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Species dynamics in modified hill farming systems in north eastern India – a comparative analysis

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Abstract

In north-eastern India, the hot humid climate favours luxuriant weed growth that results in reduction of crop yield. Field evaluation was carried out for two consecutive years in four agroforestry systems on the occurrence and distribution dynamics of weed flora. The four systems were compared simultaneously with the traditional abandoned *jhum* (AJh) and agricultural crops (sole). The four agroforestry systems (AFS) investigated were – mandarin (*Citrus reticulata*), alder (*Alnus nepalensis*), cherry (*Prunus cerasoides*) and albizia (*Paraserianthes falcataria*) with different cropping systems. Among the six systems compared, it was observed that the number of weed species remained consistently higher in the abandoned *jhum*, followed by the sole crop and was least in the four AFS with the number of perennial weed species being higher in the former than in the latter. Annual weeds (therophytes) dominated the four AFS and sole crop situations with the density of weeds like *Ageratum conyzoides, A. haustonianum, Bidens pilosa* and *Galinsoga parviflora* being high during the cropping season. In the abandoned *jhum* situation, perennial grass species like *Arundinaria bengalensis, Imperata cylindrica* and *Digitaria sanguinalis* were dominant. Weed biomass was lower in the AFS due to regular soil working, intercultural operation and competition of resources with the associated crops. Species diversity (H') of both grasses and herb species was highest in the AJh situation over the four seasons. Among the four AFS, the mandarin based AFS had a higher species diversity compared with the sole crop situation. Ordination by Correspondence Analysis (COA) indicated that the occurrence of weeds across seasons varied among the systems due to the higher abundance of one or more weed species. The weed species showed fluxes in their abundance patterns which are linked with the spring and rainy season. The study indicates that weed infestation could be greatly reduced under suitable agroforestry systems in north-eastern India which in turn can contribute to enhancement of crop yields and provide additional benefits to farmers by way of fruits, firewood, and soil amelioration and at the same time protect the environment.

Key words : *Alnus nepalensis*, Abandoned jhum, *Citrus reticulata*, Diversity indices, Ordination, *Paraserianthes falcataria, Prunus cerasoides*, Weed dynamics

Introduction

The hilly terrain of North Eastern India with its tropical evergreen forests and hot humid climate is considered a centre of origin of many economically important plants. The inhabitants are mostly natives who continue to practice 'slash & burn' agriculture (*jhum* cultivation). The *jhum* cultivation practice in this region includes cutting and burning of forest vegetation on sloping lands and using the site for 2-3 years for growing a number of crops in mixtures and there after moving to a fresh site and repeating the process (Singh and Dhyani, 1996). Deforestation and forest fragmentation due to continued anthropogenic disturbances pose a serious challenge to biodiversity conservation and ecosystem security in the region, as a result of which more than 20 per cent of the area has been converted into wastelands.

In the humid climate weed growth is luxuriant during the *kharif* (summer and rainy) season due to favorable climate, and their presence in agricultural fields is a major reason for low crop yields. Patel *et al.,* (1988) observed that proper weed control can increase crop yields by 38 per cent. However, weeds are considered to be an essential ingredient of traditional ecosystem in various parts of the world including north-eastern India (Misra and Ramakrishnan, 1983; Singh and Dhyani, 1996).

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Most weeds are strong light demanding species and an effective way of controlling their incidence is through canopy closure and shading the undergrowth as in intercropping (Moody, 1980). Lower weed yield under hedge rows (Yamoah *et al*., 1986) with *Acacia albida* (Bashir Jama *et al*., 1991), control of *Imperata* infestation in alley cropping (Aken-Ova and Atta-Krah, 1986), rubber plantations (Menz and Grist, 1996) and shift in weed composition following alley cropping with hedge row species (Siaw *et al*., 1991) are some of the examples of reduced weed infestation by introducing tree based agroforestry systems.

To overcome this problem of subsistence agriculture and reduced fallow cycle of 2-3 years (compared to 20-25 years in the past) suitable agroforestry systems have been recommended (Dhyani and Chauhan, 1995, Samra *et al,*. 2002). The use of trees and herbaceous cover crops for weed management in small holder farms is a promising alternative to the unsuitable traditional shifting cultivation system (Ekeleme *et al*., 2004) and growing trees to control weeds in the semi-arid region of West Africa has been reported as a sustainable and efficient alternative (Gworgwor, 2007). Several compatible systems have been identified that are both ecologically compatible and help in maintaining sufficient canopy cover leading to reduction in soil erosion (Dhyani *et al*., 2005) as well as improving soil hydro-physical properties (Saha *et al*., 2007). The impact of the integration of trees, as agrisilviculture components, on crop yields has been described earlier (Dhyani and Tripathi, 1999, 2000). It was observed during these studies that weeds constitute a major component of the biomass and they reduce crop yields substantially.

This paper reports on the weed dynamics in four agroforestry systems (AFS), which have been compared with the abandoned *jhum* (AJh) and sole crops in order to determine the patterns of species occurrences in the agroforestry systems being investigated.

