534-542

15

沙棘对中国亚湿润干旱区的杨树人工林养分分布及生物循环影响

~~57553~~

S718.55+.2

刘世荣
(中国林业科学研究院森林生态环境与保护研究所,北京 100091)

摘要:通过将沙棘(*Hippophae rhamnoides* L.)与三种杨树品种(小黑杨(*Populus* 'Xiaohei')、昭林6号杨(*P.* 'Zaolin06')和欧美杨64号,(*P. euramericane* cv. 'N3016'))的人工林分别按株混和行混两种方式进行混交实验,研究了固氮植物沙棘对亚湿润干旱区的杨树人工林养分分布和循环的影响,连续3a的观测研究得到以下结果:沙棘叶片的氮、磷和钾的元素浓度显著地高于杨树叶片,混交林中杨树各器官的养分浓度大于纯林中的杨树,但是养分浓度随元素和杨树品种而异;混交林中的土壤的总氮含量和有效氮含量分别比纯林高86%~164%和19%~36%;混交林中杨树生物量增加不总是与叶片的氮素浓度正相关,但是与氮素年吸收量的增加有关;由于混交林中养分的归还与吸收比率大于纯林,所以杨树混交林中养分的年归还量增加,这意味着杨树与沙棘混交之后有大量的养分进入再循环过程。研究结果表明,沙棘在杨树人工林中作为氮泵起到了维持土壤中稳定的氮素有效性以满足杨树迅速生长的作用。

关键词:亚湿润干旱区;沙棘;杨树人工林;养分分布;生物循环

Effects of seabuckthorn (*Hippophae rhamnoides* L.) on nutrient distribution and biological cycling of poplar plantations in dry subhumid area of China

LIU Shi-Rong (*Research Institute of Forest Ecology, Environment and Protection, Chinese Academy of Forestry, Beijing, 100091, China*)

Abstract: Effects of seabuckthorn (*Hippophae rhamnoides* L.) on nutrient distribution and nutrient cycling of poplar plantations in dry subhumid area of China were examined over 3 years by introducing seabuckthorn into three poplar stands of different varieties (*Populus* 'Xiaohei', *P.* 'Zaolin06' and *P. euramericane* cv. 'N3016'), and in two different mixing designs (individual-or strip-mixing patterns). The concentrations of N, P and K were found to be significantly higher in the seabuckthorn leaves than in the poplar leaves. Nutrient concentrations in poplar tissues were frequently larger in the mixed stands than in the pure stands, but the nutrient concentrations varied with elements and varieties. The concentrations of soil total N and available N were 86%~164% and 19%~36% higher in the mixed stands than in the pure stands. The enhanced growth was not always correlated with foliar N concentration, but related to the increased annual amount of N uptake. The annual nutrient returns in the poplar mixed stands were enhanced, as the ratios of annual nutrient return to uptake were higher in mixed stands than in pure stands. This implied that there was a large amount of nutrients involving in the nutrient recycling processes in the poplar stands when mixed with seabuckthorn. The results indicated that seabuckthorn, acting as a N pump, plays an important role in maintaining sufficiently stable N availability in concert with rapid poplar tree growth.

Key words: dry subhumid area; seabuckthorn; popular plantation; nutrient distribution; biological cycling

文章编号:1000-0933(1999)04-0534-09 **中图分类号**:S718.55+4.2 **文献标识码**:A

Received date: 1998-03-16

1 Introduction

Seabuckthorn (*Hippophae rhamnoides* L.) has long been recognized as an important nitrogen-fixing and drought-resistant tree species. In northwest of China, seabuckthorn was widely used to stabilize and enrich infertile soils, while to provide fruits for drink-making industry. Although it has fallen out of favor as a plantation species, seabuckthorn is considered as a good companion of many broad-leaved tree species. The presence of seabuckthron within a forest may result in significant changes to the internal cycling of nitrogen.

Poplar is a fast-growing and high-yielding plantation species in dry subhumid area of China, but the growth is affected by nutrient and water stresses. This problem is increasingly concerned under successive rotations with continuous cropping[1,2]. Introduction of the seabuckthorn into pure poplar plantations by mixing approach may lead to significant changes in organic matter decomposition and nutrient recycling, and hence to an increase in tree growth and biomass production. Little is known, however, about how the presence of seabuckthorn affect soil nutrient availability, foliar nutrient concentrations, and nutrient biological cycling in poplar plantations, and how these effects vary with mixing patterns or poplar varieties. Early studies reported only growth responses and foliar nutrient status of young poplar trees after mixed with seabuckthorn, and few published experiments have formally addressed long-term effects of seabuckthorn on biomass production and nutrient cycling of poplar plantations[3].

