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Chapter 1 : Table of contents for Mycorrhizae in crop production

Extraradical Arbuscular Mycorrhizal Mycelia: Shadowy Figures in the Soil (Chantal Hamel) Nature of the Extraradical Arbuscular Mycorrhizal Mycelium Specific Associations with Specific Outcomes Influences on the Development of the Extraradical Mycelium in Cropping Systems Conclusions Chapter 2.

Atul-nayyar Mycorrhiza We hypothesized that arbuscular mycorrhizae enhance the Keywords Arbuscular mycorrhizal fungi. This was tested under controlled glasshouse con- N mobilization. The fate of the N contained in the OR patch, as Introduction influenced by Glomus claroideum, Glomus clarum, or Glomus intraradices over 24 weeks, was determined using Nitrogen N availability often limits plant growth. A large 15 N as a tracer. AM fungal species enhanced N mineralization amount of N is stored in soil organic matter, but plants from OR to different levels. Some plants have developed the ability extraradical development in soil. Mobilization of N by G. We show that AM hyphae modify soil functioning , while others rely on specialized symbiotic associa- by linking plant growth to N mineralization from OR. AM tions to exploit organic N sources Read While the species enhance N mineralization differentially leading to metabolism of ectomycorrhizal and ericoid mycorrhizal species-specific changes in the quality of the soil environment fungi gives their host plant Abuzinadah and Read ; Leake and Read the ability to use organic matter as a source of N in heath lands and forests, the role of arbuscular mycorrhizae in plant acquisition of organic N is unclear. The AM fungi are known as obligate biotrophs relying A. Hanson on C provided by their host plant rather than on dead Semiarid Prairie Agricultural Research Centre, organic matter Nakano et al. Box , 1 Airport Rd. The AM hyphal network A. Germida is important in giving plants access to low mobility ions Department of Soil Science, University of Saskatchewan, 51 Campus Drive, located far from the root surface. The soil had a pH of 6. The soil soil organic particles St. This loamy Hawkins et al. Based on sand is preferentially used by our group, as it is light and the observation of hyphae and vesicles of AM fungi in retains good physical properties during greenhouse experi- decomposing leaves of Myrica parvifolia, Myrica pubescens, ments. Pots were inoculated with one of three different and Paepalanthus sp. All pots that AM fungi enter decomposing leaves through vascular also received 2 ml of a filtrate Whatman no. The ability of AM proportion to also provide inoculum-specific microbial fungi to use dead organic substrates Talbot et al. Each mycorrhizal treatment a matter of debate, but even if this ability is small or received 1 g of root inoculum thoroughly mixed with the soil. All AM fungal species for most of the N mineralization, particularly in grassland were multiplied from spores using corn Zea mays L. Arbuscular mycorrhizal fungi Sunnyvee grown for 60 days in a greenhouse. Non-inoculated control plants received 1 g of recycling from litter and soil organic matter. As plant demand increases with time, we expect that a study of longer duration may Experimental design reveal better the availability of N to plant from decomposing organic matter. We also hypothesized that different AM Four Russian wild rye seedlings colonized by one of the fungal species may have different influence on organic three AM fungal species or non-mycorrhizal were trans- matter mineralization. A patch of 15N-labelled organic residues In this paper, we propose a key role of the AM was inserted in each pot at the time of transplanting. The symbiosis in linking the process of N mineralization to organic residue OR patch was made of 4 g of 15N-labelled plant N demand in soil, where the AM symbiosis regulates root and shoot of wheat ground and mixed with some the recycling of plant residue N into living plant biomass pasteurized soil. The organic material contained 22 mg N, and, in the process, changes the soil environment. Nevski and three AM fungal species in a polyvinyl chloride ring. The patch was placed in the root organic residues contained in nylon mesh, which we buried zone with mesh facing toward the center of the pot. We examined the effect of arbuscular mycorrhizae on small patch volume 0. Pots were the soil environment, and microbial community structure filled with the pasteurized loamy sand. Nitrogen mg after 24 weeks. The percentage of greenhouse. Saucers were used, and watering was done parsimoniously to prevent all N loss during the experiment. Plants were grown for a period of 24 weeks where 15Ns and 15Nr are the percentages of 15N measured between 22

