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ANALYSIS OF FARMLAND WEEDS SPECIES DIVERSITY AND ITS CHANGES IN THE DIFFERENT CROPPING SYSTEMS

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Abstract

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The species diversity and its changes of farmland weeds in the different cropping systems along the Yangtze River Basin in Anhui Province were examined in the present study. The results revealed a total of 272 species of weeds of 65 families in all the plots, with the highest number of species of summer-ripening fields and paddy fields presenting the least. The weed species diversity indices S, H′, D, and J were 272, 4.7253, 0.9985, and 0.8429, respectively. In different fields, the species diversity indices S, H′, and J had higher values in summer-ripening fields, followed by autumn-ripening fields and paddy fields; in contrast, the D index showed a higher value in summer-ripening fields, followed by paddy fields and autumn-ripening fields. The results of a Canonical Correspondence Analysis (CCA) indicated correlation between environmental factors and weeds species. The factors affecting weed distribution are geographic location, cultivation system, and irritation days in paddy fields, cropland types and pH in summer-ripening fields and geographic location in autumn-ripening fields.

Key words: Arable weeds, weed species diversity, CCA analysis, Yangtze River, Anhui Province

Abbreviations: SA1, Species Axis1; SA2, Species Axis2; EA1, Environmental Factors Axis1; EA2, Environmental Factors Axis2; N1, Northern latitude; E1, East longitude; Om, Organic matter; N, Quick-acting nitrogen; P, Quick-acting phosphorus; K, Quick-acting potassium; Id, Irrigation days; Tg, Topography; Cs, Cultivation system; St, Soil type; Ct, Cropland type; s, samples

Introduction

The farmland areas along the Yangtze River in Anhui Province in the middle and lower reaches of the Yangtze River Basin are situated in low hills and mountains between the Yangtze River and Huihe River and southern Anhui. The western portion borders Jiangxi Poyang Lake Plain, and the eastern portion links the Yangtze River Delta of Jiangsu and Zhejiang Provinces, including the cities of Anqing, Chaohu, Tongling, Wuhu, Xuancheng, and Maanshan and more than 20 counties of 700 towns. The farmland soils of these important agricultural regions in Anhui Province consist of paddy soils, grey moist soils, yellow and red soils, and brown soils. The main crops are rice, rape, cotton, wheat, sweet potato, peanut, bean, and tobacco, and the major crop rotation systems include paddy and upland crops that mature once or twice per year (Qiang, 1988).

The farmland area along the rivers in Anhui Province presents a long agriculture history with perfect cropping systems. Although weed control in farmland is one of the most important components in agricultural production, there was no research on the weed communities along the rivers in Anhui Province prior to 1980. Qiang conducted a survey from 1985 to 2005 on the type, distribution, and crop damage of farmland weeds along the rivers in Anhui Province (Qiang, 1988; Qiang, 2005). From 1996 to 2003, several other researchers performed qualitative studies on farmland weeds in wheat, corn, and rape fields along the rivers (Du et al., 2001; Fang et al., 2001; Wang et al., 2002; Zhang et al., 2002), whereas other groups have investigated the weeds in the paddy fields of Anhui Province (Tai et al., 2003; Wang et al., 2003; Xiao et al., 2003).

The soil type and crop rotation system are the determining factors in weed community types in croplands. Due to the use of large amount of herbicides, changes in tillage system,

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and cultivation structure, the weed communities along the Yangtze River Basin have been greatly altered, resulting in some weeds gradually disappearing from fields, some becoming secondary weeds, and the infestation of some becoming worse (changes in the degree of weed damage) (Alison, 1995; Buhler, 1995; Clements, 1994; Zhang et al., 1999). Studies on the features of weed species diversity and weed variation and the relationship between weeds and the environment are very important for the prediction and control of weeds under a high and stable agricultural yield.

Materials and Methods

The farmlands can be divided based on three different types of paddy, summer-ripe and autumn-ripe fields (according the crop maturation phase). Seven-grade visualization estimation methods were used in the present study: 0, 0.5, 1, 2, 3, 4, and 5, as defined by the relative cover degree, relative height, and abundance (Qiang, 2001). We randomly selected 10 quadrates of approximately 667 m^2 in all plots in every type of field and recorded the weeds species, dominance degree, and frequency in each cropland. Simultaneously, we recorded the environmental factors, such as geographic location, landform, farmland type, soil type, crop species, and tillage method. Along the same plots investigated by Qiang (1985-1987), the study was performed at the time of crop maturity in 2004-2006. A total of 228 plots in three types of fields, including 95 plots in paddy fields, 73 plots in summer-ripening fields, and 60 plots in autumn-ripening fields, were investigated. The important value and species diversity indices of weeds were calculated for all the quadrates (Chen et al., 2001; Qiang, 2002; Shi et al., 1998). CCA (Canonical Correspondence Analysis) of the relationship between weeds and environmental factors was performed (Ter Braak, 1986). All the data were analyzed using Excel 2003, SPSS 17.0, MVSP v.3.131 software, first calculating the important value for weeds in every quadrate, totaling the values, calculating the standard deviation, and t-testing comparisons, and CCA analysis.