The objectives of the study were: to determine responses of soil nutrient availability and nutrient cycling processes of poplar plantations after mixed with seabuckthorn; The study was expected to provide scientific information for maintenance of sustainable site productivity of poplar plantations under successive rotations with continuous cropping.

2 Materials and methods

2.1 Site description The study area is located on fluvial plain sites in Heishui, Jianping county, Liaoning Province, in the northwest of China (40°17′～42°20′N, 110°10′～120°02′E). The typical dry subhumid continental climate is overwhelmingly dominated in the study area. Annual mean temperature is 7.9℃. Annual average precipitation is 470.5mm, falling mainly in July through August, and annual mean evaporation is 2113.7mm. The mean relative air humidity is only 52.3%. Soils are a nutrient-poor sandy loam at fluvial plains, with relatively scarce organic matter and low soil fertility. The sites are considered of low productivity in a landscape, which suffers water shortage and nutrient deficiency. The experiment was designed with three poplar varieties (*Populus* 'Xiaohei', *P.* 'Zaolin06' and *P. euramericane* cv. 'N3016') and in the two mixing patterns (individual-or strip-mixing), i. e. treatment Ⅰ: *P. euramericane* cv. 'N3016' mixed with seabuckthorn in strips at spacing of 2m×3m for both popular and seabuckthorn, and the control of *P. euramericane* cv. 'N3016' pure stand at a spacing of 2m×3m; treatment Ⅱ: *P.* 'Zaolin06' mixed with seabuckthorn in strips at spacing of 2m×3m and 1.5m×3m for poplar and seabuckthorn, respectively; and the control of *P.* 'Zaolin06' pure stand at a spacing of 3m×4m; treatment Ⅲ: *P.* 'Xiaohei' mixed with seabuckthorn in individual-tree mixture at spacing of 3m×4m for both poplar and seabuckthorn (one poplar tree together with two seabuckthorn plants were planted in a group), and the control of *P.* 'Xiaohei' pure stand at a spacing of 3m×4m. The stands of treatment Ⅰ and Ⅱ were established in 1987, and that of treament Ⅲ was established in 1985. In treatment Ⅲ, seabuckthorn plants were removed in 1990 from the mixed poplar stand by cutting at ground level with minimum soil disturbance, and thereafter regenerated naturally.

2.2 Growth and biomass measurement Measurements of the stand growth were made annually during 1993～1996 in the predetermined six plots of $300m^2$ each, including the three poplar mixed stands with seabuckthorn and the three controls. By applying the method of stand survey, all trees grown in sampling plots were measured and recorded for tree height and diameter at breast height(*DBH*). Destructive harvests for above-ground biomass measurement were made at the end of August of 1993 and 1996, respectively. Trees were selected based on diameter dimension and number percentage in each diameter class for above-ground harvest. The total fresh weight of trunk, bark, branches and leaves were directly measured by weighing. Biomass of various components or organs in expressed in dry mass. Biomass data of the organs from the destructive sampling were used to establish allometric relationships with *DBH* and tree height. The allometric equations were used to quantify the same variables of the trees for whole investigation plots. Biomass of seabuckthorn, herb and litter was directly measured by harvesting and weighing all plant tissues respectively from three $5\times5m^2$ and $1\times1m^2$ subplots.

2.3 Litter fall measurement Ten litter fall traps of $1\times1m^2$ were randomly placed in an $300m^2$ plot within each treatment to qualify litter input to the forest floor, and litter fall was collected twice a month. After separation into different components by species, tissues and site origin, the litter fall was weighed and then dried at 40℃ on oven for 48h. The dry mass of litter fall was weighed and analyzed for nutrients. The measurements of litter fall were conducted simultaneously on all plots in 1993 and were repeated for two years.

2.4 Primary productivity The net primary production (*NPP*)of the stand components was calculated by the following formulae: $NPP=G+L+A$[4], Where G is annual net biomass production, L is annual litter fall production of the current biomass production, and A is herbivore consumption which is assumed to be negligible and not considered in the calculation. The annual above-ground net biomass production was calculated by an average of the total net biomass production during 1993～1996.

2.5 Soil sampling For the strip mixing stands, 27 frames were taken in each plot and divided into 3 groups of 9 frames each. The group 1,2 and 3 were selected within the rows of poplar trees, within the space between poplar strip and seabuckthorn strip, and within the rows of seabuckthorn, respectively. Sampling underneath the litter layer was by depth increments of 0～5, 5～20, 20～50cm, using soil drill. Within each group, nine cores from each depth were collected systematically and pooled in 3 single samples. For individual mixing stands, 9 frames were randomly taken in each plot, and pooled into 3 single samples. Soil samples were collected at three sublayers by the same depth horizons as described above.

