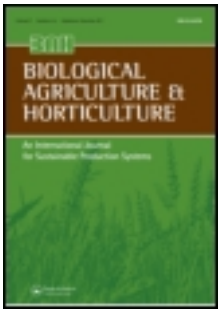
This article was downloaded by: [santiago schalamuk]
On: 10 January 2013, At: 15:55
Publisher: Taylor & Francis
Informa Ltd Registered in England and Wales Registered Number: 1072954 Registered office: Mortimer House, 37-41 Mortimer Street, London W1T 3JH, UK



Biological Agriculture & Horticulture: An International Journal for Sustainable Production Systems

Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/tbah20

Dynamics of arbuscular mycorrhizal fungi spore populations and their viability under contrasting tillage systems in wheat at different phenological stages

S. Schalamuk [a b], S. Velázquez [b c] & M. Cabello [c d]

[a] Facultad de Ciencias Agrarias y Forestales, UNLP, 60 y 119 (1900), La Plata, Buenos Aires, Argentina

[b] CONICET, Buenos Aires, Argentina

[c] Instituto de Botánica Spegazzini, Facultad de Ciencias Naturales y Museo, UNLP, 53 # 477 (1900), La Plata, Buenos Aires, Argentina

[d] CICPBA, Buenos Aires, Argentina

Version of record first published: 10 Jan 2013.

To cite this article: S. Schalamuk , S. Velázquez & M. Cabello (2013): Dynamics of arbuscular mycorrhizal fungi spore populations and their viability under contrasting tillage systems in wheat at different phenological stages, Biological Agriculture & Horticulture: An International Journal for Sustainable Production Systems, DOI:10.1080/01448765.2012.753397

To link to this article: http://dx.doi.org/10.1080/01448765.2012.753397

PLEASE SCROLL DOWN FOR ARTICLE

Full terms and conditions of use: http://www.tandfonline.com/page/terms-and-conditions

This article may be used for research, teaching, and private study purposes. Any substantial or systematic reproduction, redistribution, reselling, loan, sub-licensing, systematic supply, or distribution in any form to anyone is expressly forbidden.

The publisher does not give any warranty express or implied or make any representation that the contents will be complete or accurate or up to date. The accuracy of any instructions, formulae, and drug doses should be independently verified with primary sources. The publisher shall not be liable for any loss, actions, claims, proceedings,

demand, or costs or damages whatsoever or howsoever caused arising directly or indirectly in connection with or arising out of the use of this material.

Downloaded by [santiago schalamuk] at 15:55 10 January 2013

Biological Agriculture & Horticulture, 2013
http://dx.doi.org/10.1080/01448765.2012.753397

Taylor & Francis
Taylor & Francis Group

Dynamics of arbuscular mycorrhizal fungi spore populations and their viability under contrasting tillage systems in wheat at different phenological stages

S. Schalamuk[a,b]*, S. Velázquez[b,c] and M. Cabello[c,d]

[a]*Facultad de Ciencias Agrarias y Forestales, UNLP, 60 y 119 (1900), La Plata, Buenos Aires, Argentina;* [b]*CONICET, Buenos Aires, Argentina;* [c]*Instituto de Botánica Spegazzini, Facultad de Ciencias Naturales y Museo, UNLP, 53 # 477 (1900), La Plata, Buenos Aires, Argentina;* [d]*CICPBA, Buenos Aires, Argentina*

