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Species-diversified plant cover enhances orchard ecosystem resistance to climatic stress and soil erosion in subtropical hillside*

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Abstract: Naturally occurring plants in agroecosystem evidently play an important role in ecosystem stability. Field studies on the ecological effects of native plants conserved in orchard and their resistance to adverse climatic stress, and soil erosion were conducted from 1998 to 2001 in a newly developed Changshan-huyou (*Citrus changshan-huyou* Y.B. Chang) orchard. The experimental area covered 150 ha in typical red soil hilly region in southeastern China. The experimental design was a randomized complete block with six combinations of twelve plant species with four replications. All species used were native in the orchard. Plots were 15×8 m^2 and separated by 2 m buffer strips. Precipitation, soil erosion in rainstorm days and aboveground biomass of plant community when rainstorm days ended, soil temperature and moisture under various plant covers during seasonal megathermal drought period, antiscourability of soil with different root density under various simulated rainfalls were measured. Plant cover significantly decreased the daily highest and mean soil temperature and its daily variation in hot-drought season, but there was no significant difference of the alleviation among various plant covers. Plant covers significantly increased the soil moisture in seasonal megathermal drought period. Better moisture maintenance and soil erosion reduction was found when the plant species numbers in cover plant communities increased from one to eight. Higher root density in plant communities with higher species richness increased significantly the antiscourability of the soil. It was suggested that conserving plant communities with diversified native species could produce the best positive ecological effects on citrus orchard ecosystem stability.

Key words: Diversified cover plant, Soil erosion, Antiscourability, Stress alleviation, Subtropical area
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INTRODUCTION

The subtropical and tropical zones in China are covered with red soil equivalent to *Ultisols* in the taxonomy of the United States (He and Zhu, 1998). This region with an area of 2.2 million km^2 (23% of China's territory) has one of the greatest potential productivity of agricultural areas for the country's food supply. Mountain and hilly areas account for 79% of the total area. Utilization of the mountain and hilly resources to develop agriculture is an important way to feed the growing population in this area. The utilization of the slope land resources for agriculture, soil erosion, and degradation of soil fertility have become major problems (Zhao, 1995; Sun and Zhao, 1995; Yuan *et al.*, 2002a; 2002b; Li *et al.*, 2002). To tackle these problems, many studies had been conducted and practices such as afforestation, soil conservation engineering had been introduced (Li *et al.*, 2002; Yang, 1999). But using native perennial plants to increase plant covers and enhance the resistance of hilly upland to

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soil erosion and climatic stress was less frequently practiced.

Many native perennial plants had been viewed as agroecosystems weeds that adversely influence the growth and yield of target crops. Herbicides, mechanical control and manual hoeing are commonly used to control these plants. But these controlling methods may lead to environmental pollution, simplification of plant biodiversity and serious soil erosion (Buhler *et al*., 2000; Chen *et al*., 1999). Recent studies showed that native perennial plants evidently play an important role in maintaining the ecological equilibrium of agroecosystems. Attempts to more effectively manage native perennials to increase biodiversity in the agricultural landscapes and provide positive ecological functions in agroforestry ecosystems had been attracting more attention from governments, the public and scientists (Altieri, 1999; Buhler *et al*., 2000; Chen *et al*., 2000; 2002a; 2002b; 2004; Lagerlof and Wallin, 1993; Risch, 1983; Wyss, 1996).

However, the ability of native perennial plant communities to alleviate the stress of seasonal megathermal drought and reduce soil erosion in the rainy season is still poorly known. This study demonstrates the possibility of using native plant communities with various species number to reduce the soil erosion in orchards and to alleviate the stress of seasonal megathermal drought. A native plant management strategy for subtropical orchards is also presented.