CCA was performed to determine the degree of dominance of 36 weeds with a frequency of more than 20% and 11 variables of environmental factors in 95 paddy fields. The environmental factors included N1 (northern latitude), E1 (eastern longitude), pH, Om (organic matter), N (quick-acting nitrogen), P (quick-acting phosphorus), K (quick-acting potassium), Id (irrigation days), Tg (topography), Cs (cultivation system), and St (soil type). CCA on the dominance degree of 59 weeds with a frequency of more than 20% and 11 variables of environmental factors was performed for 73 summer-ripening fields. The environmental factors included N1, E1, pH, Om, N, P, K, Tg, St, Cs, and Ct (cropland type). CCA on the dominance degree of 41 weeds with a frequency of more than 20% and 10 variables of environmental factors in 60 autumn-ripening fields was performed. The environmental factors included N1, E1, pH, Om, N, P, K, Tg, Ct, and St.

We calculated the important value, species diversity, and community similarity index of weeds using the following formula:

Frequency = quadrat number for the emergence of certain species / total quadrat number × 100%

Relative frequency = frequency of certain weeds / total frequency of all weeds × 100%

Dominance degree = ∑ (quadrat number for emergence per grade × grade value 0,5)

Important value = (relative frequency + relative dominance degree) × 100 / 2

Species richness (S) = the number of species

Simpson index (D) = $1-\Sigma P_i^2$

Shannon-Wiener index (H′) = $-\Sigma P_i \ln P_i$

Pielou evenness index (J) = H′ / lnS

Sorensen community similarity index (Cs) = 2j / (a+b).

In the above formulas, P_i is the relative proportion of the importance value of species i, $P_i=N_i/N$, N_i is the importance value of species i, N is the total importance value of every species in all quadrates, j is the same species number in communities A and B, and a and b are the total number of species in communities A and B.

Results and Discussion

Weed species

There were 272 species of weeds in 65 families in the fields along the Yangtze River in Anhui Province. Among these, 41 families with 123 species were observed in paddy fields, 40 families with 164 species were observed in summer-ripening fields, and 42 families with 142 species were observed in autumn-ripening fields. The number of weed species of the summer-ripening fields tended to be higher than the species of the autumn-ripening and paddy fields (Table 1). The ten key weeds found were *Leptochloa chinensis*, *Alternanthera philoxeroides*, *Beckmannia syzigachne*, *Echinochloa crusgalli* var. *mitis*, *Ludwigia epilobioides*, *Eclipta prostrata*, *Alopecurus aequalis*, *Malachium aquaticum*, *Conyza canadensis*, and *Cyperus iria*. The ten major families were Gramineae (49 species, the same below), Compositae (30), Cyperaceae (27), Polygonaceae (14), Fabaceae (10), Cruciferae (10), Labiatae (9), Scrophulariaceae (9), Rosaceae (7), and Amaranthaceae (7).

Species diversity

The weed species diversity indices S, H′, D, and J were 272, 4.7253, 0.9985, and 0.8429, respectively. Based on the total quadrates, the species diversity indices S, H′, and J were higher in the summer-ripening fields, followed by the autumn-ripening and paddy fields; however, index D showed a higher value in the summer-ripening fields, followed by the paddy and autumn-ripening fields (Table 1).

In the paddy fields, index S was higher in the middle-season paddy fields, followed by the early-season paddy fields, single-season late paddy fields, and double-season late paddy fields. The H′ and D values were higher values in the single-season late paddy fields, followed by the middle-season paddy fields, early-season paddy fields, and double-season late paddy fields. The values for the J index were higher in the single-season late paddy fields, followed by the double-season late paddy fields, early-season paddy fields, and middle-season paddy fields. In the summer-ripening fields, the indices S, H′, and D were higher in rape fields, followed by wheat fields, whereas J was higher in wheat fields, followed by rape fields. For the autumn-ripening fields, the indices S and H′ were higher in cotton fields, followed by other autumn-ripening fields, whereas the D and J values were higher in other autumn-ripening fields, followed by cotton fields. The results of t-testing showed that the differences in the species diversity indices in different fields were significant (Table 1).

For the different fields, the indices S and H′ were higher in the summer-ripening fields, followed by the autumn-ripening fields and paddy fields; in contrast, the D and J were higher in the paddy fields, followed by the autumn-ripening fields and summer-ripening fields. The differences were significant (Table 2).