Downloaded by [santiago schalamuk] at 15:55 10 January 2013

Arbuscular mycorrhizal fungi (AMF) are influenced by soil management. The use of different tillage systems affects AMF activity. AMF spores are formed in soils or roots and provide a long-term reservoir of inoculum in the field. As spores can persist in soils, they reflect the accumulated sporulation history of the respective soil and not necessarily the current symbiosis of the crop. The aim of this study was to evaluate the AMF spore population dynamics and spore viability in conventional tilled and non-tilled soils throughout the wheat growing cycle and its fallow in the warm temperate Argentine Pampas. It was found that the differences in spore abundance between both tillage systems depend on the phenological stage of the crop. In both years, at the early phenological stages of the wheat crop, spore counts were about two or three times higher in no-tillage (NT) than in conventional tillage (CT). The lower spore counts in CT at the end of the fallow and at the early crop stages could be explained by the dilution of the AMF propagules in the zone of seedling establishment by ploughing. The percentages of viable spores varied with the treatments and the sampling periods, with values ranging from 10.5% to 58.8%, and were higher in CT in all the phenological stages and significantly higher at tillering stage. Assuming that a viable spore could be newly formed, then the lower percentages of viable spores in NT may suggest a higher accumulation of old residual spores.

Keywords: conventional tillage; Glomeromycota; no-tillage; number of spores; vital stain

Introduction

The Argentine Pampas region is one of the most important cropping regions in the world and accounts for more than 90% of the national grain production, with soyabean, wheat, corn and sunflower as the main crops (Magrin et al. 2005). Limited tillage systems, especially no-till, have spread widely in recent years, currently occupying around 70% of the surface devoted to annual crops (Alvarez & Steinbach 2009; Derpsch et al. 2010).

Arbuscular mycorrhizal fungi (AMF), which belong to the phylum Glomeromycota (Schüβler et al. 2001), are heavily influenced by soil management. The use of different tillage systems affects AMF activity (Sieverding 1991; Curaqueo et al. 2011), AMF community structure (Jansa et al. 2003; Schalamuk et al. 2006; Schnoor et al. 2011) and other soil properties and microbial abundance (Aon, Cabello, et al. 2001; Aon, Sarena, et al. 2001). AMF are able to colonize host plants by three inoculum sources: spores, mycorrhizal roots and extraradical mycelia (Smith & Read 2008), which comprise the so-called

*Corresponding author. Email: sschala@yahoo.com.ar

© 2013 Taylor & Francis

propagule bank (Schalamuk & Cabello 2010). It is well known that tillage negatively affects AMF colonization (McGonigle & Miller 1996; Schalamuk et al. 2004; Kabir 2005). The most studied mechanisms by which tillage reduces AMF colonization are the destruction of the mycelial network (Alvaro-Fuentes et al. 2008) and the dilution of the AMF propagules in the zone of seedling establishment by ploughing below this depth (Kabir 2005).

AMF spores are formed by differentiation of vegetative hyphae in the soil or roots and provide a long-term reservoir of inoculum in soils. As spores can persist in field soils, they reflect the accumulated sporulation history of the respective soil and not necessarily the current symbiosis of the crop (Hijri et al. 2006). From all mycorrhizal characteristics, the number of spores has been mentioned as an early and useful indicator of the effect of tillage systems on mycorrhizal propagules in short-term experiments (Castillo et al. 2006). As in field soils, spore populations are heterogeneous in age, taxa and viability, thus assessing the viability of spores allows determining their potential as propagules (An et al. 1998). Viability can also be potentially evaluated as an indicator of changes in mycorrhizal activity. To the knowledge of the authors there are no studies on the influence of tillage on spore viability.

Some studies have shown higher spore counts in no-tilled soils than in tilled soils (Jansa et al. 2002; Schalamuk et al. 2003). However, few studies have compared the influence of tillage on spore counts at different phenological stages of a crop, including the fallow (Troeh & Loynachan 2003; Castillo et al. 2006). Most of the studies comparing AMF population and/or activity in conventional tillage (CT) and no-tillage (NT) have carried out only one sampling in the growing season (Jansa et al. 2002; Alguacil et al. 2008). However, under field conditions, sporulation patterns have been found to fluctuate with the season or host phenology (An et al. 1993). Hence, further studies on the dynamics of the number of spores throughout a crop cycle and on how it is influenced by tillage are required.

