International Journal of Environmental Monitoring and Analysis
2021; 9(6): 162-169
http://www.sciencepublishinggroup.com/j/ijema
doi: 10.11648/j.ijema.20210906.11
ISSN: 2328-7659 (Print); ISSN: 2328-7667 (Online)

Vegetation Restoration and Carbon Sink Function Evaluation of the Grain for Green Project

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To cite this article:

Ma Wei, Wang Ping, Liu Qiongge, Dong Yunfei, Sun Yujun. Vegetation Restoration and Carbon Sink Function Evaluation of the Grain for Green Project. *International Journal of Environmental Monitoring and Analysis*. Vol. 9, No. 6, 2021, pp. 162-169.
doi: 10.11648/j.ijema.20210906.11

Received: October 20, 2021; **Accepted**: November 11, 2021; **Published**: November 17, 2021

Abstract: Evaluation of the ecological process and carbon sink function of vegetation restoration is subject to afforestation activities, particularly after conversion of farmland to forests at different de-farming times. Based on the survey of sample plots ranging from 7 to 46 years in *Larix olgensis* plantation after returning farmland to forest, dynamic changing of vegetation restoration and carbon storage in representative region of Lesser Khingan Mountains were analyzed in the plantation. Firstly, community diversity situation was evaluated by Sorensen similarity index, Shannon-Wiener index, Peilou evenness index, Margalef richness index. Secondly, biomass of community was estimated by sampling harvest and allometric dimension analysis, and translated it to carbon storage via carbon rate. Thirdly, carbon storage quantity was conversed to the amount of CO_2 fixation and O_2 release according to the plant photosynthesis principle. At last, the economic benefit of CO_2 and O_2 were calculated through the current market price. The results showed that: (1) the ecological efficiency of the man-made communities raised as the reforested time increased, such as the number, richness and diversity index of species reached to 46, 6.443 and 1.733 respectively. Composition and biodiversity characteristics of plantation community changed significantly after reforested the cultivated land. (2) Carbon density of community, including arbor, shrub, herb and down woody material, increased over stand ages. Mean carbon density was 74.711 $t{\cdot}hm^{-2}$, and the carbon storage in regions of study was 106.624t, equaled to 13000.252t CO_2 and 2585.938t O_2. After conversion, economic benefit of 436.887 thousand RMB indicated remarkable benefits of the plantations. In conclusion, our study showed that the Grain for Green Project improved the land-use pattern, as farmland transformed to forests, aims of degenerated ecosystem restoration or reconstruction and plantations carbon sink potential development were achieved.

Keywords: Grain for Green Project, Vegetation Restoration, Carbon Storage, *Larix olgensis* Plantation, Economic Benefit Evaluation

1. Introduction

Nowadays, the fact that forest is playing obvious role in ecological restoration and carbon sink are becoming more recognized [1-3]. Grain for Green Project (GGP) is the largest ecological environment construction project in world, which restoring natural covered surface reconstruction through improving land use pattern. It is promoting the increasement of forest area, and is known as one of the main afforestation activities in China and the world [4, 5]. Lots of researches and practices about the woodlands technology reform mode, vegetation recovery and carbon sink function have been taken in a deep understanding of ecological principles and dynamic principle basis, and also has make significant progress [6-9]. But, there are few studies involve the ecological process and mechanism of vegetation restoration at different de-farming times. And, carbon sink function evaluation could not be expressed accurately and effectively in monetary method yet [10, 11]. Thus, this paper took some *Larix olgensis* plantations at different de-farming times as research objects for a comprehensive study of vegetation restoration regularity from levels on individual species, each layer, and community. Also, the time-space distribution characteristics of carbon storage and its economic value had been analysed. This article helps to reflect the ecological restoration effect of GGP timely and accurately, also helps to provide scientific guidances for developing afforestation activities for carbon sink and forestry compensation policy formulation, and provides data to support and scientific basis for future carbon trading and global climate change negotiations.

