第 21 卷第 3 期
2001 年 3 月

生 态 学 报
ACTA ECOLOGICA SINICA

Vol. 21, No. 3
Mar, 2001

埋藏和环境因子对辽东栎(*Quercus liaotungensis* Koidz)种子更新的影响

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摘要:辽东栎萌生丛零散地分布在北京山区，虽然其种子量很大，但自然状况下的实生苗非常稀少。鼠类搬运并吃掉大量散落在地表的辽东栎种子，但鼠类是否影响辽东栎的自然更新尚不清楚。本研究主要在于了解:(1)将种子埋入土层内后对辽东栎种子出苗率的影响;(2)环境因子(如坡向、地表植被等)对辽东栎种子出苗率的影响。1996 年 9 月 24 日，选取 5 块样地(Site)，在每块样地各设置 1 条样线(Transect)，每条样线上设置若干样点(Plot)，样点间隔 10 m，用于种子埋藏实验。在每个样点设置 6 条平行线 (Parallel transect)，间隔 10 cm，各埋入 10 粒种子，种子间隔 2cm;第 1、2、3、4、5、6 条线的埋藏深度分别为 0、2、4、6、8、10cm。分别于 1997 年 6 月 15 日和 10 月 4 日调查出苗情况。研究结果表明，夏季和秋季辽东栎种子出苗率均与埋藏深度呈正相关。埋藏通过改善湿度和减少鼠类等动物的取食而增加了出苗率，其贡献分别占 18%和 12%。但鼠类对埋入土层内种子的取食率依然很高(87%)。辽东栎种子在阴坡和阳坡的最终出苗率都很高，但阳坡出苗要早于阴坡。夏季辽东栎种子出苗率均与地表植被覆盖度呈负相关。地表植被可能是通过与辽东栎种子竞争水分和养分而降低辽东栎种子出苗率的。辽东栎幼苗的高度与地表植被盖度和高度相关不显著。从夏季到秋季，辽东栎种子出苗率有所增加，主要是由于埋藏在深处或阴坡处的种子出苗较晚的缘故。

关键词:辽东栎(*Quercus liaotunggensis*);更新;鼠类;埋藏深度;种子采食;小气候

Effect of burial and environmental factors on seedling recruitment of *Quercus liaotungensis* Koidz

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Abstract: The Liaodong oak (*Q. liaotungensis* is sparsely distributed in the mountain areas of Beijing, China. Although with good acorn production the natural regeneration of the oak by direct seeding is extraordinary low. Previous studies indicated that rodents are very important in affecting seedling recruitment of the oak. The purpose of this study aims to investigate (1) impact of burial on the seedling recruitment; (2) impact of environmental factors (e.g. slope, ground vegetation cover) on seedling recruitment. On September 24, 1996, 37 plots of 5 sites were selected for acorn placement test. Six parallel 20 cm transects were located on each plot at 10 cm interval. Ten acorns were placed on the soil surface at 2 cm interval along the first transect of each plot. Acorns were then buried at 2 cm interval along the 2^{nd} transect of each plot, and acorns were planted similarly at increasing depths (4 cm, 6 cm, 8 cm, 10 cm) along the other transects within each plot. The numbers of seedlings was checked on June 15, 1997 and October 4, 1997 respectively. The seedling recruitment rate (seedlings/acorns, %) is positively correlated to the burial depth in both summer and autumn. The burial improved the seedling recruitment by both increasing the micro-climate (+18%) and reducing predation by rodents (−2%). However the predation rate by ro-

Foundation item: The project was sapported by National Natural Science Foundation of China (No. 39893360) and by Chinese Academy of Sciences (KZ 951-B1-106, KZ 952-S1-107)。

Recived date: 2000-04-16; **Accepted date**: 2000-06-10

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dents on acorns buried in soil was still very high (87%). Seedlings grew equally well in both sunny or shade slopes by autumn, but acorns planted in sunny slope germinated earlier. The seedling recruitment rate was significantly and negatively correlated with the ground vegetation cover only in summer. Dense ground vegetation cover reduced seedling recruitment probably by increasing competition for water or nutrition with the acorns. The seedling height was not significantly correlated with either grass cover or grass height. There was an increase of seedling numbers from June to October, and most of this increase came from the increase of seedlings planted deeper or in shade sites.

