Pak. J. Bot., 47(4): 1391-1398, 2015.

UNDERSTORY PLANT DIVERSITY IN MIXED AND PURE PLANTATIONS OF *JATROPHA CURCAS* VS. NATIVE VEGETATION IN THE LOWER-MIDDLE REACHES OF THE LANCANG-MEIKONG RIVER WATERSHED, CHINA

GUANG-LONG OU, HUAN-CHENG MA, HUI XU* AND JUN-RONG TANG

Key Laboratory of State Forestry Administration for Biodiversity Conservation in Southwest China, Southwest Forestry University, Kunming 650224, China
**Corresponding author: zyxy213@126.com*

Abstract

22 plots at the Xiaoheijiang base, located in the lower-middle reaches of the Lancang-Meikong River in China, were investigated to analyze the understory biodiversity of *Jatropha curcas* plantations. Two kinds of mixed modes of *J. curcas* (mixed plantation with *Macadamia integrifolia* and mixed plantation with shrub species) and a pure plantation of *J. curcas* were planted, while the native vegetation served as a control. The plots were distributed along the gradients of forest management, succession and elevation by CCA analysis. Species richness was not significantly different for the different types of plantation, but the evenness of species could be affected, especially for the total community and the understory by planting *J. curcas.* The diversity and evenness indices of species were affected for the mixed plantation with different proportions of *M. integrifolia*, especially for the shrub layer, the Shannon diversity index and Pilou evenness index showed significant differences. And for the different mixed shrub species, only the Shannon diversity index and Pilou evenness index were significantly different. Finally, from the perspective of biological diversity, *J.curcas* plantation with shrub species would be a recommended planting model for ecological restoration in a dry-hot valley area, while *J. curcas* plantation with *M. integrifolia* would be an effective planting model to balance crop yield and food security.

Keywords: Understory; Plant diversity; *Jatropha curcas* plantation; CCA ordination; Lancang-Meikong River; China

Introduction

Biodiversity has long been an important objective of forest management because it provides a broader array of ecosystem services (Hooper *et al*., 2005; Carnus *et al*., 2006). Forest plantations have increased in area considerably in the last decades all over the world and this trend is predicted to continue (Anon., 1999; Moore & Allen, 1999; Hartley, 2002; Lachat *et al*., 2006). Forest plantations provide a range of forest products on a relatively limited land surface and can therefore contribute to reducing deforestation and degradation of natural forests (Anon., 2001). The biodiversity of plantations has been a topic of much discussion (Brockerhoff *et al*., 2008). Especially for fast-growing plantations, it has been debated internationally whether they cause local biodiversity to increase or decrease (Anon., 1989; Tang *et al*., 2007; Zhao *et al*., 2007). A common perception of plantation forests is that they are ecological deserts that do not provide habitat for valued organisms (Magura *et al*., 2000; Raman, 2006; Lachat *et al.*, 2006). However, numerous studies in many countries have documented that plantation forests can provide habitat for a wide range of native forest plants, animals, and fungi (Parrotta *et al*., 1997; Oberhauser, 1997; Humphrey *et al*., 2000; Brockerhoff *et al*., 2003; Barbaro *et al*., 2005; Carnus *et al*., 2006). Moreover, it has been generally acknowledged that the biodiversity of mixed forests is greater than that of pure forests. Carnevale & Montagnini (2002) found that species richness and abundance were greatest in mixed-species plots.

Jatropha curcas, a bush/small tree belonging to the family of Euphorbiaceae, is a native of tropical America. That now also thrives in many parts of the tropics and sub-tropics in Africa and Asia. It grows under a wide range of rainfall regimes from 200 to over 1500 mm per annum (Openshaw, 2000). It has gained attention in many countries for its hardiness, easy propagation, drought endurance high oil content, rapid growth, and adaptation to wide agro-climatic conditions. Thus it has been promoted in southern Africa, Brazil, Mali, India, Nepal and China etc. (Kumar & Sharma, 2008; Divakara *et al*., 2010). In China plans have been made to use this bio-energy plant to develop a material forest which will provide 6 billion litres of biodiesel oil by the end of 2020 (Stewart & Liu, 2011). In Yunnan, a province in the southwest of China, a project began in 2007 to form a bio-energy forest base of *J. curcas* with an area of 667 000 hm^2 by 2016 (Liu, 2007). The massive investment in new *Jatropha* plantations worldwide, however, is not sufficiently based on a profound scientific knowledge of its ecology (Maes *et al*., 2009). In particular the artificial pure forest may present some ecological problems, it has been found that water extracts from leaves of *J. curcas* has an allelopathic effect on its seed germination (He *et al*., 2009). *J. curcas* is susceptible to various diseases and insect pests (Shanker & Dhyani, 2006; Wu *et al*., 2008; Li *et al*., 2008; Xu *et al*., 2011). Despite some initial investigation of the mixed forest and the establishment of several models (Ou et al. 2008), there is almost no reports about *Jatropha* plantation biodiversity.

J. curcas was planted in the slope area in the valley area of southwest China, in the dry-hot valley which is typically an ecologically fragile area. This type of region features sparse vegetation, dry and barren soil, and serious water and soil erosion (Li *et al*., 2011). Vegetation restoration has been considered a serious challenge in this area. *J. curcas* had grown mainly scattered around houses or planted for hedgerows before the large-scale cultivation in this region began. To improve the vegetation restoration, we planned to use the mixed plantation model of planting *J. curcas* with native shrub species, but first we would need to predict the potential biodiversity changes caused by planting *J. curcas*.