Wheat is one of the most important crops in the Argentine Pampas (Covacevich et al. 2007) and the most cultivated in winter. Under the warm temperate conditions of the Pampas region, there is one short fallow between two consecutive winter crops, which occurs from summer to autumn, with a variable presence of weeds (Poggio et al. 2004). The conditions of the fallows in Argentina notably differ from those of other agricultural regions where mycorrhizal seasonal changes have been studied (Thompson 1987; Troeh & Loynachan 2003). Understanding the effect of the fallows on the number of AMF spores and its viability is relevant for managing mycorrhizal populations (Smith & Read 2008). To the knowledge of the authors, there is no information on spore counts in the fallows under different tillage systems in the Argentine Pampas.

The aims of this study were: (i) to evaluate the AMF spore population dynamics in tilled and non-tilled soils throughout the wheat growing cycle and its fallow in the warm temperate Argentine Pampas over 2 years and (ii) to determine the viability of indigenous mycorrhizal fungal spores present in different tillage systems and a non-disturbed control (NDC) over the course of 1 year.

It was hypothesized that sporulation in field soils is linked to crop phenology and that the accumulation of spores from previous periods can influence spore count and viability determinations. Therefore, total spore counts will not reflect crop phenological changes.

Materials and methods

The field experiment was carried out at the agricultural experimental station Ingeniero Agrónomo Hirshhorn, Faculty of Agriculture, University of La Plata (Buenos Aires, Argentina). The climate is temperate and the mean annual temperature is 15.8°C, with the highest monthly mean temperature in January (24.2°C) and the lowest in July (10.5°C).

Downloaded by [santiago schalamuk] at 15:55 10 January 2013

Downloaded by [santiago schalamuk] at 15:55 10 January 2013

Rainfall is mainly concentrated in autumn and spring, and the mean annual rainfall is 1000 mm.

The samples were collected from a long-term field tillage experiment initiated in 1993, composed of two tillage treatments: NT and CT, autumn ploughed and disked before planting. The previous crops had been: 1993, soyabean; 1994, corn; and since 1995, wheat. AMF spore counts were carried out from 2002 to 2004, when the tillage experiment was sown with wheat (*Triticum aestivum* L.), a mycorrhizal crop plant. The wheat cultivar used was Buck Pronto. The CT plots were tilled to a depth of 25 cm. The treatments were arranged in randomized, split-plot design and replicated three times and the size of each plot was 3.8 m × 12 m. Samples were taken from plots without N and P fertilization. In the fallow, the plots were invaded by weeds, mostly *Cynodon dactylon* (L.) Pers. Details of the experimental design are described in Schalamuk et al. (2006).

From 2003, another field treatment was added called the 'NDC' on the edges of the field experiment, which had not been cultivated for more than 20 years. These plots had the following plant species: *Ammi visnaga* (L.) Lam., *Avena fatua* L., *Briza minor* L., *Cynara cardunculus* L., *C. dactylon*, *Deyeuxia viridiflavescens* (Poir.) Kunth, *Ipomea purpurea* (L.) Roth, *Lolium perenne* L., *Plantago lanceolata* L., *Vicia* sp. and *Xanthium cavanillesii* Schouw ex Didr.

The rhizospheric soil was sampled at three phenological stages of wheat, tillering, flowering and grain filling, stages Z25, Z65 and Z95, respectively, using the scale proposed by Zadoks et al. (1974), and at the end of the following fallow of both growing cycles (2002–2003 and 2003–2004), after primary tillage operations in CT treatments. Composite random (Dick et al. 1996) soil samples were collected at a depth of 5–20 cm from all phenological stages. In places where each sample was collected, five to six subsamples (250 g) from square areas of approx. 3 m^2 were pooled. Such composite samples were collected and stored at 4°C until processed. AMF spores were isolated from 100 g (fresh weight) soil samples using the wet-sieving and decanting method (Gerdemann & Nicolson 1963) and the supernatant was centrifuged in a sucrose gradient (Walker et al. 1982). Only apparently healthy spores were counted in a 9-cm Petri dish by direct observation under a stereomicroscope. Spore counts were reported as the number of spores per 100 g dry soil. Soil moisture content was calculated for each soil sample as per cent oven-dry weight of soil by drying at 80°C for 48 h.

