited above). In spite of relatively high root colonization by mycorrhizal fungi the DRC (degree of root colonization seemed not to have positive or negative relation to both, yield or nematode number.

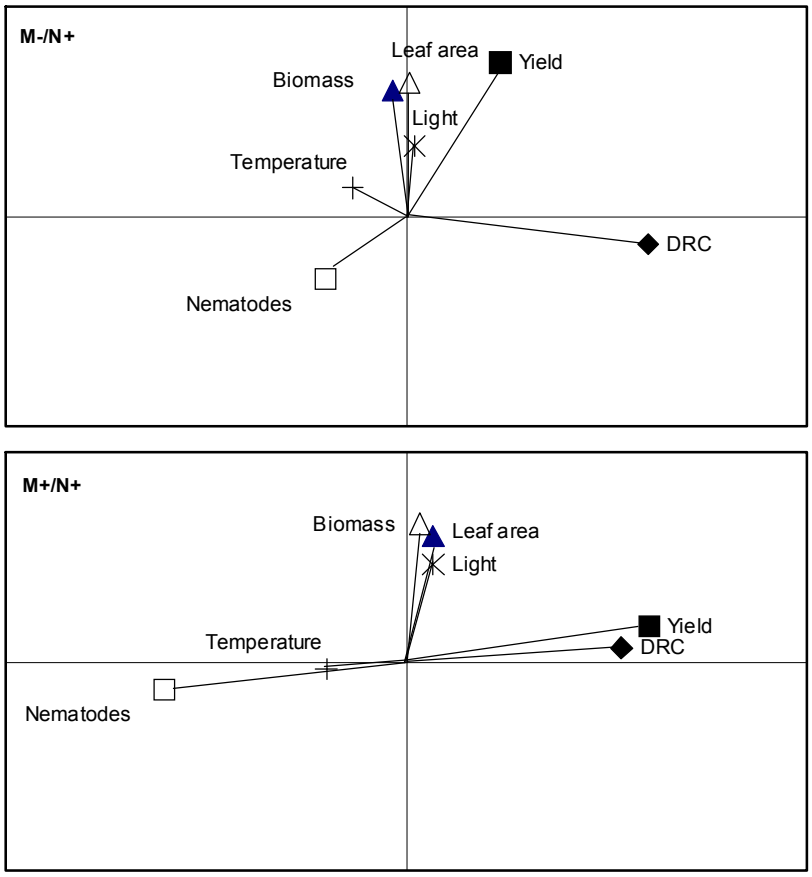


Figure 3. Interrelationship between evaluated parameters and yield (Principal components factoring of data matrix containing abiotic and biotic measures and growth data). Above: without additional mycorrhizal inoculation but with nematode stress (M-/N+). Below: with mycorrhizal inoculation and nematode stress (M+/N+). DRC: degree of root colonization [%]

On that background the change of the interrelationships between the factors after inoculation of mycorrhizal symbionts was exciting: the factors “yield” and “DRC” were approximated tightly

now and showed in the opposite direction of the factor “nematode number”. At the same time, the influence of biomass, leaf area and abiotic factors became smaller than in the variants without additional mycorrhizal inoculation. This result underlines the importance of the inoculation practice and the successful use of the mycorrhizal technology as already shown in Table 2.

In a subsequent test we studied the possibility to transfer the experiences made for the cucumber variety ‘Tyria’ to other promising varieties. Figure 4 shows the yield of plants after inoculation with mycorrhizal inoculum. Interestingly, all tested non-inoculated varieties were tolerant to high nematode numbers and produced the same yield without mycorrhizal inoculation. But dependent on the variety the responsiveness of cucumber was observed to be variable (significantly positive to non-significantly different). Negative effects of mycorrhiza inoculation were observed in case of cv. ‘Phoenix’ and ‘Euphorbia’.

