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Arbuscular mycorrhizal colonization and spore density across different land-use types in a hot and arid ecosystem, Southwest China

Ling-Fei Li[1], Yan Zhang[1], and **Zhi-Wei Zhao[1]***

[1] Laboratory for Conservation and Utilization of Bio-resources, Yunnan University, Kunming 650091, P.R. China

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Summary

We investigated the arbuscular mycorrhizal (AM) colonization and spore density in cropped land, fallow land, and an undisturbed savanna ecosystem under hot and arid climatic conditions in a valley of southwest China. Plants surveyed in the three land-use types showed heavy arbuscular mycorrhizal colonization, indicating a high mycorrhizal dependency of plants in this environment. One-way analysis of variance (ANOVA) showed that the colonization of different AM structures and the spore density varied greatly among plant species both within and between different land-use types. The AM colonization and spore density were higher in undisturbed than in fallow or cropped land. No significant correlation between AM colonization and spore density was observed when land-use types were either considered separately or together. Cluster analysis based on the similarity in AM status with respect to both colonization and spore density showed similarities between fallow land and the undisturbed savanna. The results indicate that continuous cropping reduces AM colonization and spore density. These parameters appear to nearly fully recover when the land has been left to fallow for 4 years.

Key words: mycorrhiza / colonization / spore density / restoration

1 Introduction

Arbuscular mycorrhizal fungi (AMF) are widespread from the tropics to polar regions, from wetlands to arid regions, and are associated with the roots of approximately 80% of all terrestrial plants species (*Schüßler* et al., 2001; *Smith* and *Read*, 1997). They are considered to be essential components of sustainable soil-plant systems, particularly in marginal environments (*Hooker* and *Black*, 1995). Benefits derived by plants from AMF include a higher uptake of nutrients, especially of phosphorus, an increased drought-stress tolerance, and an improved tolerance to some pathogens (*Koide* and *Mosse*, 2004). They also play an important role in the formation and stability of soil aggregates and contribute to soil fertility and quality (*Wright* and *Upadhyaya*, 1998). It has been suggested that AMF can influence the plant diversity, productivity, community structure, and ecosystem processes (*van der Heijden* et al., 1998). Because all of these beneficial effects on plant performance and soil health, AMF are crucial for the reclamation and restoration of degraded ecosystems (*Cuenca* et al., 1998). In recent years, there has been a growing demand for the re-establishment of vegetation in degraded semi-arid and arid ecosystems using AM technology (*Estaún* et al., 1997). This is also the case of the area of Yuanmou in semi-arid southwest China.

Yuanmou is predominantly covered by sparse bush vegetation. Only 6% of the area is covered by a poor-quality mixed forest and some tree plantation, while 14% of the land has no vegetation cover at all. Overgrazing and wood chopping have intensively disturbed this ecosystem in recent years. Intense rainfall during the short wet season accelerates soil erosion and land degradation. Large efforts are required to restore such degraded ecosystems. One possible strategy comprises to leave the cropped land to fallow for extended periods, permitting the re-establishment of secondary grassland or forest. To date, little is known about the level of mycorrhization and spore densities in this environment as affected by changing land use. Due to the importance of AMF for vegetation re-establishment in such fragile and degraded ecosystems, we assessed the current status of AMF colonization, spore density, and species composition, comparing cropped land, fallow land, and undisturbed savanna ecosystems in a typical valley of Yuanmou. Specific objectives were to investigate the level of plant mycorrhization and AMF spore density under different forms of land use and to analyze the variation of AMF colonization and spore density during the conversion of undisturbed to cropped land and the subsequent restoration under fallow management.