Despite the fact that it is largely undomesticated, *Jatropha* needs resources like any other crop to achieve high productivity. If *Jatropha* has to compete for land with food crops or high carbon stocks, it loses its acclaimed sustainability advantages. The considerable lack of knowledge about the genetics, input responsiveness and agronomy of *Jatropha* makes its yields hard to predict (Achten *et al*., 2008; 2010). Scientists in Brazil and India are increasingly concerned as to whether biofuels will cause the disappearance of natural habitats or replace food production (Schaldach *et al*., 2011). Because the concept and practice of production of feedstocks for biofuels remain contested as to the threat they pose to food security, Jingura *et al*. (2011) assessed the availability and suitability of various land types as well as agro-ecological conditions for the production of *Jatropha* in Zimbabwe. For the sustainable development of *Jatropha* for bio-energy we would need to find a balance between the yield of *Jatropha* fruit and food security. A model that would appear to fit the facts would be the mixed model with some economic trees. But first we would need to understand any potential understory biodiversity change of the mixed plantations.

So we set out to research the understory biodiversity of *J. curcas* plantation. Taking into consideration the afforestation of the barren slope area and the balance between planting *Jatropha* and food security, combined with the basic condition of the site, we planted two kinds of mixed modes of *J. curcas*. One was a mixed plantation of *J. curcas* with *Macadamia integrifolia* (with different mixed ratios); the other was a mixed plantation of *J. curcas* with shrub species. A pure plantation of *J. curcas* was also planted. The native vegetation around the site was analyzed as a control.

The objectives of the research are to compare species richness, diversity and evenness at the different layers of the understory for the different *J. curcas* plantations and the native communities plots, and discuss the different plantations in terms of the ecological restoration of the planting area and the balance between the *Jatropha* yield and food security from the perspective of biodiversity, i.e., whether or not the two kinds of mixed modes are worth promoting from the perspective of biological diversity.

Materials and Methods

The object of the study was 4 years' growth of *Jatropha curcas* plantation at a base in Xiaoheijiang in Yunnan province, located in the lower-middle reaches of the Lancang-Meikong River in China. The plantation and local native vegetation communities had been investigated in 2011. The communities were initially divided by CCA ordination, and the succession of *J. curcas* plantation and the communities' biodiversity along environmental gradient and forest management had been analyzed. Biodiversity differences among the varied mixed proportions of *J. curcas* and the two kinds of mixed shrubs in the plantation had been researched. Finally the forest management and ecological restoration of the plantation had been discussed to provide advice and references for its cultivation and management.

Study site

The experimental area was located in Shuangjiang county, southwestern Yunnan province, China. The county, through the North Tropic of Cancer Cross, is located at 99°35′15″-100°09′33″E, 23°11′58″-23°48′50″N, east of the Lancang-Mekong River and north of the Xiaohei River which is a first level branch of the Lancang-Mekong River. The highest elevation in Shuangjiang county is 3223.5m and the lowest is 662.0m. The climate is subtropical montane monsoon where the mean annual temperature is 19.5℃ and the mean annual rainfall is about 1007.4 mm. The main rainfall period is from June to October, while the period from November to May is relatively dry.

The sampling data were mainly collected at the demonstration base of high yield cultivation technique on the *J. curcas* plantation near the Xiaohei River in Shuangjiang county. The altitude there ranges from 800m to 1500m. The soil belongs to the latosolic red earth group derived from schist, phyllite and alluvial deposits of ancient rivers, and is light loam in texture, deep and hardened (Hu *et al*., 2010). The main types of forestation land are grassland and shrub-grassland which are dominated by *Dodonaea viscosa*, *Woodfordia fruticosa*, *Phyllanthus emblica*, *Heteropogon contortus*, and *Eupatorium odoratum*, and some land that had been planted with some commercial trees, such as *Macadamia integrifolia*. *J. curcas* plantation had been planted at the site in 2007 and the proportion of *J. curcas* at the tree layer is from 60 to 100 % (Fig. 1).

Data collection: Twenty-two plots were investigated during the sampling in August 2011. The sampling plot size was $100m^2$.

The environmental features of each plot were described by altitude, slope, aspect, etc. Any human impacts, such as forest management, past logging or grazing, etc., were recorded.

Most of the plant species were identified in the field using botanical keys and local knowledge. Species that could not be identified in the field were identified at the herbarium of Southwest Forestry University.

Data analysis: The height, number and coverage of the species and the base diameter of the trees were measured. The Important Values (*IV*s) of each species and some diversity indices of each sample were computed.

$$IVs = (D_r + H_r + C_r) / 3 \qquad (1)$$

where

D_r is species relative abundance of a plot,
H_r is species relative height of a plot,
C_r is species relative dominance of trees, or species relative coverage of the shrubs and herbs at a plot.

According to the computing methods of plant community diversity which had used the important value (*IV*) calculated by Ma *et al*. (1995), four diversity indices were selected: the Gleason diversity index (D_g), Shannon-

Wiener diversity index (H_{sw}), Simpson diversity index (D_{sm}) and Pielou evenness index (E_{pi}). Their values were computed as follows:

$$D_g = S / \text{In}A \quad (2)$$

$$D_{sm} = 1 - \sum P_i^2 \quad (3)$$

$$H_{sw} = -\sum P_i \text{In} P_i \quad (4)$$

$$E_{pi} = H_{sw} / H_{\max} \quad (5)$$

$$H_{\max} = \text{In}S \quad (6)$$

where

S is the number of species,

A is the area of the plot,

P_i is proportion of the total sample belonging to the *i*th species,

H_{max} is the potential maximum value of Shannon-Wiener diversity.

The diversity indices of the shrub layer and herb layer were measured by Microsoft Office Excel 2003. The environmental factors included elevation, slope, aspect of slope and the average height of *J. curcas*. A species matrix of *IV*s and the environmental factors was thus formed. Then CCA ordination of the matrixes was performed by CANOCO (Ter Braak, 1986).Next one-way ANOVA was used to detect variations of the plant diversity indices among the main vegetation types reflected by CCA ordination. In this paper the ANOVA of the diversity indices was analyzed respectively by shrub layer and herb layer and carried out by SPSS 13.0 statistical software. And LSD-test was used for the comparison, and the significance level was set to 0.05.