2.6 Laboratory analysis Soil samples were air-dried, and ground to pass through No. 40 stainless mesh screen. The total N content was determined by the Kjeldahl method, P by continuous flow method (molybdenum-vanadium method), and concentrations of Ca, Mg and K were measured by atomic absorption spectrophotometry. Exchangeable NH^+ and combined $NO_2^- + NO_3^-$ were determined from 2 M KCl extracts (1:4v/v) by alkaline steam distillation, and exchangeable K and soluble P were determined using 1.0 M ammonium acetate extraction (pH 4.65;1:10v/v). Plant samples were dry-ashed at 550℃ for 5 hours, dissolved in 5%(v/v) HNO_3, and were analyzed for total N, P, K, Ca and Mg with the same method as described above[5]. Chemical analysis of plant and soil samples were conducted at Chemical Analysis Center, Chinese Academy of Forestry.

2.7 Nutrient calculation The nutrient standing stock was calculated by multiplying the standing crop by the corresponding mean elemental concentration. The above-ground annual nutrient uptake was defined as the sum of the maximum nutrient pool size of current stem and branch, and foliar biomass plus the net annual increment in the nutrient pool of stems and branches older than current year. The annual nutrient retention was defined by the annual net increment in nutrient pool of perennial tissues. All these estimates of those of pool size of biomass and nutrient content of different components are expressed on an oven-dry weight basis and on an annual basis as weight per hm².

3 Results

3.1 Nutrient concentrations in plant tissues　Nutrient concentrations in plant tissues were shown in fig. 1. Nutrient concentrations varied with organs and varieties, but nutrient concentrations were frequently greater in the leaves than in the other organs. The concentrations of N, P and K were significantly higher in the seabuckthorn leaves than in the poplar leaves.

Nutrient concentrations in poplar tissues were frequently larger in the mixed stands than in the pure stands in most cases of this study, but the nutrient concentrations varied with elements and treatments. For example, the foliar N and P concentrations of poplar trees in the mixed stands were 1.2 and 1.2, 1.7 and 1.2, and 1.4 and 1.1 times higher for treatment Ⅰ, Ⅱ and Ⅲ, respectively, compared to that in the pure stands. Regardless of poplar variety, the nutrient concentrations of woody tissues were relatively lower for poplar trees in the mixed stands than in the pure stands.

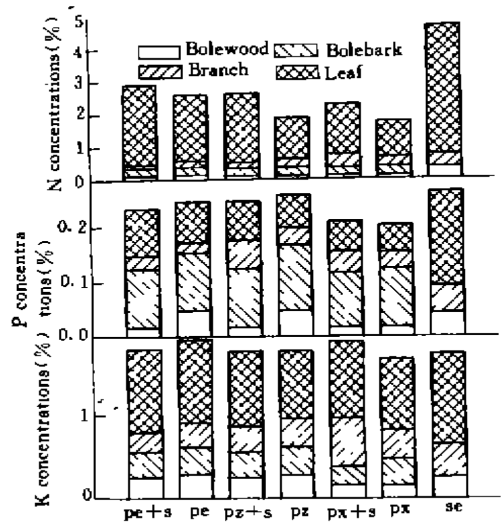

Fig. 1　Nutrient concentrations of plant tissues

3.2 Nutrient concentrations in soil　Nutrient concentrations in soils varied with soil depth, and mixing patterns(see table 1). The total N, Ca and Mg, and available N, P and K concentrations were significantly decreased with soil depth, but total P and K were found to increase slightly with soil depth. Nutrient concentrations of soils were frequently higher in the mixed stands than in the pure stands. These increase in the total N and available N concentration were 164% and 36% for the treatment Ⅰ, 132% and 37% for the treatment Ⅱ, and 86% and 19% for treatment Ⅲ, respectively.

3.3 Nutrient standing crop　In the strip-mixing patterns, the total above-ground standing crop of nutrients in tree layers was found to be larger in the pure stands than in the mixed stands, but only difference in N standing crop were not statistically significant. In addition, the standing crop of nutrients in the woody tissues was less in the mixed stands than in the pure stands, while the standing crop of nutrients in the leaves was larger in the mixed stands than in the pure stand. This was due largely to either the relatively higher nutrient concentrations or the larger biomass of woody tissues in the pure stands than in the mixed stands. In treatment Ⅲ, however, the total above-ground standing crop of nutrients in the tree layer was significantly higher in the mixed stand than in the pure stand, regardless of element or organ(see Tabable 2). The total foliar N standing crop of tree layers increased by 18%, 32% and 269% after poplar trees mixed with seabuckthorn for treatment Ⅰ, Ⅱ and Ⅲ.