Materials and Methods

The experimental site is located at the ICAR Research Farm, Barapani (Meghalaya), India, between 25°39' and 25°41' N latitude and 91°54' and 91°63' E longitude. The altitude of the farm varies between 952 and 1082 m above msl. The climate of the area is humid subtropical with 2138 mm of annual rainfall, of which more than 90% is received during April to October. The year can be divided into four season *viz*. spring, rainy, autumn and winter. Spring (Summer) season is relatively warmer with low rainfall while winters are very cold. The mean maximum temperature in December and January declines to about 6°C but sometimes the temperature decreases to 2°C.

The experiment was initiated in August 1987 with planting of one year old nursery seedlings of the tree species in mini-terraces (contour bunds, with an average terrace width of 3 m) on the hill slopes (32 to 41.8% slope). The experiment was conducted in a split plot design with three replications, four tree species in the main plots and three cropping treatments in the subplots. To segregate the effect of weeds on crop yields under trees and sole crop, plots were kept where weeding was not undertaken. The four agroforestry systems include tree species *viz*. mandarin (*Citrus reticulata* Blanco), alder (*Alnus nepalensis* D. Don), Himalayan wild cherry *(Prunus cerasoides* D. Don.) and *albizia* (*Paraserianthes falcataria* (L) Nielsen syn. *Albizia falcataria* (L) Forsberg) all of which were six and seven year old. The intercrops under the four systems were: (a) soybean (*Glycine max* (L.) Merr., linseed (*Linum usitatissimum* L.), for three years, then groundnut (*Arachis hypogea* L.) – mustard (*Brassica campestris* L.) for three years followed by soybean-linseed crop rotation in the seventh year; (b) groundnut-mustard for three years, then soybean-linseed for three years and groundnut-mustard in seventh year; (c) sole trees (without intercrops). Intercrops soybean and groundnut were grown during *kharif*, and linseed and mustard during *rabi*. All the intercrops included in the experiment were also planted in an adjacent field in sole stands (without trees). The experimental details for trees and crops, their varieties and agronomic schedules followed during the study period have been presented in Dhyani and Tripathi (1999, 2000). During the cropping period no weedicides were used and only hand weeding was carried out whenever necessary. The experiment was conducted under rainfed condition.

Weed flora in the above four agroforestry systems (AFS), sole crops and an adjoining abandoned '*jhum*' (AJh) dominated by young regeneration of khasi pine (*Pinus kesiya*) was studied over a period of two years (1992-94). Six quadrats (50 x 50 cm) were laid down randomly every month in each of the six systems being studied. Individuals of each species falling within the quadrats were identified, and counted for their abundance. The species were broadly grouped into three categories - grasses and sedges, legume forbs, and non-legume forbs and further the species were classified into different life forms following Raunkaier (1934).

Abundance data on species (weeds) occurrences across a year were grouped for both the years into 4 seasons : winters (January – March), spring (April – June), rainy (July – September) and autumn (October – December). These values were used to compute Richness index (Margalef, 1958), Simpson's index (ë,, Simpson, 1949) (this index varies between 0 and 1 and gives the probability that two individuals drawn at random from a population belong to the same species), Shanon's index (H') of diversity (Shannon and Weaver, 1949), where H' is the measure of the average degree of 'uncertainty' in predicting to what species an individual chosen at random from a collection of S species and N individuals will belong, and evenness of species distributions (J') of Pielou (1975), where J' = H'/l n(s), which expresses H' relative to the maximum value it can obtain assuming that all of the species are evenly distributed (i.e. = 1 individual per species).

In order to determine whether some species are more closely related to another due to local climatic situations or a resource gradient, we used ordination by correspondence analysis (COA) which allows 'corresponding' SU's and species ordination to be obtained simultaneously. In this technique, sampling units (SU's) are arranged in relation to one or more coordinate axes so that their relative positions to the axes and to each other reveals their ecological similarities. Seasons were used as sampling units (SU's), *i.e.* – 1, 2, 3, 4 being winters, spring, rainy and autumn for the first year and 5, 6, 7 and 8 being the same seasons in the second year. Species abundances for each plant type in each system were averaged for each season (called SU's) and ordination analysis carried out.

Whenever these affinities could not be determined, we adopted the cluster analysis approach, computed % dissimilarity between the SU's and prepared dendrograms. For both these analysis we used a PC based basic programme and prepared diagrams, indicating the most dominant populations or species in each of the AFS.

Results and Discussion

Species distribution patterns

The occurrence and distribution of weeds in all the six systems studied revealed that their occurrence is strongly influenced by changes of season, especially during the rainy season. In general, the total number of species recorded in the abandoned 'jhum' (AJh) and sole crop was more than that recorded in the four agroforestry systems in both the years (Table 1).

Among the grasses, species like *Brachiaria villosa, Digitaria adscendens* and *Setaria glauca* were common to all the systems except in case of AJh, where *Arundinella bengalensis* was a very invasive species and effectively curbed the occurrence of lesser invasive species. Among the forbs *Bidens pilosa, Borreria hispida, Oxalis corniculata* were common in the six systems, while *Brachiaria villosa, Trifolium repens, Ageratum conyzoides, Galinsoga ciliata* and *Richardsonia pilosa* were common in the four agroforestry systems and sole crops, but were completely absent in the AJh. *Chrysopogon* was the only species that occurred in the four AFS and was noticeably absent in the other two systems, while *Alternanthera* was the single species that occurred only in the 'sole crop' plots (Table 2).

