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Nitrogen, phosphorus and potassium recycling in an agroforestry ecosystem of Huanghuaihai Plain: with *Paulownia elongata* intercropped wheat and maize as an example

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Abstract—The studies show that in the whole community, P is deficient, and N and K are basically balanced. N, P and K are accumulated in plant tissues and litters, but depleted in soil. N and P contents in surface soil(0—20 cm) are the main factors affecting crop growth, and P contents in 20-80 cm soil layer is the major affecting *Paulownia elongata* growth. The absorption coefficients of N, P and K in the communities are 0.078, 0.014 and 0.052 respectively, their utilization coefficients are 0.95, 0.90 and 0.94, and the recycling coefficients are 0.042, 0.05 and 0.063 respectively.
Keywords: nitrogen; phosphorus, potassium; recycling; agroforestry ecosystem.

1 Introduction

The purposes of inputting N, P and K to agroforestry systems are to improve its productivity, to obtain more agroforestry products of superior quality as well as to attain better economic benefit. Reasonable determination of fertilizer consumption and scientific control of harvest can not be achieved until the recycling process of N, P and K in the agroforestry systems is understood, and their input, output, accumulation and deficiency are accurately worked out. Therefore, on the basis of the study on the recycling of nutrient elements in natural forestry ecological system, we studied N, P and K recycling in the communities of *Paulownia elongata*—*Triticum sativum* and *Zea mays* in an agroforestry ecosystems. The purpose of the study is to provide a scientific basis for consistent and stable improvement of biological and economic productivity of communities.

2 Region and procedures

2.1 General conditions of test field

The test field locates in Fengqiu Agro-Ecological Experimental Station of Chinese Academy of Sciences, in Fengqiu County, Henan Province. The region is dominated by monsoon climate of the temperate zone. The annual average temperature is 14.4℃, annual average precipitation is 678.5mm, annual accumulative temperature of $\geqslant 0$℃ is 5272.8℃, annual accumulatative temperature of $\geqslant 10$℃ is 4692.6℃. The soil is "two in one soil", with deep layers, and the forest is *Paulownia elongata*, crops are *Triticum sativum* (summer crop) and *Zea mays* (autumn crop). The dendrometry characteristics of the test field are listed in Table 1.

Table 1 Characteristics of dendrometry factors

No. of tree zone	Distances between trees, m	Distances of row spacing, m	Stand density plant$(hm^2)^{-1}$	Average tree height, m	Average chest diameter, cm	Height below branch, m	Crown	Age yr.
1	5	40	50	9.63	23.0	2.80	6×5	6
1	5	40	50	9.84	23.8	2.94	6×5	6

2.2 Procedure of study

2.2.1 Determination of standing biomass of *Paulownia elongata*

One forest zone was selected for tree investigation, and these trees were classified by their chest-diameters. Outside the forest zone, at a place where the cite conditions are similar, two standard trees were selected for each class and the fresh weight of the branches, trunks and leaves of the trees were measured with the method of "layer cutting" after they were cut down in October 1989. The whole root system below surface was obtained with whole digging method, and then weighed for fresh weight after the soil on it was removed. Meanwhile, samples of 1kg weight were collected for each part of the tree both on the surface and underground. The samples were brought to the laboratory and dried to constant weight in the oven at 105℃, and the dry weight was measured. Standing biomass was worked out with relative growth. Here are the regression equations for the biomass and chest-diameter of all the samples: two sample pits of 1 m by 1m were set up at 3, 5, 10, 15 and 20 m to the forest zone, harvest method was applied for measuring standing biomass.

2.2.2 Determination of annual productivity

Chest-diameters of standard trees were measured at the end of March and the beginning of October in 1989, when it was the beginning and the end of growing season, respectively. Biomass of the *Paulowina elongata* in the beginning and the end of growing season were worked out with the regression equations for the biomass and chest-diameters of each part. The annual productivity of the *Paulownia elongata* was then obtained after deducting the biomass in the beginning of growing season from the biomass in the end of growing season. The annual productivity of a crop is its annual standing biomass.

2.2.3 Determination of litters

Ten litters collection frame of 1m by 1m were mechanically set up in the test field (3 between crops, 7 between zone, one for each at 0.3, 1.2, 2, 4, 10, 15 and 20 m to the forest zone). One collection was made each month, and then weighed for dry weight, the dry weight of surface litters was then obtained for unit area. Ten sample pits of 0.5 m by 0.2 m were mechanically set up according to the distances between trees and between zones of the forest (distribution is the same as that on the surface). The pits were dug with a depth of 80 cm to collect dried roots, and the dry weight was measured. In this way, the weight of dried roots below surface can be determined for unit area.

