The Journal of Animal & Plant Sciences, 26(4): 2016, Page: 988-1001
ISSN: 1018-7081

EFFECT OF GAP DISTURBANCES ON SOIL PROPERTIES AND UNDERSTORY PLANT DIVERSITY IN A *PINUS MASSONIANA* PLANTATION IN HUBEI, CENTRAL CHINA

Wen-Jie Hu[1], [3]Peng-ChengWang[1,2*], Yu Zhang[1], Ming-JunTeng[1] and Zhi-XiangZhou[1]

[1]College of Horticulture and Forestry Sciences, Huazhong Agricultural University, Wuhan 430070, China;
[2]Ecological Modelling and Carbon Science Lab., Institute of environment sciences, University of Quebec at Montreal, Montreal, H3C 3P8, Canada)
[3]Hubei Academy of Forestry, Wuhan 430075, China
Corresponding Author E-mail: pengchengwang@163.com

ABSTRACT

The response of plant species composition, diversity and soil nutrient availability to different canopysizes and age gaps in a *Pinus Massoniana* plantation were surveyed in Taizishan, Hubei province, central China. The soil chemical properties of 27 gaps and 3 non-gaps were measured and compared. The study objectives were: (a) confirm whether and when nutrient pulses emerged in small gaps; (b) determine the effects of gap sizes and ages on the soil properties and species diversity in gaps; and (c) determine the response of species diversity to soil nutrient variables in gaps. The understory plants of all canopy gaps and non-gaps were identified. Diversity indices were employed in this study, and the relationship between understory plant diversity and soil chemical properties were analyzed by detrended canonical correspondence analysis (DCCA). The results showed that soil properties and species diversity were significantly impacted by forest gaps, and the effects of the gap ages were more extensive than those of the gap sizes. The nutrient pulses occurred in gaps, but the emergence of nutrient indicators pulses in different age and size gaps was different.

Keywords: disturbance; gap size; gap age; soil properties; species diversity.

INTRODUCTION

China possesses the largest plantations in the world, and *Pinusmassoniana* plantationscomprisethe largest area. Plantations generate many ecological problemsdue to their simplifiedvegetation structure, such as biodiversityloss, frequent outbreaks of plant diseases and insect damage. Therefore, enhancing thebiodiversity and stability of plantationsis an important objectin forest management,after implementing natural forest protection projects. Thinning is the most important method for adjusting the plantation structureand enhancing theproductivity of foreststands, whichhas been widely used in plantation management in China. Artificial canopy gaps, withsizes ranging from 30m^2 to 200m^2, havebeen hypothesized to be important in providingfrequent, small-scale disturbances in plantations after thinning**.** Therefore, small openings in forest canopies are common and important in providingspatial heterogeneity in forest ecosystems (*Clinton, 2003*). The changes insolar radiation intensity (*Denslowet al.,1998; Ritter et al.,2005*), temperature and air humidity(*Ritter et al., 2005*),soil moisture (*Runkle 1*982; *R*itter and*Vesterdal,2006*) and nutrient(*Denslowet al.*,1998;*PetterssonandHogbom, 2004*) occur in disturbed forests with thinning gaps.Theheterogeneity habitats accompanied by edge habitats wouldthereforeinfluence species composition and population dynamicsin plantations withgaps.

The physiological and ecological habits of plants are dominant factors in the abundance and diversity of understory plant species. The different formation stage (*Uhl et al., 1988; Spies et al., 1990*)and, sizes (*Zhang and Zak, 1995; Bouchard et al., 2005;Heitheckerand Halpern 2006;Muscolo et al., 2007;Griffiths et al., 2010*) of gaps have various influential and intensive impacts on both the habitats and regeneration of understory plants (*e.g., Dirzo et al., 1992; Schumann et al., 2003*).Previous studies addressed paid the responses of tree species grown under canopygaps (*Frelichand Reich 1995*), analyzedand simulatedthe gap dynamics(*e.g., Vepakommaet al.,2008*),as well as theregeneration characteristics under the gap(*Gagnon, et al., 2004; Kukkonenet al.,2008; Prévostand Raymond,2012*). However, afew studies havefocused on the influence of thinning gap disturbances on thesoil properties in thegaps (*Adele et al.,2007;Griffiths,2010; Muscoloet al.,2010*);and the correlations between thesoil properties and understory species diversity of aplantation(*Arunachalamand Arunachalam,2000; Muscoloet al.,2007*).Previous studies have shown that the effects on soil nutrients of forest gaps were significantly greater than inthe understory, and these effects increased with the gap size(*Denslowet al.,1998*);moreover, larger and older gaps increased species diversity, but diversity then decreased when the sizes or age increased to a certain extent(Fred *et al*.,2000).Some studies focus onthechanges in nutrient availability for short intervals after gap creation, and it ispoorly understood whether and how changes in nutrient availability persist over longer periods of time(*Denslowet al.,1998;Thiel and Perakis,2009*).Some results suggest that many treefall gaps may be too small to produce detectable changes in soil nutrient processes(Vitousekand Denslow,1986; Denslow 1987), butDenslow*et al.*(*1998*) presumed the nutrient pulses affecting the growth of seedlings and saplings would be found in small treefall gaps.

Here, we aim to: (1) measure the effects of different gapsizes and ageson gap soils, and (2) determinewhich are the primary factors controlling thegap composition of species and species diversity in a*Pinusmassoniana*plantation.Thus, the authors hope to compiledirect evidence not only on our perception of ecological processes but also on the quality of management practices when gap dynamics are adopted as a template for ecosystem-based management.

MATERIALS AND METHODS

Study Area: The study site is located inTaizishan(112°48-113°03′E, 30°48-31°02′N), Hubei province, Central China. It has a typically subtropical humid monsoon climate with hot and rainy summer and cold winter. The annual average precipitation is 1090 mm, the annual average temperature is 16.4℃. The forest types in this region mainly are evergreen coniferous forests and coniferous broad-leaved mixed forests and evergreen broad-leaved forest.The three major soil types were yellow-brown soil, mountain yellow-brown soil and yellow-cinnamon soil.

*Pinusmassoniana*is one of Chinese endemic species. Based on the results of felling age, thinning age and intensive of *Pinusmassoniana*plantation(*Ding et al., 2002;Yu et al.,2011*), the optimum felling age of pulpwood plantation and building timber plantation were 14-20a and 18-28a, respectively. The first thinning disturbance starts from 7-10a in high density stand or 11-14a in low density stand, and Thinning interval is about 3-6a(*Ding et al., 2002*). The intensity of thinning is about 15% to 35%. Therefore, three sizes of canopy gap (S1 with an area of 50-70m^2 for contractible gap,S2 with an area of100-120m^2 forcentralgap,andS3 withan area of 150-200m^{2}for extended gap), three ages of gap (A1 is after gap formation 1a,A2 is 3a,A3 is5a), and CK (Non-gap) were chosen in *Pinusmassoniana*plantation.Nine gaps were chosen to every size gradient, every three of this nine gaps belong to different age gradient (A1, A2, and A3), respectively. Three samples were chosen to benon-gap.

Since compass orientation of gaps might influence the diversity of species, the oriented north-south (N-S) and oriented east-west (E-W) transects in each expanded gaps (EG) chosen for study overlap at the center of the canopy gap (CC). We placed five uniform 2 m × 2 m quadrants on each N-S and E-Wtransects with mean distance in each expanded gap (1 quadrat is overlapped between 2 transects in each gap) except area about 50-70m^2 gaps in which three uniform 2 m × 2 m small quadrats on each transects were placed. Hence, a total of 27 gaps and 3 non-gaps samples, 60 belts transect and 468 small quadrats were surveyed.

Data Collection: In each canopy gap, three random soil profiles were excavated, and soil samples of every layer(0-20cm and 20-40cm) were obtained in each profile. The pH, soil organic matter(SOM), total nitrogen (TN), hydrolysable nitrogen(HN), total phosphorus(TP), availablephosphorus(AP),total potassium(TK), andavailable potassium(AK) were measured using the cytometermethod, soil bath potassium dichromate oxidation method, automatic Kjeldahl method, diffusion method, acid solution-molybdenum antimony resistance to colorimetric method, molybdenum antimony resistance to colorimetric method, acid solution-flame photometry, and ammonium acetate extraction-flame photometry, respectively. In each 2 m × 2 m quadrant, theheight, coverage and number of each wood and herb species were measured. These factors (community characteristics, soil chemical property factors) were included in theDCCA ordination.