The total N and P standing crops of stands were larger in the mixed stands than in the pure stands, irrespective of poplar variety or mixing pattern, but there was no statistically significant differences in the P standing crop between the mixed stands and the pure stands in treatment Ⅰ and Ⅱ. In treatment Ⅰ and Ⅱ, the total K, Ca and Mg amount of stands were frequently less in the mixed stands than in the pure stands, while they were significantly larger in the mixed stands than in the pure stands in treatment Ⅲ. The standing crop of herb in this case comprised a negligible proportion of total above-ground nutrient pool size, but the amount of nutrients accumulated in seabuckthorn plants made a great contribution to the total nutrient

Table 1 Total element contents and exchageable nutrients in soils. The soils were sampled at the three soil depths of 0～5cm, 5～20cm and 20～50cm. pe, pz and px represent three experimental stands composed of *Populus* × *Xiaohei*, *Populus* × Zaolin06 and *Populus* · *euramericane* cv. 'N3061', respectively. S indicates poplar mixed stands with seabuckthorn. The ± values are the s. e. of the mean of three replicates

Depth (cm)		Total content (%)					Exchangeable (mg/100g)		
		N	P	K	Ca	Mg	N	P	K
0～5	pe+s	0.053±0.014	0.093±0.018	1.80±0.41	2.38±0.27	0.798±0.094	2.47±0.46	0.285±0.063	12.3±3.1
	pe	0.046±0.008	0.091±0.009	1.56±0.09	2.45±0.52	0.858±0.123	1.64±0.32	0.197±0.058	11.9±2.0
	pz+s	0.074±0.019	0.103±0.013	1.49±0.05	3.09±0.34	0.918±0.095	1.91±0.11	0.368±0.108	16.3±2.4
	pz	0.032±0.009	0.097±0.002	1.66±0.06	2.51±0.62	0.731±0.128	1.22±0.92	0.229±0.072	6.6±1.2
	px+s	0.117±0.089	0.059±0.009	2.20±0.67			2.97±0.34	0.594±0.054	11.0±3.2
	px	0.065±0.012	0.045±0.011	2.10±0.32			2.61±0.23	0.251±0.044	8.0±2.8
5～20	pe+s	0.039±0.017	0.103±0.017	2.02±0.92	2.12±0.32	0.732±0.036	1.79±0.30	0.177±0.016	7.9±2.0
	pe	0.014±0.009	0.095±0.013	1.64±0.05	2.46±0.37	0.775±0.023	1.45±0.30	0.146±0.026	4.1±0.3
	pz+s	0.043±0.004	0.088±0.011	1.60±0.11	3.25±0.44	0.862±0.081	1.68±0.12	0.179±0.037	8.8±0.5
	pz	0.013±0.016	0.090±0.009	1.72±0.12	2.20±0.56	0.635±0.095	1.31±0.03	0.146±0.003	3.8±0.3
	px+s	0.055±0.012	0.045±0.003	2.31±0.88			2.97±0.23	0.594±0.045	4.4±0.4
	px	0.024±0.007	0.045±0.009	2.28±0.78			2.61±0.32	0.251±0.034	4.3±0.3
20～50	pe+s	0.015±0.005	0.111±0.022	2.34±0.62	1.95±0.44	0.608±0.045	1.13±0.05	0.259±0.096	2.8±0.8
	pe	0.009±0.005	0.090±0.008	1.63±0.03	2.43±0.82	0.659±0.152	0.78±0.39	0.193±0.038	1.9±0.1
	pz+s	0.011±0.008	0.125±0.011	1.82±0.16	2.23±0.27	0.674±0.083	1.10±0.39	0.247±0.014	4.7±1.8
	pz	0.010±0.012	0.094±0.005	1.75±0.34	2.38±0.44	0.703±0.119	0.89±0.29	0.141±0.153	4.3±1.8
	px+s	0.029±0.021	0.069±0.003	1.92±0.25			0.77±0.71	0.029±0.008	3.1±0.9
	px	0.019±0.007	0.040±0.005	2.03±0.33			0.71±0.56	0.013±0.007	2.6±0.8

standing crop of the stands. For example, the N amount in seabuckthorn plant accounted for 31%, 56% and 22% of the total N amount of stands for treatment Ⅰ, Ⅱ and Ⅲ, respectively (see table. 2).