February and 26 July PLFA were analyzed as described weight. Roots were recovered on a 2-mm sieve and previously Hamel et al. Briefly, soil lipids were thoroughly washed with tap water to remove adhering soil. Lipid-class separation was before subsampling for further analysis. The OR patch conducted in silica gel columns. Roots were cut from the phospholipid fraction were created through mild into 1-cm fragments, weighed fresh, and subsampled. The second identification was based on comparison of retention times to root subsample was used for the determination of AM root known standards Bacterial Acid Methyl Esters U, colonization using the gridline intersect method Giovannetti Supelco, Bellefonte, USA. The fatty acid spectrometer Optima. Hydroxy groups are indicated by OH. Hyphae Mycorrhiza Hyphae were stained for 5 min with trypan blue Koske and Gemma in the Mycorrhizal development filtration unit. The stain was washed with distilled water and hyphae were counted under a dissecting microscope. All three AM fungal species produced AM colonization Hyphal lengths were calculated using the following levels ranging from Colonization was Where N is the number of intersects between hyphae and highest in G. Conversely, filter, and H is the total length of lines. Background values from uninoculated control were subtracted, and values Mineralization of organic residue and microbial community above control were considered AM hyphal length densi- in OR patches ties HLDAM. The carbon-to-nitrogen ratio in the OR patch material had Statistical analysis decreased from an initial level of Differences in soil microbial community compo- systems Table 1. Inoculation treatments induced qualitative changes in the structure of microbial communities in the OR patch material but did not significantly influence total microbial biomass, as estimated by the sum of microbial PLFA biomarkers in lipid extracts data not shown. Russian wild rye in symbiosis with G. Root dry mass of Non-mycorrhizal G. This indicates that plants were P sufficient, but N inoculation treatments on the microbial community structure in limited, a limitation that was relieved by G. Plants organic residue patches after 24 weeks. Microbial communities in colonized by G. Variation in microbial community structure in OR patches was due to modifications in bacterial and fungal saprotrophic populations. Six bacterial biomarkers Discussion It appears that plants can stimulate the mineralization of OR 5 b in soil through C investment in AM fungi development. The data show residues that was recovered by Russian wild rye plants inoculated or not with different AM fungal species. It appears that stimulation or N mineralization by AM Andrade et al. We found no hyphae may be regulated by plant N demand, as high soil N difference in active soil microbial biomass between treat- availability reduces AM fungi extraradical development Liu ments at harvest, but it could have been larger in AM- et al. We can attribute plant growth enhancement in G. Increased plant also be responsible for faster organic matter decomposition tissue N concentration and absence of effect on tissue P in the presence of arbuscular mycorrhizae. The AM fungi concentration clearly indicate that G. The cause of improved plant growth different mechanisms, including modification in plant sig- with G. Finally, inoculation with G. Although all AM et al. Extraradical hyphae of AM fungi may bring species could enhance N mineralization from the OR patch, available C to microorganisms of the hyphosphere, allowing this effect was not always associated with improved plant them to mineralize recalcitrant soil organic matter, as productivity, showing difference in functionality among the described in the model of Schimel and Weintraub However, a biomass similar in size but more active duced less extraradical hyphae in the bulk soil but enhanced could have enhanced mineralization in that study. In most N mineralization. The fact that the growth of fungus addition, hyphospheric effects could have been diluted and may have been preferentially stimulated in the OR patch masked by a large soil volume in the OR compartment used. Better plant growth directly or not, these fungi can enhance substantially N performance with G. These differ- N transfer from decomposing organic matter to plants via ences may reflect both the influence of arbuscular mycor- AM fungal hyphae. Change in the patches in the presence of AM fungal hyphae could be due soil microbial community with decomposing organic to direct or indirect effects. Direct effects of arbuscular residue was reported in other studies Aneja et al. Decrease in the abundance of easily due to enzymatic decomposition by extraradical AM metabolized compounds with time drives a microbial hyphae. The mycelium of AM fungi proliferates in organic succession for decomposing residues. Different carbon-to- residue Ravnskov et al. Various hydrolytic