2.2.4 Determination of precipitation, penetration precipitation and stem flow

Two MS-1 raingauge were randomly placed in the region where only crops were planted (the height of the raingauge shall be higher than that of crops). Volume of precipitation was measured after each precipitation. Two MS-1 raingauge were placed at locations where crown is closure and crowns of two trees were overlying, to measure the volume of precipitation penetrating the crown.

2.2.5 Determination of percolation water and volumetric weight of the soil

The volume of percolation water is determined by water collectors placed at 80 cm depth of 3 soil sections (below the tree, overlying are of tree and crop and crop area). Soil samples of 0—20, 20—40, 40—60 and 60—80 cm were collected at each soil section for determining the volumetric weight of the soil.

2.2.6 N, P and K analysis procedure

N was analyzed with steam distill method, P was analyzed with ultra-violet spectra-spectacle method, and K was analyzed with atom-absorption spectra-spectacle method.

3 Results and analysis

3.1 Analysis of N, P and K in plant tissues

Plant tissues are the major storage of nutrient elements in the system. It is very important for the study of the recycling of nutrient elements in the community to understand the storage and distribution of nutrient elements in the tissues. Table 2 shows the N, P and K contents in each part of the plant.

Table 2 Contents of N, P and K in various of plants ($mg \cdot g^{-1}$)

Element	*Paulownia elongata*					Wheat/maize			
	Trunk	Branch	Live leaves	Dead leaves	Root	Stem	leaves	Root	Seed
N	0.748	4.679	10.482	7.805	3.414	4.834	5.125	5.714	18.438
						4.796	7.106	7.424	16.189
P	0.475	0.948	3.556	2.044	3.559	0.884	1.123	0.934	4.145
						0.943	1.933	0.917	3.743
K	0.981	2.932	4.884	3.066	6.428	8.121	5.754	7.486	6.198
						13.178	13.489	12.925	3.234

3.1.1 Standing biomass of community and the accumulation and distribution of N, P and K

N accounts for the most storage in the plant tissues, approximately 4.2 times P storage and 1.3 times K storage (refer to Table 3). This is determined by the physiological characteristics of the plant, however, it also reflects that the plant tissues have the most demand for N. But the soil analysis revealed a very low N content in local soil layers (average $0.56 \mu g \cdot g^{-1}$), it is classified as poor. The N content is therefore the major factor affecting the productivity of plant tissues.

3.1.2 Annual N, P and K absorption and distribution in the community

The annual absorption of certain element in the plant tissues is the sum of annual remain and annual return (the annual return will be analyzed later in the plant litters).

Analysis shows the absorption of N, P and K by the plant tissues are 286.724, 64.703, and

223.337 kg·$(hm^2)^{-1}$ respectively, in which N, P and K account for 2.86%, 5.4% and 2.9% in *Paulownia elongata* tissues and 97.14%, 94.6%, respectively, and 97.1% in crop tissues, respectively (Table 4).

Table 3 Accumulation of all nutrient elements and N, P and K in parts of plants (kg·$(hm^2)^{-1}$)

Item	*Paulownia elongata*					Crop (wheat and maize)					
	Trunk	Branch	Leaves	Root	Sub-total	Stem	Leaves	Root	Seed	Sub-total	Total
Standing biomass	2949.1	2551.0	361.3	1511.3	7372.7	8366.6	6047.1	2347.1	10851.6	27612.4	34985.1
%	8.43	7.29	1.03	4.31	21.06	23.92	17.29	6.71	31.02	78.94	100.0
N	2.22	11.95	3.81	5.13	23.11	40.38	37.32	16.15	184.66	278.51	301.62
%	0.74	3.96	1.26	1.70	7.66	13.39	12.37	5.35	61.23	92.34	100.0
P	1.40	1.40	2.41	5.24	10.45	7.63	9.25	2.14	42.23	62.25	71.70
%	1.95	1.95	3.37	7.30	14.57	10.65	12.89	2.99	58.90	85.43	100.0
K	2.88	7.49	1.79	9.68	21.84	85.01	57.90	26.46	47.49	216.86	238.72
%	1.21	3.14	0.75	4.05	9.15	35.61	24.26	11.08	19.90	90.85	100.0

Table 4 Uptake amounts of all nutrient elements and N, P and K in parts of plants (kg·$(hm^2)^{-1}$)

Item	*Paulownia elongata*					Crop (wheat and maize)					
	Trunk	Branch	Leaves	Root	Total	Stem	Leaves	Root	Seed	Total	Total
Annual productivity	644.7	560.9	364.2	377.9	1947.7	8366.6	6047.1	2347.1	10851.6	27612.4	29560.1
%	2.18	1.91	1.23	1.28	6.59	28.30	20.46	7.94	36.71	93.41	100.0
N	0.49	2.62	3.82	1.28	8.21	40.38	37.32	16.15	184.66	278.51	286.72
%	0.17	0.91	1.33	0.45	2.86	14.08	13.03	5.63	64.20	97.14	100.0
P	0.31	0.53	1.30	1.35	3.49	7.59	9.25	2.14	42.23	61.22	64.71
%	0.48	0.82	2.01	2.09	5.40	11.73	14.29	3.30	65.28	94.60	100.0
K	0.64	1.64	1.78	2.43	6.49	85.01	27.90	26.46	47.49	216.86	223.35
%	0.28	0.73	0.80	1.09	2.90	38.06	25.92	11.85	21.27	97.10	100.0