3.4 Nutrient biological cycling Regardless of poplar variety or mixing pattern, the annual amounts of N, P, K, Ca and Mg uptakes and returns were larger in the mixed stands than in pure stands. For example, the annual amount of N uptake was increased by 56%, 151%, and 268%, respectively, for treatment Ⅰ, Ⅱ and Ⅲ, after poplar stands mixed with seabuckthorn. In the mixed stands, the relative contributions of seabuckthorn to the total annual amount of above-ground N uptake accounted for 29%, 56% and 23%, respectively, for the treatment Ⅰ, Ⅱ and Ⅲ, and the relative contributions of seabuckthorn to the total annual amount of above-ground N return accounted for 28%, 55% and 20%, respective-

Table 2 Effects of seabuckthorn on nutrient standing crops of stands (kg/hm^2). pe, pz and px represent three experimental stands composed of *Populus* × Xiaohei, *Populus* × Zaolin 06 and *Populus* × *euramericane* cv. 'N3061', respectively. S indicates poplar mixed stands with seabuckthorn. Values are the means of three replicates.

Items		pe+s	pe	pz+s	pz	px+s	px
N	Poplar	206	215	100	105	159	79
	Seabuckthorn	92	0	126	0	44	0
	Sum	298	215	226	105	203	79
P	Poplar	23	29	15	23	20	12
	Seabuckthorn	7	0	10	0	4	0
	Sum	30	29	25	23	24	12
K	Poplar	208	262	120	151	164	92
	Seabuckthorn	39	0	53	0	19	0
	Sum	247	262	173	151	183	92
Ca	Poplar	412	551	269	345	455	284
	Seabuckthorn	31	0	39	0	13	0
	Sum	443	551	308	345	468	284
Mg	Poplar	71	102	44	60	59	43
	Seabuckthorn	9	0	12	0	4	0
	Sum	80	102	56	60	63	43

ly, for treatment I, II and III (Table 3).

Table 3 Effects of seabuckthorn on nutrient biological cycling of poplar plantations (kg/hm²·a). pe, pz and px represent three experimental stands composed of *Populus* × Xiaohei, *Populus* × Zhaolin 06 and *Populus* × *euramericane* cv. 'N3061', respectively. S indicates poplar mixed stands with seabuckthorn. Values are the means of three replicates

	Items	pe+s	pe	pz+s	pz	px+s	px
N	uptake	102.1	65.3	70.9	28.3	64.4	17.5
	retention	14.3	9.6	12.1	5.0	7.3	4.5
	return	87.8	55.7	58.8	23.3	57.1	13.0
	return/uptake	0.86	0.85	0.83	0.82	0.89	0.74
P	uptake	6.18	5.62	3.86	3.27	3.01	1.28
	retention	2.93	3.6	2.17	2.08	1.20	0.63
	return	3.25	2.02	1.69	1.19	1.81	0.65
	return/uptake	0.53	0.34	0.44	0.36	0.60	0.51
K	uptake	84.8	64.1	48.1	34.7	53.2	18.6
	retention	23.6	20.3	16.5	11.0	8.0	5.5
	return	61.2	43.8	31.6	23.7	45.2	13.1
	return/uptake	0.72	0.68	0.66	0.68	0.85	0.70
Ca	uptake	136.8	121.7	79.3	73.2	111.6	46.5
	retention	42.7	44.0	26.2	21.2	22.5	17.4
	return	94.1	77.7	53.1	52.0	89.1	29.1
	return/uptake	0.69	0.64	0.67	0.71	0.80	0.63
Mg	uptake	31.5	25.8	18.4	11.7	21.8	8.2
	retention	6.3	7.2	4.2	3.3	2.8	3.5
	return	25.2	18.6	14.2	8.4	19.0	4.7
	return/uptake	0.80	0.72	0.77	0.72	0.87	0.57

The annual amount of nutrient return by leaf litter fall comprised a relatively larger proportion of the total annual amount of nutrient uptake in the mixed stands than in the pure stands, and thus the ratios of nutrient return to uptake were frequently higher in the mixed stands than in the pure stands. The increase in the ratios of nutrient return to uptake was more pronounced for the mixed stand with the individual-mixing pattern than for the mixed stand with the strip-mixing pattern.