2 Materials and methods

2.1 Study site

The study site is located in Yuanmou (101°35′–102°06′ E, 25°23′–26°06′ N) in southwest China. The annual mean temperature is 21.9°C, reaching up to 43°C during May and dropping to 14.9°C in December. Most of the mean annual precipitation of 629 mm falls between June and October while rainfall during the 7-month dry season (November to May) rarely exceeds 100 mm. With 3729 mm, the evaporation exceeds by nearly six times the precipitation (35-year data from the Meteorological Station of Yuanmou County). Three representative land-use types included (1) land continuously cultivated with field crops since about 30 years (sorghum, groundnut, sweet potato, and Chinese onion cultivated during the wet season), (2) formerly cultivated land that has been left to natural fallow regrowth for 4 years, and (3) undisturbed natural savanna land. All three land-use types were located adjacently on the slope of one valley (about 8 km × 5 km). The undisturbed "valley-type savanna" (*Jin* and *Ou*, 2000)

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* Correspondence: Dr. Z.-W. Zhao; e-mail: zhaozhw@ynu.edu.cn

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was dominated by grasses and bushes with some rare trees (*i.e.*, *Heteropogon contortus* Beauv. ex Roem. & Schult., *Bothriochloa pertusa* (L.) A. Camus, and *Dodonea viscose* Jacq.). The fallow land was recolonized by diverse indigenous grasses and herbs. Additionally, there was some regrowth of groundnut, sorghum, and some "exotic" *Azadirachta indica* A. Juss. and *Cajanus cajan* (L.) Millsp. that were transplanted into the fallowed land in 2001.

2.2 Sample collection

Main cultivated species, such as sweet potato, maize, groundnut, and sorghum (cropped land), some residual crops and re-establishing natural vegetation (fallow land), and the dominant natural vegetation species (undisturbed land) were sampled. Plant roots and rhizosphere soil were collected to a depth of 5–30 cm during the dry season of 2004 (November). Three to six samples for each plant species were collected from each land-use type. Roots were washed with tap water, fixed in ½ FAA (formalin + glacial acetic acid + 70% ethanol in a 1:1:18 ratio), and stored at 4°C. About 500 g of soil were air-dried for 2 weeks and stored in sealed plastic bags at 4°C until analysis.

2.3 Soil assessment

The soil in the study area is a clay soil. Selected physical and chemical properties of soils were analyzed using the methods described by *Tan* (1996): soil pH was determined by potentiometric method; organic carbon was determined by the K_2CrO_7 wet-combustion method; total N was determined by the Kjeldahl method; total P and total K were digested by HNO_3 + $HClO_4$ + HF and were measured by inductively coupled plasma–atomic emission spectrometry (ICP-AES); available P and available K were extracted with NH_4HCO_3 + DTPA (Diethylenetriaminepentaacetatic acid) and were measured by ICP-AES. These properties of soils under the three contrasting land-use regimes are presented in Tab. 1.

2.4 Assessment of arbuscular mycorrhizal colonization

Roots were taken out from ½ FAA, washed several times in tap water, and cleared in 10% (w/v) KOH by heating to approximately 90°C in a water bath for 2–3 h. The cooled root samples were washed, stained with 0.5% acid fuchsin, and then examined for AM fungal structures under a compound-light microscope (OLYMPUS-BX51) at 200- to 400-fold magnification. Fungal colonization was estimated using the magnified intersection method (*Li* et al., 2005). The percentage of root length with hyphae (*RLH*), hyphal coils (*RLHC*), vesicles (*RLV*), arbuscules (*RLA*), and total AM colonization (*RLC*) were quantified by examining 150 intersections per sample.

2.4 Assessment of arbuscular mycorrhizal fungal spores

Rhizosphere soil samples were wet-sieved for spores using the method described by *Zhao* et al. (2001). All healthy AMF spores (spore with noncollapsed surface and contents and no evidence of parasitism) of each sample were counted. Some spores were tightly grouped in a sporocarp, it was difficult to count the number of the spores in such cases, and a sporocarp was considered as one unit. The spore densities were expressed as the numbers of spores and sporocarps per 20 g of soil.