In the AJh plot, fourteen grass species, twenty four herb species and five shrub species were recorded over a period of two years. Four new species – *Arundianaria bengalensis, Ageratum haustonianum, Blumea barberata, Commelina bengalensis* were recorded during 1993-94, while seven weed species *viz.*, *Cyperus rotundus, Paspalum* sp., *Crotolaria striata, Lindenbergia*

Table 1: Variations in the number of grass (G), herb (H) and shrubs (Sh) species across four seasons in four agroforestry systems compared with abandoned jhum (AJh) and sole crop.

System	Seasons											
	Winter			Spring			Rainy			Autumn		
	G	H	Sh	G	H	Sh	G	H	Sh	G	H	Sh
AFS1	4	6	-	8	8	-	5	9	-	6	8	-
AFS2	4	6	-	6	10	-	6	9	-	5	8	-
AFS3	5	5	-	5	8	-	6	8	-	5	7	-
AFS4	5	9	-	9	15	-	9	14	-	7	12	-
Sole crop	5	9	-	8	10	-	9	15	-	5	13	-
AJh	9	11	5	13	18	5	11	19	5	13	18	5

All values mean of two years. Winter: January to March; Spring: April to June; Rainy: July – Sept.; Autumn: October – December.
AFS 1 : Alder based system, AFS 2 : *Albizia* based system, AFS 3: Cherry based system,
AFS 4 : Mandarin based system. AJh: Abandoned *jhum*

Table 2 : Occurrence of species in various systems measured across two years and their life-forms(%).

Sl. No.	Species	AFS1		AFS2		AFS3		AFS4		Sole crops		AJh		Habit	Life Form
	Year	I	II	I	II	I	II	I	II	I	II	I	II		
	Grasses & Sedges														
1.	*Arundinella bengalensis*(Sprng.)Dr.	-	-	-	-	-	-	-	-	-	-	+	+	P	H
2.	*Brachiaria villosa* A. Camus	+	+	+	+	+	+	+	+	+	+	-	-	A	Th
3.	*Carex baccans* Nees	-	-	-	-	-	-	-	-	-	-	+	+	P	H
4.	*Chrysopogon* sp.	+	-	+	-	+	-	+	-	-	-	+	+	A	Th
5.	*Cynodon dactylon* Pers.	-	-	-	-	-	-	-	+	+	-	-	+	P	H
6.	*Cyperus rotundus* L.	-	-	-	-	-	-	-	-	+	-	+	-	P	H
7.	*Digitaria adscendens* (HBK) Hen.	+	+	+	+	+	+	+	+	+	+	+	+	A	Th
8.	*D. sanguinellis* (L.) Sep.	+	+	+	+	+	+	-	-	-	+	+	+	A	Th
9.	*Echinochloa crusgalli* (L) Beauv.	+	+	-	-	-	-	-	-	+	-	-	-	A	Th
10.	*E. colonum* (L) Link	-	-	+	-	-	-	-	-	+	+	+	+	A	Th
11.	*Eleusine indica* (L) Gaertn.	-	+	-	+	-	-	+	+	+	+	-	-	A	Th
12.	*Eulalia fastigala*(Nees) Iiaines	-	-	-	-	-	-	-	-	-	-	+	+	P	H
13.	*E. quadrinervis* Hack.	-	-	-	-	-	-	-	-	-	-	+	+	P	H
14.	*Fimbristylis companulata* (Retz.)Link	-	-	-	-	-	-	-	-	-	-	-	-	A	Th
15.	*Imperata cylindrica* Beauv.	-	-	-	-	+	-	-	-	+	-	+	+	P	H
16.	*Setaria glauca* Beauv.	+	-	+	+	+	-	+	+	+	+	+	+	A	Th
17.	*Oplismenus* sp.	-	-	+	+	-	-	+	+	+	+	-	-	A	Th
18.	*Kyllinga melanosperma* Nees.	-	+	+	+	-	-	+	+	+	+	-	-	P	C
19.	*Panicum montanum* Roxb.	-	-	-	-	-	+	+	+	-	+	+	+	P	Ch
20.	*Paspalum* sp.	+	-	-	-	-	-	-	-	-	-	+	-	P	Ch
	Sub-total	**7**	**6**	**8**	**7**	**6**	**4**	**8**	**8**	**11**	**9**	**13**	**12**		
	Legumes														
21.	*Cassia occidentalis* L.	-	-	-	-	-	-	-	-	-	-	+	+	P	Ch
22.	*Crotalaria striata* DC	-	-	-	+	-	-	+	+	-	-	+	-	A	Th
23.	*Desmodium microphyllum* Miq.	+	+	-	+	+	+	+	+	+	+	-	+	A	Th
24.	*Eriosaema chinense* Vogel.	-	-	-	-	-	-	-	-	-	-	+	+	P	G
25.	*Mimosa pudica* Roxb.	-	-	+	-	+	-	-	-	+	+	+	+	P	Ch
26.	Macroptilium atropurpureum*(DC)Ur.*	-	-	+	-	-	-	-	-	-	-	-	-	A	Th
27.	Stylosanthes guianensis *(Aubl.)Sw.*	-	-	-	-	-	+	-	-	-	-	+	+	P	Ch
28.	*Trifolium repens* L.	+	+	+	+	+	+	+	+	+	+	-	-	A	Th
	Sub-total	**2**	**2**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**5**	**5**		
	Forbs														
29.	*Ageratum conyzoides* L.	+	+	+	+	+	+	+	+	+	+	-	-	A	Th
30.	*A. haustonianum* Mill.	-	+	-	-	-	-	+	+	+	-	+	+	A	Th
31.	*Alternanthera phylaxeroides* Griseb.	-	-	-	-	-	-	-	-	+	+	-	-	A	Th
32.	*Ambrossia artemisifolia* L.	-	-	-	-	-	-	+	-	+	-	+	+	A	Th
33.	*Bidens pilosa* L.	+	+	+	+	+	+	+	+	+	+	+	+	A	Th
34.	*Borreria hispida* (L) Schum	+	+	+	+	+	+	+	+	+	+	+	+	A	Th
35.	*Blumea barberata* DC	-	+	-	-	-	-	+	+	+	+	-	-	A	Th
36.	*Chenopodium album* L.	-	-	+	+	+	+	+	+	+	+	-	+	A	Th
37.	*Commelina benghalensis* L.	-	-	+	-	-	-	+	+	+	+	-	+	A	G
38.	*Curcuma montana* Roxb.	-	-	-	-	-	-	-	-	-	-	+	-	P	Th
39.	*Emilia sonchifolia* DC	+	-	+	-	-	-	+	-	+	-	-	+	A	Ch
40.	*Chromolaema odoratum* L.	-	-	-	-	-	-	-	-	-	-	+	+	P	Ch
41.	*C. adenophorum* Spreng.	-	-	-	-	-	-	-	-	-	-	+	+	P	Ch
42.	*Galinsoga ciliata* (Raf.) Blake	+	+	+	+	+	+	+	+	+	+	-	-	P	Ch
43.	*Hedychium* sp.	-	-	-	-	-	-	-	-	-	-	+	+	P	G
44.	*Inula cappa* DC	-	-	-	-	-	-	-	-	-	-	+	+	P	Ch
45.	*Lantana camara* L.	-	-	-	-	-	-	-	-	-	-	+	+	P	Ch