MATERIALS AND METHODS

Experimental site description and experimental design

The experiments were conducted in a citrus orchard that was newly developed in October of 1998–December of 2001. The about 150 ha experimental site was located in a typical red soil hilly region in Changshan County of Zhejiang Province in eastern China (28°54′N, 118°30′E). Trees of Changshan-huyou (*Citrus changshan-huyou* Y.B., Chang) (Zhang, 1991) were transplanted in 1997 to a 4 m×3 m plot with only about 10% ground vegetation cover. The soil had a clay texture with 70.50% clay, 10.63% silt, 18.79% sand and pH of 5.4. The soil had 44.32±5.16 mg/kg extractable N, 9.27±0.78 mg/kg extractable P, and 54.6±5.34 mg/kg extractable K. The native perennial plant species that are common in this area are species in the families of Gramineae, Leguminosae, Asteraceae, Polygonaceae, Lamiaceae, Euphorbriaceae, Violaceae, Molluginaceae, Ranunculaceae, Primulaceae, Brasssicaceae, Cyperaceae, and Amaranthaceae.

Twelve common native annual and perennial species found in the orchard were selected for the experiment. The criteria used for the selection included carbon and nitrogen fixation, growth duration, root type, shoot character and arbuscular mycorrhizal fungi (AMF) colonization. The characteristics of the selected species are given in Table 1. By

Table 1 Characteristics of plant species used in the experiment

Species	Height (cm)	Root system	Growth duration	Nitrogen fixation	Mycorrhizal colonization
Artemisia argyi Levl. et Vant.	30–50	T	Mar.–Oct.	N-L	Light
Conyza canadensis (L.) Cronq.	50–100	T	Apr.–Oct.	N-L	Moderate
Digitaria ciliaris (Retx.) Koel.	30–80	F	Apr.–Oct.	N-L	Light
Eragrostis pilosa (Linn.) Beauv.	20–50	F	Mar.–Oct.	N-L	Heavy
Euphorbia supine Raf.	5–20	T	Mar.–Oct.	N-L	Light
Gnaphalium affine D.Don	10–30	T	Nov.–Jun	N-L	Moderate
Kummerowia striata (Thunb.) Schindl.	5–20	T	Mar.–Oct.	L	Heavy
Oxalis corniculata L.	5–15	F	Perennial	N-L	Heavy
Phyllanthus urinaria L.	10–30	T	Mar.–Oct.	N-L	Light
Poa annua L.	8–30	F	Nov.–May	N-L	Heavy
Trifolium repens L.	5–15	F	Perennial	L	Moderate
Vicia hirsuta (Linn.) S.E.Gray	10–30	F	Nov.–May	L	Heavy

T: Tap root system; F: fibrous system; L: leguminous species; N-L: non-leguminous species using these twelve species, six native plant communities were formed to represent the commonly existing native communities found in local citrus orchards. Plant combinations were based on the characteristics of species (Table 2). Except treatment T_1 and T_2, each combination was comprised of annual and biennial species that co-existed temporarily in the spring and early summer.

The experimental design was a randomized complete block with 6 treatments (0, 1, 2, 4, 8, 12 species combinations) and 4 replications. Plot size was 15 m×8 m and separated by 2 m-wide bare buffer strips. Seed mixtures were sown and covered with soil by hand in each October of 1998–2000. Similar plant densities (about 1500 seedlings per plot) were achieved by thinning once seeds had germinated. Seeds germinated and plant died naturally based on their life cycle. Any other annual or biennial species that appeared in the plots were removed. At the end of each October of 1999–2001, plants and their residues were plowed back into the soil.

Measurement

Soil erosion was determined in 1999 and 2000. Soil temperature, moisture, soil antiscourability and root density, plant biomass aboveground at the end of rainy season, root biomass and rootlet numbers were measured in 2001.

(1) Rainfall and soil erosion

A small weather station consisting of an automatic siphoned pluviograph and a class *A* pan evaporation tank, a chart-recording hygrothermograph located near the plots was used to monitor precipitation, temperature, relative humidity and evaporation.