2.5 Statistical analyses

Statistical analyses were carried out with SPSS software (version 12.0). Data on percentage of AM colonization were transformed by arcsin $x^{1/2}$ and spore densities were transformed by log(x+1) to fulfill the assumption of normality and homogeneity of variances before analysis of variance. Means given in tables were untransformed. Transformed data were subjected to one-way ANOVA to test the differences in AM colonization and spore density among plant species both within and between different land-use types. Mean separation was done by Duncan's multiple-range test at the 0.05 level of probability. The relationship between AM colonization and spore density was determined by Pearson's correlation analysis. A hierarchical cluster analysis using Ward's method and squared Euclidean distance was applied to determine the similarity between land-use types with respect to both colonization of different AMF structures and spore density.

3 Results

3.1 Arbuscular mycorrhizal colonization

All of the surveyed plants formed typical AM symbiosis because at least vesicles or arbuscules were found in the root tissues. Intra- and intercellular hyphae, hyphal coils, vesicles, arbuscules of AMF were abundant in most of plant roots and sometimes occurred in clusters and occasional intraradical spores were observed. In the present study, the AMF hyphae were so prevalent in all samples that *RLH* were very high and were equal to or a little bit lower than RLC (Tab. 2).

In a given land-use type, *RLH, RLHC, RLV, RLA,* and *RLC* varied greatly among plant species and showed significant differences. The ranges of AMF colonization were very wide within each land-use type. For example, *RLC* varied from 24% (for *Helianthus annuus* L.) to 77% (for *Phaseolus vulgaris* L.) in cropped land, from 2% (for *Arachis hypogaea* L.) to 77% (for *C.*

Table 1: Selected physical and chemical properties of the experimental soils under three different types of land use.

Land-use types	Texture	pH	Organic C (g kg^{-1})	Total N (g kg^{-1})	Total P (g kg^{-1})	Available P (mg kg^{-1})	Total K (g kg^{-1})	Available K (mg kg^{-1})
Cropped land	clay	6.6	9.4	0.8	0.4	10.4	15.0	132.00
Fallow land	clay	6.5	11.7	0.7	0.4	12.1	14.2	97.90
Undisturbed land	clay	6.2	20.1	1.1	1.5	7.9	6.1	130.00

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Table 2: Effect of land use on the arbuscular mycorrhizal colonization of roots and spore density in the rhizosphere soil of dominant plant species (semi-arid savanna environment, China, 2004).