2. Materials and Methods

2.1. Site Descriptions

Our study was carried out in Dongzhelenghe forest farm (46°31'—46°49'N; 128°55'—129°15'E)—a plain-mountain transition region of Songnen Plain and Small Xing Anling in central Heilongjiang, China. The slope averages of this hilly topography is about 7°, the soils are dark brown forest soils, and the thickness is from 30 cm to 60 cm, little gravel was found in the study area. The strong continental climate in this area is wet continental monsoon climate, characterized with an average annual precipitation of 618 mm and mean annual temperature of 0.36°C, and 2050°C total accumulative temperature; the average air relative humidity was 68%, the annual average frost-free period around 100 days, the annual average sunshine hours of 2453 hours. The peak of growing season usually starts in early July and ends in late August in this area.

Due to the irrational farming in large area, soil erosion was aggravated. Since the mid-1960s, the forest farm gradually took back farm lands on wetland, riverside, road side and slope. Then, trees were planted, and returning to forest belt for protection of road and river, water conservation forest and public good forest. Plots of returning farmland to forest were selected to be the research target as similar site condition in *Larix olgensis* plantations, where elevation, aspect, soil thickness were alike. Stand ages, same as de-farming time, were from 7 years to 46 years, and they constitute a relatively complete series (Table 1). Meanwhile, the stages of forest land we chose into 5 stage groups, including immature, juvenile, mid-aged, near-mature and mature. In arbor layer of the plantation, *Larix olgensis* accounted for more than 60% of volume, which was the most steady domainant tree species. Shrub species were mainly *Philadelphus schrenkii*, *Sorbaria sorbifolia*, *Lonicera chrysantha*, *Acanthopanax senticosus* and *Deutzia parviflora*, the average coverage were 8%. Herb species were mainly *Cardamine leucantha*, *Filipendula palmata*, *Carex callitrichos*, *Pteridium aguilinum*, *Impatiens noli-tangere*, the average coverage were 53%. Down woody materials (DWM) on the ground formed by fallen wood, dead branches and litter, which divided into fine woody debris (FWD), coarse woody debris (CWD) and residue pile (RP).

Table 1. *Basic status of sampling sites of Larix olgensis plantation at different stages after de-farming.*

Stages	Area /hm^2	Plots	Stand Age /a	Altitude /m	Slope degree /°	Aspect /°	Slope position	Soil depth /cm	DBH /cm	Height /m	Density /$N\cdot hm^{-2}$	Crown density
I	90	1	7	300	9	SW60	Lower	40	3.0	3.0	1663	0.16
		2	11	367	6	SW12	Bottom	41	7.2	11.7	1637	0.49
II	181	3	15	308	7	SE62	Bottom	45	11.5	12.4	1623	0.65
		4	19	296	7	SW30	Middle	46	12.7	13.9	1560	0.76
III	32	5	23	354	10	SW6	Bottom	45	15.2	15.8	1352	0.83
		6	27	304	5.5	SE39	Lower	43	15.8	16	1114	0.80
IV	19	7	32	376	6	SE15	Bottom	40	16.1	16.3	936	0.75
		8	37	383	6	SW58	Bottom	37	16.6	17.2	783	0.73
V	7	9	46	309	9	SE75	Lower	55	27.4	26.3	520	0.57

2.2. Methods

2.2.1. Vegetation Restoration Survey

A floristic survey was made of arbors factors in 68 10m*10m samples, such as species, plant number, height, DBH (5cm≤). Especially in immature stands, trees with height≥1m were considered arbor. Shrubs and herbs were investigated respectively in 56 and 224 quadrats, including species, number (clump), height and coverage. Importance values were accurated by values of relative density, frequence and significance (arbor) or coverage (shrub&herb). Sorensen similarity index, Shannon-Wiener diversity index, Pielou evenness index and Margalef richness index were used as indicator of community structure and similarity, help to analyse the level of species diversity in community. The indexes can be summarized as followed:

1) Importance value:

$$IV=(RD+RF+RDO)/3 \quad (1)$$

In formula (1), *IV* was Importance value, *RD* was relative density, *RF* was relative frequence, *RDO* was relativesignificance or coverage.

2) Sorensen index:

$$CC=2a/(b+c) \quad (2)$$

In formula (2), *a* was the number of same species in 2 communities, *b* and *c* were the number of species in 2 communities respectly.