treatments indicates that OR mineralization had proceeded enzymes such as cellulose, pectinase, and xyloglucanase further in the presence of AM hyphae and, thus, that have been reported in external mycelium of AM fungi different qualities of soil organic matter could select soil Garcia Romera et al. These enzymes are known to be involved in the degradation Results suggest new pathways of influence by arbuscular of plant material in soil. The AM fungi can arguably be mycorrhizae on plantâ€"soil ecosystems. We have shown that involved directly in the mineralization of organic residues arbuscular mycorrhizae link plant N needs and growth to OR Talbot et al. Soil microbial growth can be stimulated Secilia and Bagyaraj ; Andrade and the soil microbial community Acknowledgments We thank Dr. Nitrogen transfer in birch from organic material. Wiley, New York, mycorrhizal fungi. Annu Rev Plant Biol Varma A, Abbott L, doi: Bacteria from rhizosphere and hyphosphere soils of different doi: Microb Ecol sphaerospermium and some bacteria isolated from fish viscera. Hamel C, Plenchette transfer in the arbuscular mycorrhizal symbiosis.

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Extraradical Arbuscular Mycorrhizal Mycelia: Shadowy Figures in the Soil (Chantal Hamel) Nature of the Extraradical Arbuscular Mycorrhizal Mycelium Specific Associations with Specific Outcomes.

Find articles by Ricardo A. Received May 26; Accepted May Abstract Consistency of response to arbuscular mycorrhizal AM inoculation is required for efficient use of AM fungi in plant production. Here, we found that the response triggered in plants by an AM strain depends on the properties of the soil where it is introduced. Two data sets from different experiments assessing the outcome of a total of replicated single inoculation trials conducted either in soils with a history of 1 high input agriculture HIA; replicated trials or 2 in more pristine soils from coffee plantations CA; replicated trials were examined. Plant response to inoculation with different AM strains in CA soils planted with coffee was related to soil properties associated with soil types. The strains Glomus fasciculatum-like and Glomus etunicatum-like were particularly performant in soil relatively rich in nutrients and organic matter. Paraglomus occultum and Glomus mosseae-like performed best in relatively poor soils, and G. Acaulospora scrobiculata, Diversispora spurca, G. Acaulospora scrobiculata and Diversispora spurca strains performed best in Chromic Alisols and Rodic Ferralsols. There was no significant relationship between plant response to AM fungal strains and soil properties in the HIA soil data set, may be due to variation induced by the use of different host plant species and to modification of soil properties by a history of intensive production. Consideration of the performance of AM fungal strains in target soil environments may well be the key for efficient management of the AM symbiosis in plant production. Adaptation, Effectiveness, Soil properties, Soil type, Soil classification, AM inoculant, Consistency of response Introduction The arbuscular mycorrhizal AM symbiosis has evolved in most terrestrial environments as an efficient system of phosphorus uptake in plants Brundrett But despite increasing fertilizer costs and disappearing world phosphorus reserves Gilbert , progression in the use of the AM symbiosis in plant production has been slow. Although the causes of this poor performance have been diverse, it is true that the conditions for the expression of mycorrhizal effectiveness are poorly known, leading to inconsistency in response to AM inoculation see Ryan and Graham According to principles in ecology, the success of an AM symbiosis depends not only on the plant and fungal genotypes, but also on the conditions of the environment. The functional specificity that exists between plants and AM fungi has been documented Helgason et al. The soil environment certainly imposes a strong selection pressure on AM fungi Hamel ; Helgason and Fitter , but the influence of the soil on AM genotypes is ill understood Feddermann et al. The factors controlling the effectiveness of an AM fungal strains must be understood before reliable AM inoculation technologies for field crops can be produced, and the soil is likely a key determinant of AM fungi effectiveness. We know that plants influence importantly AM fungi through the provision of C substrate, but the influence of the soil on these fungi should not be overlooked. The soil not only provides mineral nutrients to AM fungi, but also constitutes the chemical and physical environment where both these fungi and their plant associates live. There is much evidence supporting the hypothesis of a large influence of soil properties on AM fungi Hamel et al. The properties and environment of a soil may have different influence on different AM isolates. Liming the soil decreased root colonization by Acaulospora laevis, but increased root colonization by G. It appears that AM strains may survive and function well only within a range of soil environmental conditions. The effectiveness of AM symbioses created through plant inoculation may depend on the adaptation of the AM fungal strains used to the soil where they are introduced. We tested this hypothesis using data generated by an important research effort made between and in Cuba to develop AM fungi inoculation technologies. Here, we used multivariate analysis of data from inoculation trials to reveal relationships existing between the plant response to inoculation with different AM fungal strains and soil properties. Another analysis was performed on data from 68 experiments conducted in more pristine coffee plantation soils that yielded a total of data points which were averages of four replicates representing coffee plant response to different AM strains. In all