Key words: *Quercus liaotungensis*; oak regeneration; rodent; burial depth; acorn predation; seedling recruitment; micro-climate

文章编号:1000-0933(2001)03-0374-11 **中图分类号**:Q958 **文献标识码**:A

1 INTRODUCTION

Warm temperature broad-leaved forest is the primary zonal typical vegetation in the mountainous regions near Beijing, China. Primitive Liaodong oak forests, however, no longer exist because of extensive harvesting and burning, and the land being converted to cultivation since the early 1900s. Only small patches of secondary Liaodong oak forests or scrubs remain scattered among shrub and grass sites[1]. At present, efforts are being made to re-establish these forests. Before these reforestation efforts can be successful a full understanding of the natural regeneration process of these oak forests is essential.

Prior studies indicate that rodents are a primary factor in the survival of oak acorns. Acorn predation by rodents is thought to be responsible for the failure of oak regeneration on small fragment plots or on low-density forests. [2,3] Oak acorns that fall or are placed on the soil surface are quickly removed by predating vertebrates. Rodents are considered the primary culprit[2,4~7]. In most situations, the majority of seeds are sufficiently damaged by rodents to render them incapable of germination[2,8,9]. During years with abundant seed production, however, the existing rodent population is incapable of eating all the seeds and a large proportion escape predation. [10~13] Rodents also are recognized to have positive impacts on natural oak regeneration through their contribution towards seed dispersal and their tendency to bury uneaten seeds[14]. Acorn germination is poor for most oak species unless they are buried.

Sowing technique affects acorn predation and seedling recruitment[2,9]. Burying and scattering seeds reduces possible encounters with seed predators[5,7,15,17]. Rodents rely heavily on olfactory cues to locate seeds. Thus, their ability to detect seeds declines as burial depth increases or the size of a seed cache decreases[18~21]. Oak acorns also are vulnerable to desiccation through exposure to direct sunlight or high temperatures[20]. Therefore, burial also increases germination by protecting seeds from environmental factors.

Early survival of seedlings can be greatly increased by excluding small mammals and birds. Seeds placed on the soil surface beneath a wire mesh had a germination rate of 20.9%, while 39% of the seeds buried at a depth of 5 cm beneath an exclosure germinated[22]. These data indicate that predation is probably a primary factor in the natural oak regeneration rates of less than 0.1% (unpublished data). Unfortunately, wire mesh exclosures are not a feasible alternative to facilitate oak regeneration because they are costly to build and time-consuming to install, and unless removed they hinder seedling growth. Seed burial, however, also increases regeneration success and is a feasible option. This study addressed the two objectives: (1) determine the effects of burial depth on seedling recruitment; (2) determine the role of environmental factors seedling recruitment of Liaodong oak.

2 METHODS

2.1 Study area

The study was conducted on the Chinese Academy of Sciences's Beijing Forest Ecosystem Research Station located in the Xiaolongmen Forest Farm, Mentougou District. The station is approximately 114 km northwest of Beijing, at a latitude and longitude of 40°03' N, and 115°26'E. Elevation of the study area ranges from 800 to 1600m, and environmental conditions are typical for a warm-temperate zone. Dominant natural tree species in the area includes the Liaodong oak, birch (*Betula* spp.), poplar (*Populus davidiana*) and walnut (*Juglans mandshurica*). Filbert (*Corylus* spp.), lespedeza (*Lespedeza bicolor*) and spirea (*Spirea trilobata*) are the common shrubs. Chinese pine (*Pinus tabulaeformis*) and larch (*Larix princiis-rupprechtii*) are common in forest planted by local forest farms.