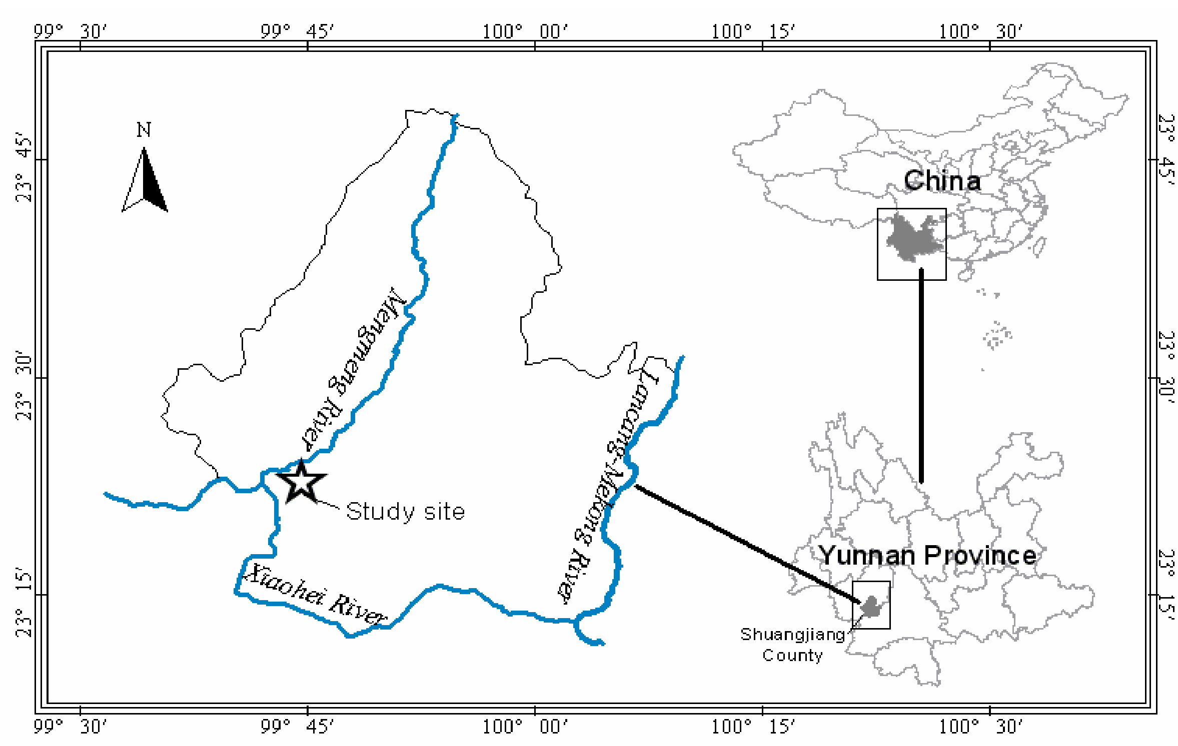

Fig. 1. Map of the study site.

Results

CCA ordination: The eigenvalues of the CCA axes and the correlations between the vegetation and environment axes are listed in Table 1. The CCA axes are closely related to those for the environment. The first CCA axis is much more significantly correlated with environmental variables and incorporated much more ecological information, with an eigenvalue of 0.536 (Zhang, 1995). The CCA ordination of the 22 plots is shown in Fig. 2.

Four types of vegetation can be classified from the distribution of plots in Fig. 2. One of the types is native vegetation of afforestation land, while the others are various plantations of *J. curcas*. The classification of the plots is listed in Table 2.

Type I is the pure plantation of *J. curcas*, where the proportion of *J. curcas* at the dominant layer is greater than 90%.

Type II is the mixed plantation of *J. curcas* with *Macadamia integrifolia*, where the proportion of *J. curcas* at the dominant layer is 60 to 90%.

Type III is the mixed plantation of *J. curcas* with shrub species, which can be divided into two types: Type III-A is the mixed plantation of *J. curcas* with *Phyllanthus emblica* which is located at the lower altitude area, while Type III-B is the mixed plantation of *J. curcas* with *Dodonaea viscosa* which is located in an area with altitude of above 1200m.

Type IV is the native vegetation of afforestation land, named shrub-grassland according to Jin's study (Jin, 1992) and includes two types. Type IV-A, dominated by *Eupatorium odoratum*, *Phyllanthus emblica*, *Woodfordia fruticosa* and *Themeda gigantea*, is mainly found in areas with an altitude below 1100m. Type IV-B is dominated by *Dodonaea viscos* and *Heteropogon contortus*, and found in areas with altitudes above 1200m.

The distribution of plots in Fig. 2 reflects the influence of environmental factors on vegetation. This suggests that the first CCA axis is closely related to the height of *J. curcas* in the plots, and the second axis to elevation. This also can be seen from the correlation coefficients between environmental variables and CCA axes (Table 3). The tree height is an important index to reflect the degree of forest management of the plantation. The first CCA axis reflects a gradient change along the difference of forest management. In Fig. 2 the change gradient from native vegetation of afforestation land, to the mixed plantation of *J. curcas* with shrubs species, to pure plantation of *J. curcas* and the mixed plantation of *J. curcas* with *Macadamia integrifolia* can be found along the first CCA axis. For the second CCA axis, elevation is an important factor because of its influence on the distribution of water and heat, followed by species composition, community structure and abundance distribution and so on.