Data Analysis: The important value (IV) of the species is calculated using the following formulas (*Li, 2012; Wang et al.,2012*): IV shrub and herb = (relative height + relative coverage + relative frequency) ×100/3; Patrick richness index $R = S$;Simpson index, $D = 1 - \sum P_i^2$; Shannon-Wiener index,$H = -\sum P_i \ln P_i$;Pielou evenness index,$J = (-\sum \ln P_i)/\ln S$; P*i* is the relative IV of the species; and S is the total species (*Wang et al., 2012*). The similarity among communities (β-diversity) is calculated usingJaccard's index: $C_s = c/(a + b - c)$,whereCs is the similarity index;a and barethe species number of community A and B, respectively; andc is the number of common species between community A and B.

The effects of gap sizes, gap ages and soil layers, and thetwo-way interactions of gap sizes and gap ages on the soil properties were examined using anAnalysis of Variance (SAS, 2005). All data were tested for homogeneity of variance before performing specific statistical procedures. A multiple comparison was used to determine any significant differences of thesoil properties index, and thediversity index among thesizes or ages of thecanopy gap was determined usingSAS's t-tests (SAS, 2005). Significant differences are reported at the P<0.05 probability levels. Detrended canonical correspondence analysis (DCCA) of CANOCO4.5 software was used to analyze the relationship between thespecies insample plots (based on the importance values of species) andthesoil propertiesvariables(0-20cm), as well as to discuss key influential factors (*Wang et al., 2012*). The soil properties variables determined in the lab were includedas passive variables inthis analysis. All figures were drawnusing Origin 8.0.

RESULTS

Different Size and Age Gaps Effect on Soil Chemical Properties: *Tab. 1* reports the significantdifferencesof thechemical properties of soils in different sizesor age gaps. The results obtained showed that the soils' chemical and physical property measurements were significantly different among thedifferentgap ages, and the pH, TP, AP, and TK of thesoils were significantly different among the different gapsizes. With the interaction of size and agegaps, the SOM, TN, HN, and AK of thesoils were significantly different among the size and age gaps.

*Fig.1*presents the data on the soil properties variability in the 1a, 3a, and 5a gaps, and theunder canopy cover sites (CK),as well asin the 50-70m^2, 100-120m^2, and 150-200m^{2}areasand theunder canopy cover sites (CK).For the soil in the*Pinusmassoniana* plantation, the pH, SOM, HN, TN, TK, AK, TP and AP levels varied significantly among thedifferent gapages. Regardless of the soil in the0-20cm or 20-40cmlayers, the pH level was different between theage gap sites,and the 3a gap showed the highest value. The SOM, HN and TN levels all increased withthe increasing age of the gaps.

The measured values of TK and AK in the 0-20cm layer were was significantly higher in the3aold gaps than inthe other age gap plots and the adjacent under canopy cover sites. The AP values of the0-20cm layer also increased with theincreasing age of the gaps. The amount of AP was highest in the5a age gaps. A similar trend for the AP values of the 20-40cm layer was also observed (*Fig. 1*). The trend for the TP values of the different age gaps is similar to those of TK or AK.The highest values of TP for the0-20cm and 20-40cmlayerswere both found in 3agaps.

In contrast to the results of thesoil chemical properties to different age gaps, approximately half of themeasured values of the soil chemical properties varied significantly among thedifferent size gaps, such as the pH, TK, TP and AP. The pH inboth soillevel layerswas significantly higher inthe150-200m^2 gaps and non-gaps than in the50-70m^2 gaps. The TK values of the0-20cm soil layerwere significantly higher in the150-200m^2 gaps than in about the100-120m^2 gaps, andthe TK values wereslightly higher than in the 50-70m^2 gaps and canopy cover sites adjacent to thegaps. The TK levels increased with increasing size of the gaps in the 20-40cmlayer. The amount of AP in the0-20cmlayerwas highest in the 50-70 m^2 gaps (255.42 mg·kg^{-1} soil) and decreased with increasing gap size with avalue of 221.75 mg·kg^{-1}inthe100m^2 gaps and 198.06 mg·kg^{-1}in the 150-200m^{2}gaps. The same results of the availablephosphorus (AP) in the20-40cmlayerof different size gaps were observed. The total phosphorus(TP) values ofthe0-20cm layerwere significantly higher in the150-200m^2 gaps than in the canopy cover sites adjacent to thegaps.

The interaction effects of the gap size and age onthe surface soil (0-20cmlayer) chemical properties are presented in *Fig. 2*. The SOM and TN were significantly higher in the 5agaps and 50-70m^2 gaps than those of other gaps and non-gaps, respectively. Higher values ofHN in the surface soil were found in the 5agapof all size gaps. The values ofAK were higher in the3agapof all size gaps than those of other gaps.

Different Size and Age Gaps Effect onSpecies Compositionand Species Diversity of Plant: A total of 152 species were sampled in the study sites, including 31 arbor species, 57 shrub species and 64 herb species. The results obtained showed that a significant difference existed in theprimarywoody and herb species composition among thedifferent age gaps and non-gaps. A similar result wasobtained when comparing the different size gaps with non-gaps *(Fig.3)*.

*Fig.3*presents the number of species in different size gaps, age gaps and non-gaps. The results showed that the numbers of total species in 3a or in 5a gaps were significantly higher than those in 1a gaps or non-gaps.The differenceinthe number of total species might due to the difference inthe number of arbor species and shrub species, because no difference in thenumber of herb specieswas foundamong the different age gaps and non-gaps.

The Jaccard's index (β diversity) of shrub layer is the highest between the 100-120 m^{2}and 50-70m^{2}gaps, and itis the lowest between the50-70m^{2}gapsand non-gaps. However, the index of theherb layer is the highest between the100-120m^{2}and 50-70m^{2}gaps, and itis the lowest between the100-120m^2 and non-gaps. Simpson diversity indices of arbor species, shrub species and herb species for different age gaps and size gapsaredescribed in *Fig.3-B*. The results show that 5a gaps have the highest Simpson diversity indices; the 100-120m^2 gaps havethe highest Simpson diversity indices of shrub species and aresignificantly higher than thoseof50-70m^2 gaps and non-gaps, but they are only slightly higher thanthose areas where the gaps are greaterthan 150m^2.

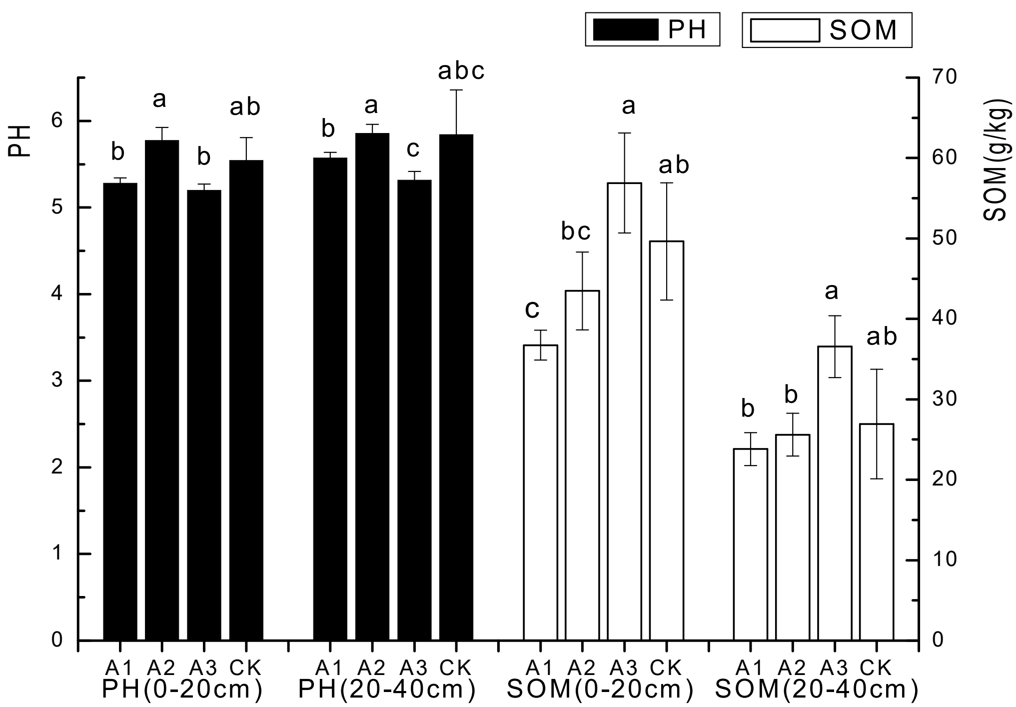
The Shannon-Wiener diversity indices were thesame asthe trends of theSimpson diversity indices,except thatthe Shannon-Wiener diversity indices of theshrub species inthe5a and 3a gaps were significantly higher than in 1a age gaps and non-gaps (*Fig.3-C*).The Evenness indices of thearbor, shrub and herb species for different age and size gaps were alsosimilar to the trends of theSimpson diversity indices, andthe Evenness indices of thearbor species were the same as theother three indices(*Fig.3-A* ,*Fig.3-D*).