The viability of AMF spores was evaluated by vital staining in samples from 2003 to 2004, following the procedure by An and Hendrix (1988). Spore suspensions were diluted 1:1 with a stock solution of 0.5 mg ml^{-1} 3-(4,5-dimethyltiazol-yl)-2,5-diphenyl-2H-tetrazolium (MTT, Merck®, Germany) and incubated for 40 h. By this method, AMF viable spores develop a red colour with the tetrazolium bromide vital stain. The viability was expressed as a percentage of viable spores. When dark-coloured spores were encountered, which are difficult to stain, viability was confirmed by breaking these spores under stereomicroscope because the content of viable spores is purple coloured, whereas that of non-viable spores is hyaline. In the case of the values given as percentages, data were subjected to an arcsine square-root transformation to ensure homogeneity of variances. Then, the differences in total spore counts and percentage of viable spores between field treatments were compared with ANOVA and Least Significant Difference (LSD) tests.

Results

The number of spores strongly depended on the phenological stage of the wheat crop and the season, with values ranging from 80 to 390 spores in 100 g of soil in CT, from 300 to 560 in NT (Figures 1 and 2) and from 280 to 600 in NDC (Figure 2).

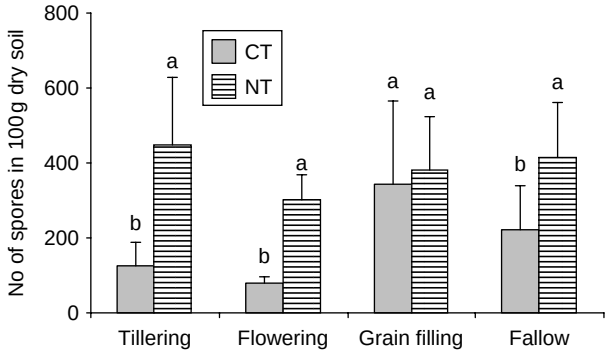


Figure 1. Number of spores in 100 g of soil as influenced by tillage at tillering, flowering, grain filling and fallow in the growing season 2002–2003 in CT and NT. Data are means of three replicates. Error bars: Standard Error. The same letter above bars indicates that the values did not differ significantly within each sampling period between management treatments as determined by LSD ($p < 0.05$).

In 2002–2003 (Figure 1) and 2003–2004 (Figure 2), there were higher spore counts ($p < 0.05$) in NT than in CT at tillering, flowering and in the fallows following the wheat crop. In 2003–2004, the NDC treatment was included. In NDC, which was not cultivated with wheat (Figure 2), similar spore counts were observed over the sampling period and an increase in autumn, when the cultivated plots were in fallow.

The percentages of viable spores in different treatments and phenological stages in the growing season 2003–2004 are shown in Table 1. At tillering, significant differences among the three treatments were observed, with the lowest values in NT and the highest in NDC. In the following phenological stages, within the cultivated plots, the percentages of viable spores were higher in CT than in NT, although differences were not significant. However, at grain filling and fallow, the percentages of viable spores in CT were significantly higher than those in NDC.