3) Diversity indexes:

a. Shannon-Wiener indexes:

$$H' = 3.3219(\lg N - \frac{1}{N}\sum_{i=1}^{s} n_i \lg n_i) \quad (3)$$

b. Pielou indexes:

$$J_{sw} = (-\sum_{i=1}^{s} P_i \log_2 P_i) / \log_2 S \quad (4)$$

c. Margalef indexes:

$$D_{Ma}=(S-1)/LnN \quad (5)$$

In formulas of (3), (4), (5), *S* was the number of species in samples, n_i was the number of species *i*, *N* was the total number of species, *pi* was the relative value of species *i*, $p_i=ni/N$, 3.3219 was conversion factors of $\log_2$ turned into 10.

2.2.2. Biomass and Carbon Storage Estimation

(i). Biomass Estimation

Field investigation methods in Forest Inventory and Monitoring (FIM) system was adopted to measure biomass [12]. Every cluster-plot covered an area of 505.1—673.5 m^2, consisted by 3-4 micro-plots, which were circle samples. Small scale and high accuracy survey were took on micro-samples, quadrats and transects. According to the result of tally survey, 2-3 mean trees of *Larix olgensis* outside each plot were selected and cut, add up to 21 in all. Stratified cut the above ground part and also dig under ground part from up to down of each mean tree to measure its fresh weight. Biomass of other species trees were estimated by the previous studies [13]. Fresh weight of understory layer (shrub& herb) and FWD were measure by harvest method, via 90 herb samples of 1.5m*1m, 24 shrub 2.4m and 66 5.69m long FWD transects [12]. With 24 14.64m long CWD transect, using diameter of both ends and length of CWD, volume were extrapolated, and then fresh weight. In a similar way, 38 RP circular samples within radius of 7.32m, shape, length, wide and height were used to calculate RP volume. Combined with another key variate—compactness, we would get fresh weight of RP [14, 15]. Considering forest biomass refers to the dry weight of organic matter on an unit area of forest, translated fresh weights into dry weight after drying the collected samples at 105°C. Finally, we figured out biomass of trees and stands by using estimate models of organs or components, while calculated biomass of undergrowth and down woody material according to the sampling proportion.

(ii). Carbon Storage Calculation

Pure carbon amount is the proportion of carbon in biomass. The relationship between carbon amount and biomass is:

$$M_C = \sum B_i \times c_i \quad (6)$$

In formula (6), M_C was pure carbon amount, B_i was biomass, c_i was carbon rate, *i* meant different organs or components. For the reason that the area of forest (*S*) is difficult to measure accurately, we usually take carbon density (ρ_C, carbon storage in a unit area) to express carbon storage. Using a formula expressed as:

$$\rho_C = M_C / S \quad (7)$$

2.2.3. Carbon Sink Economic Valuation

Pure carbon amount can be changed into CO_2 and O_2 with the chemical equation of photosynthesis, as followed:

$$CO_2(264g)+H_2O(108g)\rightarrow Glucose(180g)+O_2(192g)\rightarrow Polysaccharides(162g) \quad (8)$$

Thus, transformation relationships between C, CO_2 and O_2 were given:

$$M_{CO_2} = M_C \times 3.67 \quad (9)$$

$$M_{O_2} = M_C \times 2.67 \quad (10)$$

In formula (9) and (10), M_{CO_2} was the fixed quantity of CO_2, and M_{O_2} was the emission of O_2.

Afforestation cost method was the general method for calculating the value of CO_2, which is according to the relationship between CO_2 amount (absorbing by forest) and expense of afforestation [16]. The average afforestation cost was 260.90 RMB/t (same as 240.03 RMB/m^3 wood, changeless in 90 years) in China. The value of O_2 is 377.85 RMB/t, according to industrial oxygen price [17, 18].

3. Results and Analysis

3.1. Ecological Restoration

3.1.1. Community Structure Development

Plant species alternation and environmental heterogeneity were the main manifestation of *Larix olgensis* community after de-farming. "Species and Importance value" (Table 2) listed some primary arbors, shrubs and herbs of communities at different stages. Differences of species compositions visually reflect the recover, development and various structure characteristics of vegetation.