Relationship between weeds and environmental factors

Paddy fields

The CCA results showed correlation coefficients between the environmental factor axis and species axis when they reached 0.83 and 0.71, respectively. The N1, E1, and Cs environmental factors showed relatively higher relationships with Axis1 (0.60 and 0.71, 0.60 and 0.72, and 0.56 and 0.67, respectively), but Id had a better relationship with Axis2 (0.49 and 0.68). From the slope of environmental factors and sorting axis, length of vector, and correlation coefficient, N1, El, and Cs highly influenced the degree of weed dominance; Id had less influence, and the other factors were insignificant. Axis1 mainly reflected changes in pH and Id, and Axis2 reflected changes in Cs and St (Table 3; Figure 1).

We observed a degree of similarity in the weed species with habitat factors in the paddy fields (Figure 2). Axis1 reflected the changes in paddy field weeds with geographic lo-

Table 1
Weed species diversity in the fields (all the quadrates)

Farmland types(number of quadrats)	S	H′	D	J
Paddy fields (95)	123	3.8148	0.9955	0.7927
Early season paddy fields (29)	85±4.10cdCD	3.7079±0.17abA	0.9943±0.005aA	0.8346±0.02aA[a]
Middle season paddy fields (43)	103±5.06dD	3.7844±0.21bA	0.9958±0.007abA	0.8165±0.02aA
Single-season late paddy fields (11)	74±4.84bcBCD	3.7927±0.20aA	0.9967±0.010abA	0.8812±0.02aA
Double-season late paddy fields (12)	50±3.87eE	3.3175±0.19cB	0.9914±0.008bcAB	0.8480±0.02aA
Summer-ripe fields (73)	164	4.1518	0.9958	0.8141
Rape fields (57)	151±7.96aA	4.1202±0.26aA	0.9956±0.104bAB	0.8212±0.03cC
Wheat fields (16)	124±8.87abAB	4.1173±0.29abA	0.9949±0.015cB	0.8542±0.03cC
Autumn-ripe fields (60)	142	4.0234	0.9926	0.8119
Cotton fields (47)	138±6.78bcABC	4.0161±0.23abA	0.9925±0.012bAB	0.8151±0.03bB
Other autumn-ripe fields (13)	88±7.31bcBCD	3.8698±0.21abA	0.9931±0.006abA	0.8643±0.02abAB
Total (228)	272	4.7253	0.9985	0.8429

[a]Values±standard deviation; different lowercases mean significant difference (P<0.05) in the same column; different capital letters show extremely significant difference (P<0.01) in the same column. The same below.

Table 2
Weed species diversity in fields (average from quadrates)

Fields type	S	H′	D	J
Paddy fields	24±5.34cC	2.8918±0.23bB	0.9844±0.007aA	0.9217±0.02aA
Summer-ripe fields	34±8.21aA	3.0292±0.27aA	0.9781±0.012bB	0.8644±0.03cC
Autumn-ripe fields	29±6.87bB	3.0052±0.22aA	0.9807±0.011bAB	0.8978±0.03bB

cation and cultivation system, and this was related to the soil humidity, thus reflecting a water requirement for these weeds. *Echinochloa crusgalli* var. *austro-japonensis, Leptochloa chinensis, Rotala indica, Fimbristylis dichotoma, Lindernia procumbens, Cyperus difformis, Alternanthera philoxeroides*, *Ludwigia epilobioides*, and *Lemna minor,* which are observed on the right side of Axis1, had relatively higher water tolerance, mostly emerging in early-paddy fields, double-season late paddy fields, and single-season late paddy fields. *Hemarthria altissima, Oenanthe javanica, Hydrocotyle sibthorpioides, Bidens frondosa, Aeschynomene indica*, and *Cyperus iria*, on the left side of Axis1, showed a relative tolerance to

Table 3
Correlations between environment variables and CCA axes in paddy fields

	SA1	SA2	EA1	EA2	Nl	El	pH	Om	N	P	K	Id	Tg	Cs	St
SA1	1														
SA2	-0.03	1													
EA1	0.83	0	1												
EA2	0	0.71	0	1											
Nl	0.6	-0.26	0.71	-0.36	1										
El	0.6	-0.28	0.72	-0.39	0.58	1									
pH	0.25	0.01	0.3	0.01	0.41	0.11	1								
Om	0.14	-0.14	0.17	-0.19	0.03	0.15	0.18	1							
N	-0.15	0.01	-0.18	0.02	-0.29	-0.07	-0.28	0.13	1						
P	-0.26	0.19	-0.31	0.27	-0.5	-0.37	-0.23	-0.33	0.02	1					
K	0.08	-0.08	0.1	-0.12	-0.15	-0.04	-0.01	0.17	0	0.09	1				
Id	0.24	0.49	0.29	0.68	0.06	0.04	0.11	0.15	0.02	-0.12	0.09	1			
Tg	0.16	-0.07	0.19	-0.1	0.03	-0.07	-0.01	0.13	-0.08	-0.06	0.23	-0.12	1		
Cs	0.56	0.36	0.67	0.5	0.14	0.22	-0.05	0.08	0.07	-0.03	-0.03	0.28	0.15	1	
St	-0.14	0.12	-0.17	0.17	-0.15	-0.34	-0.1	-0.03	-0.06	0.13	-0.06	-0.16	0.61	0.11	1