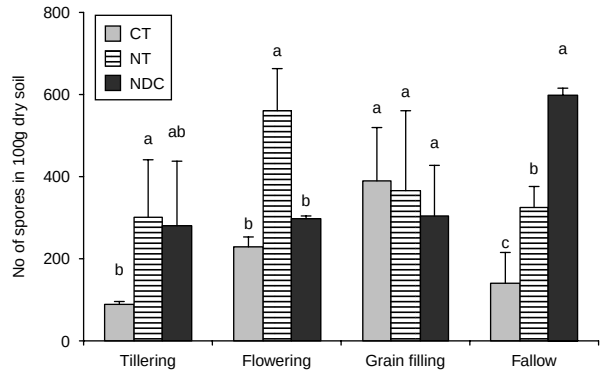


Figure 2. Number of spores in 100 g of soil as influenced by tillage at tillering, flowering, grain filling and fallow in the growing season 2003–2004, in CT, NT and in the NDC. Data are means of three replicates. Error bars: Standard Error. The same letter above bars indicates that the values did not differ significantly within each sampling period among management treatments as determined by LSD ($p < 0.05$).

Downloaded by [santiago schalamuk] at 15:55 10 January 2013

Table 1. Percentage of viable spores in the different wheat phenological stages (tillering, flowering, grain filling) and fallow in the treatments: CT, NT and NDC, in the growing season 2003–2004.

Treatments	Tillering	Flowering	Grain filling	Fallow
CT	30.0 b	52.0 a	58.8 a	32.9 a
NT	24.3 c	46.7 a	40.1 ab	17.6 ab
NDC	42.1 a	36.7 a	32.8 b	10.5 b

Notes: Data are means of three replicates. Values within a column followed by the same letter are not statistically significant within each sampling period among management treatments as determined by LSD ($p < 0.05$).

Discussion

Several researchers have found higher number of spores in NT than in CT in different crops (Kabir et al. 1998; Jansa et al. 2002). Most of these studies were carried out at only one sampling in the crop growing season. In contrast, in this study, spores were sampled at different phenological stages of the wheat crop and in the following fallow and it was found that the differences in spore abundance between tillage systems depend on the phenological stage of the crop. In both years, at tillering and flowering the spore counts were higher in NT than in CT. In the fallows of both growing seasons, which were sampled after primary tillage operations, higher spore counts were found in NT than in CT.

The higher spore counts in NT than in CT in the fallows of both growing seasons can be explained by the dilution of the AMF propagules in the zone of seedling establishment by ploughing (Kabir 2005). Therefore, this could also explain the lower spore counts in CT at the end of the fallow and at the early crop stages. On the other hand, tillage enhances aeration of the soil, speeding degradation of organic matter (Aon, Sarena, et al. 2001), and hence, disappearance of old spores. The NDC treatment, which was covered with spontaneous vegetation and was not cultivated, had similar spore counts throughout the evaluation period, but spore counts increased when the cultivated treatments were in fallow (end of autumn). Agricultural systems with annual crops show two periods with marked differences: a part of the year when there is a high density of host plants, belonging to the same species and growing simultaneously, and a fallow period after harvesting, with no hosts or, in some cases, with the presence of weeds. In contrast, non-agricultural soils, which are not mechanically disturbed (similarly to NT soils), show a given diversity of host plant species of varying age and seasonality hosting AMF, and spore counts reflect the phenological stage of the diverse plant community (Vandenkoornhuyse et al. 2002). In NDC plots, plant species were found which had been mentioned as mycorrhizal (see Wang & Qiu 2006). Differences between cultivated and non-cultivated treatments could be explained by the differences in the seasonality of plants hosting AMF.

On the other hand, it was found that the percentages of viable spores were higher in CT than in NT throughout the crop cycle, with significant differences at tillering. Although the age of spores could not be determined in this study, it can be speculated that there is a relationship between the age of spores and their viability (An et al. 1998). Assuming that a viable spore could be newly formed, then the lower percentages of viable spores in NT may suggest a higher accumulation of old residual spores in this treatment, formed during the fallow or in the previous crop.