The interaction effects between thegap size and age onthespecies diversity are presentedin *Tab. 1*. With respect to thearbor species of thesample plots, the 5a of the 100-120m^2 gaps hadthe highest Patrick richness index (6.33), highestSimpson's diversity index (1.78) and highestShannon-Wienerindex (0.82) among the gaps and non-gapstands. The 1a of the50-70m^2 and 100-120m^2 gaps had alower Pielou evenness indices (J) than theother gaps and non-gapstand. With respect to theshrub species of thegaps and non-gapstands, ahigher Patrick richness index (R) was found in 3afor the100-120m^{2}and 150-200m^2 gaps, which weresignificantly higher than those in thenon-gap and 1aof all size gaps, except for the100-120m^{2}gap. The higher Simpson's diversity indices (D) were found in 3a of the100-120m^2 gap (3.16) and 5a of the150-200m^2 gap (3.17), and the higher Shannon-Wienerindices (H) were found in 1a of the100-120m^2 gap (0.95) and 5a of the150-200m^2 gap (0.95).The highest Pielou evenness index (J) was found in1a of the100-120m^2 gap (0.93). However, no difference was foundinthePatrick richness index (R) of theherb species among the combination of different size and age gaps and non-gapstands.

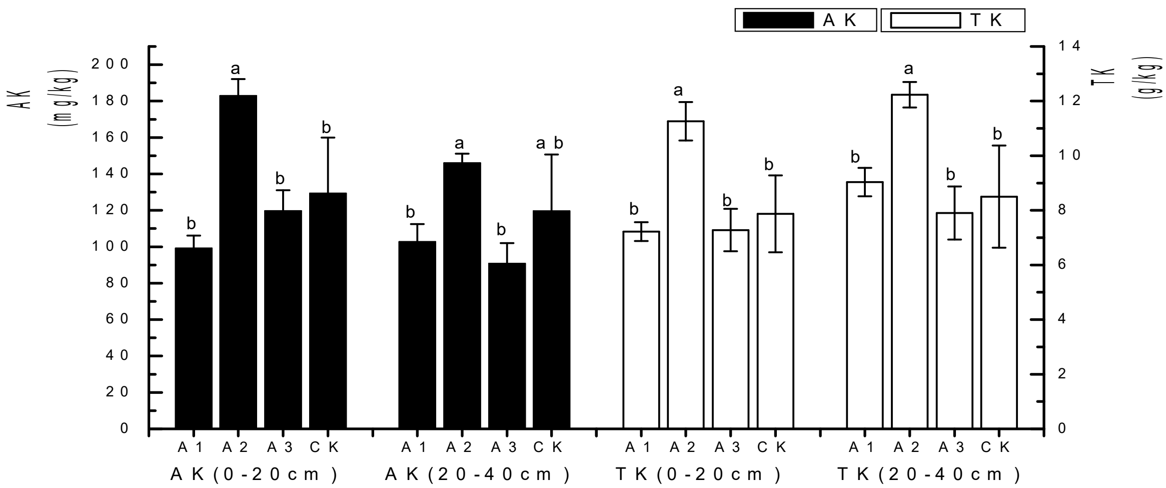
Table 1. Significant differences in the chemical properties of soils in different size or age gaps, and the interaction effects between gap size and gap age on species diversity

Source	Soil characters									Species diversity											
										arbor				shrub				herb			
	DF	PH	SOM	TN	HN	TP	AP	TK	AK	R	D	H	J	R	D	H	J	R	D	H	J
A	2	*	*	*	*	*	*	*	*	*	*	*	--	*	*	*	*	--	--	--	--
S	2	*	--	--	--	*	*	*	--	*	--	--	--	*	*	*	*	--	--	--	--
A*S	4	--	*	*	*	--	--	--	*	--	--	--	--	*	*	*	*	--	--	--	*

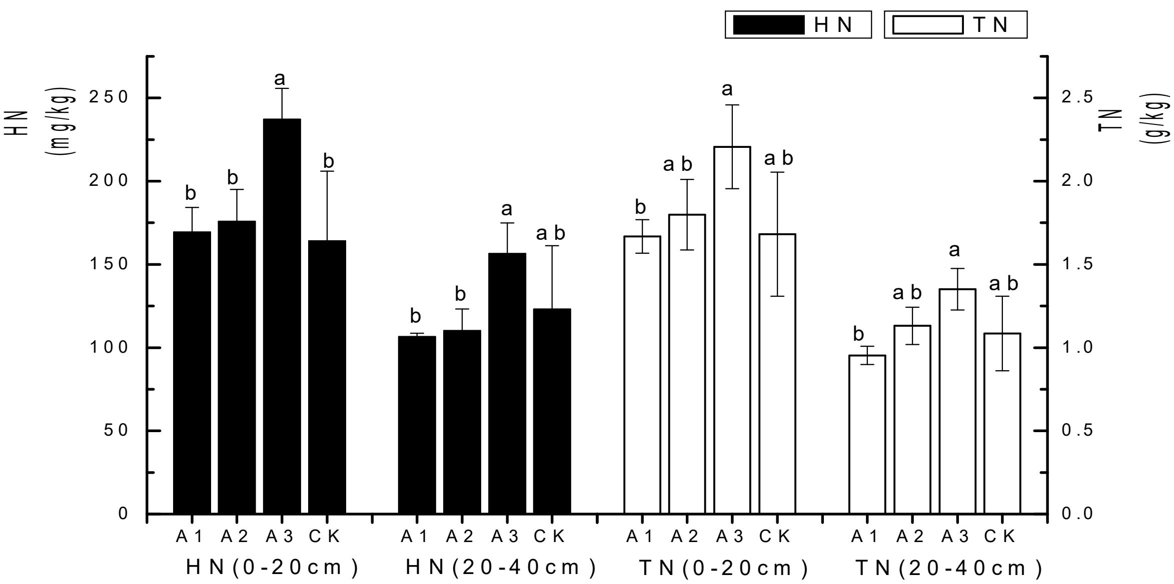
A： gap age; S: gap size; L: soil layer; DF: degree of freedom； pH： The pH value; SOM: soil organic matter; TN: total nitrogen; HP: hydrolyzable nitrogen; TP: total phosphorus; AP: availablephosphorus; TK: total potassium; AK: available potassium;R:Patrick richness index, D:Simpson's diversity index; H:Shannon-Wiener index; J:Pielou evenness index;S1:area about 50-70m^2 gap；S2:area about 100-120m^2 gap； S3: area more than 150m^2 gap；A1: age of 1a gap; A2: age of 3a gap; A3: age of 5a gap; CK: non-gaps; *: significantly different，statistically different at P = 0.05.



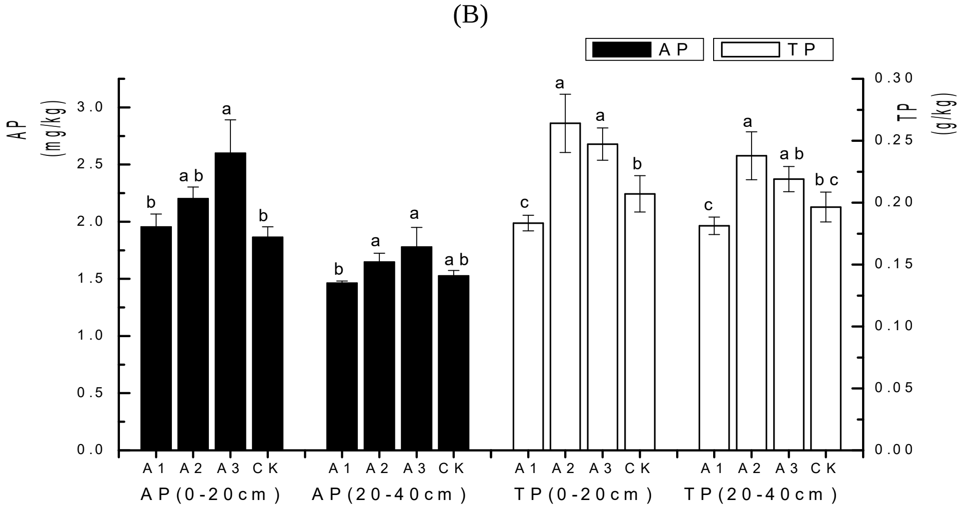
(A)


AK
TK
AK (mg/kg)
TK (g/kg)
AK(0-20cm)
AK(20-40cm)
TK(0-20cm)
TK(20-40cm)