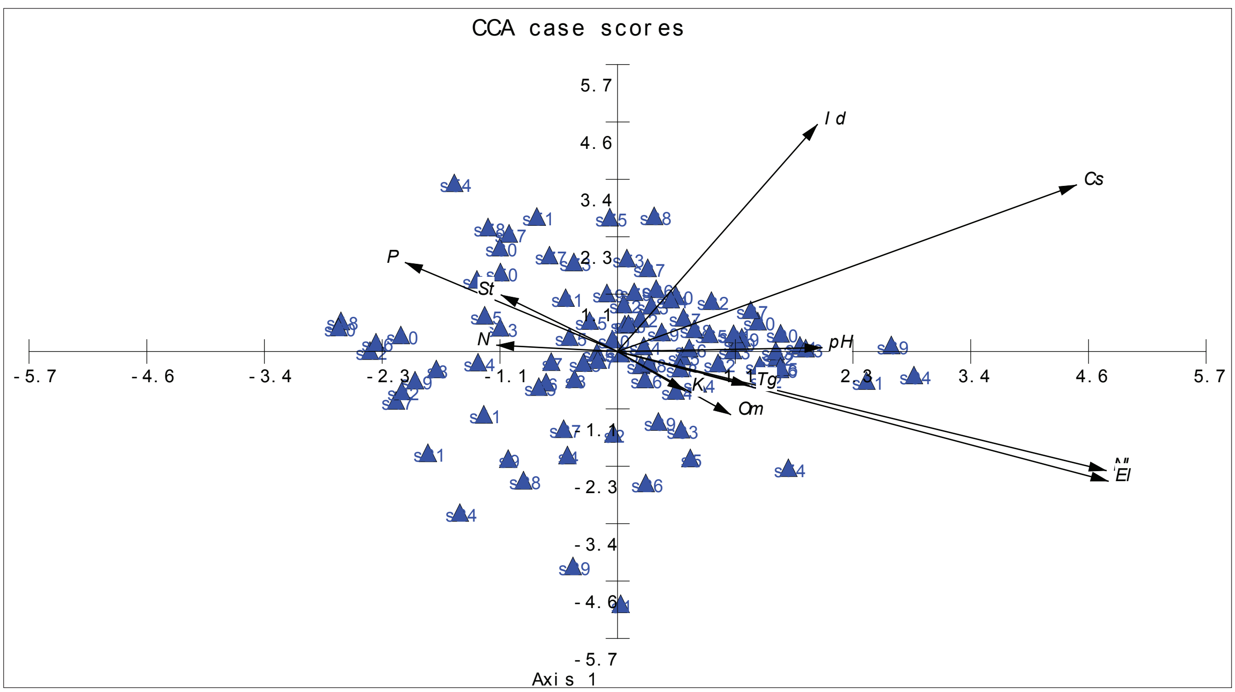

Fig. 1. Scatter plot of CCA two-dimensional ordination of quadrats (samples) and environmental factor variables in paddy fields

drought, mainly emerging in middle-season paddy fields. Axis2 mainly reflected the weeds changes with regard to irrigation days. *Riccia glauca, Echinochloa crusgalli* var. *austro-japonensis, Rotala indica, Leptochloa chinensis, Fimbristylis miliacea, Ludwigia epilobioides, Lemna minor, Kyllinga brevifolia, Lindernia crustacea, Eleocharis yokoscensis, Juncellus serotinus, Najas minor*, and *Echinochloa crusgalli,* which are above Axis2, emerged in paddy fields with more irrigation days. In contrast, *Hemarthria altissima, Hydrocotyle sibthorpioides, Bidens frondosa, Oenanthe javanica, Aeschynomene indica, Cyperus iria*, and *Mazus japonicus,* which are below Axis2, emerged in paddy fields with less irrigation days.