In arbor layer, Larix olgensis population number was declining; its importance value reduced from 83.06 to 57.65, due to the relatively difficult natural regeneration. But, other associated species populations number were growing, they entered the upper canopy gradually. In shrub layer, some dominant species replaced small shrubs and formed stable shrub populations, for instance, Corylus mandshurica Maxim. In herb layer, some sun herbs were pioneer population, like Artemisia stolonifera (Maxim.) Komar.. Then, Carex spp. Populations covered ground quickly in the beginning of conversion. Finally, Impatiens nolitangere L. and other humid type herbs developed into dominant species, with dynamic variation of increasing canopy density, decreasing under canopy light and moist soil. Species alternation in community (especially herbs) showed the changes of habitat and interspecific competition. This also revealed the phenomenon that the relatively even distribution of light, heat and water resources became uneven, which also caused the environmental heterogeneity [19].

With the comparisons between different stages communities by Sorensen index, we found that species compositions in communities varied with the stages. Specifically, the arbor layers were medium similar, but understory vegetations and phytocommunities were medium dissimilar. According to dynamic life-form spectrum, the development of community can be generally described as: annual herbs+small shrubs+ *Larix olgensis* seedlings→*Larix olgensis* +perennial herbs+big shrubs+broad-leaved trees→*Larix olgensis* +big shrubs+broad-leaved trees→mixed broadleaf- conifer forest with dominant *Larix olgensis* populations. Obviously, most species of formed communities were natural, except *Larix olgensis* was the only artificial species. Or, it might be thought that artificial plantation developed into natural ecosystem gradually.

Table 2. *Importance value and number of species of Larix olgensis plantation at different stages after de-farming.*

Layers	Specise	I	II	III	IV	V
Arbor layer	Specise Number	4	5	8	13	9
	Larix olgensis	83.06	73.00	68.31	69.53	57.65
	Quercus mongolica Fisch.	5.84				
	A. mono Maxim.	5.63	7.00	9.71		
	Fraxinus mandshurica Rupr					
	Ulmus pumila L.		10.00		5.46	14.08
	Betula platyphylla.			5.37	12.91	
	Picea jezoensis var. komarovii					7.80
Shrub layer	Specise Number	4	7	14	12	9
	Spiraea salicifolia L.	53.81				
	Rosa multiflora Thunb	16.19				
	Lonicera Chrysantha Turcz	30.00	18.29			
	Viburmum sargentii koehne		31.43	27.30		
	Corylus mandshurica Maxim		11.52	25.87	11.75	12.94
	Sorbaria kirilowii (Reqel) Maxim			26.83	18.61	15.90
	Philadelphus schrenkii Rupr.				14.44	17.28
Herb layer	Specise Number	41	34	24	21	20
	Artemisia stolonifera (Maxim.) Komar.	17.93				
	Dryopteris crassirhizoma Nakai.	4.98	6.06		8.12	9.31
	Filipendula palmata (Pall.) Maxim.	10.18	6.49	8.96		
	Cardamine leucantha (Tausch) O. E. Schulz	3.38	18.52	6.42	12.11	
	Carex lanceolata Boott	28.92	15.21	32.02	14.71	19.42
	Impatiens nolitangere L.		10.58	6.80	15.90	12.32
	Sium suave Walt			9.99	9.19	9.44
	Oxalis corniculata L.					15.91

3.1.2. Plant Diversity

Shannon-Winner diversity index (*H'*), Pielou evenness index (*J*) and Margalef richness index (*D*) were adopted for further quantitative analysis on communities species diversity. Firstly, as figure 1 showed, the trend of *H'* values of communities appeared as a reserve S-shape line. *H'* value was low at the beginning of conversion, then rose slowly, and maintaining a stable state, finally it reached a maximum rapidly at stage V [20]. But because of *Larix olgensis*'s dominant position, *H'* values were down overall. Secondly, *D* values showed a "hump-shaped" trend like the change rule of canopy density, and the peak value 7.180 occurred during III stage. Thirdly, with the growing in colonies of broad-leaved trees, shrubs and herbs, *J* shows "S" curve down trend, evenly distributed pattern of plantation space turned into mosaic heterogeneity. It was observed that diversity indexes as indicators of species composition and vegetation mortality dynamic.