Contd...

Contd...

46. Lindenbergia indica *(L.)Kuntze*	-	-	-	-	+	-	-	-	-	+	+	-	A	Th
47. Lindernia crustacean *(L.) F. Muell*	-	-	+	+	-	-	-	-	-	-	-	-	A	Th
48. *Murdania spirata* (L.) Bruck	+	-	-	-	-	-	+	+	+	+	-	-	A	Th
49. *Mikania micarantha* HBK	-	-	-	-	-	-	-	-	-	-	+	+	P	H
50. *Osbeckia chinense* L.	-	-	-	-	-	-	-	-	-	-	+	-	P	Ch
51. *Oxalis corniculata* L.	+	-	+	-	-	+	-	+	+	+	+	+	P	Ch
52. O. deppei *Lodd.*	-	+	-	+	-	-	+	-	-	-	+	-	P	Ch
53. *Phyllanthus urinaria* L.	-	-	-	-	-	-	-	-	-	-	+	+	A	Th
54. *Polygala glomerata* Lour	-	-	-	-	-	-	-	-	-	-	+	+	P	Ch
55. *Pteridium aquilinum* L. (fern)	-	-	-	-	-	-	-	-	-	-	+	+	P	H
56. *Rubus moluccanus* L.	-	-	-	-	-	-	-	-	-	-	+	+	P	Ch
57. *Richardsonia pilosa* HBK	+	+	-	+	+	+	+	+	+	+	-	-	A	Th
58. *Spilanthus paniculata* DC	-	-	-	-	+	-	-	-	+	+	-	-	P	Ch
59. *Sida rhomboidea* Roxb.	-	-	-	-	-	-	-	-	-	-	+	+	A	Ch
60. *Spermacoceae hispida* L.	-	-	+	-	-	-	+	+	-	-	-	-	A	Th
61. *Uraria alopecuroides* Wt.	-	-	-	-	-	-	-	-	-	-	+	-	P	Ch
Sub-total	8	8	10	8	8	7	14	12	15	13	21	18		
Life forms														
Ch-Chamaephyte	15.05		12.70		20.20		16.10		13.15		36.20			
H-Hemicryptophyte	-		-		3.00		4.05		5.15		20.80			
G-Geophyte	3.15		5.15		-		2.15		3.70		7.80			
Th-Therophyte	81.80		82.15		76.85		77.70		78.00		35.20			

+Present; -Absent; I- Ist year, II- second year, A-Annual; P-Perennial, AFS 1-4, AJh as in Table 1

Table 3 : Diversity indices of grass and herb species in four agroforestry systems compared with sole crop and abandoned jhum (AJh) situations, across four seasons.