By using snare traps baited with fresh acorns of Liaodong oak as well as by direct observation, we found that rodents removed nearly all acorns placed on soil surface. The abundant rodent species included field mouse (*Apodemus speciosus*), striped field mouse (*A. agrarius*), white-bellied rat (*Rattus confucianus*), rat-like hamster (*Cricetulus triton*), gray squirrels (*Sciurotamias davidianus*), and chipmunks (*Eutamias sibiricus*). Though less abundant in the region other species that may prey on acorns include the house mouse (*Mus musculus*), Norway rat (*R. norvegicus*), brown-backed vole (*Clethrionomys rufocanus*). Prior studies have demonstrated that these species do consume oak acorns[7,23,26].

Oak scrubs sparsely occur across all elevations found within the study area and are present on both the southern and northern slopes of mountains. Oak acorns ripen towards the end of September through early October, and production varies greatly among years. Acorns were very abundant in 1995 and 1996, but sparse in 1997 and 1998. Acorns weight approximately 1.5g with no wind-dispersal features. Like most other oaks, acorns fall to the ground and dispersal is dependent on birds and mammals[14].

2.2 Burial depth and environmental conditions

Liaodong oak acorns were collected between September 20 and 22, 1996. Only acorns determined to be fresh, ripe and intact were used in the seed placement test. Five sites representative of different slopes were selected for the study (Table 1). Five plots were established along a transect at 10 m intervals on three of these sites (A, B, C), and 10 and 12 plots were established in the same manner on the other two sites (D, E). Subsequently, 6 parallel 20 cm transects were located on each plot at 10 cm intervals. Ten oak acorns were placed on the soil surface at 2 cm intervals along the first transect of each plot. Acorns were then buried at 2 cm interval along the 2nd transect of each plot, and acorns were planted similarly at increasing depths (4 cm, 6 cm, 8 cm, 10 cm) along the other transects within a plot. The test was initiated on September 24, 1996. Survival and height of Liaodong oak seedlings were recorded for all transects on June 15 and October 4, 1997. Vegetation ground cover and grass heights also were recorded for all plots. Vegetation ground cover is the proportion of grass cover within a plot area (20 cm × 60 cm), and was judged by nuke eye. Grass height is the average grass height above ground within the plot, and measured by using a ruler.

2.3 Data analysis

SPSS for Windows was the statistical program used to assess the results of the study. Correlation among seedling recruitment rate, seedling height and burial depth were identified with the Pearson correlation matrix. While the correlation among seedling recruitment rate, vegetation ground cover, and seedling height were determined with the Kendall correlation matrix. *T*-tests (2-tailed) for independent or dependent samples were used to compare means for seedling recruitment rate, seedling height among plots and seedling burial depth.

Table 1 Environmental conditions of five sites when checked on June 15 and October 4, 1997 (Means±SD)

Date	Slope	Site				
		A Facing south	B Facing west	C Facing north	D Facing east	E Facing east
Jun. 15	Grass height (cm)	6±2.2 (n = 5)	48±8.4 (n = 5)	14±5.5 (n = 5)	42±33.6 (n = 10)	30±16.5 (n = 12)
	Vegetation cover (%)	5±0 (n = 5)	18±5.7 (n = 5)	13±2.7 (n = 5)	16.5±4.1 (n = 10)	17.5±6.2 (n = 12)
Oct. 4	Grass height (cm)	5±0 (n = 5)	60±7.1 (n = 5)	46 ±18.2 (n = 5)	87±8.9 (n = 10)	67.1±19.1 (n = 12)
	Vegetation cover (%)	5±0 (n = 5)	16±4.2 (n = 5)	9±4.2 (n = 5)	26.5±7.5 (n = 10)	24.6±14.6 (n = 12)

Table 2 The seedling recruitment of the Liaodong oak (*Quercus liaotungensis*) after acorns were buried in soil when checked on June 15 and October 4, 1997. Diff. denotes the difference of seedling recruitment rates or seedling height from June to October (Means ± SD)