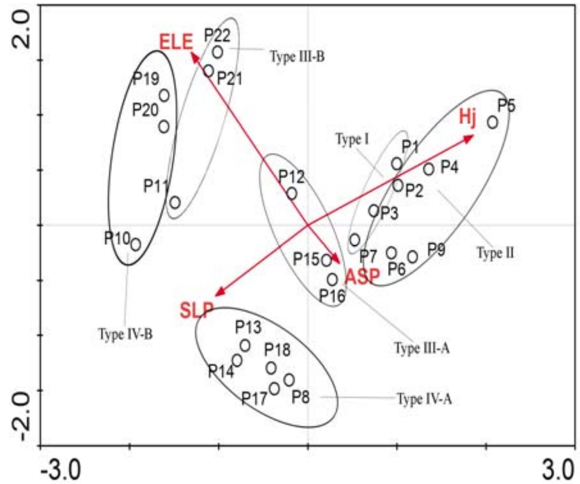

Fig. 2. Biplot of 22 plots and environmental variables from CCA analysis.
Note: ELE = Elevation, SLP = Slope, ASP = Aspect of slope, and Hj = Height of *Jatropha curcas* at the plots.

Table 1. Eigen values and species-environment correlations of CCA axes.

CCA	**Axes**			
	Axis1	**Axis2**	**Axis3**	**Axis4**
Eigenvalues	0.536	0.432	0.319	0.267
Correlations	0.975	0.960	0.891	0.894

Table 2. Vegetation types classified by CCA.

Types		**Name**	**Plots code**
Type I		Pure plantation with *J. curcas*	P1,P3,P7
Type II		Mixed plantation of *J. curcas* with *Macadamia integrifoli*	P2, P4, P5, P6, P9
Type III	Type III-A	Mixed plantation of *J. curcas* with *Phyllanthus emblica*	P12, P15, P16
	Type III-B	Mixed plantation of *J. curcas* with *Dodonaea viscos*	P11,P21, P22
Type IV	Type IV-A	Shrub-grassland dominated by *Eupatorium odoratum*, *Phyllanthus emblica*, *Woodfordia fruticosa* and *Themeda gigantea*	P8, P13, P14, P17, P18
	Type IV-B	Shrub-grassland dominated by *Dodonaea viscos* & *Heteropogon contortus*	P10, P19, P20

Table 3. Interset correlations of environmental variables with CCA axes.

Environmental variables	**CCA axes**			
	Axis1	**Axis2**	**Axis3**	**Axis4**
Slope (SLP)	-0.483	-0.298	0.709	-0.143
Aspect (ASP)	0.167	-0.160	-0.102	-0.862
Elevation (ELE)	-0.611	0.727	-0.148	0.072
Average height of *J. curcas*(Hj)	0.867	0.377	0.187	-0.095

Table 4. One-way ANOVA analyzing the diversity indices of four types.

Factors		**Type I**	**Type II**	**Type III**	**Type IV**	***F* Value**	**Sig.**
D_g	Shrub layer	2.027(0.663)a	1.520(0.595)a	1.665(0.224)a	1.439(0.505)a	1.124	0.365
	Herb layer	2.895(1.026)a	2.779(0.622)a	2.570(0.254)a	2.579(0.317)a	0.435	0.731
D_{sm}	Shrub layer	0.731(0.043)a	0.727(0.163)a	0.690(0.110)a	0.673(0.203)a	0.165	0.918
	Herb layer	0.665(0.310)ab	0.839(0.065)a	0.730(0.116)ab	0.652(0.122)b	1.849	0.175
H_{sw}	Shrub layer	1.683(0.237)a	1.475(0.379)a	1.511(0.303)a	1.477(0.532)a	0.200	0.895
	Herb layer	1.739(0.865)ab	2.133(0.34)a	1.741(0.315)ab	1.551(0.324)b	1.973	0.154
E_{pi}	Shrub layer	0.770(0.039)a	0.777(0.090)a	0.741(0.112)a	0.806(0.223)a	0.192	0.900
	Herb layer	0.657(0.260)ab	0.842(0.070)a	0.706(0.126)ab	0.627(0.117)b	2.695	0.077

Note: *F* Value is the *F* statistical value, Sig. is the significance difference with LSD test at $p<0.05$. Type I is the pure plantation of *Jatropha curcas*, Type II is the mixed plantation of *J. curcas* with *Macadamia integrifolia*, Type III is the mixed plantation of *J. curcas* with shrub species, Type IV is the native vegetation of afforestation land. D_g = Gleason diversity index, D_{sm} = Simpson diversity index, H_{sw} = Shannon-Weiner diversity index, and E_{pi} = Pielou evenness index

Biodiversity of the different types: The diversity indices comparison of the four types of vegetation is listed in Table 4. Differences among the various types were not significantly different at $p<0.05$ for both shrub and herb layers.

The indices did not differ significantly among four types, and value of significance test were exceed 0.05, but comparing every two types, the D_{sm}, H_{sw} and E_{pi} of the Type II herb layer were significantly higher than for Type IV. In other words, the diversity and evenness of the herb layer would be improved by employing the mixed plantation with *Macadamia integrifolia*, but it would not affect the species richness of the herb layer or the diversity of the shrub layer. Furthermore the modes of mixed plantation with shrub species and of pure plantation would not bring about significant change for understory diversity.

Biodiversity of the mixed plantation of *Jatropha curcas* with *Macadamia integrifolia*: The diversity indices comparison of 1) the pure plantation (Type I), 2) two mixed plantations with different proportion of *Macadamia integrifolia* (Types II-A and II-B) and 3) two native communities (Types IV-A and IV-B) is listed in Table 5. For the different mixed plantations, 2 D_gs and 2 H_{sw}s were not significantly different, and only D_{sm} and E_{pi} of the shrub layer were significantly different at $p<0.05$.

The D_gs of the plantations (including both mixed plantations and pure plantation) were not significant different from native vegetations except that Type II-B was significantly higher than Type II-A.

For the herb layers, the D_{sm}, H_{sm} and E_{pi} of Type II-B were significantly higher than Type IV-A, but not significantly different from Type IV-B. Meanwhile for the shrub layer, the D_{sm} and E_{pi} of Type II-B were significantly higher than Type IV-B. And while the D_{sm} and H_{sm} of the Type II-B shrub layer were not significantly different from Type IV-A, the E_{pi}s of the plantation was significantly lower than for Type IV-A.