4 Discussion

As known that seabuckthorn is a N-fixing plant with root nodules by which they fix N_2 from the air into soils, and consequently leads to an increase in availability of soil N. Zhang *et al.* [6] reported that the activity of N-fixing enzyme in the root nodule was 36.23～470.4 acetylene μmol. fresh mass^{-1}. min.$^{-1}$, and the activity of N-fixing enzyme was higher in the fluvial plains than in the hill slope sites[7]. In this study, the substantial increases in total soil N and exchangeable N concentrations occurred in the mixed stands, irrespective of poplar variety or mixing pattern, and this increase was accompanied by the concomitant increase in the poplar leaf N concentrations. Because of a positive correlation between photosynthesis and nitrogen at current ambient atmospheric CO_2 condition[8], the increase in leaf N concentration may be due partially to the increased soil N availability after seabuckthorn introduction and this could provide a sufficient available N in concert with the increasing demand of rapid tree growth. However, leaf N concentrations from poplar trees in the treatment I were not statistically significant different, thereby tree growth may not highly related to the leaf N concentrations in this case, due to the differences in tree growth rates and the resultant dilution effects. This suggested that increased soil N availability may enhance tree growth but leaf N concentration may not necessarily increase in compatible with growth enhancement. The similar phenomena was hypothesized by Tschaplinski and Norby[9], and Kim *et al.* [10] that leaf N concentration was a poor indicator of response to N fertilizer or increased soil N availability, and therefore it was not closely related to plant growth response. In addition, this phenomena also occurred in many impact experiment studies that leaf N concentration has been decreased due to the dilution effects resulted from foliar starch accumulation while rapid plant growth was frequently observed in response to elevated CO_2[11].

Positive effects of seabuckthorn plants on poplar tree growth were observed during the study period regardless of poplar variety or mixing pattern. Although the contribution of seabuckthorn to the total biomass of the stands comprised relatively small proportions (12%, 23% and 9% for treatment Ⅰ, Ⅱ and Ⅲ, respectively), its contribution to the total nutrient pool size increased dramatically. For example, the N standing crops of seabuckthorn were access to 30%, 56% and 22% of the total N pool size for treatment Ⅰ, Ⅱ and Ⅲ, respectively. Similarly, they occupied relatively larger proportions of the total annual vascular biomass production (20%, 41% and 23% for treatment Ⅰ, Ⅱ and Ⅲ, respectively) and of total annual vascular N uptake.

The seabuckthorn played an important role in nutrient cycling through accelerated N recycling processes and increased soil available N. The annual N uptake by seabuckthorn accounted for 29%, 56% and 23% of the total annual N uptake for treatment Ⅰ, Ⅱ and Ⅲ, respectively, as a result of higher N concentrations in its tissues. In addition, the seabuckthorn returned 82%, 80% and 76% of its total annual N uptake to forest floor for treatment Ⅰ, Ⅱ and Ⅲ, respectively, by its litter fall which is easily decomposed by soil microbes with rapid biomass turnover and N recycling. At the same time, the seabuckthorn also enhanced nutrient biological cycling of poplar trees by either the increased nutrient concentrations of poplar leaf tissues or the increased annual amount of nutrient uptake and return. The increases in annual N uptake of poplar trees after mixed with seabuckthorn were 111%, 110% and 283% for treatment Ⅰ, Ⅱ and Ⅲ, respectively, while the annual N returns were increased by 114%, 113% and 352% for treatment Ⅰ, Ⅱ and Ⅲ, respectively. As a result, the total annual N uptake of the mixed stands were increased by 156%, 251%, 368% for treatment Ⅰ, Ⅱ and Ⅲ, respectively. In addition to the increased annual nutrient uptake, the annual nutrient returns of the mixed stands were also enhanced as the ratios of annual nutrient return to uptake were higher in the mixed stands than in the controls. This implied that there was relatively larger amount of nutrient elements involving in nutrient recycling processes in the mixed stands than in the pure stands. Although poplar is referred as a deciduous tree that returns a large amount of litter fall by annual leaf senescence, the quality of its litter fall was poor than that of seabuckthorn due to the relatively lower nutrient concentrations of its litter tissues in contrast to seabuckthorn. This was manifested in treatment Ⅱ, especially for N, i.e. the annual N return by seabuckthorn litter fall was 123% higher than that by poplar litter fall.