Although the *J* value was highest, the *H'* and *D* values were lower, I stage had a great difference among other stages. Large diversity variation indicated that transitional period from I stage to V stage was in crucial period of restoration, tending wound conduct or increase natural evolution process. In V stage, optimum plants grew up readily, *H'* increased rapidly, *J* drop off precipitously, all revealed the effect of restoration. The research showed that, the average values of species, *H'*, *D*, and *J* of *Larix olgensis* plantations in this area were respectively 46, 1.733, 6.4439 and 0.128. In generally, the increasment of species improved the diversity and enhanced stability of reforestation ecosystem.

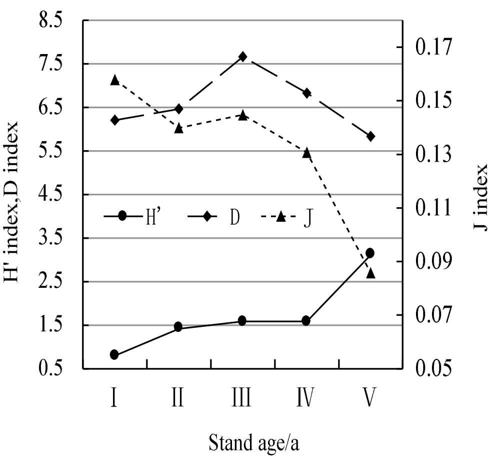

Figure 1. *Diversity index of communities at different stages.*

3.2. Carbon Density

3.2.1. Carbon Rate

Experiments indicated that carbon rate range of *Larix olgensis* organs was from 0.4742 to 0.5365, and there was no significant difference among different ages. In particular, the average carbon rate of each organs, such as stem, bark, branch, foliage and root, were 0.4969, 0.5267, 0.5212, 0.5075 and 0.5332. In understory vegetation, the average carbon rate of shrubs and herbs were 41.9135 and 46.2854. About down woody materials, the average carbon rate of FWD, CWD and RP were 34.3150, 37.3694 and 40.5195. All values the above-mentioned were similar with international general standards [21].

3.2.2. Community Carbon Density

(i). Arbor Layer-biomass-carbon

According to field survey data, we used fitting equations to estimate biomass of *Larix olgensis* and other trees. From figure 2 and figure 3, we can see that biomass and carbon density of *Larix olgensis* plantation increased over afforestation age. The average carbon density of arbor was 63.511t·hm^{-2}, which was 7.02 times than that of DWM, and 29.54 times than understory vegetation. The truth that arbor was more dominant than other layers suggest the fact of organic material production and accumulation of plantation. In particular, aboveground parts biomass held *Larix olgensis* 85% left and right sides of biomass, trunk took the lead, the follows were branches, roots and foliage. Though *Larix olgensis*'s biomass was growing, the ratio of it in whole arbor layer had been constantly on the decrease. For instance, the ratio of *Larix olgensis*'s biomass on the IV stage was only 58.28%, but that of other trees reached 41.72%, which reflected a growth trend of other tree species during restoration process. But, after experienced management of tending, biomass and its ratio arrived at the highest value on V stage.

Table 3. *Biomass of Larix olgensis plantation at different stages after de-farming t·hm^{-2}·(%).*

Stages	Tree	Biomass of tree organs				*Larix olgensis*	Other trees
		Trunk	Branch	Foliage	Root		
immature	5.283	1.651 (31.25)	0.943 (17.85)	1.754 (33.2)	0.935 (17.7)	4.024 (76.17)	1.259 (23.83)
juvenile	79.107	51.304 (64.85)	11.528 (14.57)	5.491 (6.94)	10.784 (13.63)	59.158 (74.78)	19.949 (25.22)
mid-aged	125.697	79.342 (63.12)	25.012 (19.9)	5.827 (4.64)	15.516 (12.34)	83.954 (66.79)	41.743 (33.21)
near-mature	168.563	105.749 (59.76)	43.460 (24.56)	9.398 (5.31)	18.359 (10.37)	106.636 (58.28)	61.927 (41.72)
mature	273.527	178.054 (67.16)	46.479 (17.53)	7.411 (2.8)	33.181 (12.52)	203.197 (77.36)	70.330 (22.64)
Mean	130.436	83.220 (63.72)	25.484 (19.14)	5.976 (4.92)	15.756 (12.22)	91.394 (70.93)	39.042 (29.07)

(ii). Understory Layer

Results showed that with the years passing by, understory biomass of *Larix olgensis* plantations were increased continually with a curve of J-shaped (R^2=0.9453, P<0.001, n=9). Since stand density had fallen, shrubs had good condition for survival and development of space. The rapid growth of shrub promoted understory vegetation's biomass; so biomass productivity of understory was still rising, though that of herbs reduced. Table 4 indicates understory carbon density varied from 0.907—5.006t·hm^{-2}, and the average value was 2.15t·hm^{-2}. Understory vegetation visually reflects the dynamic of revegetation and biodiversity, even though its carbon density accounting for only 2.88% of the whole reserves.