In other words, we found that the understory diversity of the different mixed proportions of *Jatropha curcas* were not significantly different. The plantation with the higher mixed proportion of *Jatropha curcas* with *Macadamia integrifolia* could affect the understory diversity for native vegetation, but there were different effects on different layers (herb or shrub).

Biodiversity of the mixed plantation of *Jatropha curcas* with shrub species: The diversity indices comparison of 1) pure *Jatropha* plantation (Type I), 2) the mixed plantation with different shrub species (Types III-A and III-B) and 3) the native vegetation types (Types IV-A and IV-B) is listed in Table 6. For the different mixed plantations, 2 D_gs and 2 H_{sw}s were not significantly different, and only D_{sm} and E_{pi} of the shrub layers were significantly different at $p<0.05$.

There was no significant difference among Type III-A, Type III-B and Type I for the 4 indices for the 2 layers. In other words, for both the mixed plantations and pure plantation, the diversity indices were not significantly different for the shrub and herb layers.

The D_gs of the plantations (including both mixed plantations and pure plantation) were not significantly different from the native vegetation, except for the shrub layer. The D_{sm}, H_{sm} and E_{pi} of the plantations were significantly higher than shrub-grassland dominated by *Dodonaea viscosa* and *Heteropogon contortus* (Type IV-B), but not significantly different from Type IV-A, shrub-grassland dominated by *Eupatorium odoratum*, *Phyllanthus emblica*, *Woodfordia fruticosa* and *Themeda gigantea.*

Discussion

Biodiversity changes with different types of plantations: Compared to native vegetation, the Gleason index of *Jatropha curcas* plantation was not significantly different. It indicated that the change of communities did not significantly affect the number of species in plots. For the plant diversity index and evenness index, the biodiversity of the shrub layer did not change significantly, but for the diversity of the herb layer there are significant differences. For the *J. curcas* plantation mixed with *Macadamia integrifolia*, the Simpson diversity index, Shannon-Weiner diversity index and Pielou evenness index were all significantly higher than those for pure forest and native vegetation. When the *J. curcas* plantation was mixed with shrub species, the diversity index and evenness index were higher than those for pure forest and native vegetation, but the difference was not significant. The diversity and evenness indices for the pure forest also did not differ significantly from the native vegetation; most indices were slightly less than the native vegetation. The outcome of planting *J. curcas* was that while species richness was not significantly affected, the evenness of species could be impacted.

When the *J. curcas* plantation was mixed with different proportions of *M. integrifolia*, *Jatropha* pure forest and native vegetation, the amount of species richness among the types did not change significantly, i.e., the impact of species abundance for mixed proportion changes was not significant. Differences in diversity were also insignificant among *Jatropha* plantations with different mixed proportions of *M. integrifolia*. Compared to the relatively pure forest of *Jatropha*, however, mixed forests showed a significant increase in both the diversity evenness indices. For the diversity index, the differences between the two kinds of *Jatropha* plantation mixed with *M. integrifolia* and two kinds of original vegetation were not significant. For the evenness index, however, both mixed forest plantations were significantly higher than one of the native communities (the *Phyllanthus emblica*, *Eupatorium odoratum* community), but showed no significant difference compared to the other (the *Dodonaea viscosa*, *Heteropogon contortus* community). The findings showed that species richness was not significantly different, but the diversity and evenness indices of species could be affected by the mixed plantations with different proportion of *M. integrifolia*, especially for the shrub layer, where the Shannon diversity index and Pilou evenness index showed significant differences.

Table 5. One-way ANOVA analyzing the diversity indices of the pure *Jatropha* plantation, the mixed plantation with *Macadamia integrifolia* and the native vegetation types.

Factors		Type I	Type II-A	Type II-B	Type IV-A	Type IV-B	*F* Value	Sig.
D_g	Shrub layer	2.027(0.663)a	1.158(0.332)b	2.063(0.461)a	1.433(0.626)ab	1.448(0.332)ab	1.561	0.252
	Herb layer	2.895(1.026)a	2.606(0.783)a	3.04(0.307)a	2.475(0.329)a	2.751(0.251)a	0.436	0.780
D_{sm}	Shrub layer	0.731(0.043)a	0.659(0.157)ab	0.828(0.149)a	0.796(0.097)a	0.468(0.155)b	4.264	0.025
	Herb layer	0.665(0.310)ab	0.818(0.080)ab	0.872(0.023)a	0.588(0.107)b	0.760(0.036)ab	1.905	0.180
H_{sw}	Shrub layer	1.683(0.237)ab	1.315(0.422)ab	1.715(0.168)ab	1.735(0.462)a	1.049(0.347)b	2.035	0.159
	Herb layer	1.739(0.865)ab	2.015(0.418)ab	2.31(0.093)a	1.369(0.263)b	1.855(0.089)ab	2.037	0.158
E_{pi}	Shrub layer	0.770(0.039)b	0.785(0.126)b	0.766(0.002)b	0.960(0.028)a	0.548(0.119)c	13.424	0.000
	Herb layer	0.657(0.260)ab	0.818(0.073)a	0.877(0.069)a	0.564(0.104)b	0.731(0.023)ab	2.897	0.073

Note: *F* Value is the *F* statistical value, Sig. is the significance difference with LSD test at $p<0.05$. Type I = the pure plantation of *Jatropha curcas* where proportion of *J. curcas* at tree layer is from 90 to 100%, Type II-A = the plantation of *J. curcas* with *Macadamia integrifolia* where proportion of *J. curcas* at tree layer is from 75 to 90%, Type II-B = the plantation of *J. curcas* with *M. integrifolia* where proportion of *J. curcas* at tree layer is from 60 to 75%, Type IV-A = shrub-grassland dominated by *Eupatorium odoratum*, *Phyllanthus emblica*, *Woodfordia fruticosa* and *Themeda gigantea*, Type IV-B = shrub-grassland dominated by *Dodonaea viscosa* and *Heteropogon contortus*. D_g = Gleason diversity index, D_{sm} = Simpson diversity index, H_{sw} = Shannon-Weiner diversity index, and E_{pi} = Pielou evenness index

Table 6. One-way ANOVA analyzing the diversity indices of the pure *Jatropha* plantation, the mixed plantation with different shrub species and the native vegetation types.