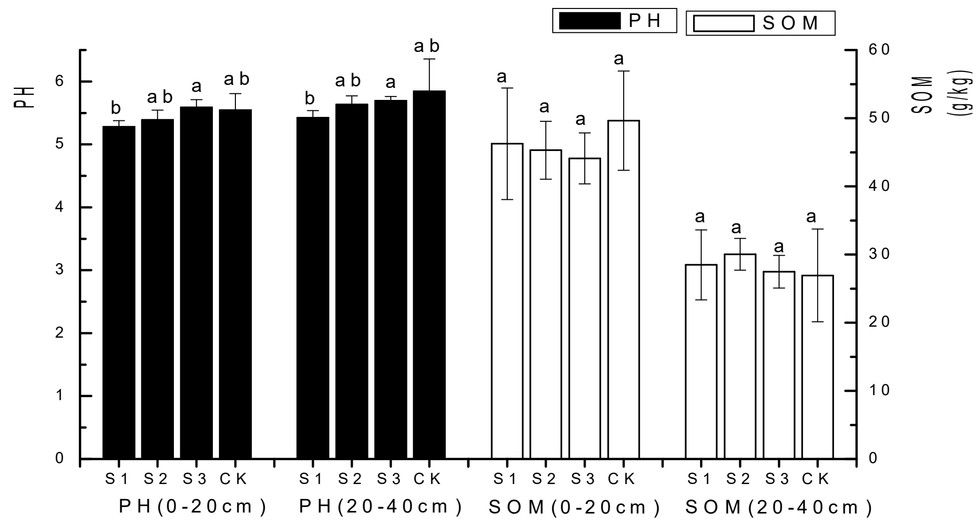
(C)


HN
TN
HN (mg/kg)
TN (g/kg)
HN(0-20cm)
HN(20-40cm)
TN(0-20cm)
TN(20-40cm)

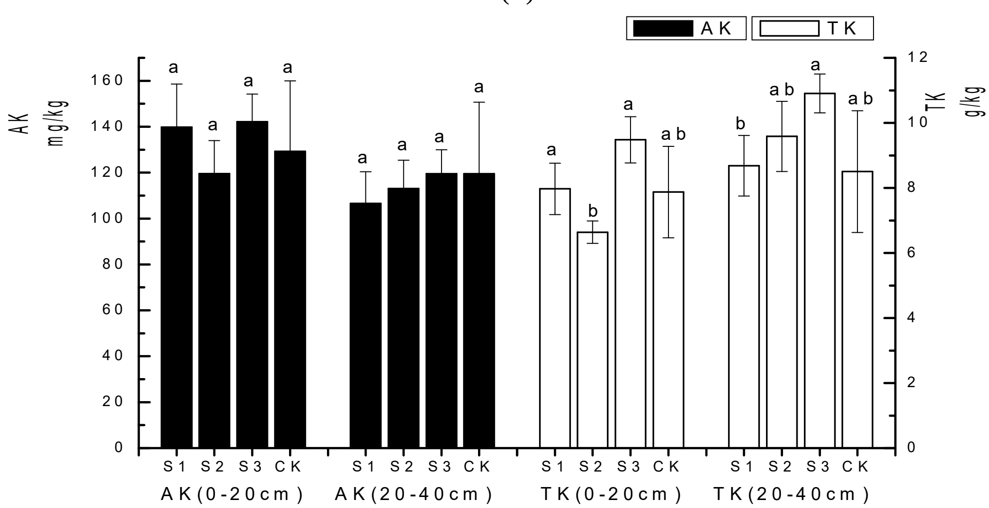
(B)


AP
TP
AP (mg/kg)
TP (g/kg)
AP(0-20cm)
AP(20-40cm)
TP(0-20cm)
TP(20-40cm)

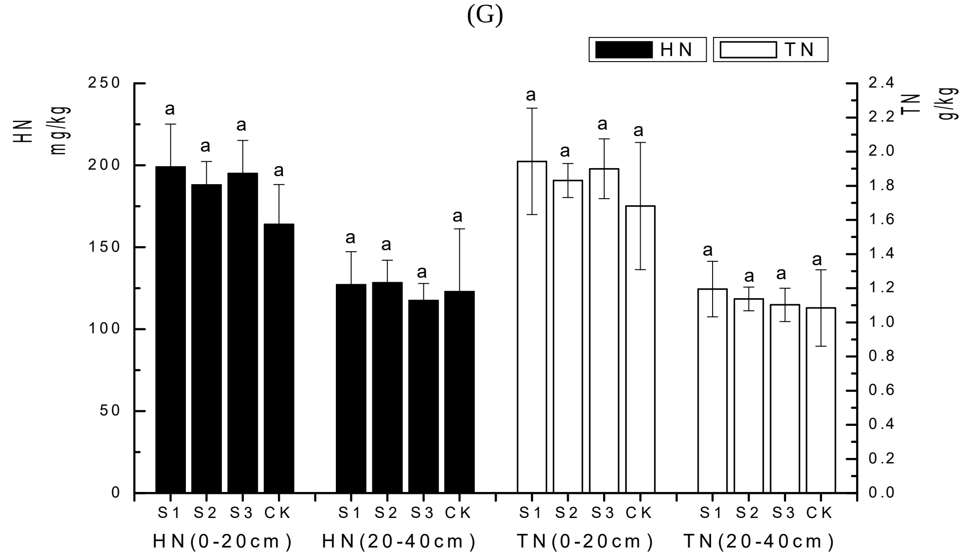
(D)


PH
SOM
PH
SOM (g/kg)
S1 S2 S3 CK
PH(0-20cm)
PH(20-40cm)
SOM(0-20cm)
SOM(20-40cm)

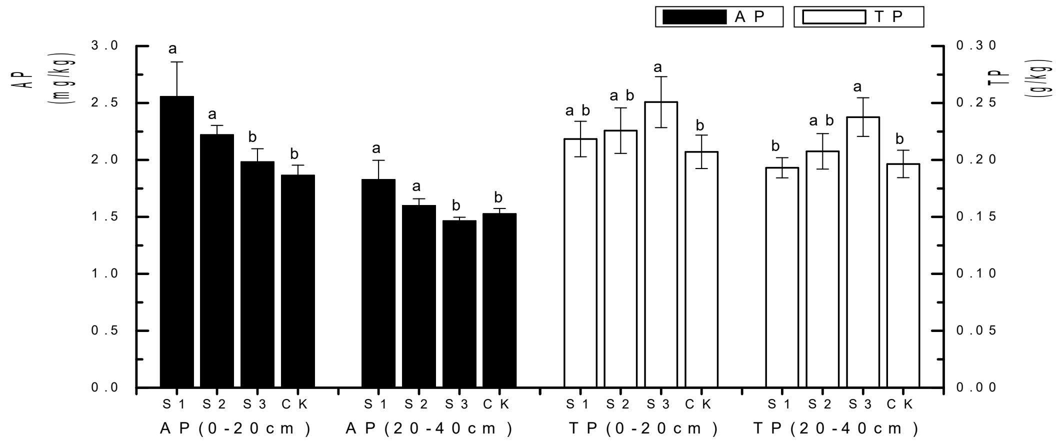
(E)


AK
TK
AK mg/kg
TK g/kg
S1 S2 S3 CK
AK(0-20cm)
AK(20-40cm)
TK(0-20cm)
TK(20-40cm)

(G)


HN
TN
HN mg/kg
TN g/kg
S1 S2 S3 CK
HN(0-20cm)
HN(20-40cm)
TN(0-20cm)
TN(20-40cm)

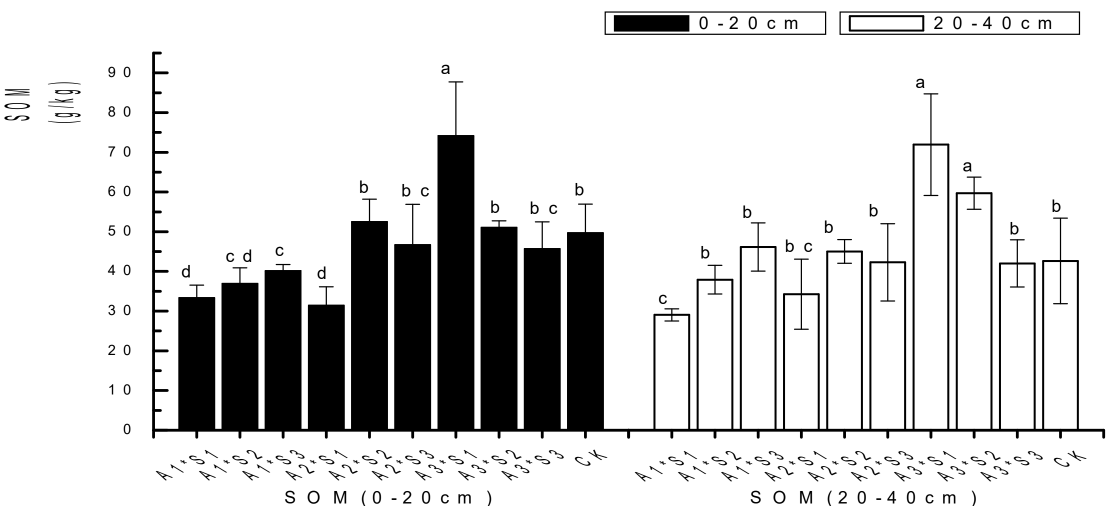
(F)