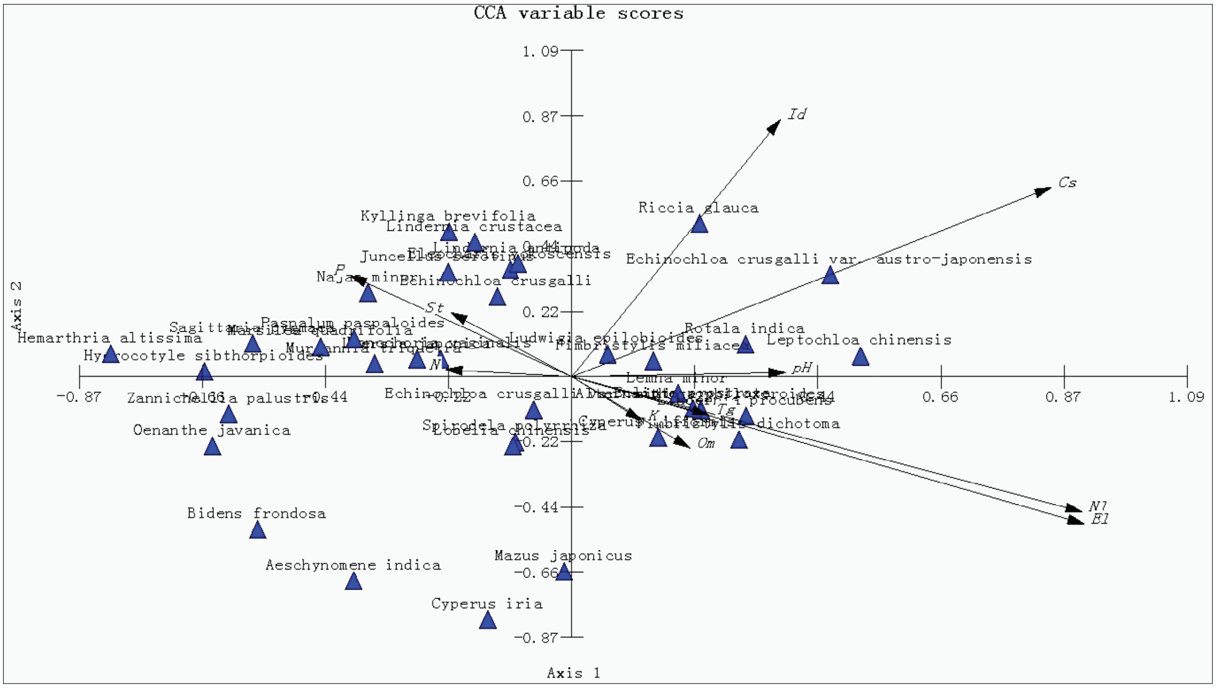

Fig. 2. Scatter plot of CCA two-dimensional ordination of weeds and environmental factor variables in paddy fields

Table 4
Correlations between environment variables and CCA axes in summer-ripening fields

	SA1	SA2	EA1	EA2	Nl	El	pH	Om	N	P	K	Tg	St	Ct	Cs
SA1	1														
SA2	0.11	1													
EA1	0.81	0	1												
EA2	0	0.72	0	1											
Nl	-0.42	0.38	-0.52	0.52	1										
El	-0.63	0.03	-0.78	0.05	0.59	1									
pH	-0.04	0.67	-0.05	0.93	0.38	0.07	1								
Om	-0.34	-0.04	-0.42	-0.06	0.15	0.13	-0.02	1							
N	0.01	-0.2	0.02	-0.27	-0.37	-0.21	-0.24	0.17	1						
P	0.31	-0.07	0.38	-0.1	-0.51	-0.4	-0.13	-0.36	0.07	1					
K	-0.04	0.09	-0.05	0.13	-0.07	-0.04	0.01	0.2	0.06	-0.03	1				
Tg	0.17	-0.06	0.21	-0.09	0.07	-0.04	-0.07	0.18	-0.07	-0.1	0.23	1			
St	0.26	-0.1	0.32	-0.15	-0.11	-0.32	-0.13	0.16	0.01	0.03	0.05	0.62	1		
Ct	0.62	0.07	0.76	0.1	-0.26	-0.35	0.02	-0.09	-0.06	0.28	0.04	0.47	0.37	1	
Cs	0.11	-0.08	0.13	-0.11	0.01	-0.1	-0.2	0.1	-0.06	0.13	0.02	0.51	0.32	0.42	1

Summer-ripening fields

The CCA results generated correlation coefficients between the environmental factor axis and species axis of 0.81 and 0.72, respectively. Ct had a relatively high relationship with Axis1 (0.62 and 0.76), whereas pH and N1 had better relationships with Axis2 (0.67 and 0.93 and 0.38 and 0.52, respectively). From the slope of environmental factors and sorting axis, length of vector, and correlation coefficient, pH and Ct had higher influences on the degree of weed dominance, and the N1 influence was less to some extent; the other factors were insignificant. Axis1 mainly reflected changes in Ct, and Axis2 reflected changes in N1 and pH (Table 4, Figure 3).