System	Season	Grass species				Herb Species			
		R	λ	H'	E'	R	λ	H'	E'
AFS1	Winter	1.127	0.375	1.061	0.766	1.074	0.257	1.461	0.858
	Spring	1.805	0.432	1.218	0.615	1.504	0.266	1.495	0.770
	Rainy	1.077	0.361	1.232	0.777	1.586	0.380	1.345	0.627
	Autumn	1.301	0.220	1.519	0.892	1.588	0.253	1.653	0.795
AFS2	Winter	0.848	0.457	0.884	0.787	0.999	0.294	1.348	0.791
	Spring	1.251	0.571	0.841	0.500	1.920	0.266	1.508	0.663
	Rainy	1.196	0.293	1.467	0.814	1.550	0.287	1.485	0.698
	Autumn	1.089	0.267	1.389	0.878	1.493	0.264	1.487	0.735
AFS3	Winter	0.944	0.540	0.867	0.573	0.860	0.372	1.113	0.743
	Spring	0.923	0.550	0.838	0.560	1.541	0.258	1.515	0.731
	Rainy	1.335	0.340	1.296	0.723	1.611	0.270	1.501	0.723
	Autumn	1.113	0.256	1.404	0.872	1.522	0.274	1.458	0.724
AFS4	Winter	1.235	0.329	1.270	0.789	1.660	0.252	1.571	0.782
	Spring	1.935	0.271	1.610	0.738	3.034	0.216	1.843	0.683
	Rainy	1.770	0.241	1.714	0.801	2.731	0.196	1.910	0.724
	Autumn	1.622	0.258	1.521	0.782	2.420	0.183	1.888	0.774
Sole crop	Winter	1.031	0.606	0.792	0.491	1.609	0.310	1.506	0.685
	Spring	1.681	0.257	1.615	0.790	1.563	0.343	1.513	0.672
	Rainy	1.885	0.280	1.580	0.742	2.436	0.219	1.908	0.713
	Autumn	1.016	0.483	1.014	0.630	2.380	1.191	1.967	0.767
AJh	Winter	1.865	0.241	1.631	0.742	2.979	0.110	2.067	0.879
	Spring	2.380	0.182	1.911	0.723	4.831	0.102	2.409	0.835
	Rainy	1.987	0.218	1.796	0.750	4.186	0.008	2.548	0.875
	Autumn	2.391	0.193	1.911	0.757	4.141	0.058	2.490	0.862

R- richness of species, λ – Simpson’s concentration of dominance, H’- Shannon’s index of diversity, E’- evenness of species distribution, AFS 1-4, AJh as in Table 1.

indica, Osbeckia chinense, Oxalis deppei and *Uraria alopecuroides* present during 1992-93 did not appear during 1993-94.

The weed species exclusively present in the four agroforestry systems (AFS) and sole crops during the two years of study are:

AFS (1-4)

1992-93: *Chrysopogon* sp. *Setaria glauca, Paspalum* sp., *Emilia sonchifolia, Murdania* spirata, Oxalis corniculata

1993-94: *Elusine indica, Kylingia melanosperma, Ageratum haustonianum, Blumea* Barbarata, Oxalis deppei Sole crop

1992-93: *Cynodon dactylon, Cyperus rotundus, Echinochloa crusgalli, E. colonum,* Eleusine indica, Imperata cylindrica, Setaria glauca, Ageratum haustonianum, Oplismenus, Ambrossia artemisifolia, Emilia sonchifolia

1993-94: *Digitaria sanguinalis, Panicum montanum, Lindenbergia indica*

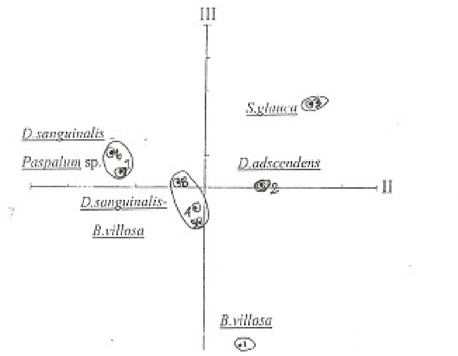

Fig.1 Ordination by correspondence analysis of grass species measured across four seasons and two years in AFS1. Numbers 1,2,3,4 correspond to winter, spring, rainy and autumn season of the first year and numbers 5,6,7,8 to the same seasons in the second year, taken as sampling points.

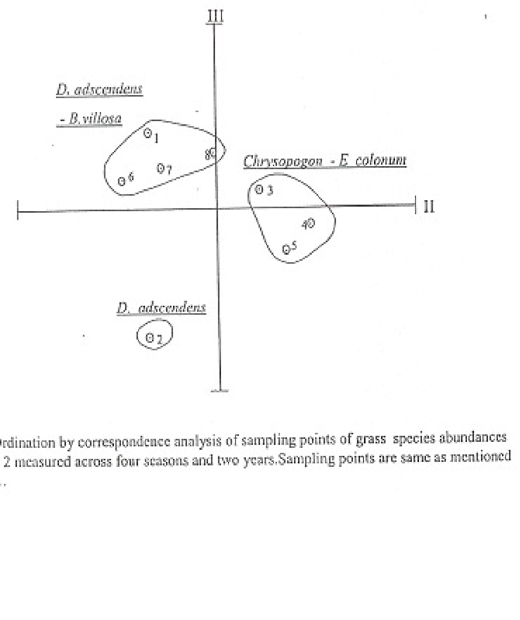

Fig 2 Ordination by correspondence analysis of sampling points of grass species abundances in AFS 2 measured across four seasons and two years.Sampling points are same as mentioned in Fig.1.

Distribution patterns of life forms

The number of perennial weeds was highest in the abandoned jhum (AJh) (25) than in the four agroforestry systems and sole crop in both the years (Table 2). The number of annual species were highest in the sole crop situations, followed by the agroforestry system, although overall the abandoned *jhum* system supported the highest range of all plant types, indicating the suitability of the system for supporting a large plant diversity.