Factors		Type I	Type III-A	Type III-B	Type IV-A	Type IV-B	*F* Value	Sig.
D_g	Shrub layer	2.027(0.663)a	1.810(0.125)a	1.520(0.217)a	1.433(0.626)a	1.448(0.332)a	0.965	0.462
	Herb layer	2.895(1.026)a	2.389(0.000)a	2.751(0.251)a	2.475(0.329)a	2.751(0.251)a	0.637	0.646
D_{sm}	Shrub layer	0.731(0.043)a	0.708(0.163)a	0.672(0.054)a	0.796(0.097)a	0.468(0.155)b	4.292	0.022
	Herb layer	0.665(0.310)a	0.685(0.138)a	0.774(0.093)a	0.588(0.107)a	0.760(0.036)a	0.908	0.490
H_{sw}	Shrub layer	1.683(0.237)ab	1.650(0.360)ab	1.372(0.204)ab	1.735(0.462)a	1.049(0.347)b	2.113	0.142
	Herb layer	1.739(0.865)a	1.587(0.375)a	1.895(0.190)a	1.369(0.263)a	1.855(0.089)a	1.031	0.431
E_{pi}	Shrub layer	0.770(0.039)b	0.777(0.155)b	0.705(0.061)b	0.960(0.028)a	0.548(0.119)c	11.351	0.000
	Herb layer	0.657(0.260)a	0.662(0.156)a	0.750(0.099)a	0.564(0.104)a	0.731(0.023)a	1.031	0.431

Note: *F* Value is the *F* statistical value, Sig. is the significance difference with LSD test at $p<0.05$. Type I = the pure plantation of *Jatropha curcas*, Type III-A = the mixed plantation of *J. curcas* with *Phyllanthus emblica*, Type III-B = the mixed plantation of *J. curcas* with *Dodonaea viscos*, and Type IV-A = shrub-grassland dominated by *Eupatorium odoratum*, *Phyllanthus emblica*, *Woodfordia fruticosa* and *Themeda gigantea*, Type IV-B = shrub-grassland dominated by *Dodonaea viscos* and *Heteropogon contortus*. D_g = Gleason diversity index, D_{sm} = Simpson diversity index, H_{sw} = Shannon-Weiner diversity index, and E_{pi} = Pielou evenness index

Diversity changes in herb layers species were not significant when comparing diversity among the two types of *J. curcas* plantation with shrub species, the *Jatropha* pure forest, and the two kinds of native vegetation. However, for the shrub layer, while the Gleason richness index and Shannon-Weiner diversity index did not show significant change, the Simpson diversity index and Pielou evenness index revealed significant changes. The Pielou evenness index of *J. curcas* plantation mixed with *Phyllanthus emblica* was higher than for the *Dodonaea viscosa*, *Heteropogon contortus* community, but significantly lower than that for the *Phyllanthus emblica*, *Eupatorium odoratum* community. Therefore, species richness was not significantly different for different mixed shrub species; only the Shannon diversity index and Pilou evenness index for the shrub layer showed significant differences.

A planting model for ecological restoration: *Jatropha curcas* plantation with shrub species: Reforestation's contribution to the acceleration of natural succession and the recovery of late-successional vegetation has been widely recognized (Honnay *et al*., 2002), and specifically the restoration of degraded lands by the reintroduction of woody species (Keenan *et al*., 1997; Lugo, 1997; Carnevale & Montagnini, 2002; Maestre & Cortina, 2004; Li *et al*., 2005). *J. curcas* has been grown mainly in tropical regions, especially the dry-hot valley area with its hot and dry climate, sparse vegetation, dry and barren soil, and serious water and soil erosion (Li *et al*., 2011). The vegetation is mainly dry-hot shrub-grassland. Representative types are shrub-grassland dominated by *Eupatorium odoratum*, *Phyllanthus emblica*, *Woodfordia fruticosa* and *Themeda gigantea*, and shrub-grassland dominated by *Dodonaea viscos* and *Heteropogon contortus*. Restoration of the vegetation has long been an important goal, but the restoration cost is very high, Francis *et al*. (2005) proposed that *J. curcas* could play a special role, as it is can produce biofuel and enhance socioeconomic development while reclaiming marginal and degraded lands in (semi-)arid regions in India.

This study has shown that *J. curcas* plantation with shrub species would not cause the decrease of community biodiversity, but could even improve the biodiversity of the area. *J. curcas* plantation with shrub species has the potential to achieve certain economic goals, at the same time as it can be used as an important plant for ecological restoration. Therefore the planting model of *J. curcas* plantation with shrub species would be highly suitable for the ecological restoration of the dry-hot valley area.

A planting model which attempts to balance crop yield and food security: *Jatropha curcas* plantation with *Macadamia integrifolia*: *Macadamia integrifolia* is an important nut tree, which is mainly planted in tropical areas in China. In Yunnan province, the planting area was more than 3000hm^2 in 2000. At the study site the spacing of row planting is about 3 meters and the array pitch is about 4 meters. The soil for planting *M. integrifolia* is hypertrophy. In the study area the spacing of the *J. curcas* plantation is about 1square meter. For improving the yield of *J. curcas*, it must be planted in fertile soil, but there is a shortage of fertile soil. Intercropping *J. curcas* at the understory of *M. integrifolia* plantation would be the best solution to save soil resources and ensure the best yield of *J. curcas*. In this paper, we found that species richness of the mixed plantation was not significantly different, but the diversity and evenness indices of species could be positively affected. Especially for the shrub layer, the Shannon diversity index and Pilou evenness index were significantly higher than for the native vegetation alone. From the perspective of biological diversity, the planting mode of *J. curcas* plantation with *M. integrifolia* could prove to be a successful model to balance crop yield and food security.