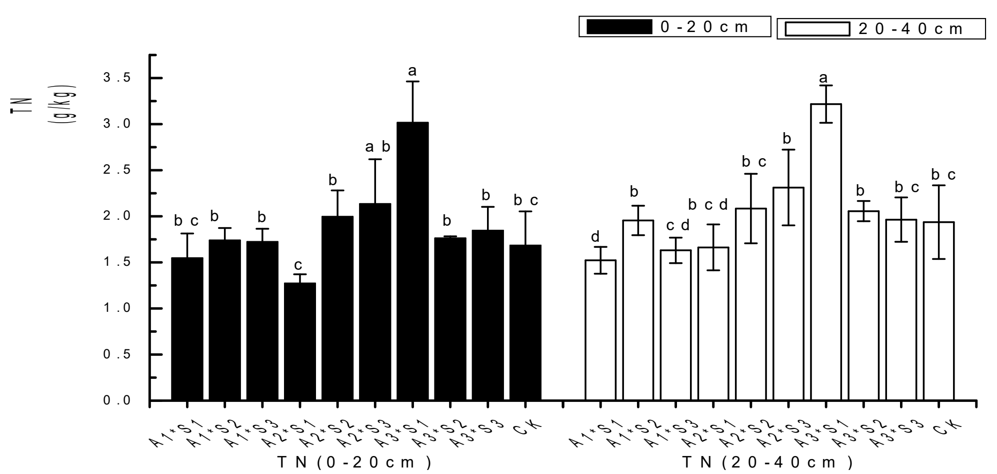
(H)

Fig.1 The soil chemical properties in different age and size gaps

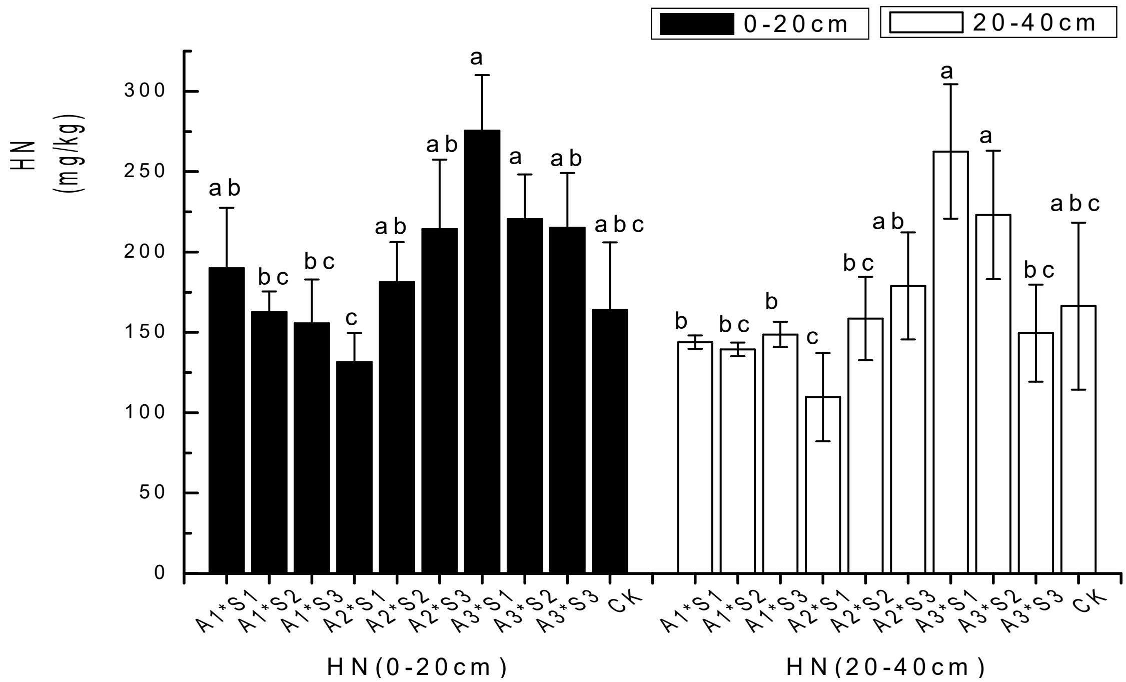
A1: age of 1a gap; A2: age of 3a gap; A3: age of 5a gap; CK: Non-gap; pH：The pH value; SOM: soil organic matter; TN: total nitrogen; HN: hydrolyzable nitrogen; TP: total phosphorus; AP: available phosphorus; TK: total potassium; AK: available potassium; bars refer to standard error; Values in the figure to the same factor and soil layer, followed by the same letter, are not statistically different at P = 0.05



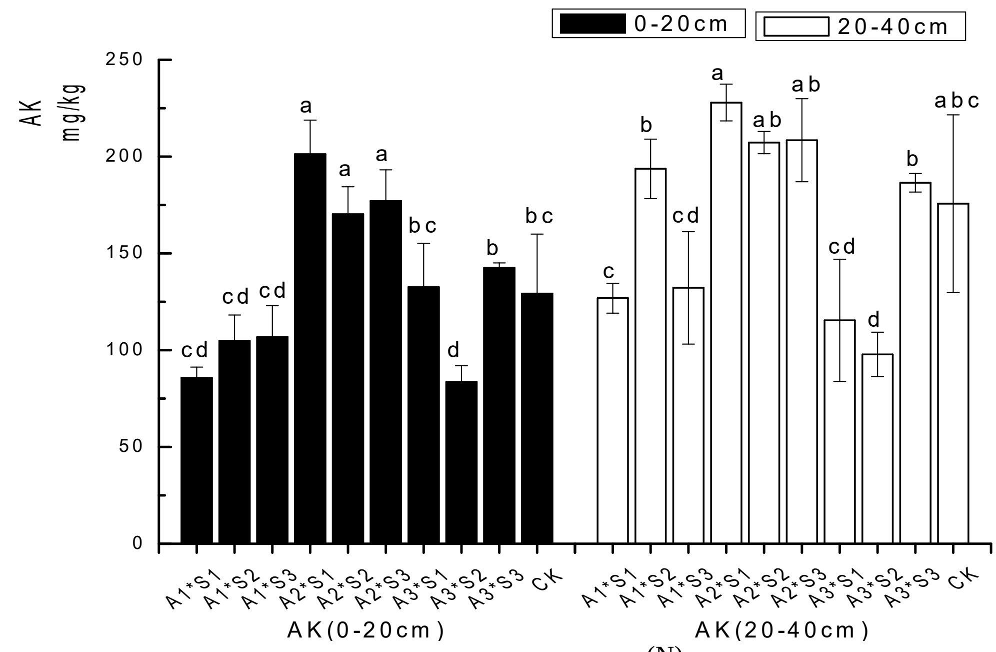
(I)



(M)



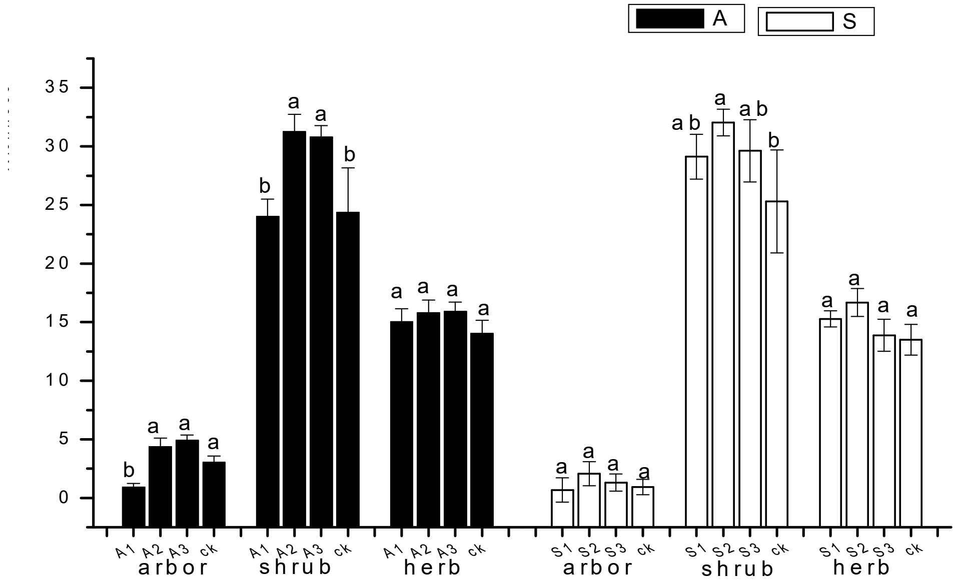
(J)