The ratio of annual to perennial species (A/P ratio) was greater in the four agroforestry systems and sole crop (2.5-4.7) than in the abandoned *jhum* (0.5-0.6). In contrast to the first year, the A/P ratio was higher during the second year in all situations except for cherry-and-alder based system where it declined. Among the four agroforestry system the least A/P ratio was recorded in the mandarin system in both the years and in cherry based system in the second year, indicating that the proportion of perennial weeds in these systems was higher in comparison to the other two agroforestry system. The number of forbs was greater than grasses and sedges in both the years in all the situations. Out of the three leguminous species recorded for two years in alder-albizia-cherry-system and sole crop, only one was a perennial legume species, while in the mandarin-system two perennial legumes species were recorded. However, in the AJh, six leguminous species were recorded, out of which four were perennial species.

Variation in species diversity (H') patterns in the six systems

Diversity of grass species was low (<1.0) in AFS 1, 2 and 3 but was >1.50 in the other 3 systems (Table 3). It was highest in the AJh situation where it remained high all through the year and was dominated by *A. bengalensis – I. cylindrica* associations. The abundance of these two species increased significantly with the arrival of spring and peaked in the rainy season, along with the number of grass species (Table 1). In AFS 2 and AFS 3, diversity value of grass species was nearly similar, while values from AFS 1 and 4 were similar during winter and spring with values being on the higher side in AFS 4 that was dominated by *Digitaria adscendens – I. cylindrica* associations along with a number of annual species. AFS 1, 2 and 3 were dominated by *Brachiaria villosa – D. adscendens* associations, along with other species during spring and rainy season.

Diversity (H') of herb species in all the six systems remained more than 1.0 all through the year, the values of H' being the highest in AJh and nearly similar in the

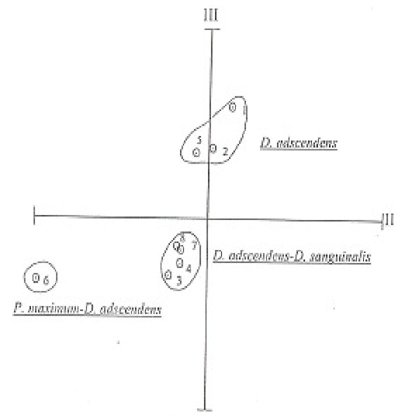

Fig. 3 Ordination by correspondence analysis of sampling points of grass species abundances in AFS 3, measured across four seasons and two years. Sampling points are same as mentioned in Fig.1.

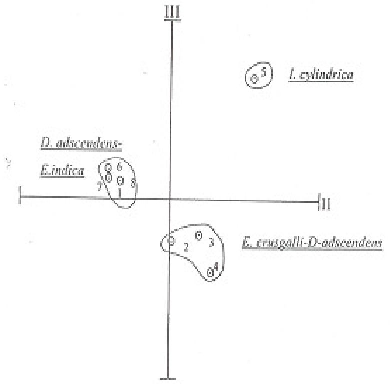

Fig. 4 Ordination by correspondence analysis of sampling points of grass species abundances in AFS 4, measured across four seasons and two years. Sampling points are same as mentioned in Fig.1.

four AFS and sole crop (Table 3). *Galinsoga ciliata* and *Ageratum conyzoides* were the common herb species in AFS 1, 2 and 3, while in 4, *Bidens pilosa* joined the earlier two species during the spring and rainy season. In the sole crop situation, the number of herb species recorded across the four seasons was less than the AJh situation and consistently remained higher than the AFS (Table 1). The sole crop situation supported a number of species across a year, usually dominated by *G. ciliata – A haustonium, G. ciliata – Richardsonia pilosa, G. ciliata – Borreria hispida, A. haustonium – A. conyzoides* associations in winter, spring, rainy and autumn seasons, respectively. However in the second year, *A. haustonianum* became a very aggressive weed during the spring and effectively limited the occurrence of *G. ciliata*.

Within the four AFS, the number of species recorded over a year were higher in the mandarin based system (AFS 4) and remained nearly similar in the other three AFS (Table 1). The diversity value of the herb component in the AFS 4 was 1.57, 1.84, 1.91 and 1.88 in winter, spring, rainy and autumn season, respectively. *A. conyzoides* and *B. pilosa* occurred throughout the year, while *G. ciliata* was abundant during spring, rainy and autumn months. These three species were also common in the alder–albizia and cherry based system, indicating that these species are shade tolerant and shall continue to thrive in these agroforestry systems.

Evenness of species distribution patterns in the six systems

Evenness of distribution patterns indicate as to how equally individuals of different species are distributed in a given site. Values of evenness (J') nearing 1.0 indicate that all the species encountered are perfectly distributed over the plots. The distribution patterns of grasses in the six systems studied (Table 3) indicate that a nearly perfect distribution was observed in the abandoned *jhum* plots with no change across a year. This may be attributed to the large scale presence of *A. bengalensis – I. cylindrica – Eulalia fastigala* all through the year, the last species being more wide spread in the rainy season. These values also indicate that the *A. bengalensis – I. cylindrica* association was quite invasive and effectively limited the appearance and establishment of other grass species. Evenness of herb species distribution in this system remained almost constant (0.835 - 0.880) across a year with *Ageratum haustonium* being widespread in the rainy season and *Cassia occidentalis, Bidens pilosa* and *Phyllanthus urinaria* being regularly present all through the year.