Date		Burial depth						
		0 cm	2 cm	4 cm	6 cm	8 cm	10 cm	Total
Jun. 15	Seedling recruitment rate (%)	0.0±0.0 (n = 37)	1.6±6.9 (n = 37)	3.5±9.8 (n = 37)	2.7±7.32 (n = 37)	7.6±17.4 (n = 37)	8.1±14.1 (n = 37)	3.9±9.3 (n = 222)
	Seedling height (cm)		5.7 ± 2.3 (n = 6)	6.5 ± 1.5 (n = 13)	6.2 ± 2.3 (n = 10)	4.8 ± 1.8 (n = 28)	5.3 ± 2.4 (n = 30)	5.4 ± 2.1 (n =87)
Oct. 4	Seedling recruitment rate (%)	0.0±0.0 (n = 37)	0.2±1.6 (n = 37)	4.3±13.4 (n = 37)	6.2±13.6 (n = 37)	11.6±17.6 (n = 37)	13.2±18.9 (n = 37)	5.9±10.9 (n = 222)
	Seedling height (cm)		5.5 (n = 1)	7.7 ± 3.9 (n= 16)	6.0 ± 2.5 (n = 23)	6.2 ± 2.0 (n = 43)	5.6 ± 2.0 (n = 49)	6.0 ± 2.2 (n = 132)
Diff.	Seedling recruitment rate (%)		−1.4 ns	+0.8 ns	+3.5 ns	+4.1 ns	+5.1 ns	+2.0 *
	Seedling height (cm)			+1.2 ns	−0.2 ns	+1.4 * *	+0.3 ns	+0.6 *

n is the sample size. ns-not significant * $p < 0.05$ ** $p < 0.01$ *** $p < 0.001$

3 RESULTS

3.1 Burial depth

Seedling survival and height varied depending on burial depth when measurements were taken on June 15, 1997 (Table 2). The seedling recruitment rate was defined as: seedlings/acorns×100%. The seedling recruitment rate was positively and significantly correlated to burial depth on all sites ($r = 0.9439$, $p < 0.01$) and across Site A ($r = 0.9155$, $p < 0.01$), Site E ($r = 0.8729$, $p < 0.05$). T-tests also revealed that seedling recruitment rates for acorns planted deeper were greater than those placed on the surface or planted shallower. Though not significantly there was a tendency for a negative correlation between seedling height and increasing burial depth (Table 2). T-tests did indicate a significantly greater plant height for seedlings from acorns planted at 4 cm than for seedlings from acorns planted at either 8 cm ($p < 0.01$) or 10 cm ($p < 0.001$).

Table 3 Seedling recruitment of Liaodong oak in five sites when checked on June 15 and October 4, 1997. Diff. denotes the difference of seedling recruitment rate or height from June to October (Means ± SD)

Date		Site				
		A	B	C	D	E
Jun. 15	Seedling recruitment rate (%)	11.3 ± 20.4 ($n = 5$)	0.3 ±1.8 ($n = 5$)	3.7 ± 10.0 ($n = 5$)	0.8 ± 4.2 ($n = 10$)	5.0 ± 10.7 ($n = 12$)
	Seedling height (cm)	4.3 ± 1.5 ($n = 34$)	3 ($n = 1$)	5.6 ± 1.9 ($n = 11$)	6.6 ± 1.5 ($n = 5$)	6.4 ± 2.3 ($n = 36$)
Oct. 4	Seedling recruitment rate (%)	9.7 ±16.9 ($n = 5$)	2.3 ± 9.7 ($n = 5$)	12.3 ± 21.3 ($n = 5$)	3.8 ±11.5 ($n = 10$)	5.0 ± 11.0 ($n = 12$)
	Seedling height (cm)	4.1 ± 1.4 ($n = 29$)	6.2 ± 1.4 ($n = 7$)	7.2 ± 3.1 ($n = 37$)	5.8 ± 1.8 ($n = 23$)	6.4 ± 2.3 ($n = 36$)
Diff.	Seedling recruitment rate (%)	−1.7 ns	+2.3 ns	+8.7 *	0 ns	+2.0 *
	Seedling height (cm)	−0.2 ns		+0.6 *	−0.8 ns	+0.6 *

n is the sample size. ns-not significant * $p < 0.05$ ** $p < 0.01$ *** $p < 0.001$