Plants	**Land-use type**	**English name or growth form**	**AM colonization**					**Spore density** (per 20 g soil)
			RLH	*RLHC*	*RLV*	*RLA*	*RLC*	
Allium fistulosum L.	cropped land	shallot	72.7 ab	8.7 a	0.9 e	55.8 a	72.9 ab	197.7 b
Allium sativum L.	cropped land	garlic	64.2 abc	8.9 a	3.3 bcde	29.8 abc	65.3 abc	113.0 b
Arachis hypogaea L.	cropped land	groundnut	46.3 abcd	1.3 b	5.8 ab	3.1 de	46.3 abcd	297.5 a
Cajanus cajan (L.) Millsp.	cropped land	shrub	61.8 abc	2.4 b	10.0 a	17.6 cde	62.0 abc	305.0 a
Capsicum annuum L.	cropped land	capsicum	35.8 bcd	3.6 ab	3.3 bcde	20.7 bcde	35.8 bcd	170.0 b
Helianthus annuus L.	cropped land	sunflower	23.6 d	1.6 b	1.3 cde	10.0 cde	23.6 d	133.3 b
Ipomoea batatas (L.) Lam.	cropped land	sweet potato	44.2 abcd	4.6 ab	4.7 abcd	22.3 bcd	44.4 abcd	173.5 b
Lycopersicon esculentum Mill	cropped land	tomato	29.8 cd	4.4 ab	1.1 de	22.4 bcd	29.8 cd	167.0 b
Pachyrhizus erosus (L.) Urb.	cropped land	pachyrhizus	42.2 abcd	2.0 b	5.1 abc	22.2 bcd	42.2 abcd	139.7 b
Phaseolus vulgaris L.	cropped land	bean	77.3 a	2.4 b	3.1 bcde	47.8 ab	77.3 a	301.7 a
Sorghum bicolor (L.) Moench	cropped land	sorghum	26.4 d	4.7 ab	2.0 bcde	1.6 e	26.9 d	289.0 a
Zea mays L.	cropped land	maize	53.7 abcd	2.7 b	2.0 bcde	35.3 abc	53.7 abcd	138.5 b
Andropogon yunnanensis Hack.	fallow land	grass	7.3 de	0.4 ab	2.7 abcd	1.6 cd	7.3 de	350.7 abc
Arachis hypogaea L.	fallow land	groundnut	2.4 e	0 b	0.4 d	0 d	2.4 e	278.7 bc
Azadirachta indica A. Juss.	fallow land	shrub	48.9 ab	1.7 ab	4.4 abc	0.5 cd	49.1 ab	323.5 abc
Bidens bipinnata L.	fallow land	shrub	19.6 bcde	1.8 a	1.3 bcd	5.3 cd	19.6 bcde	438.3 a
Bothriochloa pertusa (L.) A. Camus	fallow land	grass	42.9 abc	0 b	6.9 a	4.7 c	42.9 abc	367.3 ab
Cajanus cajan (L.) Millsp.	fallow land	shrub	77.3 a	1.8 ab	8.2 a	45.1 a	77.3 a	314.7 bc
Heteropogon contortus Beauv. ex Roem. & Schult.	fallow land	grass	18.2 bcde	1.1 ab	3.1 abcd	4.0 c	18.2 bcde	241.7 c
Psoralea corylifolia L.	fallow land	shrub	36.4 bcd	0 b	6.2 ab	18.9 b	36.4 bcd	360.0 abc
Sorghum bicolor (L.) Moench	fallow land	sorghum	10.5 cde	0.2 b	1.0 cd	1.2 cd	10.5 cde	299.5 bc
Atylosia scarabaeoides (L.) Benth.	undisturbed land	shrub	71.8 ab	1.6 ab	10.0 b	7.3 b	71.8 ab	319.3 ab
Bothriochloa pertusa (L.) A. Camus	undisturbed land	grass	73.1 ab	3.6 ab	12.0 ab	6.4 b	73.6 ab	399.0 a
Cajanus cajan (L.) Millsp.	undisturbed land	shrub	40.2 bc	0.7 b	8.4 b	3.3 b	40.2 bc	212.0 b
Capillipedium parviflorum Stapf	undisturbed land	grass	49.1 abc	4.2 ab	10.7 b	6.0 b	49.6 abc	320.3 a
Dodonaea viscosa Jacq.	undisturbed land	shrub	20.7 c	1.8 b	8.2 b	3.8 b	20.9 c	339.0 a
Heteropogon contortus Beauv. ex Roem. & Schult.	undisturbed land	grass	76.9 a	6.0 a	22.2 a	8.5 b	77.6 a	470.3 a
Themeda caudata (Nees) A. Camus	undisturbed land	grass	62.0 ab	4.7 ab	17.8 ab	20.0 a	62.7 ab	368.7 a

Means followed by the different letters (a–e) in each column are significantly different within a given land-use type according to Duncan's multiple-range test at the 0.05 level of probability; *RLH, RLHC, RLV, RLA,* and *RLC* are percentages of root length with hyphae, hyphal coils, vesicles, arbuscules, and total colonization, respectively.

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Table 3: F value from one-way ANOVA for AM colonization and spore density of the same species between different land-use types.