We found that Axis1 reflected alterations in the weeds in the summer-ripening fields with cropland type, whereas the cropland type was mainly related to the soil humidity, representing the water requirements of these weeds (Figure 4). *Commelina communis, Allium macrostemon, Polygonum aviculare, Oxalis corniculata, Avena fatua, Acalypha australis, Setaria viridis,* and *Polygonum perfoliatum*, which are observed on right side of Axis1, had a relatively high tolerance to drought, mostly emerging in unirrigated fields. *Alopecurus japonicas, Lapsana apogonoides, Bidens frondosa, Beckmannia syzigachne, Lobelia chinensis, Mazus japonicus*, and *Alternanthera philoxeroides,* which are observed on the left side of Axis1, are weeds that prefer water, mainly emerging in irrigated fields. Axis2 mainly reflected the alterations in weeds as a function of pH. *Euphorbia helioscopia, Cirsium setosum, Aster subulatus, Daucus carota, Polypogon fugax, Kalimeris indica, Artemisia annua, Calystegia hederacea, Rorippa indica, Veronica anagallis-aquatica, Torilis scabra*, and *Vicia sativa*, as observed above Axis2, emerged in slightly alkaline soil, whereas *Stellaria uliginosa, Gnapha-*

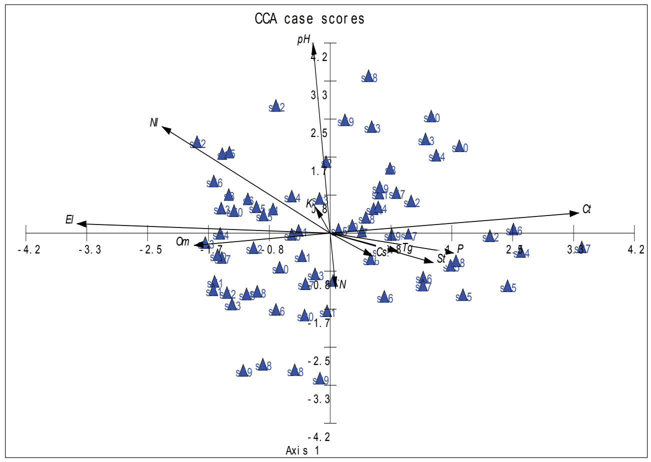

Fig. 3. Scatter plot of CCA two-dimensional ordination of quadrats (samples) and environmental factor variables in summer-ripening fields

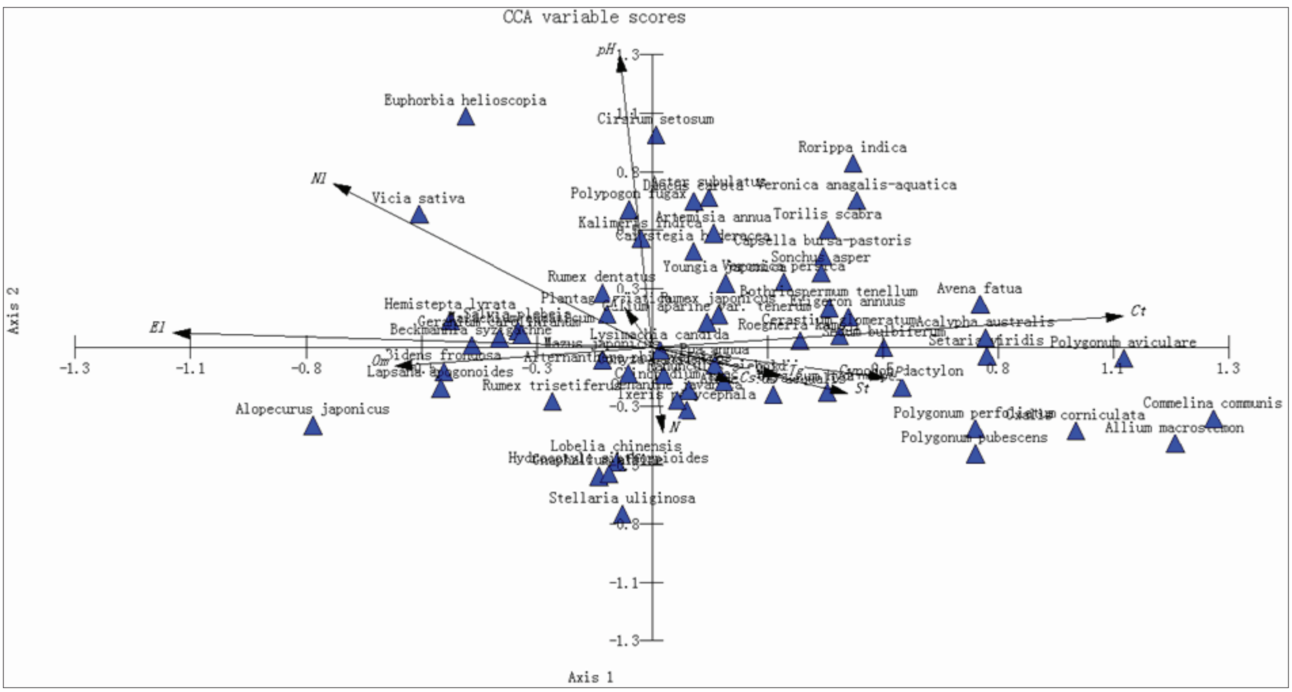

Fig. 4. Scatter plot of CCA two-dimensional ordination of weeds and environmental factor variables in summer-ripening fields

lium affine, Lobelia chinensis and *Alopecurus japonicas*, as observed below Axis2, mainly grew in slightly acidic soil.