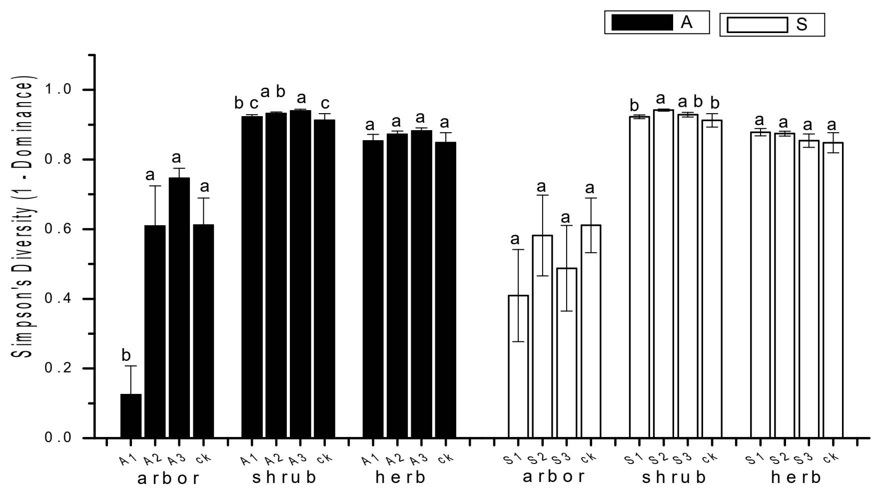
(N)

Fig. 2 The interaction of gap age and gap size on the soil chemical properties

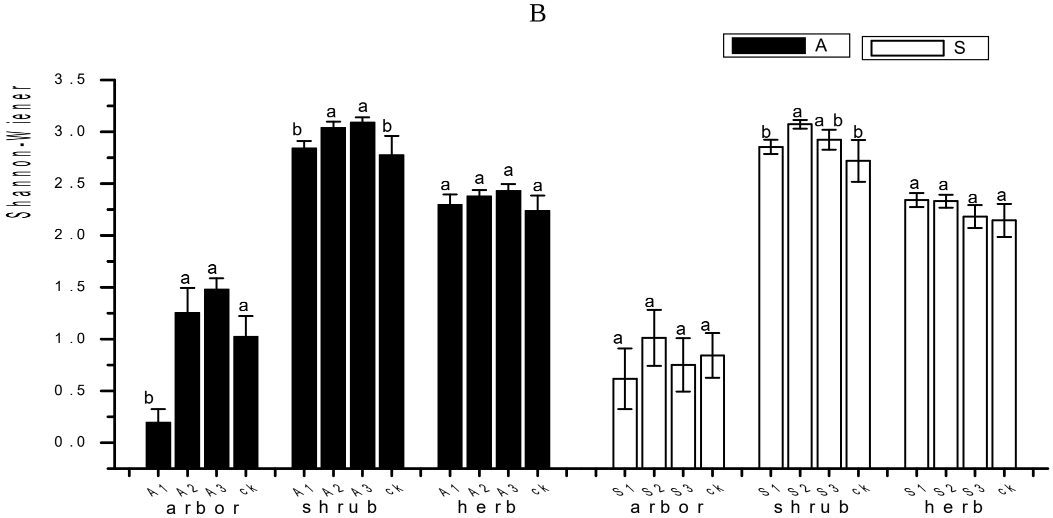
A：gap age; S: gap size; L: soil layer;S1:area about 50-70m^2 gap；S2:area about 100-120m^2 gap； S3: area more than 150m^2 gap；A1: age of 1a gap; A2: age of 3a gap; A3: age of 5a gap; CK: canopy cover sites adjacent to gaps; pH：The pH value; SOM: soil organic matter; TN: total nitrogen; HN: hydrolysable nitrogen; TP: total phosphorus; AP: available phosphorus; TK: total potassium; AK: available potassium; bars refer to standard error; Values in the figure to the same factor and soil layer, followed by the same letter, are not statistically different at P = 0.05


A
S
35
30
25
20
15
10
5
0
A1 A2 A3 ck
arbor
A1 A2 A3 ck
shrub
A1 A2 A3 ck
herb
S1 S2 S3 ck
arbor
S1 S2 S3 ck
shrub
S1 S2 S3 ck
herb

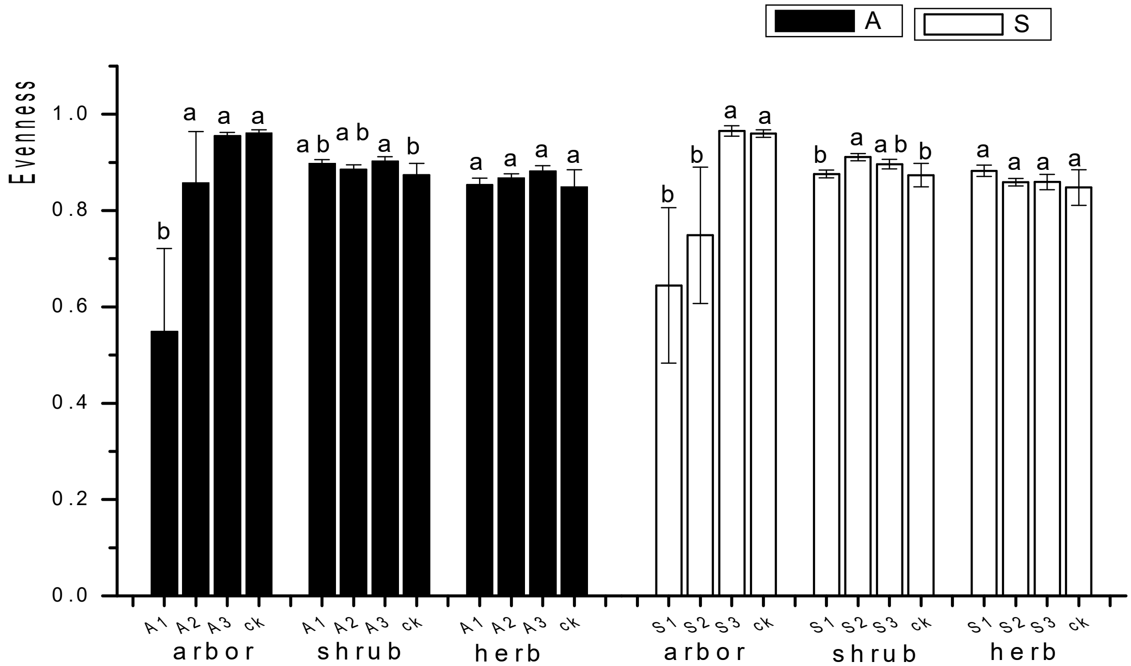
A


A
S
Simpson's Diversity (1 - Dominance)
1.0
0.8
0.6
0.4
0.2
0.0
A1 A2 A3 ck
arbor
A1 A2 A3 ck
shrub
A1 A2 A3 ck
herb
S1 S2 S3 ck
arbor
S1 S2 S3 ck
shrub
S1 S2 S3 ck
herb

B


A
S
Shannon-Wiener
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
A1 A2 A3 ck
arbor
A1 A2 A3 ck
shrub
A1 A2 A3 ck
herb
S1 S2 S3 ck
arbor
S1 S2 S3 ck
shrub
S1 S2 S3 ck
herb

C



D

Fig.3 The species diversity index in different age and size gaps

A1: age of 1a gap; A2: age of 3a gap; A3: age of 5a gap; CK: Non-gap; bars refer to standard error; Values in the figure to the same factor, followed by the same letter, are not statistically different at P = 0.05

Table 2. The numbers of pioneer species and shade-tolerant species in different size gaps, age gaps and non-gaps.

		non-shade-tolerant(pioneer species)						**shade-tolerant**					
		Woody		**Herb**		**total**		**Woody**		**Herb**		**total**	
Factors	levels	Number	%	Number	%	Number	%	Number	%	Number	%	Number	%
	A1	13.56	54.5	8.11	54.1	21.67	54.3	1.89	7.6	2.89	19.3	4.78	12
A	A2	17.22	48.4	8.33	52.8	25.55	49.8	3.78	10.6	4.67	29.6	8.45	16.5
	A3	17.67	49.5	8.67	54.6	26.34	51.1	3.33	9.3	4.11	25.9	7.44	14.4
	S1	15.89	52.2	8.44	54.2	24.33	52.9	4	13.1	4.22	27.1	8.22	17.9
S	S2	16.56	48.4	8.66	51.6	25.22	49.5	3	8.8	4.22	25.1	7.22	14.2
	S3	18.44	58.7	8.89	62	27.33	59.7	3	9.5	3.22	22.5	6.22	13.6
	CK	14	51.2	7.67	54.8	21.67	52.4	3.33	12.2	4	28.6	7.33	17.7

Table 3. Correlations of variables of soil chemical properties to the first two DCCA axes of woody(A) and herb(B) species.

soil chemical properties variables	**Correlations Axis1**	**Correlations Axis2**	**soil chemical properties variables**	**Correlations Axis1**	**CorrelationsAxis2**
PH	0.057	**-0.844**	PH	-0.275	-0.466
SOM	**-0.623**	0.483	SOM	-0.278	**0.702**
TP	**-0.59**	-0.354	TP	**-0.545**	0.281
TN	-0.578	0.452	TN	-0.17	0.585
TK	-0.107	**-0.72**	TK	-0.468	-0.535
AP	-0.804	0.501	AP	-0.497	0.525
HN	**-0.592**	0.331	HN	-0.16	**0.803**
AK	-0.357	**-0.538**	AK	**-0.66**	-0.516

A B

pH: The pH value; SOM: soil organic matter; TN: total nitrogen; HN: hydrolyzable nitrogen; TP: total phosphorus; AP: availablephosphorus; TK: total potassium; AK: available potassium.