Plants	**Land-use types**	**AM colonization and the order of land-use types by colonization**					**Spore density** (per 20 g soil)
		RLH	*RLHC*	*RLV*	*RLA*	*RLC*	
Arachis hypogaea	CL, *FL*	21.18** (*CL > FL*)	8.96* (*CL > FL*)	11.36* (*CL > FL*)	8.20* (*CL > FL*)	21.18** (*CL > FL*)	0.24 (*CL > FL*)
Bothriochloa pertusa	FL, *UL*	7.59 (*UL > FL*)	29.16** (*UL > FL*)	6.89 (*UL > FL*)	0.29 (*UL > FL*)	8.01* (*UL > FL*)	0.41 (*UL > FL*)
Cajanus cajan	CL, *FL*, UL	1.78 (*FL > CL > UL*)	1.09 (*CL > FL > UL*)	0.12 (*CL > UL > FL*)	7.30* (*FL > CL > UL*)	1.74 (*FL > CL > UL*)	3.36 (*CL > FL > UL*)
Heteropogon contortus	FL, *UL*	18.06* (*UL > FL*)	18.09* (*UL > FL*)	42.89** (*UL > FL*)	3.26 (*UL > FL*)	19.76* (*UL > FL*)	8.83* (*UL > FL*)
Sorghum bicolor	CL, *FL*	3.76 (*FL > CL*)	22.60** (*FL > CL*)	2.12 (*FL > CL*)	0.70 (*FL > CL*)	3.73 (*FL > CL*)	0.14 (*CL > FL*)

CL cropped land; *FL* fallow land; *UL* undisturbed land; *RLH, RLHC, RLV, RLA,* and *RLC* are percentages of root length with hyphae, hyphal coils, vesicles, arbuscules, and total colonization, respectively.
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

cajan) in fallow land, and from 21% (for *Dodonaea viscose* Jacq.) to 78% (for *H. contortus*) in undisturbed land.

The differences in AM colonization of the same species from different land-use types showed variable patterns (Tab. 3). For *A. hypogaea* and *Sorghum bicolor* (both grow in cropped land and fallow land), the colonization of different AM structures in cropped land was higher than those in fallow land. For *B. pertusa* and *H. contortus* (both occur in fallow land and undisturbed land), the colonization of AM structures in undisturbed land was higher than those in fallow land. While *C. cajan*, which occurred in all land-use types, showed no significant difference in most AM structures except RLA.

There were significant differences in the colonization of different AM fungal structures between land-use types (Tab. 4). In cropped land and undisturbed land, *RLH, RLHC,* and *RLC* were similar according to multiple-mean comparisons, but significantly higher than those of fallow land; *RLV* was highest (13%) in undisturbed land and lowest (4%) in fallow land; *RLA* in cropped land was 2.8-fold higher than in fallow land and undisturbed land.

3.2 Spore density of arbuscular mycorrhizal fungi

The results showed that the spores of *Glomus* and *Acaulospora* are dominant, and about 90% of the spores belonged to these two genera (unpublished data). Similar to AMF colonization, spore density also varied greatly both within and between land-use types (Tab. 2 and 4). Spore density ranged from 113 for *Allium sativum* in cropped land to 470 per 20 g soil for *H. contortus* in undisturbed land. There was no difference in spore density of the same plant species in different lands except for *H. contortus*, which showed significant difference between fallow land and undisturbed land (Tab. 3). Average spore density in fallow land (329 ± 14) and undisturbed land (347 ± 21) were significantly higher than that in cropped land (209 ± 13) (Tab. 4).

Table 4: Means for arbuscular mycorrhizal colonization and spore density in different land-use types.

Habitats	**AM colonization**					**Spore density** (per 20 g soil)
	RLH	*RLHC*	*RLV*	*RLA*	*RLC*	
Cropped land	47.61 a	3.82 a	3.84 b	22.11 a	47.79 a	208.59 b
Fallow land	30.59 b	0.84 b	3.78 b	7.95 b	30.62 b	328.81 9a
Undisturbed land	56.25 a	3.21 a	12.76 a	7.91 b	56.60 a	346.95 a

Means followed by the different letters (a–b) in each column are significantly different within a given land-use type according to Duncan's multiple-range test at the 0.05 level of probability. *RLH, RLHC, RLV, RLA,* and *RLC* are percentages of root length with hyphae, hyphal coils, vesicles, arbuscules, and total colonization, respectively.