In the sole crop situations, *Digitaria adscendens* was the most abundant grass speceis along with *I. cylindrica* and *Eleusine indica.* The herb species distribution ranged between 0.672 to 0.767 across a year *with Galinsoga ciliata – Borreria hispida, Ageratum conyzoides* occurring regularly over both the years.

In the four AFS, the evenness of grass species distribution remained more or less similar all through the year (Table 3) with the exception of mandarin based system (AFS 4), where there were a number of species in different abundances in the four seasons. Dominant among these were *D. adscendens, Setaria glauca* and *Brachiaria villosa*. Among the herb species *G. ciliata*, *A. conyzoides* and *B. pilosa* were quite well distributed within the twenty species encountered in this system. In AFS 1, 2 and 3, *D. adscendens* and *B. villosa* were quite widespread across the four seasons in both the years, with the former species being more abundant in the cherry based system. Among the herb species encountered in these three systems, *G. ciliata, A. conyzoides* and *B. pilosa* were common to all, although there were variations in their abundances during different seasons.

Species affinities in the agroforestry systems in relation to seasons

Species distribution and abundance patterns are correlated to resource availability and to an underlying affinity between various species that may change with seasons. Ordination by COA revealed that under the given site conditions, the occurrence of weeds across seasons varied between the various tree based agroforestry systems due to the higher abundance of one or more species. The occurrence of grass species in agroforestry system 1 (Fig. 1) for SU 1, 2, 3 representing winter, spring and rainy season of the first year were separated out from those SU's that were grouped together due to the occurrence of *D. adscendens – B. villosa* (SU 4,5,8) and *D. adscendens – P. indicum* (SU 6,7) association. In AFS 2 (Fig. 2) SU's 1, 6, 7, 8 and SU's 3, 4, 5 are loaded along different axis, the former being dominated by *D. adscendens - B. villosa* and the latter by C*hrysopogon* sp. and *E. colonum*. In AFS 3 (Fig. 3) grasses like *D. adscendens* and *D. sanguinalis* (SU 3, 4, 7, 8) are clumped together while SU's 1, 2, 5 representing the winter season is dominated by *D. adscendens* alone. *P. maximum* shown in SU 6 has been segregated out. In AFS 4 (Fig. 4) also, a similar segregation has taken place with the first and second year spring and rainy season species being shown on a different axis. In AFS 5, the dendrogram (Fig. 5) representing per cent dissimilarity reveals that SU's 6, 7, 2, 3 dominated by *D. adscendens – D. sanguinalis – I. cylindrica* associations are different from SU 1, 8, 4, 5 which are dominated by *D. adscendens* alone. In the secondary succession plot (AJh plot) there are little differences in the species abundance patterns (Fig. 6) in the first and second year, except that these have been placed on a different axis, with the second year SU's also including *E. fastigala*.

Ordination of SU's considering herb species revealed a pattern similar to that of grasses. Many of the herb species recorded in this study across all the 6 sites were annuals that depend on warm temperatures and rainy season for rapid biomass accumulation and seed dispersal for continuity of the generation. Ordination reveal that in all the tree based AFS, sole crop and AJh situations changes in herb species abundances were related to changing seasons, with one or two species dominating. Common to most of the AFS were *A. conyzoides, B. pilosa* and *G. ciliata* (a perennial). In the *Albizia* based systems SU's 2, 6, 7 has a higher

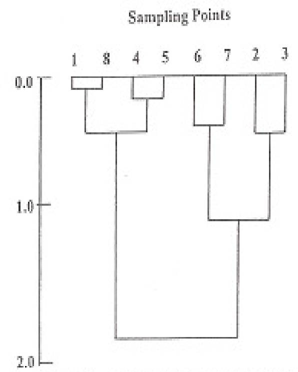

Fig. 5 Dendrogram showing % dissimilarity between various sampling points and grass species abundances in AFS 5, measured across four seasons and two years. Sampling points are same as mentioned in Fig.1.

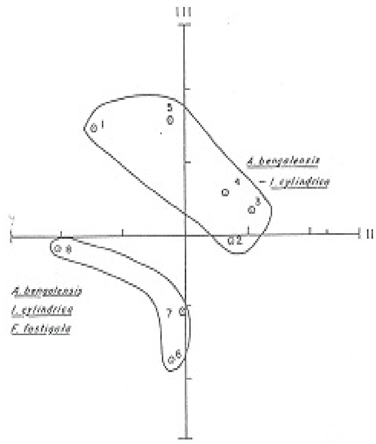

Fig. 6. Ordination by correspondence analysis of sampling points of grass species abundances in AFS 6, measured across four seasons and two years. Sampling points are same as mentioned in Fig.1.

abundance of the species mentioned earlier plus additional species like *B. hispida, L. crustacea* and *Crotolaria striata*, a legume.

In case of shrub abundances, only two species were observed to be dominant (Fig. 7). *Lantana camara,* an invasive perennial, gregarious weed, dominates the AJh site and is very abundant throughout the year. It is only in mesic sites that *C. odoratum*, another exotic fast spreading weed, was recorded in the first year, but by the end of the second year the species had disappeared, the entire area apparently having been overrun by *L. camara*.