(iii). Down Woody Material

The survey found that only a little down woody material on the long-cultivated land at the early stage of conversion. Due to the low decomposition in a cold climate, and by the contimuous growing years, fine wood debris accumulated gradually, which was the main component of forest soil floor. Simultaneously, coarse woody debris and residual pile as falling stems and branches increased attributed to natural thinning and nurturing-cutting measures. Confirmatory analysis showed that DWM carbon density increased linearly with the increase of time (R^2=0.9618, P<0.001, n=9), and varied from 2.04t·hm^{-2} to 16.527t·hm^{-2} (Table 4). The mean value was 9.051t·hm^{-2}, accounted for 12.11% of the total, which was was comparatively considerable. DWM layer played a valuable role in carbon sequestration, and also was an important transition layer for promoting forest carbon reservoir to soil organic carbon pool.

Table 4. *Carbon density and distribution of Larix olgensis plantation at different stages after de-farming t·hm^{-2}·(%).*

Stages	Arbor layer	Understory layer	Wood debris layer	Community
immature	2.676 (47.59)	0.907 (16.13)	2.040 (36.28)	5.624
juvenile	40.187 (86.30)	0.948 (2.03)	5.433 (11.67)	46.568
mid-aged	64.030 (86.12)	1.466 (1.97)	8.856 (11.91)	74.352
near-mature	87.135 (85.47)	2.422 (2.38)	12.397 (12.16)	101.954
mature	123.525 (85.16)	5.006 (3.45)	16.527 (11.39)	145.058
Mean	63.511 (85.01)	2.150 (2.88)	9.051 (12.11)	74.712

3.2.3. Community Carbon Density Spatiotemporal Structure

According to results from Table 4 and Figure 2, the *Larix olgensis* plantations series's (from year 7 to year 46 year) carbon density soared from 5.624t·hm^{-2} to 145.0581t·hm^{-2}, achieved our fast-growing and high-yielding goal. We found that there are positive interrelationships between the carbon density and restoring time (R^2=0.9327, P<0.001, n=9).

Carbon density temporal distribution was immature > juvenile > middle-aged > near-mature > mature; and the average value was 74.711 t·hm^{-2}. Besides, in forest/woodland, carbon density spatial distribution was arbor > DWM > understory vegetation, and arbor played a leading role. Ratios of the three layers were 85.76%, 10.80% and 2.46%, without apparently fluctuations. This implied that the resources efficiency improved reasonable continually in community vegetations. But in newly established open forests, herbs were an main carbon density contributor as seedlings, which were very different from other stages of forest, so ratios of the layers were 47.59%, 16.13% and 36.28%. Research directly showed strong capacity of *Larix olgensis* plantations to produce and accumulate organic material. Also showed the expectation effect of re-vegetation in plantations. The above analysises were similar to some relative researches in China [9, 10, 22].