Table 5: Pearson's correlation coefficients between total AM colonization (RLC) and different AM fungal structures.

Habitats	**AM colonization**				**Spore density** (per 20 g soil)
	RLH	*RLHC*	*RLV*	*RLA*	
Cropped land (n = 41)	0.99***	0.53***	0.49**	0.66***	0.11
Fallow land (n = 31)	0.99***	0.15	0.80***	0.59***	0.06
Undisturbed land (n = 21)	0.99***	0.50*	0.66***	0.47*	0.37
Three land use types(n = 93)	0.99***	0.49***	0.60***	0.54***	0.06

RLH, RLHC, RLV, RLA, and *RLC* are percentages of root length with hyphae, hyphal coils, vesicles, arbuscules, and total colonization, respectively.
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

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3.3 Correlation analysis

Correlation analysis indicated that RLC was positively correlated with *RLH, RLHC, RLV,* and *RLA* except for *RLHC* in fallow land (Tab. 5). There was no statistically significant relationship between *RLC* and spore density when land-use types were either considered separately or together. The relationship between *RLC* and *RLH* was very significantly positive correlation (r = 0.99, $p < 0.001$).

3.4 Similarity of AM status in different land-use types

A hierarchical cluster analysis based on the similarity in AM status (with respect to both colonization of different AMF structures and spore density) between land-use types showed that AM status in fallow land resembled undisturbed land, compared to cropped land (Fig. 1).

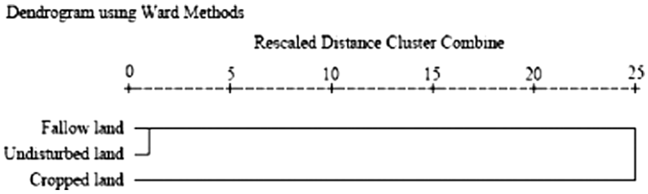

Figure 1: Dendrograms of cluster analysis based on the similarity of AM status (with respect to both colonization of different AMF structures and spore density) across three land-use types.

4 Discussions

Arbuscular mycorrhiza are the ubiquitous symbiosis in natural ecosystems. Their universality is reflected both by distributing geographically (*Schüßler* et al., 2001) and by forming the symbiosis with the majority of plant species due to their non-specific nature (*Smith* and *Read*, 1997). It is demonstrated that AM occur in large numbers of tropical trees, annual plants, and grasses, and in almost all crops (*Munyanziza* et al., 1997). In the present study, most of the target plants in cropped land, fallow land, and undisturbed land were heavily mycorrhized, indicating the high mycotrophic characters of the plants in this hot and arid ecosystem. *Li* and *Zhao* (2005) suggested that plants grown in the semiarid and arid habitats might be more dependent on AM through comparing the AMF-colonization rate and intensity of infection in roots of hot and arid ecosystems with other different ecosystems.

The colonization of different AM structures varied greatly among plant species both within and between land-use types based on one-way ANOVA. AMF-colonization levels in undisturbed land were higher compared to cropped land and fallow land. Generally, AM colonization is influenced by several factors, including soil properties, soil water content, plant phenology, predation, and propagule availability (*Muthukumar* et al., 2003a). In the present study, in most cases, different plant species were sampled and studied in different land-use types, so it is difficult to know whether the differences in AMF colonization are driven by plants or land use or other factors. Therefore, the causes that drive the differences in AMF colonization in different land-use types need to be further elucidated.