Autumn-ripening fields

The CCA results indicated a correlation coefficient between the environmental factors axis and species axis that reached 0.76 and 0.74, respectively. El had a relatively higher relationship with Axis1 (0.57 and 0.76), but N1 had a better relationship with Axis2 (0.61 and 0.82). From the slope of environmental factors and sorting axis, length of vector, and correlation coefficient, El and N1 most influenced the degree of weed dominance, whereas the other factors were insignificant. Axis1 mainly reflected changes in El, and Axis2 reflected changes in N1 (Table 5, Figure 5).

A degree of similarity in the weed species was found with habitat in the autumn-ripening fields (Figure 6). Axis1 reflected the alterations in weeds with El, whereas El was mainly related to the soil water condition. *Celosia argentea, Mollugo pentaphylla, Digitaria sanguinalis, Amaranthus retroflexus, Euphorbia supine, Cirsium setosum, Cyperus iria, Setaria viridis*, and *Melochia corchorifolia*, which are observed on the right side of Axis1, had relatively higher tolerances to drought, mostly emerging in unirrigated fields. *Fimbristylis miliacea, Bidens frondosa, Ludwigia epilobioides, Echinochloa crusgalli* var. *austro-japonensis, Digitaria chrysoblephara, Mosla dianthera*, and *Conyza canadensis*, which are observed on the left side of Axis1, are weeds that prefer water, mainly growing in irrigated fields. Axis2 mainly reflected changes in weed with N1 and pH. *Celosia argentea, Mollugo pentaphylla, Digitaria sanguinalis,* and *Melochia corchorifolia*, as observed below Axis2, emerged in slightly alkaline soil, whereas *Xanthium sibiricum, Sonchus asper, Mazus japonicas, Salvia plebeian, Ludwigia epilobioides, Fimbristylis miliacea, Bidens frondosa, Eclipta prostrata*, and *Leptochloa chinensis*, observed above Axis2, grew in slightly acidic soil.

Weed diversity changes over 20 years

There were 116 species of weeds recorded from 1985 to 1987 (Qiang, 1988) and 123 species in 2004-2006, with 69

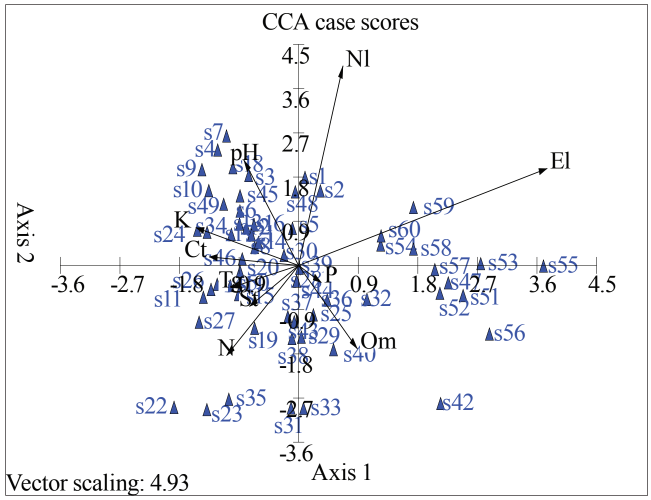

Fig. 5. Scatter plot of CCA two-dimensional ordination of quadrats (samples) and environmental factor variables in autumn-ripening fields

Table 5
Correlations between environment variables and CCA axes in autumn-ripening fields

	SA1	SA2	EA1	EA2	Nl	El	pH	Om	N	P	K	Tg	Ct	St
SA1	1													
SA2	-0.16	1												
EA1	0.76	0	1											
EA2	0	0.74	0	1										
Nl	0.1	0.61	0.14	0.82	1									
El	0.57	0.29	0.76	0.4	0.55	1								
pH	-0.13	0.32	-0.17	0.43	0.45	0.05	1							
Om	0.14	-0.25	0.18	-0.34	0.04	0.11	0.08	1						
N	-0.17	-0.27	-0.22	-0.37	-0.33	-0.13	-0.29	0.22	1					
P	0.05	-0.05	0.07	-0.07	-0.5	-0.38	-0.2	-0.34	0.02	1				
K	-0.24	0.12	-0.31	0.16	-0.09	-0.05	0.02	0.2	0.07	0.02	1			
Tg	-0.16	-0.07	-0.21	-0.09	-0.1	-0.25	-0.06	0.09	-0.01	0.01	0.13	1		
Ct	-0.21	0.03	-0.27	0.04	-0.22	-0.34	0.05	-0.17	-0.13	0.28	0.04	0.66	1	
St	-0.11	-0.12	-0.15	-0.17	-0.18	-0.34	-0.09	0.05	-0.01	0.1	-0.05	0.66	0.47	1