Seedling recruitment measurements indicated similar results when monitored on October 4 as they had in June (Table 2). Seedling recruitment rate continued to be positively correlated to the burial depth on all sites ($r = 0.9785$, $p < 0.001$), and across Site A ($r = 0.9573$, $p < 0.01$), Site B ($r = 0.8118$, $p < 0.05$), Site C ($r = 0.8881$, $p < 0.05$) and Site D ($r = 0.8637$, $p < 0.05$). The correlation coefficient between seedling height and burial depth also continued to indicate a non-significant negative trend. Height of seedlings from acorns planted at 4 cm was greater than height of seedlings from acorns planted at 10 cm ($p < 0.05$).

Rodent burrowing activities were commonly observed along transects where acorns were planted. Some trace of activity was observed along nearly all transects, an indication that rodents are able to locate buried acorns. Visual observations indicated that there was less burrowing activity along transects where acorns were buried at 8 cm or to 10 cm than along other transects.

3.3 Slope

Seedling recruitment rates on June 15 were obviously higher at Site A facing south than they were at Site B facing west ($p < 0.01$), Site D facing east ($p < 0.001$), Site E facing east ($p < 0.05$) (Table 3). Seedling height, however, was lower at Site A than they were at the other sites (Site C, $p < 0.05$; Site D, $p < 0.01$; Site E, $p < 0.001$). When rechecked on October 4, seedling recruitment was greater at both Site A facing south and Site C facing north were obviously higher than the other sites facing west or east ($p < 0.05$). Seedling height at Site A facing south was smaller than at the other sites ($p < 0.001$) and seedling height was higher at Site C facing south than at Site A, Site B and Site D ($p < 0.05$).

This result indicated that though seedling of Liaodong oak can germinate equally well in both sunny and shadow slopes by the autumn, and the seedling tend to grow higher in north facing slope.

3.4 Vegetation cover

Seedling recruitment rates varied among sites at least in part because of differences in ground cover. Seedling recruitment rate was negatively correlated to ground cover in the five sites on June 15 ($r = -0.8000$, $p < 0.05$), but the negative correlation between recruitment rates and ground cover was not significant on October 4 ($r = -0.4000$, $p > 0.05$) (Table 1 & 3). This may partially explains why the recruitment rates in Site B, D, and E with dense grass cover were much lower than that in Site A and C. Though there was a tendency for seedling recruitment rate and ground cover height to be negatively correlated this correlation was not significant. Seedling height was not correlated with either ground cover or with vegetation height. There was a positive correlation between ground cover and vegetation height on both June 15 ($r = 0.8000$, $p < 0.05$) and October 4 ($r = 1.0000$, $p < 0.01$). Similar result was achieved when all 37 plots of five sites pooled. The seedling recruitment rate was negatively correlated to vegetation cover on June 15 ($r = -0.2659$, $p < 0.05$). This correlation on October 4 was not significant ($r = -0.0784$, $p > 0.05$). The correlation between vegetation cover and height was also significantly positive on June 15 ($r = 0.6088$, $p < 0.05$) and on October ($r = 0.8104$, $p < 0.05$).

3.5 Seasonal differences

Total seedling recruitment and height significantly increased ($p < 0.05$) from June to October (Table 2). Though not significant there was a decline in seedling recruitment rate at 2 cm, an increase at 4 cm and a high increase at 6 cm, 8 cm and 10 cm (Table 2). There was a significant and positive correlation between the difference of the seedling recruitment rate from June to October and burial depth ($p < 0.01$). The correlation between the difference of seedling height from June to October and burial depth was not significant. This suggested that the seasonal increase of seedling recruitment rate mostly came from acorns buried deeper, and increase of seedling height was not much related to burial depth.