3.2 Analysis of nutrient elements in plant litters

Plant litters is an important link for the study of biological recycling of nutrient elements, it is also the major path for the returning of nutrient element from plant tissues to soil. In the said ecological system, plant litters mainly refer to dried branches, dried roots and unused parts of crops and so on.

3.2.1 Accumulation of nutrient elements in plant litters

Analysis shows that the N, P and K accumulation in plant litters are 15.586, 3.265, and 16.100kg $(hm^2)^{-1}$ respectively, in which N, P and K account for 35.9%, 44.7% and 14.0% in *Paulownia elongata* litters and 64.1%, 55.3%, and 86.0% in crop litters respectively (Table 5).

3.2.2 Annual return of N, P and K

Analysis shows that the annual returns of N, P and K are 12.062, 2.46 and 10.38 kg·$(hm^2)^{-1}$ respectively (Table 6), in which N, P and K returns are 4.6, 1.05 and 1.80 kg·

$(hm^2)^{-1}$ in *Paulownia elongata* and 5.622, 1.362 and 11.755 kg·$(hm^2)^{-1}$ in crop respectively.

Table 5 Accumulation of N, P and K in litters (kg·$(hm^2)^{-1}$)

Element	Wood plant	Crops Stem and leaves	Root	Other	Crop total	Total
N	5.590	3.415	4.741	1.84	9.996	15.586
P	1.458	0.232	0.775	0.80	1.807	3.265
K	2.259	7.05	6.211	0.58	13.841	16.100

Table 6 Annual return of N, P and K(kg·$(hm^2)^{-1}$·yr^{-1})

Element	Annual return amount				
	Paulownia elongata	Crops (stem, leaves and root)	Other (herb)	Total	Annual return rate*, %
N	4.6	5.622	1.84	12.062	4.2
P	1.05	1.362	0.80	3.212	5.0
K	1.80	11.755	0.58	14.135	6.3

* Annual return rate = element annual return amount/element annual uptake amount × 100%

3.3 Analysis of nutrient elements in soil

3.3.1 N, P and K storage in soil

Soil is the major store of nutrient elements in the system and major source of nutrient elements for normal growth of plant tissue. The N, P and K storage in soil can be calculated with following equation, i.e. nutritious elements storage = volumetric weight of soil × volume of soil × element content (Table 7).

Table 7 Accumulation of nutrient elements in soil (kg·$(hm^2)^{-1}$)

Soil depth, cm	N Total amount	N Available amount	P Total amount	P Available amount	K Total amount	K Available amount
0—20	1080	162	1478.5	74.3	16041.4	164.8
20—80	2581.1	367	2992.6	53.4	25765.7	437.1
0—80	3661.1	529	4471.1	127.7	41807.1	601.9

* Data are average of 5 profiles (0.3, 1, 2, 5, 10, and 20m from tree zone)

3.3.2 Distribution of N, P and K in soil

Analysis shows that N, P and K contents give obvious increase in the top of 0—20 cm depth of soil around the *Paulownia elongata* forest; P content gives great decrease in 20—80 cm depth of soil around the *Paulownia elongata* forest (Fig. 1 and Fig. 2).

3.4 Analysis of element exchange between tissues of the system

On studying the element recycling process in the system, the absorption factor, utilization factor and recycling factor of the ecological system can be worked out by analyzing the correlation's of element absorption, remain, return and contents in soil, we can therefore understand the element transportation in the system(Table 8).

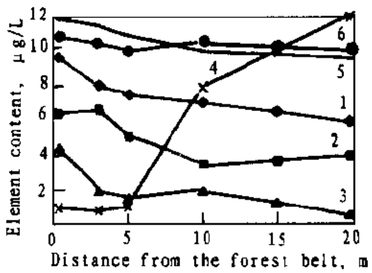

Fig.1 Horizontal distribution pattern of nutrient elements in soil

1. N(0—20 cm, ×10); 2. N(20—80cm, ×10); 3. P(0—20cm);

4. P(20—80cm); 5. K(0—20cm, ×10);

6. K(20—80cm, ×10)

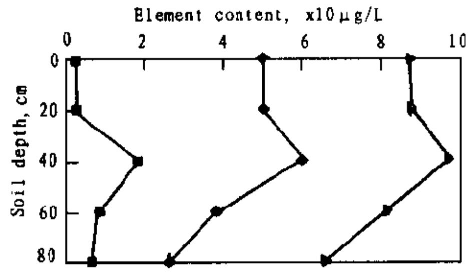

Fig.2 Vertical distribution of nutrient elements in soil profile

Table 8 Absorption, utilization and recycling coefficients of nutrient elements in agroforestry ecosystem(1989)