At tillering and flowering, higher spore counts were found in NT than in CT. Studies in greenhouse pot cultures have shown that new sporulation generally starts between 4 and 8 weeks after the onset of colonization (Morton et al. 1993; Schalamuk & Cabello 2010). Although colonization of roots was not measured in this study, the lack of mechanical

Downloaded by [santiago schalamuk] at 15:55 10 January 2013

disturbance in NT allows the presence of an extensive AMF hyphal network, which leads to a rapid and early root colonization (McGonigle & Miller 1996; Schalamuk et al. 2004; Kabir 2005). Thus, a higher sporulation due to an earlier colonization may be expected. Therefore, the higher spore counts in NT at the early phenological stages could be the result not only of spore accumulation from previous periods, but also of a higher sporulation in NT than in CT.

In both growing cycles, spore counts did not vary from grain filling to the following fallow in NT, whereas these counts declined until the fallow in CT. Considering that the spore counts at fallow were made after the primary tillage, it can be speculated that the dilution of AMF propagules cited above (Kabir 2005) was the most important factor affecting the spore counts found at fallow in CT. On the other hand, in NT, the lack of variation in the spore count from grain filling to the end of the fallow, which is throughout the fallow, seems to contradict several studies (Thompson 1987; Harinikumar & Bagyaraj 1988; Troeh & Loynachan 2003). However, the fallow conditions vary considerably depending on the cultivation practices, the soil and weather conditions, the vegetation cover and the duration of the fallow. Therefore, the impact of a short summer fallow in the warm temperate climate of the Pampas region on AMF communities may be different from that of winter fallows covered by snow in Canada, as studied by Kabir et al. (1999) or Troeh and Loynachan (2003), or from that of fallows lasting for 1 year or longer, as studied by Harinikumar and Bagyaraj (1988) and Thompson (1987). In this experiment, the warm temperate climate, which allowed weed growth, mainly the grass *C. dactylon*, in NT could lead to the formation of new spores, as this plant species can produce high number of AMF spores (Antunes et al. 2010).

In 2003–2004, when the NDC treatment was included, we observed different spore count dynamics mostly between cultivated and non-cultivated treatments. As spore production depends on the carbon supply from the host to the fungus (Smith & Read 2008), it can be inferred that, in cultivated soil, spore formation could be linked to the host phenology and concentrated in time, whereas in non-cultivated soils the spore formation could depend on the phenology and seasonality of different host plant species (Pringle & Bever 2002).

As a conclusion, this study found higher spore counts in NT than in CT, mainly at the early stages of the crop, but with lower viability percentages. This could be related to spore accumulation from AMF activity in previous crops or in the fallow. Considering the importance of AMF populations to support sustainable cropping systems, further studies should be carried out to better understand the influence of fallow on spore counts in the following crop in warm temperate conditions such as the Argentine Pampas.

Downloaded by [santiago schalamuk] at 15:55 10 January 2013

Acknowledgements

We wish to thank Dr H. Acciaresi and the anonymous reviewers for critical reading and suggestions for this article. This research was supported by grants from UNLP (11/N651 Project) and CICPBA.

References

Alguacil MM, Lumini E, Roldan A, Salinas-Garcia JR, Bonfante P, Bianciotto V. 2008. The impact of tillage practices on arbuscular mycorrhizal fungal diversity in subtropical crops. Ecol Appl. 18:527–536.

Alvarez R, Steinbach HS. 2009. A review of the effects of tillage systems on some soil physical properties, water content, nitrate availability and crops yields in the Argentine Pampas. Soil Till Res. 104:1–15.