The seasonal increase of seedling recruitment rate and height were also affected by slope. There were a significant increase ($p < 0.05$) of both seedling numbers and height at Site C facing north and Site E facing east, while there was a small but insignificant decline in seedling numbers and height at Site A facing south (Table 3). This indicated that seasonal increase of seedling numbers and height mostly came from shade or semi-shade or non-sunny sites.

4 DISCUSSION

4.1 Seedling burial

Seedling recruitment rate was higher when acorns were buried in the soil rather than simply placed on top (Tables 2). These results compared favorably with prior studies [5,7,15,17]. Ovington and MacRae found a 1% above ground germination of *Quercus petraea* in places where predation was excluded, jumped to 80% when the seeds were buried[15]. Shaw demonstrated improved germination with increasing amounts of cover[5]. Acorns placed on the surface had a germination of 48%, while germination of acorns covered with a layer of litter increased to 59%, and germination of acorns covered with a few centimeters of soil rose to 63%.

Acorn burial benefits seedling recruitment by reducing predation by vertebrates and insects and by improving the micro-climate (e.g., moisture) which enhances germination. Wire mesh exclosures that restricted access to rodents increased seedling recruitment in our prior study[22]. These results are similar to other studies where rodents were denied access to acorns[2,4~7]. Burial obviously reduces visual contacts and probably disrupts olfactory cues. Rodents can locate seeds through emitted odors[18]. Burial may reduce but does not eliminate rodent predation of acorns. We observed rodent burrowing activity along many of the transects where seeds were buried. Activity declined, however, along transects where seeds were buried the deepest, perhaps because the additional cover reduced odors. Burial does virtually eliminate acorn loss to deer and other large mammals[16], as well as birds[27]. Buried acorns also have the advantage of soil moisture. Improved moisture increases the vigor, therefore, the survival of emerging seedlings[20]. Acorns are vulnerable to low moisture, intense sunlight and low temperatures[20]. Surface-sown acorns, compared to buried acorns, are more susceptible to overheating and desiccation, failure of the radicle to penetrate the soil surface, and more vulnerable to mold[28]. Therefore, though acorn predation is extremely detrimental to seedling recruitment, burial and dispersal or acorns by some rodents is extremely beneficial.

The contribution of improved moisture and reduced predation after acorn burial on oak recruitment have been demonstrated in other studies[17,27]. Borchert demonstrated that seedling survival (8.6%) was minimal if seeds were laid on the surface with no protection from rodents[17]. Survival increased slightly if unprotected seeds were buried (31.1%). If surface seeds were laid on surface and protected from predators, survival increased to 38.6%. The best recruitment (54.5%) occurred when seeds were buried 1 to 3 cm and protected from predation. Kollman and Schill found similar tendencies, surface sown seeds had the lowest survival (2.4%), survival increased to 12% when buried without protection, and when protected from rodent jumped to 33.8% and 99.0% when surface sown and buried (5 to 6 cm), respectively[27]. Our prior study concurred with these studies, recruitment was very low if seeds were deposited unprotected on the soil surface (0.3%), improving if protected from predation (20.9%), and the greatest recruitment occurred if seeds were protected and buried (39.0%)[22]. The current study supported the previous findings, no recruitment if acorns were left on the surface, but improving with increasing burial depth (Table 2).

Operational burial of acorn benefits seedling survival through improved moisture conditions and reduced predation. Which has the greatest impact is not clear[29]. We propose the following model to interpret the benefits.

$$R_1 = R_0 \times (1 - P)$$

Where: R_1 is the recruitment rate observed with predation

R_0 is the recruitment rate in the absence of predation

P is the proportion of acorns removed by predators

The parameters in this model were calculated for three case studies (Table 4). The improved seedling recruitment in the study by Borchert *et al*[17]. was 15.9% because of micro-climate and 34.8% because of reduced predation. The recruitment rate in Kollman and Schill's study[27] increased primarily because of soil moisture (65.2%) and predation was reduced slightly (5.02%). The model applied to our study[22] with *Quercus liaotungensis* suggests that burial increased seedling recruitment 18.1% because of moisture conditions and 12.03% due to a decline in predation.