Conclusions

The plots investigated were divided into four forests and changed along the gradients of forest management, succession and elevation by CCA analysis. Species richness was not significantly different for the different types of plantation, but the evenness of species could be affected, especially for the total community and the understory by planting *J. curcas.* The diversity and evenness indices of species were affected for the mixed plantation with different proportions of *M. integrifolia*, especially for the shrub layer, the Shannon diversity index and Pilou evenness index showed significant differences. For the different mixed shrub species, only the Shannon diversity index and Pilou evenness index were significantly different. Moreover, from the perspective of biological diversity, *J. curcas* plantation with shrub species would be a recommended planting model for ecological restoration in a dry-hot valley area, while *J. curcas* plantation with *M. integrifolia* would be an effective planting model to balance crop yield and food security.

Acknowledgments

We gratefully acknowledge Mr. Dong Jihui and Mr. Rao Songyun of the Forestry Bureau of Shuangjiang county, China, for their support in field measurements. The study was financially supported by the University innovation team of Yunnan province about vegetation restoration in the dry-hot valley (No. 201108) and the 11th Five-Year Plan of National Science and Technology Supporting Program of China (No.2007BAD32B02).

References

Achten, W.M.J., L. Verchot, Y.J. Franken, E. Mathijs, V.P. Singh, R. Aerts and B. Muys. 2008. *Jatropha* bio-diesel production and use. *Biomass and Bioenergy*, 32: 1063-1084.

Achten, W.M.J., W.H. Maes, R. Aerts, L. Verchot, A. Trabucco, E. Mathijs, V.P. Singh and B. Muys. 2010, *Jatropha*: From global hype to local opportunity. *J. Arid Environ.*, 74: 164-165.

Anonymous. 1989. IFS (International Foundation for Science), Trees for development in sub-Saharan Africa. Proceedings of a seminar held in Nairobi, Kenya, Stockholm, Sweden IFS (International Foundation for Science).

Anonymous. 1999. State of the world's forests. United Nations Food and Agriculture Organization (FAO), Rome.

Anonymous. 2001. State of the World's Forests. United Nations Food and Agriculture Organization (FAO), Rome.

Barbaro, L., L. Pontcharraud, F. Vetillard, D. Guyon and H. Jactel. 2005. Comparative responses of bird, carabid, and spider assemblages to stand and landscape diversity in maritime pine plantation forests. *Ecoscience*, 12:110-121.

Brockerhoff, E.G., C.E. Ecroyd, A.C. Leckie and M.O. Kimberley. 2003. Diversity and succession of adventive and indigenous vascular understorey plants in *Pinus radiata* plantation forests in New Zealand. *For. Ecol. Manage.*, 185: 307-326.

Brockerhoff, E.G., H. Jactel, J.A. Parrotta, C.P. Quine and J. Sayer. 2008. Plantation forests and biodiversity: oxymoron or opportunity?. *Biodivers. Conserv.*, 17: 925-951.

Carnevale, N. and F. Montagnini. 2002. Facilitating regeneration of secondary forests with the use of mixed and pure plantations of indigenous tree species. *For. Ecol. Manage*., 163: 217-227.

Carnus, J.M., J. Parrotta, E. Brockerhoff, M. Arbez, H. Jactel, A. Kremer, D. Lamb, K. O'Hara and B. Walters. 2006. Planted forests and biodiversity. *Journal of Forestry*, 104(2):65-77.

Divakara, B.N., H.D. Upadhyaya, S.P. Wani and C.L.L. Gowda. 2010. Biology and genetic improvement of *Jatropha curcas* L.: A review. *Applied Energy*, 87: 732-742.

Francis, G., R. Edinger and K. Becker. 2005. A concept for simultaneous wasteland reclamation, fuel production, and socio-economic development in degraded areas in India: need, potential and perspectives of *Jatropha* plantations. *Natural Resources Forum*, 29: 12-24.

Hartley, M.J. 2002. Rationale and methods for conserving biodiversity in plantation forests. *For. Ecol. Manage*., 155, 81-95.

He, C.Z., L. Zhong, H.F. He, D. Li and H. Xu. 2009. Allelopathic effect of water extracts from leaves of *Jatropha curcas* on its seed germination. *Seed*, 28(6): 5-8.

Honnay, O., B. Bossuyt, K. Verheyen, J. Butaye, H. Jacquemyn and M. Hermy. 2002. Ecological perspectives for the restoration of plant communities in European temperate forests. *Biodivers. Conserv.*, 11: 213-242.

Hooper, D.U., F.S. Chapin III, J.J. Ewel, A. Hector, P. Inchausti, S. Lavorel, J.H. Lawton, D.M. Lodge, M. Loreau, S. Naeem, B. Schmid, H. Setälä, A.J. Symstad, J. Vandermeer and D.A. Wardle. 2005. Effects of biodiversity on ecosystem functioning: a consensus of current knowledge. *Ecological Monographs*, 75(1): 3-35.

Hu, H.R., H.C. Ma, Y.X. Wang and H. Xu. 2010. Influence of land use types to nutrients, organic carbon and organic nitrogen of Soil. *Soilland and Water Conservation in China*, 11: 40-42.

Humphrey, J.W., A.C. Newton, A.J. Peace and E. Holden. 2000. The importance of conifer plantations in northern Britain as a habitat for native fungi. *Biol. Conserv.*, 96: 241-252.

Jin, Z.Z. 1992. The natural vegetation types of Yunnan, China. A series of geobotanical monographs. *Braun-Blanquetia*, 8: 65-76.

Jingura, R.M., R. Matengaifa, D. Musademba and K. Musiyiwa. 2011. Characterisation of land types and agro-ecological conditions for production of *Jatropha* as a feedstock for biofuels in Zimbabwe, *Biomass and Bioenergy*, 35: 2080-2086.