DISCUSSION

Gap impacts on soil chemical properties: Most soil chemical properties were not significantly impacted by thedifferent size gaps. However, we did find that the contents ofthetotal phosphorus and total potassium in thegaps were higher than those under thecanopy cover sites, except for thetotal potassium in the0-20cmlayer. The same was true in the study addressed by Muscolo *et al.*(*2007*) in which they found that the amount of P was higher in the small gaps (380 m^2) than in theunder canopy cover sites. We also found the larger gaps had higher contents of total phosphorus and total potassium in both the0-20cm and 20-40cm soillayers.This result could be explained by the assumption of Denslow *et al.*(*1998*) in which the gap size effectswere found to bedue primarily to greater leaf and fine root litter densities and lower uptake by vegetation in thelarger gaps. However, opposite findings were reported by Scharenbroch and Bockheim (*2007*), who showed that the extractable base potassium was significantly greater in the forest compared to thegaps.It wasassumed that the decrease in theexchangeable base cations in thegaps was a result of leaching losses as these cations were moved out of the upper profile. Scharenbroch and Bockheim (*2007*) speculated that an increased nutrient-leaching potential would occur in relatively large (300-2,000m^2) gaps, and Parsons *et al.*(*1994*) assumed that the same conditionwouldoccur withthe removal of 15–30 tree clusters. This explanationissupported by our observation of the total potassium content at depth 20-40cm, which was greater than the content at 0-20cm,bothin thegaps andin theforest.

Vitousek and Denslow (1986) found no difference intheP and N pool sizes in 2-12 month-old gaps.Theyspeculated that the effect of the high litter inputs would be masked by high N-mineralization rates and high P adsorption and that an early, ephemeral peak in N pools would have been missed in their study. Uhl *et al.*(*1988*) also found that soil nutrient levels in single-treefall gaps did not differ fromgapsize or gap age during the first 4a. However, most soil chemical properties we measured were significantly impacted by different age gaps. We did find that the contents of thesoil organic matter, total nitrogen, hydrolysablenitrogen and total phosphorus in both the 0-20cm and 20-40cm soil layerswere higher in the5a gap than those in theother age gaps and theunder canopy cover sites. We also foundthat thepH, total potassium, available potassium,and thetotal phosphorus of thesurface soil(0-20cm) were higher in the3a gap than those in theother age gaps and under canopy cover sites. Muscolo *et al.*(*2007*) confirmed that there was a nutrient pulse in the small gaps, as speculated byDenslow *et al.*(*1998*), but theydid not providethe schedule of nutrient pulse emergence after the gaps formation. Therefore, we speculated that soil nutrient pulses in gaps would appear after the gaps formationin3-5 years, andthepulses of different nutrient type would occur in gap with a different specific area; for example, the pulse of soil organic matter, total nitrogen and availablephosphoruswould be found in smaller gaps(50-70m^2 in our study), but hydrolysable nitrogen and totalphosphorusin thesurface soil would be found in larger gaps(greaterthan 100m^2in our study).

Gap impacts on species composition and diversity: Due to the different ecological conditions in gaps and non-gap stands, the generation and growth of different plant species were differentin gaps and non-gap stands (Brown, 1993). We found a high diversity existedin the understory community as a whole (152 species found in 30 sites of approximately4,000m^2). With respect to thespecies composition ofdifferent age gaps, approximately63, 65, 40 and 38 woody species and 41, 40, 37 and 27 herb species were found in the5a, 3a, 1a gaps and non-gaps, respectively. With respect to thedifferent size gaps, approximately85, 65 and 68 woody species and 38, 46, and 44 herb species were found inthe 150-200m^2, 100-120m^2 and 50-70m^2 gaps, respectively. Our findings confirmed that gaps increase the possibility of multispecies coexistence by introducing heterogeneity into forest ecosystems (Grubb, *1977*).

The size of the canopy opening has a direct effect on light levels, which could affectvegetation growth rates (*Barton et al., 1989*). Additionally, the small gap effects observed are likely primarilydue to nutrient pulses, and the time of emergence of nutrient pulses was uncertain because itdepended on the microhabitat and litter input. We found there were proportional similarities among the different size gaps and non-gaps. Becauselight availability is the primary limitation to growth in a forest, the species most likely able to take advantage of pulses in both light and nutrient availability are pioneer, highlight demanding species (*Denslow et al., 1998*). We did find that the 150-200m^2 gap had alarger number and proportion of pioneer species (high-light demanding species), and the 50-70m^2 gaps had more shade-tolerant species than anyoftheother gaps (*Tab.2*). Our findings also confirmed that the pioneer species in small gaps were highly plastic to any variation in resources, exhibiting high dispersal rates and apersistence of seeds in the soil (*Denslow et al., 1990*;*Dalling et al., 1997*). We also found that theSimpson's diversity index,Shannon-Wiener index and Evenness index in the shrub species different among thesize gaps, and no difference in arbor species and herb specieswas found.

Spies*et al.*(*1990*) found thattheseedling density in Cascade Mountain Rangeforest gaps was more stronglyrelated to thegap age than to gap size. Poulson and Platt (*1989*) also found that patterns of species composition in hardwood forest gaps changed over time due to competition and morphological differences among species. The biotic and abiotic factors may interact with the mosaic of environments created by tree falls and gap-phase regeneration that contribute considerably to the variation in the occurrence of understory species (Dirzo *et al.,1992*). They also found that there was a low similarity between gaps and the large number of rare species and that intermediate-aged (3-5a) gaps tended to be more similar to one another than young sites (1-2a). We also found there were proportional similarities among the different age gaps and non-gaps.In addition, we found that the nutrient pulse in gaps was better related to the gap age than to gap size. Therefore, we postulated that germinationand the survival of seeds and seedlings should vary with gap microhabitat (such as light, moisture, nutrient pulses, etc.). We found that theSimpson's diversity index, Shannon-Wiener index and Evenness index in arbor and shrub species aredifferent amongage gaps and that there is no difference in herb species. This finding is similar to the study by Dirzo *et al.* (*1992*), in which they also found no effect of age on density or on thenumber of herb species, but the young gaps had the highest evenness inherb species. Different fromotherstudies'results, the lowest Simpson's diversity index and Shannon-Wienerindex of arbor species were found in the1a gaps in our study.Thus, we speculated the 1a gaps didnot haveenough dispersed or germinating seeds soon after the thinning.

In addition, the decomposition of large amountsof fresh litter from fallen trees might result in an increaseof soil nutrients, and the fortified available nutrients would significantly promote the growth of vegetation(*Denslowet al., 1998*). However,the relative indirect skylight and relative directly sunlightboth increased remarkably with the gap size and decreased remarkably with the gap age, which were important to species composition and vegetation growth.Furthermore, intermediate-aged gaps were a critical 'building phase' for species composition in forest(*Dirzoet al., 1992*).Thus, the interaction of gap size and age play a specific role in affecting soil properties and species diversity.

Soil properties impacts on species composition and diversity: Based on the species in thesample plots and thesoil properties (0-20cm) matrix, the plots distribution was analysed using DCCA. For the woody species in the sample plots, the first axis is largely associated with the availablephosphorus (correlations coefficient = -0.804), soil organic matter (-0.623), hydrolysable nitrogen (-0.592) and total phosphorus (-0.590), which representthe gradient of the N, P and SOM pulsesthat are primarily induced bytheaddition of leaf and fine root litter inthegap soil (*Tab.3*). The second axis is primarily associated with thepH (-0.844), total potassium (-0.720) and available potassium (-0.538), which represents the cations leaching losses gradients. With respect to theherb species of thesample plots, the first axis is largely associated with the available potassium (correlations coefficient = -0.660) and total phosphorus (-0.545), which represent the P and K leaching losses gradients in the gap soil (*Tab.3*). The second axis is largelyassociated with hydrolysable nitrogen (0.803) and SOM (0.702), which represent theN and SOM pulse gradients that are primarily induced bythe addition of leaf and fine root litter in gaps.