Differences among benefits found in the above studies probably reflect variation in species and density of predators, environmental conditions, alternative forages and the density of acorns. High density of acorn consuming predators obviously results in a higher predation loss. Environmental conditions also impact seedling survival, favorable conditions (e.g., rainfall, humidity, etc.) enhance germination and vigor, while unfavorable (e.g., poor soil, dry, etc.) impedes survival regardless of predation. Habitat conditions influence the density of predators and dictate the foraging choices of rodents. An abundance of acorns with relatively few predators can lead to predator saturation leaving surviving acorns untouched[10~13]. However, where high predator population exists increased acorn density is likely to attract predators. Single acorns are more likely to escape predation than clumped acorns[2]. Stapanian and Smith found the survival of buried acorns was negatively related to acorn density due to increased predator pressure on high-density nuts. Acorns on the surface also attract predators[16]. Buried acorns are more likely to be found by predators if located near a surface acorn than if buried beneath a surface barren of acorns[2]. The high acorn predation rate in this study may have been because the acorns were clumped and buried acorns were in close proximity to acorns on the surface.

Table 4 Changes of recruitment rates improved by increased moisture and reduced predation after acorns were buried in soil. R_1 is the recruitment rate observed with predation. R_0 is the recruitment rate in the absence of predation. P is the proportion of acorns removed by predators

Case study	Treatments	R_0	P	R_1
Borchert *et al.*	On surface	0.386	0.7772	0.086
	Burial[1]	0.545	0.4294	0.311
	Change	+ 0.159	− 0.3478	+ 0.225
Kollmann and Schill	On surface	0.338	0.929	0.024
	Burial[2]	0.99	0.8788	0.12
	Change	+ 0.652	− 0.0502	+ 0.096
This study	On surface	0.209*	0.9856	0.003*
	Burial[3]	0.39*	0.8653	0.0525#
	Change	+ 0.181	− 0.1203	+ 0.0495

1 burial 1～3 cm; 2 burial at 5～6 cm; 3 burial at 4～6 cm; # data from Zhang *et al.* (1998)[22]; * data from this study.

4.2 Slope

The slope of a hillside impacts seedling recruitment, because the degree and direction of the slope influences the micro-climate of the acorn. Surface sown acorns of *Quercus petraea* grow better on northwest facing slopes than on south facing slopes[27]. Blue oaks (*Quercus douglasii*) readily germinate on north facing slopes and rarely germinate on south facing slopes[28]. Andersson reported that *Q. robur* germinated equally well in open and shaded parts of a deciduous forest[30]. In our study acorns planted on north and south facing slopes germinated equally well by the autumn. This result also concurred with the observation that Liaodong oak forests occur in both sunny and shade slope. The reason why acorns planted in south facing slope germinated earlier might be because earlier warm soil temperatures permitted earlier sprouting on south-facing slopes relative to north-facing slopes. However, seedlings grew shorter in sunny slope than it grew in shade slope (Table 3). The poor growth of seedling in sunny slope may be caused by lack of water during the dry very period from summer to autumn of 1997. Moisture may also affect the seedling recruitment of this year similarly. Both seedling numbers and height increased in shade slope Site C, while seedling numbers and height decreased in sunny slope Site A. We did observe some dead and dry seedlings in sunny slope Site A, which not only reduced seedling number but also the average seedling height of the group. These dead seedlings were not due to clippings by animals.

4.3 Vegetation

Existing vegetation can compete with new plants for light, water and nutrients, or benefit them by providing cover and alternative food sources for animals. Stapanian and Smith reported oak seedling recruitment to be positively correlated with increasing canopy cover and more mesic micro-sites at low elevations, but to be negatively correlated with these same factors at the cooler, high elevation sites[16]. Vegetation also provides increased cover for predators. Borchert *et al.* found acorn predation to increase under oak canopies[17]. The scrubs and trees on our study sites were too low and sparse to form a significant canopy, and probably had minimum impact on seedling recruitment.