these experiments, plants were inoculated with different AM fungal strains with potential for use in inoculants, and their performance at stimulating plant growth was recorded. Thus, the responses to inoculation generated by these experiments were standardized by calculating the relative response to inoculation RI in each single inoculation trial as: The RI values used in the two analyses were the average of the replicates of each inoculation treatments.

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Consistency of response to arbuscular mycorrhizal (AM) inoculation is required for efficient use of AM fungi in plant production. Here, we found that the response triggered in plants by an AM strain depends on the properties of the soil where it is introduced.

The abundance of the phospholipid fatty acid marker Active extraradical AM fungal cultural, native, and restored in Grasslands National Park, biomass had significantly positive linear relationship with Canada were assessed in periods of moisture sufficiency the abundance of two early season grasses, Agropyron and deficiency typical of early and late summer in the cristatum L. The community structure of AM fungi, as deter- relationship was found under dry conditions. The AM mined by polymerase chain reaction-denaturing gradient symbioses formed under conditions of moisture sufficiency gel electrophoresis, varied with sampling time and plant typical of early summer at this location appear to be community. Soil properties other than soil moisture did not important for the nutrition of grassland plant communities, change significantly with sampling time. The DNA but no evidence of mutualism was found under the dry sequences dominating AM extraradical networks in dry conditions of late summer. DNA sequences of Glomus viscosum, Glomus mosseae, and Glomus hoi were dominant under conditions Introduction of moisture sufficiency. In total, nine different AM fungal sequences were found suggesting a role for the AM Arbuscular mycorrhizal AM fungi are found in the soil of symbioses in semiarid areas. Significant positive linear most ecosystems where they form mutualistic associations with a large number of terrestrial plant species [64]. They are known as critical components of soil, and functional C. Perez links between soil and plants [12, 27]. They can influence Semiarid Prairie Agricultural Research Centre, many important processes such as nutrient cycling [2, 31, Swift Current, Saskatchewan, Canada 47], soil structure stabilization [61, 62], organic matter C. AM fungi are important Xianyang, Shaanxi, China associates of plants and the composition of their community e-mail: Perez 22], plant drought resistance [19], primary production [23], Universidad Nacional de Colombia, and ecosystem dynamics [64]. Sede Medellin, Colombia Much research effort was spent to understand the R. Berbara interactions taking place between AM fungi and plants Soil Dept. Previous research works have examined been re-seeded into native mixed grasses and forbs species the distribution of AM fungi in sandy area [4], in at some point in the last 10 years by the Park officers and agricultural soils [45], and in certain natural ecosystems were in various stages of recovery. Total precipitation for [18], but few of them have looked into grasslands [56], May and June in was Low AM fungal normal for this location Fig. The months of July [35] and a recent study in Kansas prairie ecosystems and August had lower amount of precipitation revealed that AM colonization of plant roots may be 8. According to the United Nations Environment American Great Plains, especially in the warm period of the Program [63], the climate in this area is semiarid aridity growing season when water availability to plants is low index was 0. We also observed abundant septate hyphae in the roots variation in climate creates a seasonal pattern in vegetation of plants growing in Southwest Saskatchewan prairie soils, cover where cool-season plant species are followed by which concur with reports from semiarid grasslands made warm-season species. Competition with other fungal endophytes for root occupation could limit the distribution of AM fungi Soil and Plant Sampling in dry areas. These sampling times were selected the mandate to preserve Canadian prairie grasslands. We used katchewan summer. The percentage of soil coverage communities of Grasslands National Park. In particular, by each species was evaluated visually and used to describe we wanted to document AM fungal diversity and plant community structure. One soil core 0â€”20 cm depth was taken from each Methods quadrate using a 5 cm diameter hand-operated soil sampler. One soil core was used for soil bulk density, which was Study Site Four different locations in Grasslands National Park, 20 70 Southwest Saskatchewan Canada, where three adjacent grassland plant communities one agricultural, one native, 15 60 and one restored at each of four locations totaling 12 Mean daily temperature oC 10 50 research plots met were examined. The latitude and Precipitation