The position soil core ^{151}Eu (Europium) tracer method was adopted to determine soil erosion (Tian *et al*., 1992; Yang *et al*., 1999) during rainy season in 1999 and 2000. Each tracing soil core was 10 cm in diameter and 10 cm in height. Ten tracing soil cores, mixture of 10 mg Eu and 1.5 g SiO_2 with soil were placed in each experimental plot one month before the rainy season began (at the end of May). Soil samples were collected from the tracing soil cores when the rainy season ended in late July. Soil samples were dried at 105 °C for 24 h and ground with a grinder. Eu concentration was determined with a Neutron Activation Analysis (INAA) instrument equipped with a coaxial germanium detector, pulse counter and preprogrammed computer system (Yang, 1999). Soil erosion was calculated by the changes of Eu concentration in soil core (Yang *et al*., 1999).

(2) Soil temperature and moisture measurement

Soil temperature and moisture were tested in 2001. Temperature of soil surface and 5 cm depth was monitored by thermometer installed on soil surface and at soil layer of 5 cm depth during hot-dry season (from end of July to end of August). Soil temperature was recorded manually at 2-hr intervals during 6:00–20:00 of each measuring day. In this experiment the temperature at 14:00 was considered to be the daily maximum high temperature and the average of temperature measured in 8 time phases in a day was defined as daily mean temperature. Soil moisture at 5 cm depth in the soil was measured at 14:00 each day by using MPM-160 hygrostat during hot-dry season (from end of July to

Table 2 Plant species combinations in the experiments

Treatment	Treatment description
T_1	Weeds were manually removed. Soil remained bare during the experiment
T_2	One species (*Kummerowia striata*) between citrus tree rows
T_3	Two species (*Kummerowia striata* and *Poa annua*) mixture between tree rows
T_4	Four species (*Kummerowia striata*, *Poa annua*, *Eragrostis pilosa* and *Trifolium repens*) mixture between tree rows
T_5	Eight species (*Kummerowia striata*, *Poa annua*, *Trifolium repens*, *Eragrostis pilosa*, *Euphorbia supina*, *Vicia hirsuta*, *Gnaphalium affine* and *Oxalis corniculata*) mixture between tree rows
T_6	Twelve weed species (*Kummerowia striata*, *Poa annua*, *Trifolium repens*, *Eragrostis pilosa*, *Euphorbia supina*, *Vicia hirsuta*, *Gnaphalium affine*, *Oxalis corniculata*, *Conyza canadensis*, *Artemisia argyi*, *Digitaria ciliaris* and *Phyllanthus urinaria*) mixture between tree rows

end of August).

(3) Measurement of aboveground biomass

Aboveground biomass of various plant communities was determined after the rainy season ended around July 20 of 2001. Three samples with an area of 1 m^2 were taken from each plot. The aboveground plant biomass of each weed species was separated, dried and weighed.

(4) Soil antiscourability, rootlet number and biomass

A modified method, described by Li *et al.* (1993), was adopted to determine soil antiscourability. The inclining gradient of the scouring sulcate, used for determining antiscourability was 15°. Three 20×20×10 cm^3 soil quadrates were collected in each plot in late August. The soil quadrates of plants above ground were removed and scoured under three simulating rainfall events with intensities 60 mm/h, 120 mm/h, and 180 mm/h respectively. Each simulating scour event lasted 13 minutes. Soil antiscourability was expressed as soil loss in one minute.

Root number and biomass was determined when the antiscourability determination was finished. All roots in every quadrate were washed from the soil. Number of rootlet (diameter of root <1 mm) was counted. Root biomass was measured after being dried at 80 °C for 48 h.

(5) Data analysis

All the experimental data were analyzed using the general linear model (GML) in SPSS version 10.0 for factorial analyses and one-way analysis of variance (ANOVA). Least significant difference (LSD) at 5% and 1% confidence levels were used for comparisons of treatments.