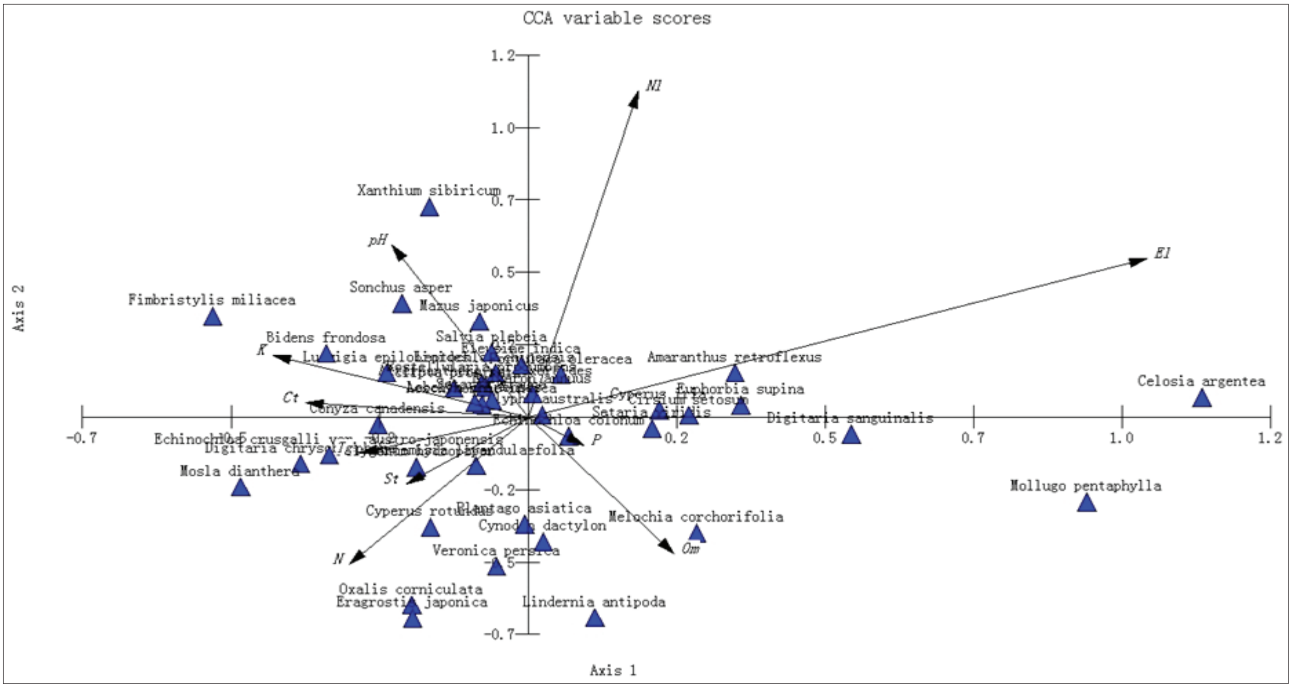

Fig. 6. Scatter plot of CCA two-dimensional ordination of weeds and environmental factor variables in autumn-ripening fields

same weed species occurred in the two different periods in the paddy fields. The community similarity index (Cs) was 0.5774. When compared to the earlier period, there were 7 new species of weeds. There were 147 species of weeds recorded during 1985-1987 (Qiang, 1988) and 164 species in 2004-2006, with 87 same species of weeds occurred in the two different periods in the summer-ripening fields. The community similarity index (Cs) was 0.5595. When compared to the earlier period, there were 17 new species of weeds. Between 1985 to 1987 (Qiang, 1988), there were 127 species of weeds recorded and 142 species in the 2004-2006 period, with 79 same species occurred in the two different periods in the autumn-ripening fields. The community similarity index (Cs) was 0.5874. There were 15 new species of weeds when compared to the earlier period.

Conclusions

There were 272 species of weeds in 65 families found in the farmlands along the Yangtze River in Anhui Province, including 41 families with 123 species in paddy fields, 40 families with 164 species in summer-ripening fields, and 42 families with 142 species in autumn-ripening fields.

In different fields, the weed species diversity indices S, H′, and J had higher values in summer-ripening fields, followed by autumn-ripening fields and paddy fields; but the D index showed a higher value in summer-ripening fields, followed by paddy fields and autumn-ripening fields (total quadrates).

The CCA results indicated the correlation coefficients between the environmental factor axis and species axis, reaching 0.50 in the three types of fields. In the paddy fields, N1, El, and Cs could influence the degree of weed dominance. In the summer-ripening fields, pH and Ct were found to influence the degree of weed dominance. In the autumn-ripening fields, El and N1 influenced the degree of weed dominance (weed distribution).

The increase in weed species in fields over 20 years is obvious. Weeds have evolved in response to cropping system practices by adapting and occupying the niches left available. The pressure created by our cropping practices over time has led to the weed diversity we observe today (Dekker, 1997).

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