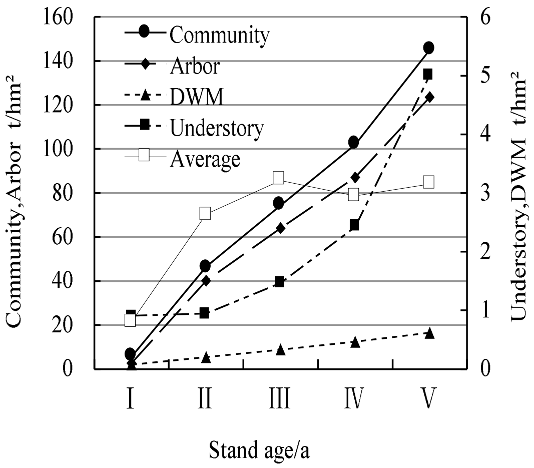

Figure 2. *Carbon density of community at different stages after de-farming.*

3.2.4. Plantation Carbon Sequestration Potential

Carbon density and its annual value were selected to weight the carbon sequestration potential. The difference of carbon density between forest and farmland truly reflect the benefit of GGP. It had been reported that crop carbon density and the annual values of net primary productivity were 4.995t·hm^{-2} and 2.094t·hm^{-2} in the northeast of China [23], which could be used as reference values. As Figure 3 showed, net primary productivity differences among stages suggested that: productivity was comparatively higher from stage 1 to 3 with sufficient develop resources and no serious competition; then, increased competition caused mortality, so productivity at a low level in stage 4. But, productivity rose gradually in stage 5 after trending and natural thinning. Meanwhile, forest carbon density was less than that of farmland at stage 1. But, from then on, forest carbon density were continued to increase, which was 1.51 times than that of farmland had accumulated in the past 46 years in stage 5. And the net increment between two land-use styles grew more and more.

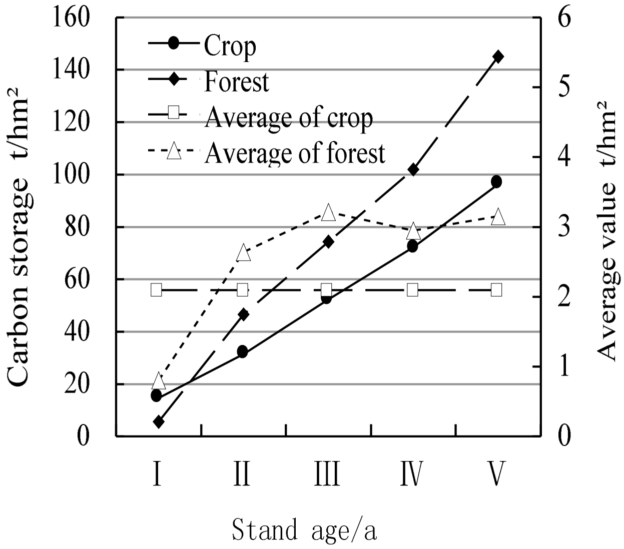

Figure 3. *Carbon storage and its annul value between farmland and forest.*

3.3. Carbon Fixation and Oxygen Release Benefit Evaluation

According to forest areas with different conversion years, and values about CO_2 and O_2, carbon fixation and oxygen release benefit evaluation can be obtained. The calculation results in Table 5 showed that, carbon storage of all grain for green land reached 106.624t, equaled to 13000.252t CO_2 and 2585.938t O_2 simultaneously. In addition, these amounts could converted into 339.177 thousand RMB CO_2 and 97.71 thousand RMB O_2, the total value of these two values was 436.887 thousand RMB, which meant remarkable economy benefit. It also showed juvenile forest's leading role in carbon fixation and oxygen release in Table 5, followed by middle-aged, near-mature and mature forest, except immature forest could not fully play its role yet. In this forest farm, majority of forest areas were in stage 1 and 2, so we could concluded that the farm had huge carbon fixation and oxygen release potential to exploit and play.

Table 5. *Economic benefits of CO_2 and O_2 of Larix olgensis plantation after de-farming.*

Items		**immature**	**juvenile**	**mid-aged**	**near-mature**	**mature**	**Total**
C density (t·hm^{-2})	Crop	14.655	31.404	52.339	72.228	96.305	266.931
	Plantation	5.623	46.568	74.352	101.954	145.058	373.555
	Difference	-9.032	15.164	22.013	29.726	48.753	106.624
Quantity(t)	CO_2	-2983.23	10073.012	2585.216	2072.786	1252.468	13000.252
	O_2	-593.37	2003.67	514.208	412.3	249.13	2585.938
Benifit (thousand RMB)	CO_2	-77.832	262.805	67.448	54.079	32.677	339.177
	O_2	-22.420	75.709	19.429	15.579	9.413	97.71
	Sum	-100.253	338.514	86.878	69.658	42.090	436.887

4. Discussion

With the analysis of the preceding context, we could accept that *Larix olgensis* plantation community on returned land had shaped a rational structure with efficient carbon sequestration function ultimately. Here, we presented and discussed some points about grain for green land, which still well worth further studying on.