RESULTS

Soil erosion in rainy season

The precipitation at the experimental site during the rainy months of late June to late July was 441.6 mm and 417.4 mm in 1999 and 2000 respectively. Cover plant communities with various species numbers had significant effects on soil erosion during rainy season (Table 3). Soil erosion decreased significantly as the species number increased up to 8 and 4 species in 1999 and 2000 respectively, but no significant difference of soil erosion was found between the treatments with 8 species and 12 species in both 1999 and 2000.

Soil temperature and moisture in hot-dry season

Soil temperature at both soil surface and 5 cm depth was significant higher in the treatment without plant cover than the treatments covered with plants during time phase of 10:00–16:00 in a day, but there was no significant difference among the treatments with various species numbers (Fig.1).

The soil moisture at 5 cm depth measured at 14:00 in a day during the middle June to middle July was significant higher under the plant cover treatments than under the bare soil. Soil moisture increased significantly as species number increased from 0 to 8 species, but no difference was found between the treatments with 8 species and 12 species (Table 4).

Soil antiscourability

Plant species numbers had significant effects on soil antiscourability under simulating rainfall intensities of 60 mm/h, 120 mm/h and 180 mm/h

Table 3 Soil erosion during the rainy season of middle of June to middle of July (kg/ha·month)

Species number	1999				2000			
	Mean	*P*<0.05	*P*<0.01	*SE*	Mean	*P*<0.05	*P*<0.01	*SE*
0	35.74	a*	A	1.66	32.31	a	A	2.57
1	17.40	b	B	1.17	16.03	b	B	0.56
2	9.03	c	C	1.69	7.03	c	C	1.11
4	6.93	cd	C	0.63	4.89	c	C	0.97
8	5.14	d	C	0.47	4.78	c	C	0.34
12	4.74	d	C	0.45	4.63	c	C	0.55

*Treatments with the same letter in a column are not significantly different

Table 4 Soil moisture at 5 cm depth under different treatments

Species number	Mean (%)	Significant *F* test		*SE*
		F<0.05	*F*<0.01	
0	5.29	a*	A	0.56
1	10.65	b	B	0.46
2	15.57	c	C	0.25
4	17.05	d	CD	0.21
8	19.43	e	D	0.75
12	19.55	e	D	0.51

* Treatments with the same letter in a column are not significantly different

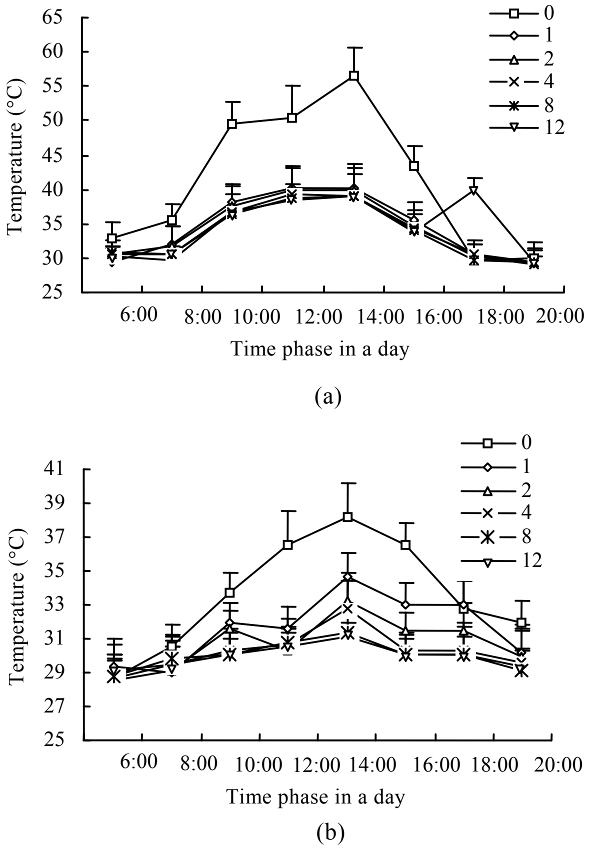

Fig.1 Changes of soil temperature in a day under different treatments. Values are mean±*SE*
(a) temperature at surface soil; (b) temperature at 5 cm depth of soil