Alvaro-Fuentes J, Arrue JL, Cantero-Martinez C, Lopez MV. 2008. Aggregate breakdown during tillage in a Mediterranean loamy soil. Soil Till Res. 101:62–68.
An ZQ, Guo BZ, Hendrix JW. 1993. Populations of spores and propagules of mycorrhizal fungi in relation to the life cycles of tall fescue and tobacco. Soil Biol Biochem. 25:813–817.
An ZQ, Guo BZ, Hendrix JW. 1998. Viability of soilborne spores of glomalean mycorrhizal fungi. Soil Biol Biochem. 30:1133–1136.
An ZQ, Hendrix JW. 1988. Determining viability of endogoneous spores with a vital stain. Mycologia. 80:259–261.
Antunes PM, Koch AM, Morton JB, Rillig MC, Klironomos JN. 2010. Evidence for functional divergence in arbuscular mycorrhizal fungi from contrasting climatic origins. New Phytol. 189:507–514.
Aon MA, Cabello MN, Sarena DE, Colaneri AC, Franco MG, Burgos JL, Cortassa S. 2001. I. Spatio-temporal patterns of soil microbial and enzymatic activities in an agricultural soil. Appl Soil Ecol. 18:239–254.
Aon MA, Sarena DE, Burgos JL, Cortassa S. 2001. (Micro)biological, chemical and physical properties of soils subjected to conventional or no-till management: an assessment of their quality status. Soil Till Res. 60:173–186.
Castillo CG, Rubio R, Rouanet JL, Borie F. 2006. Early effects of tillage and crop rotation on arbuscular mycorrhizal fungal propagules in an Ultisol. Biol Fert Soils. 43:83–92.
Covacevich F, Echeverria HE, Aguirrezabal LAN. 2007. Soil available phosphorus status determines indigenous mycorrhizal colonization of field and glasshouse-grown spring wheat from Argentina. Appl Soil Ecol. 35:1–9.
Curaqueo G, Barea JM, Acevedo E, Rubio R, Cornejo P, Borie F. 2011. Effects of different tillage systems on arbuscular mycorrhizal fungal propagules and physical properties in a Mediterranean agroecosystem of Central Chile. Soil Till Res. 113:11–18.
Derpsch R, Friedrich T, Kassam A, Li HW. 2010. Current status of adoption of no-till farming in the world and some of its main benefits. Int J Agric Biol Eng. 3:1–26.
Dick RP, Thomas DR, Turco RP. 1996. Standarized methods, sampling, and sample treatment. In: Doran JW, Jones AJ, editors. Methods for assessing soil quality. Madison, WI: SSSA Special Publication. p. 107–121.
Gerdemann JW, Nicolson TH. 1963. Spores of mycorrhizal *Endogone* species extracted from soil by wet sieving and decanting. Trans Br Mycol Soc. 46:235–244.
Harinikumar KM, Bagyaraj DJ. 1988. Effect of crop rotation on native vesicular-arbuscular mycorrhizae in soil. Plant Soil. 110:77–80.
Hijri I, Sykorova Z, Oehl F, Ineichen K, Mader P, Wiemken A, Redecker D. 2006. Communities of arbuscular mycorrhizal fungi in arable soils are not necessarily low in diversity. Mol Ecol. 15:2277–2289.
Jansa J, Mozafar A, Anken T, Ruh R, Sanders IR, Frossard E. 2002. Diversity and structure of AMF communities as affected by tillage in a temperate soil. Mycorrhiza. 12:225–234.
Jansa J, Mozafar A, Kuhn G, Anken T, Ruh R, Sanders IR, Frossard E. 2003. Soil tillage affects the community structure of mycorrhizal fungi in maize roots. Ecol Appl. 13:1164–1176.
Kabir Z. 2005. Tillage or no-tillage: impact on mycorrhizae. Can J Plant Sci. 85:23–29.
Kabir Z, O'Halloran IP, Hamel C. 1999. Combined effects of soil disturbance and fallowing on plant and fungal components of mycorrhizal corn (*Zea mays* L.). Soil Biol Biochem. 31:307–314.
Kabir Z, O'Halloran LP, Widden P, Hamel C. 1998. Vertical distribution of arbuscular mycorrhizal fungi under corn (*Zea mays* L.) in no-till and conventional tillage systems. Mycorrhiza. 8:53–55.
Magrin G, Travasso M, Rodriguez G. 2005. Changes in climate and crop production during the 20th century in Argentina. Climatic Change. 72:229–249.
McGonigle TP, Miller MH. 1996. Mycorrhizae phosphorus absorption and yield of maize in response to tillage. Soil Sci Soc Am J. 60:1856–1861.
Morton JB, Bentivenga SP, Wheeler WW. 1993. Germplasm in the international collection of arbuscular and vesicular-arbuscular mycorrhizal fungi (INVAM) and procedures for culture development, documentation and storage. Mycotaxon. 48:491–528.
Poggio SL, Satorre EH, de la Fuente EB. 2004. Structure of weed communities occurring in pea and wheat crops in the Rolling Pampa (Argentina). Agric Ecosyst Environ. 103:225–235.
Pringle A, Bever AJ. 2002. Divergent phenologies may facilite the coexistence of arbuscular mycorrhizal fungi in a North Carolina grassland. Am J Bot. 89:1439–1446.