1) Vegetation restoration speed and quality were the key standards for judging reforestation quality. After conversion, fast-growing Larix olgensis plantation accorded with ecological environment, and helped to achieve the targets of vegetation restoration and reconstruction on degraded farmland ecosystem. Interactions between Larix olgensis plantations and environment prompted reasonable assignment of light, heat, water resources and growing space, also community structure becomed more complex and stable, all of that showed good effect of ecological restoration, as described in some previous studies [4, 7, 24]. Changes of species composition and dominant species in plantation community taken place along with the increase of stand age, such as: Larix olgensis's advantage position became weaken in arbor layer; shrubs layer had strong capability of growth and regeneration; in herbs layer, dominating species belonged to humid type gradually. Through the variety of diversity indexes consistent with forest mortality changing rule, and communities in different stages had similarity and differentiation, simplex features about plantation were obvious. Or, going a step further, community still at the succession stage, and it would take a long time to maintain at a healthy and stable level. For this reason, the recovery community laws of species composition, space structures and succession dynamic required more long-term continuous field studies.
2) The carbon density both in quantity and composition on unit area was a symbolic target to judge a community and entironment stable or not. Compare to farmland, Larix olgensis plantation proved to be a stable and efficient carbon sequestration complex after conversion, the spatial distribution was arbor> DWM> understory vegetation. Typically, carbon storage mainly accumulated in Larix olgensis, that of other species trees, shrubs and DWM were all continuing to rise, but drop ceaselessly in herbs layer. Therefore, more attention should be turned to recover the arbors and shrubs if we took carbon sequestration function as the main goal. In addition, conversion year was the main factor effected carbon reserve, the temporal distribution was immature> juvenile> middle-aged> near-mature> mature, and wasn't decreasing with the decrement of stand density's. In general, carbon density was positively correlative with the conversion years; but due to lack of over-mature forest research data, it could not be guaranteed if carbon density increased continually or stabilized on a high plane, even returned to the low level of farmland.
3) Phenomenon of vegetation restoration and carbon density increment were the comprehensive result of natural selection and artificial guided, which reflected the effectiveness of GGP reconstruction measures to a certain extent. Most important of all, choosing native species as Larix olgensis to afforest on farmland promoted revegetation rapidly. In fact, we found that juvenile and middle-aged forest maintained higher productivity for a long while, which was identical to related research [25]. Then near-mature forest was at a critical management stage, for the higher mortality rate and relatively low productivity. But since thinning and tending by nature or human accelerated the growth of trees, carbon density increment was larger than the loss of decay and mortality in mature forest. Thus, thinning and tending generally resulted in the slacken of competition by removing niche overlap species, which promoted the development of arbor-shrub-herb complex structure and enhanced vegetation carbon sequestration function.
4) In this forest farm, the forest carbon storage with different conversion years can be ranked as: juvenile> immature> middle-aged> near-mature> mature [25]. Currently, most area of afforested land was immature and juvenile forest, which had tremendous latent carbon sink capacity and economic value. If economic compensation system of forest ecological benefits was firmly established, and carbon sink benefits could be put into market directly, revenues of forest resource management main body would increase, that would consolidate GGP achievements. Forest also had such ecological functions as water and soil conserving, etc. In the long-term, method of ecological functions quantification and value assessment of afforestation land demanded a further study.

5. Conclusion

GGP prompted the transition from farmland to forest of land-use, this would be conductive to achieve the target of restoration and reconstruction on farmland, which was regarded as a typical degenerated ecosystem. Compared with the previous farmland, the number of species in *Larix olgensis* plantation community increased to 46, species richness index and diversity index also reached 6.4439 and 1.733 respectively. Simultaneously, carbon density of *Larix olgensis* plantation community increased along with the stand age, the mean value of that was 74.711 $t \cdot hm^{-2}$. The amount of carbon fixed by this farm land was 106.624t, same as 13000.252t CO_2 or 2585.938t O_2, which equated 436.887 thousand RMB economic value. In a word, our studies about vegetation restoration and carbon sink benefits in *Larix olgensis* plantations, emphatically in different afforested years after the conversion from farm land, offered a theory base and reference for the GGP development and carbon sequestration market construction.

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