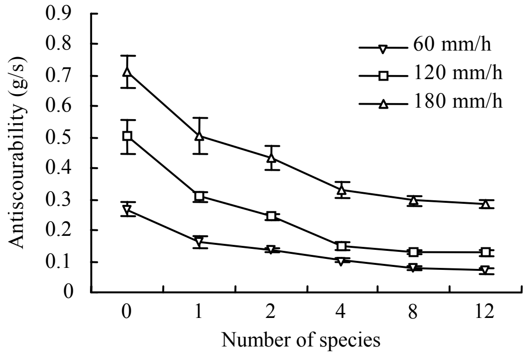

Fig.2 Soil antiscourability under simulated rainfall intensities

(Fig.2). Soil loss decreased significantly as species number increased from 0 species to 4 species, but no difference was found between 8 species and 12 species.

Root density and root biomass

Both root biomass and numbers of rootlet (<1 mm) increased significantly as the species numbers increased from 0 to 8, but there was no significant difference between 8 species and 12 (Table 5).

Correlation of root density and antiscourability

Data analysis showed that the total root biomass correlated with soil erosion under simulating rainfalls of 60 mm/h (r=–0.9918, P<0.01), 120 mm/h (r=–0.9861, P<0.01) and 180 mm/h (r=–0.9837, P<0.01) respectively. A significant negative correlation was also found between the rootlet numbers and soil erosion under these three simulating rainfalls 60 mm/h (r=–0.9810, P<0.01), 120 mm/h (r=–0.9837, P<0.01) and 180 mm/h (r=–0.9784, P<0.01).

Correlation of shoot biomass and soil temperature and moisture in hot-dry season

The results showed that the biomass aboveground increased significantly when the number of species increased from single species (T_2) to twelve species (T_6). Treatments with higher aboveground biomass had lower soil temperatures and higher soil moisture (Table 6). The correlation between aboveground biomass and daily mean surface soil temperature, soil moisture at 5 cm depth were –0.9351 (P<0.01), –0.9517 (P<0.01), 0.9551 (P<0.01) and 0.9621 (P<0.01) respectively.

DISCUSSION

Diversity of cover plant species and orchard ecosystem resistance to climatic stress and soil erosion

Experiments have provided convincing demonstration of the effects of species richness on productivity and soil nitrogen concentration (Hooper and Vitousek, 1997; Tilman *et al*., 1997). It was also well documented that cover plants (crops) can influence soil properties, soil aggregation and soil erosion (Gomez *et al*., 2003; Wright *et al*., 2003; Sainju *et al*., 2003). The present study indicated that the remaining native plant species covering the soil between fruit trees in orchard could alleviate the stress of high temperature and drought during hot-dry season. Density of rootlets, root biomass and root characteristics can reduce soil erosion (Gyssels and Poesen, 2003). Our experiment showed that increasing the number of species from 0 to 4 species could reduce soil erosion and increase soil antiscourability significantly. These effects were mainly due to the enhancement of rootlets (<1 mm) with increasing species numbers (Table 5) and the characteristics of root systems of different species. The species used in this experiment deployed their roots in different regions of the soil profile (Table 1). Shallow root species that deployed their roots mainly in the topsoil contributed to the reduction of soil erosion during rainy season. The increased root density with increasing species numbers contributed to enhanced antiscourability.