Compared with other forests, the amount of annual N uptake in the mixed poplar plantations ranged from 65 to 102 kg/hm²·a, which was less than 123 kg/hm²·a in oak forests reported by Duvigneaud and DenaeyerDeSmet[12], 257.7kg/hm²·a in tropical mountain rain forests reported by Zeng and Liu[13], but larger than 56kg/hm²·a in temperate larch plantation reported by Liu[14], 41.9kg/hm²·a in subtropical China fir plantation reported by Feng *et al.*[15], and 38.2kg/hm²·a in warm-temperate Chinese pine plantation reported by Nie *et al.*[16]. The significantly larger annual N uptake in mixed poplar stands than in the pure poplar stands indicated that the annual N uptake was highly dependent on responses of net productivity of the stands to the increased soil N availability, i.e. the higher stand productivity, the larger annual N uptake. The increased annual N uptake was contributed to meet with the increasing N demand of higher net productivity. Overall, seabuckthorn as a understory minor vegetation is particular significance in view of the ecological role of N pump species in the nutrient-poor poplar plantation[17], especially under the drought condition resulted from dry subhumid climate. Even though seabuckthorn does not have an important commercial value of timer production, it plays an indisputable role in the contribution to efficiency of energy flow, nutrient conservation and rapid nutrient recycling (especially N) in man-made polar plantation due to its higher ratio of leaf to stem, relatively repid leaf turnover, and high tissue nutrient concentrations, as well as its important function of N-fixation.

In addition to effects of increasing nutrient availability and recycling, seabuckthorn also plays an important role in protecting soil and water from erosion due to its thick canopy cover and wide-spread shallow root system. The measurement made of rain fall interception rate was 40%~49%, resulting in reduction of run off by 80% and of sand and suspended matter by 75%, while leading to an increase in soil moisture by 2.2%~6.6%[18]. The improved environmental conditions associated with rapid litter decomposition and the increased nutrient availability were contributed to the enhanced growth of poplar plantations after mixed with seabuckthorn.

Although the timber production was found be to relatively lower in the strip-mixing stands than in the pure stands, the strip-mixing stands could maintain the long-term stability of a high soil N availability and thereby achieve the long-term sustainability of stand biomass production. This should be considered as a sound silvicultural strategy in view of long-term interests, rather than short term interests[19,20]. Recent survey made by Sun *et al.*[2] indicated that the reductions of stand growth in terms of mean height and *DBH* were found by 24% and 11% in the secondary generation of poplar pure plantation under the continuous cropping in China, due to the associated decreases in soil available nutrient elements, especially N. This discovery and similar others[21,22,23] supported the silvicultural strategy proposed by this study, and the dense, pure poplar stands should be changed into the mixed plantations with an appropriate N-fixing species like seabuckthorn. A mixed poplar stand with seabuckthorn either in an individual-mixing pattern or a strip-mixing pattern, both can obtain a good balance between short-term economic interest from timer production and long-term site stability from maintenance of rational normal nutrient availability and recycling processes, and furthermore ensure the resultant high level of sustainable plantation productivity, in particular, under successive rotations with continuous cropping.

5 Conclusions

A growth response to the occurrence of seabuckthorn was found in poplar plantations under the nutrient-deficient and seasonal drought stress in the dry subhumid climate of China. The growth enhancement of poplar trees mixed with seabuckthorn was largely attributed to the increased soil nutrient availability, especially N, and the increased N availability was the result of one or more of the followings: the increased N inputs into the soil through N-fixation by root nodule, good-quality litter fall, rapid nutrient recycling, or improved site environments. The enhanced growth was not consistently correlated with foliar N concentration, but related to the increased annual amount of N uptake and accelerated N recycling. Seabuckthorn acts as a N pump and plays an important role in maintaining sufficiently stable N availability in concert with rapid poplar growth. Seabuckthorn was characterized by its high ratio of leaf to stem, relatively rapid leaf turnover, and high tissue nutrient concentrations, as well as its important function of N-fixation. The importance of seabuckthorn in modifying soil chemical processes and elemental cycling would be signified in view of long-term site productivity and sustainable productivity in poplar plantations, in particular, under successive rotations with continuos cropping on the same sites.

Acknowledgments

This study was supported by the International Foundation for Science (IFS grant agreement No. D/2052-1). The author would like to extend his sincere thanks to Dr. Sabine Bruns and all other staff members from IFS for their information assistance and administrative services during the project period. The field assistance and site maintenance of Mr. Limin Niu, Zuoyi Dong and Li Chen are gratefully acknowledged. The author also are grateful to the project advisor, Dr. Lars-Owe Nilsson of the Swedish University of Agricultural Sciences for providing technical suggestions on the experimental design.

References:

[1] Xu M N, Han S K, Hu M Y. *et al.* Study on dynamics of soil nutrient elements in continuous cropring Euramerican poplar plantations. Ed. By Sheng W T. *Research on Site Degradation of Timber Plantation*. Beijing, China Scientific and Technical Publishing House. 1992, 312~316.