Among the eight groups of traits listed by Gaston and Kurin (1997), abundance and distribution reflect species relationships to resource availability. Once plants get established they need to utilize available resources in order to survive and also to avoid competitive exclusion that reflects on their performance within communities. Species which grow in their peculiar 'niche' requirement are more widely distributed and abundant. We observed similar features in our study with a few species dominating the six systems investigated, in spite of the occurrence of a large number of other species. Among the grass species abundances recorded for two years, *D. adscendens – B. villosa* were abundant in AFS 1, 2 and 3 while in the mandarin based system (AFS 3), *D. adscendens - E. crusgalli* were dominant. In the sole crop situation *D. adscendens – E. indica* association dominated while in the AJh situation *A. bengalensis – I. cylindrica* were the most abundant. In case of annual forbs and herbs, seasonal fluxes in distribution patterns were not very significant and a few species appear to dominate the tree based AFS. This is also revealed in the correspondence analysis (COA) where many of the herb and forb species appear. Herb species like *A. conyzoides*, *G. ciliata* and *B. pilosa* show high abundances in the tree based agroforestry system and sole crop situations all through the year, the values peaking in the monsoons and continuing well into the autumn season. In the tree based system, diffused light all through the year (Dhyani *et al.*, 1994) and availability of fertilizers led to the appearance of a few grass and herb species that were probably nutrient demanding. The number of species of both grasses and herbs increased in spring when days become warmer but the number declined in the rainy season when only one or two grass and herb species began to dominate making full use of both moisture and nutrients already available at the site. It is in the secondary succession plots (AJh site) where species abundance is high but richness under the given conditions and a few species tend to dominate the area. These species are invasive by nature and have a tendency to adapt well to low pH soils with a high level of exchangeable Al.

It has been reported earlier that in unproductive environments competition is primarily for below ground resources (water and nutrients) and in productive environments competition is primarily for light (Tilman, 1987, 1988). In the given humid conditions, water is not a constraint but Al toxicity and rapid leaching of nutrients may be a constraint. The second reason may hold good for shallow rooted annual herbs and grasses, but it is the quantity of light available that appears to be a limiting factor. Light interception ranging from 38 to 66% has been reported in the AFS 1, AFS 2, AFS 3 and AJh, while in the mandarin based AFS 4, it was hardly 34% (Dhyani *et al.,* 1994). Apparently species that are dominant in the tree-based systems are strong competitors under the given resource conditions and this also explains their relatively high abundance

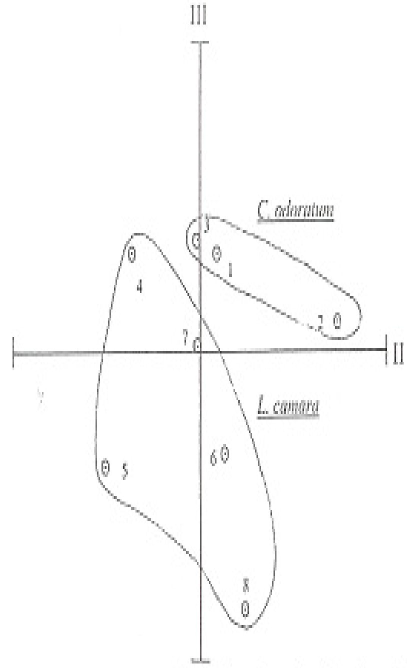

Fig. 13 Ordination by correspondence analysis of sampling points based on shrub species abundances in AFS 6, measured across four seasons and two years. Sampling points are same as given in Fig. 1.

(Newman, 1973). In the mandarin based system (AFS 4), a restricted canopy, slow growth and hence more light led to the appearance of more species, specially of herbs in comparison to other three agroforestry systems.

Furthermore, colonization and recruitment processes affect many aspects of plant community structure such as co-existence of species and species composition. It is apparent that species which are competitively superior locally and hence abundant in their own ecological niche are poor seed or propagule dispersers. In the north east, species like *I. cylindrica* and *A. bengalensis* are clearly seen to occupy mesic sites and undulating topography in the process of secondary succession. These two perennial species increase significantly in their abundances during spring and maintain their dominance well into the 2^{nd} – 3^{rd} year and show a tendency to suppress out other species.

These results make it apparent that species in the warm and humid climate of north eastern India show fluxes in their abundance patterns that are most often linked to the appearance of spring and rainy season. Since most of the species are annual by nature, there is a tendency to quickly complete the life cycle before the onset of the winters, and disperse propagules for continuation in the next year. Competition between different species and plant groups was not evident in a short period, and probably this would emerge only when resources (space, water and light) become a constraint.

These seasonal fluxes in species number and their abundances led to variations in species diversity (H') and evenness of distribution in the six systems investigated. While they were highest in the sites where secondary succession was in progress, these variations were least in the agroforestry systems where sufficient canopy cover restricted major changes in species distribution pattern that were nearly similar to each other all through the year.

Conclusion

Agroforestry has been viewed as an example of three species competition in which a secondary species (e.g. tree species) controls the weeds and releases the main crop from the strong competition that may be offered by the weed. The present study indicated reduced weed infestation under three agroforestry systems, except under mandarin based system. In the humid sub-tropical climate of NE Himalayan region, the integration of trees (both fruit bearing and other multipurpose species) with crops can effectively restrict the appearance of annual and perennial weeds. The occurrence of these weeds are related to the presence of an effective canopy cover by broad canopies trees but not in those trees with a small restricted canopy such as mandarin in the initial years.

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