Element	Absorption coefficient	Utilization coefficient	Cycling coefficient
N	0.078	0.95	0.042
P	0.014	0.90	0.05
K	0.0052	0.94	0.63

3.5 Gain and loss of N, P and K in intercropped system

The intercropping system of *Paulownia elongata-Triticum sativum* and *Zea mays* is different from the natural ecological system of forest in that large amount of nutrient elements are brought away by way of crop harvest each year. To determine an optimal fertilizer application index for a consistent and stable improvement of system productivity, the element gain and loss in the system should be thoroughly understood (Table 9).

Table 9 Input and output of nutrient elements in intercropping system (kg·(hm^2)$^{-1}$)

	Input				Output			Loss of
Element	Precipitation	Seed	Irrigation	Total	Crop	Leaching loss	Total	system
N	10.7	4.2	1.7	26.6	269	0.4	269.4	242.8
P	0.11	1.01	2.5	3.62	59	0.01	59.01	55.39
K	6.21	1.4	13.4	21.01	203	0.5	203.5	182.49
Total	17.02	6.61	17.6	51.23	531	0.91	531.91	480.68

We can see the N, P and K losses of the system in 1989 from Table 9. To stabilize the fertility of the soil as well as to consistently improve the system productivity, the annual fertilizer application can be determined according toe the annual losses of N, P and K in the system.

3.6 The recycling of N, P and K in agroforestry ecosystem

The recycling process of N, P and K is shown in Fig.3. See from Fig.3, the input and output of N and K in the agroforestry ecosystem is basically balanced, and P is deficient, N, P and K are accumulated in plant tissues and litters, but depleted in soil.

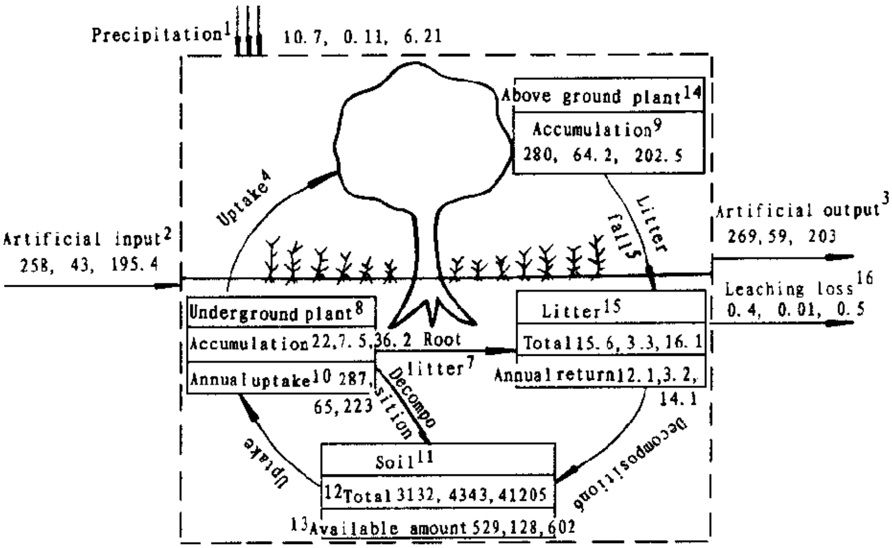

Fig.3 Recycling of N, P and K in agroforestry ecosystem(1989)

1. precipitation; 2. artificial input; 3. artificial output; 4. uptake; 5. litter fall; 6. decomposition; 7. root litter; 8. underground plants; 9. accumulation; 10. annual uptake; 11. soil; 12. total; 13. available amount; 14. above ground plants; 15. litter; 16. leaching loss

4 Conclusion

N and P contents in top 0—20 cm depth of soil are the major factors affecting the growth of crops, P content in 20—80 cm depth of soil is the major factor affecting the growth of *Paulownia elongata* .

The absorption coefficients of N, P and K in the ecological system are 0.078, 0.014 and 0.052, the utilization coefficients are 0.95, 0.90 and 0.94 and recycling coefficients, 0.042, 0.05 and 0.063 respectively.

The basis for annual fertilizer application in the ecological system is N 242.8kg$\cdot(hm^2)^{-1}$, P 55.39kg$\cdot(hm^2)^{-1}$, and K 182.49kg$\cdot(hm^2)^{-1}$.

The input and output of N and K in the agroforestry ecosystem is basically balanced, and P is deficient, N, P and K are accumulated in plant tissues and litters, but depleted in soil.

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