mm longitude of the four sampling locations are: Crested wheatgrass Agropyron cristatum L. These crested wheatgrass stands were probably established by early 0 settlers in the s to stop wind erosion. The four other cores were pooled to yield Twenty microlitres of nested PCR product were used for one composite sample per plant community at each DGGE analysis as described by Ma [37]. All DGGE analyses were run weight of the dry soil, and expressed on a percent basis [8]. Electrophoresis was for 10 min at 75 V, after Soil pH was determined by the method of Peech [50]. Soil which the voltage was lowered to 60 V for an additional organic C was determined by the method of Baccanti and 13 h. To obtain enough DNA fragments in one clone library, [7]. The second stage under the PCR conditions mentioned above. The DNA sequences in fungi. The PCR products coming from Statistical Analysis both the second and third amplifications were used to construct a clone library and denaturing gradient gel The effects of location block , sampling time, and plant electrophoresis DGGE markers. Phylogenetic distance analysis was assessed by MEGA 4. The relationships between AM 4. This is consistent with the normal pattern fungi active biomass PLFA The relationship between AM fungi active biomass almost all plant species appeared to be dormant. Glomus verruculosum AJ Names preceded by a triangle Glomus fragilistratum AJ represent the sequences obtained Glomus spp. The CA reveals differences in the composition of the AM fungal communities of different plant communities within a sampling time Fig. Rdry N moist mosseae were more frequent in the native prairie at that G. N native; A agricultural, and R and P nutrition of plants may vary with environmental restored ecosystems; moist June sampling, dry August sampling; conditions. The active biomass of extraradical networks circles represent different plant communities at different sampling times; squares represents different AM fungi. Three AM fungi could be identified biomass and their associated plant community. Multivar- to the species level by blasting our sequences in GenBank iate analysis of variance results showed that in early Table 2. These were frequently detected in early June June, AM fungi active biomass was related with the samples, but seldom found in late August. Only one abundance of crested wheatgrass Agropyron cristatum unreported species Glomus 9 was found in the early June L. Most of the AM sequences found in the late dominant in agricultural communities, and junegrass August sampling were yet unreported in public databases. But in late August, no significant relation- composition of AM fungal community had shifted from ship was found Table 3. Better-adapted AM fungi appear to 0. The absence of information 0. Adaptation to environmental conditions may occur 0. Adaptation could also involve changes in the 0. An AM hyphae contains dissimilar nuclei [26] and has a turnover time of days [59]. Dots represented plant nutrient concentration in July and August Alternatively, different temporal pattern of sporulation in during the period of moisture deficiency and crosses-represented different AM fungi may explain the temporal variation in the nutrient concentration in May and June during the period of soil frequency of detection of different AM fungal sequences moisture sufficiency observed in our study. Several AM fungi have seasonal pattern of sporulation. Whereas some AM fungi show a steady Discussion production of spores, sporulation in other taxa mainly occurs at different time in the growing season [35, 45]. Variation in AM Fungal Community Temporal changes in the frequency of detection of the different AM fungi was not restricted to the native prairie Seasonal variation in the relative abundance of AM fungi ecosystems, but also occurred in agricultural plant communi- was found in all plant communities Fig. Seasonal variations in the composition of the AM fungal with earlier results [71]. Interestingly, phylogenetic distance community of Scottish grassland ecosystems were reported by analysis Fig. Our results concur with these findings and during the growing season in Upland County, Sweden. All species 14 5 1. The in their AM fungal associates. Soil moisture is another factor low extraradical AM fungal biomass at this time might also influencing AM fungal distribution [43, 65]. In the mixed prevent the detection of any relationship in the dry period. A relationship between late season plant N cool season plant species as summer progresses. Thus, and P concentration and extraradical AM fungi biomass variation in both plant species and soil moisture availability might exist in years with better moisture. Soil water availability nutrition of the plant communities. This finding is consistent could be the factor explaining the change observed in the with several previous studies [16, 20, 32, 39]. But more relationship between active extraradical AM fungal