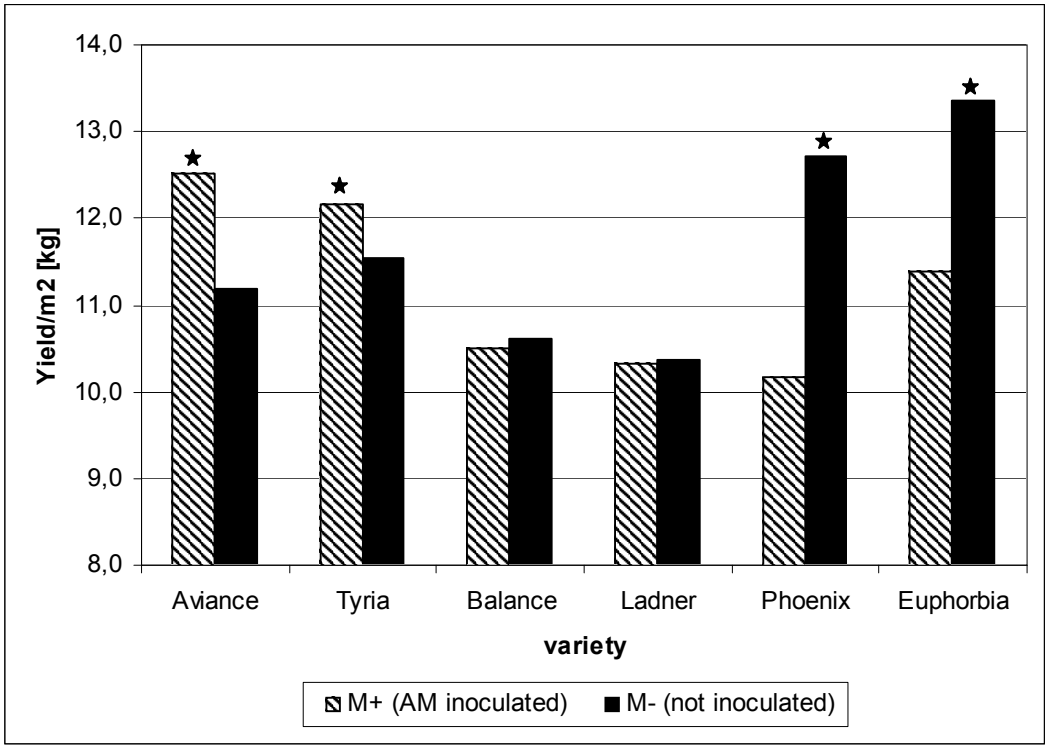


Figure 4. Yield of cucumber varities under the influence of additional mycorrhizal inoculation and with nematode stress (M+/N+). Growing conditions: compare Mat. and Meth., year 2006

## DISCUSSION

In recent years various AMF products have been introduced into the European and Chinese market for a range of purposes. Although the achieved progress in commercialization of this biotechnological supplement in the last five years is impressive, experiences obtained so far have shown that the quality of the product and, thus, quality control of production is really a bottleneck

for broad-scale application in practice. As AMF are obligate biotrophic organisms they have to be propagated commercially on living plant roots, e.g. in greenhouses. There are various conventional and modern molecular biological tests that can be applied for quality control of AMF inoculants, such as the voluntary agreements of the German Committee of Mycorrhiza Application (CMAG). The use of AMF inoculum is recently facing a highly diverse host plant spectrum and diverse substrates for specific uses at the front-end in the market. Mycorrhizal technology, therefore, has to overcome specificity of symbiontal interactions and has to adapt the application procedure (by hand or machine, integration into common procedures or use of specific technological developments) to mycorrhizal inoculum demands. The quality declaration allows choice of the proper product for a particular application, which will fulfil the expectations of the customer.

The BIOMYC project was initiated by the German Ministry of Consumer Protection, Food and Agriculture and the Chinese Ministry of Agriculture. The project was a collaboration between partners of the Chinese Agricultural University, Beijing, and the Xinjiang Academy of Agricultural Sciences, Urumqi, China, with the German Julius-Kühn-Institut (JKI, formerly Federal Biological Research Centre for Agriculture and Forestry, BBA) and the German company INOQ GmbH. BIOMYC (a) introduced new mycorrhizal technology for an integrated plant protection strategy of cucumber production to horticulture, (b) expanded the basic knowledge of scientists on the population dynamics of pests, nematodes and pathogens on vegetables under greenhouse conditions, (c) promoted the development of new plant strenghteners/biofertilizer products in Germany and China, and (d) demonstrated sustainable, consumer - oriented methods for horticulture to Chinese students, scientists, extension specialists and growers. Accordingly, future developments of Chinese plant protection strategies will have the chance to match compliance criteria of farm assurance systems which are now important in food quality control. Furthermore, the co-operation of JKI with Chinese partners increased the expertise of German scientists in the use of biological plant protection factors under biotic stresses in greenhouses, and enhanced knowledge of Chinese horticultural and agricultural plant production systems (Feldmann et al., 2007).

The results obtained in this demonstration experiments highlight the great importance of climate regulation, biotic plant strengtheners and biocontrol agents as components of integrated plant protection. Except for root-knot nematodes no relevant disease or pest incidences on cucumber were observed under favorable growth conditions over three years. Such observations are in accordance with Good Horticultural Practice of cucumber production in Europe, where up to 80% of cucumbers are produced without chemical control of pests and disease (ZMP, 2007).

In conventional production systems, plant-parasitic nematodes are generally no economic threat for cucumbers as they are generally grown in soil-less culture systems. However, in organic horticulture where those systems are not permitted or in soil systems they can cause severe damage. Here, we demonstrated that yield loss can be widely avoided if preventive mycorrhiza

inoculation takes place. if preventive mycorrhiza inoculation takes place. We calculated that at least 3 Euro can be earned more for each 1 Euro inoculum costs, what describes a really interesting value under the stress conditions tested. These results are very promising for horticultural production systems, where soil substrate is used over longer time without soil treatments. Comparable results, i.e. yield increase in practice, we revealed after mycorrhiza inoculation of cotton, field grown bell pepper, ornamentals (Long et al, 2008, Feldmann et al., 1999) and micro-propagated potatoes (Yang et al., 2008) under practical conditions.

Because AMF use is not restricted to soil substrate, the mycorrhizal technology already spreads to plant production practice using hydroponic systems (Lamb et al., 2003) and other useful plants as well (Cho et al., 1997). Recently, more and more positive cost/benefit relationships of mycorrhiza use lead to the development of bioproducts containing AMF (Schneider and Feldmann, 2007; Young, 2005; Gianninazzi et al, 2002) or combination of AMF and bacteria (Ravenskov and Jakobsen, 1999). Furthermore, mycorrhiza use is integrated into sustainable strategies ofplant production (Varghese, 2000; Feldmann, 1998). From our point of view mycorrhiza introduction was found to be a stabilizing management factor in cucumber production in spite of highly variable conditions in the greenhouse cabins, changing nematode numbers and existence of autochthonous AMF.

Something what remains unclear is how we will be able to recognize positively responsive cultivars of useful plants (compare Fig. 4). It might be necessary to take mycorrhizal dependency and responsiveness into account when breeding for new varieties. In a first step, information about cultivar characteristics already tested should be made available to practice by establishing central online data bases with world wide access.

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