Grasses and other short vegetation are more likely to compete with seedlings for resources than the sparse over-story canopy in our study. Several studies have demonstrated seedling mortality due to direct competition with existing plants[31,32]. Seedling recruitment of Liaodong oak in our study was negatively correlated with ground cover.

Dense ground vegetation also provides better cover and shelter for rodents and other seed predators. Increasing plant cover and seed removal by rodents is usually positively correlated[7,33]. Cover is an important factor favoring foraging activities of mice[34], and acorn predation and hoarding by mice is generally highest under shrubs and in non-mowed grasslands[27]. Acorns of *Quercus mongolica* usually disappear more rapidly from sites with ground cover than barren sites[7]. Conversely, Herrera reported no acorn predation under dense shrub, but 52% predation under open shrub[2]. Differences probably relate to the type of predator. Dense scrub is a good deterrent to large animals, such as most ungulates. Observations of seed predation differing among micro-habitats as a function of predator behavior are frequently reported[33,35~37]. Mice populations are probably higher in tall-grass rather than short-grass fields because of better hiding cover from avian predators[27]. Ground cover does not appear to have had a significant impact on rodent predation in our study because our prior study in the same region did not found much links between occurrence of rodents and ground cover[38].

4.4 Seasonal change

The general increase of seedling numbers from June to October indicated that acorn germination is not very synchrony. Acorns buried deeper or in shade plots would took longer time to sprout out because low temperature usually slow down the seedling growth. The seasonal change of seedling recruitment from June to October (Table 2~3) might also be affected by moisture condition. Acorns buried shallower or in south facing slope experienced less increase or even decline of seedling numbers (Table 2~3), probably due to the low moisture during the very dry summer of 1997.

4.5 Management implications

Natural regeneration of oak forests is impeded through low germination rates and high acorn predation. Herrera concluded that the prospects for the natural establishment of cork oak seedling are slim because of the current low number of potential parent trees, the lack of effective seed disperses, and a superabundance of predators, such as ungulates[2]. Santos and Telleria reported that mice were apparently responsible for the failed sexual reproduction of cork oaks in small fragmented stands[3]. The combined negative impact of these factors renders the prospect for natural regeneration to be slow at best. Jensen and Nielson reported that out of 485 planted *Quercus robur* and *Q. petrea* acorns only 12 became seedlings[14]. Herrera buried 211 acorns, of which 49 germinated but only 2 seedlings survived the first year and none survived through the second year. Jensen and Nielson estimated that for oak shrubs to extend 300m into a Danish heathland under the natural dispersal of rodents and birds required a 100 years[14].

Natural regeneration can not satisfy the urgent demand for rapid recovery of areas denuded through harvesting, fire or cultivation. Direct seeding or planting seedlings is necessary to establish desirable forests. Advantages of direct seeding are the reduced costs and the relative ease of producing and handling seeds[39]. Reforestation efforts through direct seedling, however, are often futile unless tied to measures to reduce seed predation. Repellents have been marginally effective at reducing seed consumption by vertebrates. Black reported endrin reduced mice consumption of treated Douglas-fir seeds to 52% compared to their eating 93% of untreated seeds[40]. A capsicum and thiuram mixture also offers some protection against mice predation (Dale Nolte, personal communication). Planting costs increase, but seedling establishment is greatly enhanced if seeds are sown into the soil rather than spread on the surface[41]. Unfortunately, direct planting of developed seedlings, which eliminates potential of seed predation, is expensive and requires extensive nursery facilities.

We conclude, therefore, that the most feasible means to establish Liaodong oak forests in the study regions is to sow acorns directly into the soil. A planting depth of 8 to 10 cm is recommended in dry years or on south-facing slopes, whereas 4 to 6 cm is probably better in wet years or on north-facing slopes. Ground cover removal is recommended before sowing acorns on sites with dense grass.

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