Necessity of diversity cover plant species conservation in subtropical hilly upland agroecosystem

How many species should be kept in an ecosystem to maintain the highest primary production or ecosystem stability had been of concern recently (McCan, 2000). Experiments of showed that net primary production and nutrient retention in an ecosystem increases as the number of plant species increases (Hooper and Vitousek, 1997). Agronomists found that crop production increased with crop species richness within 4–5 species in the agr-

Table 5 Root biomass and rootlet numbers under different treatments

Species number	Root weight (g/dm^3)		Rootlets (diameter of root<1 mm) ($number/dm^3$)	
	Mean	*SE*	Mean	*SE*
0	0.28a	0.02	13.14a	1.68
1	3.89b	0.21	392.13b	11.62
2	4.28c	0.21	541.58c	11.66
4	5.19d	0.15	603.75d	16.07
8	5.70d	0.16	628.19d	17.41
12	5.83d	0.10	632.84d	18.50

Table 6 Aboveground biomass and micro-climatic factors during the hot-dry season in 2001

Species number	Aboveground biomass of weed community (g/m^2)	Daily mean surface soil temperature	Extreme high temperature of surface soil	Daily temperature range (CV, %)	Soil moisture at 5 cm depth
0	0	40.99	56.6	25.44	5.31
1	388.88±34.9441	34.39	40.1	13.42	10.65
2	554.21±20.2789	33.96	39.8	12.94	15.57
4	594.56±31.9148	33.76	38.9	12.24	17.05
8	603.75±26.6853	33.58	39.0	12.08	19.43
12	638.42±24.9109	34.66	39.1	12.70	19.55

icultural system (Cai, 2000). Results from our experiment indicated that there were two patterns for the response of orchard ecosystem resistance to adverse conditions with the changes of plant species richness and composition. Soil temperature and soil moisture during the hot-dry period of July, plant coverage (aboveground biomass of the plant community as an indicator in this study) explained more of the variation than did the number of species present. For soil erosion in rainy season, plant species numbers played an important role in soil conservation.

The effects of differences in community composition are widely recognized in intercropping and agroforestry (Vandermeer, 1990). To improve total yield, much time and expense were invested in finding species or genetic varieties that can be combined to create more diverse agroecosystems (Pimm, 1997; Zhu *et al*., 2000). Native plants that may have been managed as weeds in the past may actually be used to diversify agricultural systems (Altieri, 1999; Moore, 2000; Wyss, 1996). Our experiment suggested that the conserved native plant species could be considered as an important approach to stability in the newly developed orchard where coverage of cultured plants was lower and significant amounts of bare soil are exposed. Soil loss was reduced by the presence of a ground cover plant community. However, some cover plant species are often seen as negatively reducing the growth of the cultivated crops (Chen *et al*., 2003). Our preliminary experiment showed that the growth of young trees was influenced significantly by some weed species, for example, the fruit plant height and canopy width in the plots maintaining *Artemisia argyi*, *Conyza canadensis* and *Digitaria ciliaris* were significantly lower than that maintaining other species (Chen *et al*., 2003). Therefore, aggressive species should be avoided when weeds were maintained in agroecosystem.

CONCLUSION

The present field study confirmed that establishing a cover plant system between tree rows in a *Changshan-huyou* orchard in the subtropical hilly red soil area of eastern China enhances the resistance of the agroforestry ecosystem to adverse temperatures during the hot-dry season, and reduced soil erosion during rainy season. Compared to the bare plant-free treatment, the treatments with cover plants reduced significantly the daily mean temperature and daily temperature variation. The buffering effect of plant conservation on the daily maximum temperature both on the surface soil and at 5 cm depth of soil was obvious with the effects dampening with depth. Plant community conservation also resulted in higher soil moisture maintenance. Biomass above-ground of the plant community was the key to soil temperature buffering and soil moisture maintenance. Surface soil erosion was likely reduced by higher aboveground biomass rather than the number of species in the plant community. Soil antiscourability was strengthened significantly by the root biomass and rootlet density. This study suggests that a plant community of at least 4 species will provide the benefits of enhanced ecosystem stability while not reducing the growth and productivity of the featured crop trees.

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