[2] Sun C L, Zhu Z X, Wang Z, *et al.* Study on the soil degradation of the poplar plantation and the technique to preserve and increase soil fertility. *Scientia Silvae Sinicae.* 1995, **31**(6):506~512.

[3] Wang S J. Suggestions on development of poplar plantations in China-An Overview of 5th China National Poplar Conference. Ed. by Wang S J. *Advance in Poplar Research* (1990~1995). Beijing, China Forestry Publishing House. 1995, 389~390.

[4] Leith H and Whittaker R H. Primary productivity of the Biosphere. Springerverlag, Berlin, Heidelberg, New York. 1975.

[5] Allen S E. *Chemical Analysis of Ecological Materials.* (2nd edition). Oxford, London, Edinburgh. Blackwell Scientific Publication. 1989, 118~133.

[6] Zhang J K and Zhang X M. Research advanee in endotrophic mycorhiza of root nodule of *Hippophae rhamnoides. Hippophae*, 1992, **5**(2):4~10.

[7] Lei Q D and Zhong Y H. Nitrogen-supply effects of Seabuckthorn in *Pupulous simonii* plantation. *Forest Science and Technology*. 1983, **3**:21~24.

[8] Evans J R. Photosynthesis and nitrogen relationship in leaves of C_3 plants. *Oecologia*. 1989, **78**:9~19.

[9] Tschaplinski T J and Norby R J. Physiological indicators of nitrogen response in a short rotation sycamore plantation. I. Nitrogen metabolism. *Can. J. Bot.* 1993, **71**:841~847.

[10] Kim C, Sharik T L, Jurgensen M F, *et al.* Effects of nitrogen availability on northern red oak seedling growth in oak and pine stands in northern lower Michigan. *Can. J. For. Res.*, 1996, **26**: 1103~1111.

[11] Eamus D and Jarvis P G. The direct effects of increase in the atmospheric CO_2 concentration natural and commercial temperate trees and forests. Ed. Begon M, *et al. Advance in Ecological Research.* Academic Press, Harcourt Brace Jovanovivh Publishers. 1989, **19**:1~55.

[12] Duvigneaud P and Denaeyer-DeSmet S. Biological cycling of minerals in temperate deciduous forests. *In: Analysis of Temperate Forest Ecosystems.* Ed. D E Reichle. Springer-Verlag, New York. 1970, 199~225.

[13] Zeng S Q and Liu L Z. Biogeochemical characteristics of the mountain rain forests in Hainnan Island, *China. Ecol. Sci.* 1986, **2**:36~44.

[14] Liu S R. Nitrogen cycling and dynamic analysis of man-made larch forest ecosystem. *Plant and Soil.* 1995, **168**~**169**:391~397.

[15] Feng Z W, Chen C Y and Zhang J W, Studies on the accumulation, distribution and cycling of nutrient elements in the ecosystem of the pure stand of subtropical *Cunninghamia lanceolata* forests. *Acta Phytoecol. Geobot. Sinica.* 1985, **9**:245~256.

[16] Nie D P, Dong S R and Shen G F. Studies on nutrient cycling in Chinese pine plantation. Ⅱ. Biological cycling and nutrient balance. *J. Beijing For. Univ.* 1986, **2**:8~19.

[17] Kimmins J P. A strategy for research on the maintenance of long term site productivity. in: IUFRO 19th World Congress Proceedings, *Division I.* 1990, 1(1):206~213.

[18] Luo J and Zhang Y S. A study on functions of *Populus simonii* stand mixed with seabuckthorn in Youyu. *Hippophae*, 1990, 3(2):11~18.

[19] Evans J. Long-term productivity of forest plantations-status. in: IUFRO 19th World Congress Proceedings, *Division I.* 1990, 1(1):165~180.

[20] McColl J G. Symbiotic nitrogen fixation by Daviesia Mimoisedes under eucalyptus. IUFRO Symposium on Forest Site and Continuous Productivity. USDA For. Ser. Gen. Tec. Rep. *PNW.* 1983, **163**:122~129.

[21] Gessel S P. Potential nutritional problems in maintenance of long term southern hemisphere plantation productivity. in: IUFRO 19th World Congress Proceedings, *Division* I. 1990, 1(1):181~193.

[22] Lamb D. Decomposition of organic matter on the forest floor of *Pinus radiata* plantations. *J. Soil Sci.* 1976, **27**, 206~217.

[23] Liu S R, Li X M & Niu L M. The degradation of soil fertility in pure larch plantation in the northeastern part of China. *Ecological Engineering*, 1998, **10**:75~86.