Keenan, R., D. Lamb, O. Woldring, T. Irvine and R. Jensen. 1997. Restoration of plant biodiversity beneath tropical tree plantations in northern Australia. *For. Ecol. Manage.*, 99: 117-131.

Kumar, A. and S. Sharma. 2008. An evaluation of multipurpose oil seed crop for industrial uses (*Jatropha curcas* L.): a review. *Ind. Crops Prod*., 28(1): 1-10.

Lachat, T., S. Attignon, J. Djego, G. Goergen, P. Nagel, B. Sinsin and R. Peveling. 2006. Arthropod diversity in Lama forest reserve (South Benin), a mosaic of natural, degraded and plantation forests. *Biodivers. Conserv.*, 15: 3-23.

Li, K., F.Y. Liu, Z.Y. Yang and Y.Y. Sun. 2011. Study status and trends of vegetation restoration of dry-hot valley in southwest China. *World Forestry Research*, 24(4): 55-60.

Li, Q., S.B. Zhu, G.Y. Zhao and H. Xu. 2008. Preliminary report on diseases and insect pests of *Jatropha curcas* plantation in Zhenkang county. *Forest Inventory and Planning*, 33(5): 75-79.

Li, Q.F., W.Y. Liu, Y.X. Shen, L.H. Liu and H.Q. Xu. 2005. Change of plant diversity of different rehabilitated communities on degraded mountainous area of dry-hot valley in Nanjian. *Journal of Mountain Science*, 23(5): 557-564.

Liu, E.D. 2007. Yunnan: Efforts to promote the construction of *Jatropha curcas* biomass energy. *Forestry of China*, 5: 24-25.

Lugo, A.E. 1997. The apparent paradox of reestablishing species richness on degraded lands with tree monocultures. *For. Ecol. Manage*., 99: 9-19.

Ma, K.P., J.H. Huang, S.L. Yu and L. Chen. 1995. Plant community diversity in Dongling mountain, Beijing, China:II. Species richness, evenness and species diversity. *Acta Ecologica Sinica*, 15(3): 268-277.

Maes, W.H.A., A. Trabucco, W.M.J. Achten and B. Muys. 2009. Climatic growing conditions of *Jatropha curcas* L. *Biomass and Bioenergy*, 33: 1481-1485.

Maestre, F.T. and J. Cortina. 2004. Are *Pinus halepensis* plantations useful as a restoration tool in semiarid Mediterranean areas? *For. Ecol. Manage.*, 198: 303-317.

Magura, T., B. Tóthmérész and Z. Bordán. 2000. Effects of nature management practice on carabid assemblages (Coleoptera: Carabidae) in a non-native plantation. *Biol. Conserv.*, 93: 95-102.

Moore, S.E and H.L. Allen. 1999. Plantation forestry. In: *Maintaining Biodiversity in Forest Ecosystems*. (Ed.): Hunter, Jr., M.L. Cambridge University Press, New York, pp. 400-433.

Oberhauser, U. 1997. Secondary forest regeneration beneath pine (*Pinus kesiya*) plantations in the northern Thai highlands: a chronosequence study. *For. Ecol. Manage.*, 99: 171-183.

Openshaw, K. 2000. A review of *Jatropha curcas*: an oil plant of unfulfilled promise. *Biomass and Bioenergy*, 19:1-15.

Ou, G.L., J.H. Dong, H.C. Ma, H. Xu and J.R. Tang. 2008. Preliminary study on the close-to-natural forestry construction model of the cultivation base for the improved varieties of *Jatropha curcas* in Shuangjiang county of Yunnan province. *Journal of Anhui Agriculture Science*, 36(34): 14997-14999.

Parrotta, J.A., J. Turnbull and N. Jones. 1997. Catalyzing native forest regeneration on degraded tropical lands. *For. Ecol. Manage.*, 99: 1-8.

Raman, T.R.S. 2006. Effects of habitat structure and adjacent habitats on birds in tropical rainforest fragments and shaded plantations in the Western Ghats, India. *Biodivers. Conserv*., 15: 1577-1607.

Schaldach, R., J. Priess and J. Alcamo. 2011. Simulating the impact of biofuel development on country-wide land-use change in India. *Biomass and Bioenergy*, 25(6): 2401-2410.

Shanker, C. and S.K. Dhyani. 2006. Insect pests of *Jatropha curcas* L. and the potential for their management. *Current Science*, 91: 162-163.

Stewart, N.C.Jr. and G. Liu. 2011. Bioenergy plants in the United States and China. *Plant Science*, 181: 621-622.

Tang, C.Q., X. Hou, K. Gao, T. Xia, C. Duan and D. Fu. 2007. Man-made versus natural forests in mid-Yunnan, Southwestern China: plant diversity and initial data on water and soil conservation. *Mt. Res. Dev.*, 27: 242-249.

Ter Braak, C.J.F. 1986. Canonical correspondence analysis: a new eigenvector technique for multivariate direct gradient analysis. *Ecology*, 67: 1167-1179.

Wu, J.R., H.C. Ma, T.T. Liu, J.R. Tang, H.F. Su and H. Xu. 2008. Investigation on the diseases and pest insects in *Jatropha curcas* in dry-hot valley. *Forest Pest and Disease*, 4: 18-21.

Xu, H., H.C. Ma, J.R. Wu, C.Z. He and G.L. Ou. 2011. Biomass energy plantation with *Jatropha curcas*. *Yunnan Sci. & Tech. Press*, Kunming, China.

Zhang, J.T. 1995. Quantitative methods in vegetation ecology. *China Sci. & Tech. Press*, Beijing, China.

Zhao, Y.H., Y.M. Yang, S.Y. Yang and J. Wang. 2007. A review of the biodiversity in *Eucalyptus* plantation. *Journal of Yunnan Agriculture University*, 22(5): 741-746.

(Received for publication 29 March, 2015)