Conclusions: Soil properties and species diversity are significantly impacted by forest gaps, and the effect of gap age was more extensive than gap size. Our results show that the 50-70m^2 and 3a gaps represent the silvicultural treatment capable of generating soil nutrient pulse in the surface soil, and this nutrient pulse would increase species diversity, especially pioneer species.Gap size and age are both important to the composition of species and diversity, but the impact of gap age is more pronounced.In addition, the interaction of the 50-70m^2 and 5a gap represents themost significant influence on soil properties. Therefore, we believe that the addition of small thinning gaps may be important for developing a forestry management regime capable of balancing production and biodiversity preservation.

Acknowledgements: We thank Ding-Peng Xiong, He Ji, Hai-Yan Han, Lu Li and Qin Shen for their assistance in the fieldwork. This study was supported by the Scientific and Technological Innovation Fund for Huazhong Agricultural University (2009QC028).

REFERENCES

Adele, M., S. Maria, and M. Roberto (2007).Variations in soil chemical properties and microbial biomass in artificial gaps in silver fir stands. Eur J Forest Res. 126: 59-65.

Arunachalam, A., and K.Arunachalam (2000). Influence of gap size and soil properties on microbial biomass in a subtropical humid forest of north-east India. Plant and soil.223: 185-193.

Barton,A.M., N. Fetcher, andS.Redhead (1989). The relationship between treefall gap size and light flux in a Neotropical rain forest in Costa Rica. J. Tropical Ecology.5:437-439.

Bouchard, M., D. Kneeshaw, and Y. Bergeron (2005). Mortality and stand renewal patterns following the last spruce budworm outbreak in mixed forests of western Quebec. Forest Ecology and Management. 204:297-313.

Brown, N. (1993). The implications of climate and gap microclimate for seeding growth conditions in a Bornean lowland rain forest. J. Trop. Ecol. 9:153-168.

Clinton, B.D. (2003). Light, temperature, and soil moisture responses to elevation, ever-green understory, and small canopy gaps in the southern Appalachians. Forest Ecology and Management. 186:243-255.

Dalling, J.W., M.D. Swaine and N.C. Garwood (1997). Soil seed bank community dynamics in seasonally moist low- land tropical forest, Panama. J. Tropical Ecology. 13: 659-680.

Denslow, J.S., A.M. Ellison and R.E. Sanford (1998).Treefall gap size effects on above- and below-ground processes in a tropical wet forest. J. Ecology.86:597-609.

Denslow, J.S. (1987).Tropical rainforest gaps and tree species diversity. Anni1ual Review of Ecology and Systematics. 18:431-451.

Denslow, J.S., J. C. Schultz, P. M. Vitousek, and B.R.Strain(1990). Growth response of tropical shrubs to treefall gap environmnents. Ecology. 71: 165-179.

Ding, G., X. Wu, X. Qi, and P. Wang (2002). A study on management model system and optimum cultivation patterns of patterns of Pinusmassoniana for pulpwood stand. Scientia Silvae Sinicae. 38(5):7-13.

Dirzo, R.C.,C.Horvitz, H. Quevedo, and M.A. Lopez (1992). The effects of gap size and age on the understory herb community of a tropical Mexican rain forest. J. Ecology. 80: 809-822.

Frelich, L.E., and P.B. Reich (1995). Spatial patterns and succession in a Minnesota southern boreal forest. Ecological Monograph. 65(3):325-346.

Fred, B., P. Andrew, and O. Joseph (2000). Effect of gap size and age on climber abundance and diversity in Budongo Forest Reserve, Uganda. Afr. J. Ecol. 38:230-237.

Gagnon, J.L., E. Jokela, W.K.Moser and D.A. Huber (2004). Characteristics of gaps and natural regeneration in mature long-leaf pine flatwoods ecosystems. Forest Ecology and Management. 187: 373-380.

Griffiths, R.P., A.N. Gray and T.A. Spies(2010). Soil Properties in Old-growth Douglas-fir Forest Gaps in the Western Cascade Mountains of Oregon. Northwest Science. 84(1):33-45.

Grubb, P.J. (1977). The maintenance of species-richness in plant communities: the importance of the regeneration niche. Biological Review. 52:107-145.

Heithecker, T.D., and Halpern C.B. (2006). Variation microclimate associated with dispersed-retention harvests in coniferous forests of western Washington. Forest Ecology and Management. 226: 60-71.

Kukkonen, M., H. Rita, and S. Hohnwald (2008). Treefall gaps of certified, conventionally managed and natural forests as regeneration sites for Neotropical timber trees in northern Honduras. Forest Ecology and Management. 255(7): 2163-2176.

Li, Z., Z.W. Zhang, Y.J. Wang, P.C. Wang, Y.R.Xu, and Z. X. Zhou (2012). Influence of Anthropogenic Disturbances on Understory Plant Diversity of Urban Forests in Wuhan, Central China. SainsMalaysiana. 41(12): 1495-1501.

Muscolo, A., M. Sidari, S. Bagnato, C. Mallamaci and R. Mercurio (2010). Gap size effects on above- and below-ground processes in a silver fir stand.European J. Forest Res., 129(3):355-365.

Muscolo, A., M. Sidariand R. Mercurio(2007). Influence of gap size on organic matter decomposition, microbial biomass and nutrient cycle in Calabrian pine (Pinuslaricio, Poiret) stands. Forest Ecology and Management.242:412-418.

Parsons, W.F.J., D.H. Knight, and S.L. Miller (1994). Root gap dynamics in lodgepole pine forests: ectomycorrhizal and non-mycorrhizal fine root activity after experimental gap formation. Can J For Res. 24:1531-1538.

Pettersson, F.and L. Hogbom(2004). Long-term growth effects following forest nitrogen fertilization in Pinussylvestris and Piceaabies stands in Sweden. Scand. J. For. Res. 19:339-347.

Poulson, T.L., and W.J. Platt (1989). Gap Light Regimes Influence Canopy Tree Diversity. Ecology. 70(3): 553-555.

Prévost, M., and P. Raymond (2012). Effect of gap size, aspect and slope on available light and soil temperature after patch-selection cutting in yellow birch–conifer stands, Quebec, Canada. Forest Ecology and Management.274(15): 210-221.

Ritter,E., L. Dalsgaard, and K.S. Einhorn (2005). Light, temperature and soil moisture regimes following gap formation in a semi-natural beech-dominated forest in Denmark. Forest Ecology and Management. 206:15-33.

Ritter, E., and L.Vesterdal (2006). Gap formation in Danish beech (Fagussylvatica) forests of low management intensity: soil moisture and nitrate in soil solution. European J. Forest Re. 125(2):139-150.

Runkle, J.R.(1982). Patterns of Disturbance in Some Old-Growth Mesic Forests of Eastern North America. Ecology. 63(5):1533-1546.

Scharenbroch, B.C., and J.G. Bockheim(2007). Impacts of forest gaps on soil properties and processes in old growth northern hardwood-hemlock forests. Plant Soil. 294:219-233.

Schumann, M.E., A.S. WhiteandJ.W. Witham (2003). The effects of harvest-created gaps on plant species diversity, composition, and abundance in a Maine oak-pine forest. Forest Ecology and Management. 176:543-561.

Spies, T.A., J.F.Franklin,andM. Klopsch(1990). Canopy gaps in Douglas-fir forests of the Cascade Mountains. Canadian J. Forest Research. 20: 649-658.

Thiel, A. L.,and S.S. Perakis(2009). Nitrogen dynamics across silvicultural canopy gaps in young forests of western Oregon. Forest Ecology and Management. 258: 273-287.

Uhl, C., K. Clark, N. Dezzeoand P. Maquirino (1988). Vegetation dynamics in Amazonian treefall gaps. Ecology. 69(3):751-763.

Vepakomma, U., B. St-Onge,and D. Kneeshaw (2008). Spatially explicit characterization of boreal forest gap dynamics using multi-temporal lidar data. Remote Sensing of Environment. 112(5):2326-2340.

Vitousek, P.M., and J.S. Denslow (1986). Nitrogen and phosphorus availability in treefall gaps of a lowland tropical rainforest. J. Ecology. 74: 1167-1178.

Wang, Y.J., X.P. Shi, Y. Peng, Z.C. Zhong, and J.P. Tao (2012). Effects of fine-scale pattern of dwarf bamboo on understory species diversity in Abiesfaxoniana forest, southwest China. SainsMalaysiana.41(6):649-657.

Yu, M., X. Xuand P. Ding (2011). Economic loss versus ecological gain: the outbreaks of invaded pinewood nematode in China. Biological Invasions. 13 (6):1283-1290.

Zhang, Q. and J.C. Zak (1995). Effects of Gap Size on Litter Decomposition and Microbial Activity in a Subtropical Forest. Ecology. 76(7): 2196-2204.