biomass interestingly, in our study, no such relationship was detected and plant community. Although AM fungi are drought- at the late August sampling showing that changes in soil tolerant fungi that can increase the drought tolerance of moisture modifies the relationship between AM fungal their host plant [14, 15], extreme drought can reduce both activity and their host plant. The concurrent changes in the AM fungal growth and the activity of the associated plant composition of the AM fungal community can be one reason community [6]. In our study, July and August had been explaining the change in symbiotic functionality observed. In much dryer than normal and almost all plants appeared to addition, July and August in was dryer than normal be dormant; but the possible occurrence of less mutualistic with only 8. Thus, the extremely dry AM fungi in dry soil cannot be ruled out. The level of environment in late summer could have inhibited the mutualistic ability of AM fungi dominating in dry soil expression of a mutualistic relationship. The environment remains to be tested. Swift Current, SK Canada. December 1â€”2 The AM fungi active biomass measured at the early June 8. Previous research found that AM diversity of arbuscular mycorrhizal fungi colonising arable crops. Even though some drought-tolerant AM Contrasting root associated fungi of three common oakwood fungi dominated at that time, we found no evidence of land-plant species based on molecular identification: It remains unclear if the mutualism of AM Analysing arbuscular mycorrhizal fungal diversity in shrub-symbioses breaks down under dry conditions or if the associated resource islands from a desertification-threatened drought period in Grasslands National Park was just too semiarid Mediterranean ecosystem. Appl Soil Ecol Rev Fitotec Mex The biomass of their active but not salinity determines the apparent effectiveness of halo- extraradical networks is related to plant nutrient uptake and phytes colonized by arbuscular mycorrhizal fungi. J Plant Physiol G Impact of two fluorescent pseudomonads and an arbuscular mycorrhizal fungus on tomato plant growth root architecture and P acquisition. This work was carried out with the aid of a grant from the diversity in a model system using experimental microcosms. Gupta R, Kumar P Mycorrhizal plants in response to adverse environmental conditions. Hamel C Impact of arbuscular mycorrhizal fungi on N and 1. Can J Soil Sci Soil Sci Soc Am J Soil Sampling and Methods of Analysis, 2.

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Chapter 9 : Soilâ€“strain compatibility: the key to effective use of arbuscular mycorrhizal inoculants?

Design cropping practices that make the most of the contribution of AM fungi Mycorrhizae in Crop Production is a comprehensive guide to the use of arbuscular mycorrhizal fungi (AMF) in developing sustainable cropping systems.