Downloaded by [santiago schalamuk] at 15:55 10 January 2013

Schalamuk S, Cabello M. 2010. Arbuscular mycorrhizal fungal propagules from tillage and no-tillage systems: possible effects on Glomeromycota diversity. Mycologia. 102:261–268.
Schalamuk S, Velasquez S, Chidichimo H, Cabello M. 2003. Efecto de diferentes sistemas de labranza fertilizacion sobre la simbiosis micorrizica arbuscular en cultivo de trigo. Boletín Micológico. 18:15–19.
Schalamuk S, Velazquez S, Chidichimo H, Cabello M. 2004. Effect of no-till and conventional tillage on mycorrhizal colonization in spring wheat. Boletín Sociedad Argentina Botánica. 39:13–20.
Schalamuk S, Velazquez S, Chidichimo H, Cabello M. 2006. Fungal spore diversity of arbuscular mycorrhizal fungi associated with spring wheat: effects of tillage. Mycologia. 98:22–28.
Schnoor TK, Lekberg Y, Rosendahl S, Olsson PA. 2011. Mechanical soil disturbance as a determinant of arbuscular mycorrhizal fungal communities in seminatural gassland. Mycorrhiza. 21:211–220.
Schüβler A, Schwarzott D, Walker C. 2001. A new fungal phylum, the *Glomeromycota*: phylogeny and evolution. Mycol Res. 105:1413–1421.
Sieverding E. 1991. Vesicular-arbuscular mycorrhiza management in tropical agrosystems. Deutche Gesellschaft fur Technische Zusammenarbeit, GTZ No 224. Eschborn, Germany.
Smith SE, Read DJ. 2008. Mycorrhizal symbiosis. 3rd ed. London: Academic Press.
Thompson JP. 1987. Decline of vesicular-arbuscular mycorrhizal in long fallow disorder of field crops and its expression in phosphorus deficiency of sunflower. Aust J Agric Res. 38:847–867.
Troeh ZI, Loynachan TE. 2003. Endomycorrhizal fungal survival in continuous corn, soybean, and fallow. Agron J. 95:224–230.
Vandenkoornhuyse P, Husband R, Daniell TJ, Watson IJ, Fitter AH, Young JPW. 2002. Arbuscular mycorrhizal community composition associated with two plant species in a grassland ecosystem. Mol Ecol. 11:1555–1564.
Walker C, Mize W, McNabb HS. 1982. Populations of endogonaceous fungi at two populations in central Iowa. Can J Bot. 60:2518–2529.
Wang B, Qiu Y-L. 2006. Phylogenetic distribution and evolution of mycorrhizas in land plants. Mycorrhiza. 16:299–363.
Zadoks JC, Chang TT, Konzak CF. 1974. A decimal code for the growth stages of cereals. Weed Res. 14:415–421.

Downloaded by [santiago schalamuk] at 15:55 10 January 2013