The mean spore density of AMF ranging from 113 to 470 spores (20 g soil)$^{-1}$ was higher than that of other different environments (*Duponnois* et al., 2001; *Muthukumar* et al., 2003b). Up to 15,531 spores (25 g soil)$^{-1}$ in the dry tropical ecosystems from Costa Rica were reported by *Johnson* and *Wedin* (1997). Considering less than 6% of spores established arbuscular mycorrhizas, *McGee* et al. (1997) assumed that 100 spores (20 g soil)$^{-1}$ would be required to initiate maximum levels of colonization. The relatively higher spore density in this ecosystem could be explained by the hot and arid environmental conditions. It is known that high temperature and high light intensity could increase AMF sporulation (*Cardoso* et al., 2003). Moreover, the sampling was done in the dry season (November) when the highest spore density could be expected (*Guadarrama* and *Álvarez-Sánchez*, 1999).

Spore density also differed significantly among plant species both within and between land-use types, indicating unevenly distribution of AMF spores. AM fungal sporulation is influenced by an array of factors which come from environment, host, and fungus, and spore density tend to decrease during root growth but to increase during root inactivity or senescence (*Muthukumar* et al., 2003b). *Zhao* et al. (2001) suggested that the uneven spatial distribution of AM fungal spores and the complex structure of the underground root component should be considered as major factors affecting spore density of AMF. Mean separation showed that the spore density in undisturbed land was significantly higher than that in cropped land, which further supported the view that disturbance reduced spore density (*Guadarrama* and *Álvarez-Sánches*, 1999; *Enkhtuya* et al., 2000).

It was noted that *C. cajan*, occurring in the three land-use types, has a relatively high AMF colonization, supporting the view that legumes have a high mycorrhizal dependency (*Duponnois* et al., 2001). There was no significant difference in spore density and AMF colonization of *C. cajan* except *RLA* in our study. *Duponnois* et al. (2001) suggested that to improve success in the restoration of soil fertility including biodiversity of AMF, attention should be given to legumes, because legumes could greatly enhance the AM fungal communities and the infectivity of soil.

No significant correlation between AMF colonization and spore density was observed when land-use types were either considered separately or together, which is consistent with several previous reports (*Zahka* et al., 1995). But this result was different from that found in the rainforest of Xishuangbanna, in which although spore numbers were not related to AM-fungal colonization when all the forest types were considered together, significant relationships emerged when the forest types were considered separately (*Muthukumar* et al., 2003a). It was suggested that AM-fungal spore numbers do not necessarily always correlate with AM-fungal colonization of roots (*Camargo-Raicalde* and *Dhillion*, 2003), probably due to the fact that the levels of spore production does not reflect the abundance of AMF in roots (*Daniell* et al., 2001).

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In the present study, spore density in cropped land was relatively lower, but AMF colonization was relatively higher, compared to fallow land and undisturbed land. It is well known that agricultural practices such as tillage, crop rotation, fertilizer and pesticide applications, and long fallow can influence the interactions of AMF and plants (*Douds* and *Millner*, 1999). In general, AMF populations, species richness, and root colonization are often reduced by soil disturbance resulting from agricultural activities (*Helgason* et al., 1998; *Oehl* et al., 2003). Cluster analysis based on the similarity in both colonization of different AM structures and spore density showed that fallow land resembled more undisturbed land than cropped land, which indicated that continuous cropping reduces AMF colonization and spore density. But when the land has been left to fallow for 4 years, AM status appear to nearly full recover.

It has been well shown that among the biotic factors that could favor rapid plant re-establishment, fasten plant growth, and alleviate abiotic stress, AM symbiosis is the most effective (*Duponnois* et al., 2001). This study provides basic information on the AMF status and clearly indicates differences in AMF colonization and spore density of cropped land, fallow land, and undisturbed land in the hot and arid valley, which are necessary for the reclamation and restoration of this ecosystem. The results indicated that AMF colonization and spore density was reduced by continuous cropping, and AM status appear to nearly fully recover when the land has been left to fallow for 4 years. Therefore, mixed (natural and artificial) restoration is an effective way for restoring AM status from cropped land to natural savanna ecosystem in this hot and arid ecosystem.

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