EFFECT OF BURIAL ON ACORN SURVIVAL AND SEEDLING RECRUITMENT OF LIAODONG OAK (*QUERCUS LIAOTUNGENSIS*) UNDER RODENT PREDATION *

ZHANG Zhibin WANG Fusheng

(*National Key Laboratory of Integrated Pest Management on Insect and Rodent in Agriculture, Institute of Zoology, the Chinese Academy of Sciences, Beijing*, 100080, *P.R.China*.)

Abstract: Liaodong oak (*Q. liaotungensis*) forest is the zonal typical vegetation in maintains of Beijing, China. Prior observation indicated that rodents might be involved in acorn predation and then affected oak regeneration. This study aims to investigate three questions: (1) what kind of rodent species attributed acorn disappearance of Liaodong oak? (2) can burial reduce acorn predation by rodents and improve seedling recruitment of Liaodong oak? (3) will ground vegetation affect seedling recruitment rate of the oak? In September of 1996, 37 plots of 5 sites were located for acorn placement test. Ten acorns were placed on the soil surface of each plot. Acorns on soil surface were checked 1, 10, 20 days later after acorn placement. Wooden snare traps baited with oak acorns and peanuts were used for identifying key rodent species of removing the acorns. Five sites were located for burying 50 acorns at 5 cm in soil within one square meters at each site. Seedling numbers and seedling height were measured next year. Three rodent species (i.e. *Apodemus speciosus*, *Rattus confucian* and *A. agrarius*) were found to consume the acorns, and the proportion of acorn consumed was related to their abundance. Among the 370 acorns which were placed on soil surface in 37 plots of 5 sites, 15.1% of them disappeared next day, 78.1% disappeared 10 days later and all of them disappeared 20 days later. Among 250 acorns buried in five sites, 11.2% of them sprouted out with an average height of 7.8 cm. Therefore, burial can effectively reduce acorn predation by rodents. The seedling recruitment rates in five sites tended to negatively correlate with grass cover and height. It was suggested that direct seeding can facilitate oak reforestation.

Key words: *Quercus liaotungensis*; Oak regeneration; Rodent; Burial; Seed predation; Seedling recruitment

CLC number: Q958.12; **Document code**: A; **Article ID**: 1000-1050 (2001) 01-0035-09

In mountains of Beijing, China, warm temperate broad-leaved deciduous forest is the zonal typical vegetation. Because of extensive cutting, burning and cultivation since this early century, only small patches of secondary Liaodong oak forests or scrubs scattered among

* **Foundation item**: The study was supported by the key project (39893360) of China National Natural Science Foundation and key projects (KZ951-B1-106, KZ952-S1-107) of the Chinese Academy of Sciences

Biography: Zhang Zhibin (1964-), male, PhD, Research Professor, PhD Supervisor, is engaged chiefly in rodent population dynamics and ecosystem function, E-mail: zhangzb@panda.ioz.ac.cn.

Received date: 1999-10-26; **Accepted date**: 2000-01-18

shrubs or grasses[1]. It is very essential to understand the natural regeneration of the oak for reforestation.

Many previous studies indicated that rodent is a very important factor in affecting seed-fate of oak. Oak acorns fallen or placed on the soil surface disappear very quickly due to heavy predation by vertebrates, especially rodents. It is well recognized that rodents remove most acorns[2-6]. In most situations, nearly all the removed acorns by rodents were consumed and only very few acorns were able to become seedlings[6-8]. However, in some situations, rodents only consume a small proportion when abundant seed production leads to seed predator satiation[9-12]. Predation by rodents was sometime blamed for the failure of some oak seeding regeneration in small fragments or low-density oak forests[6,13]. Rodents were also recognized as an important agent for oak regeneration because they disperse and bury acorns[14]. The germination of many oak species is very poor on soil surface without acorn burial and dispersal by rodents.

Burial is found to be a potential measure in reducing acorn predation by rodents (as well as other vertebrates) and increasing seedling recruitment[3,5,15-17]. Rodent locates seeds mainly by odor, and its success in finding seeds usually decrease as the depth of burial increase or as the size of seed cache decrease[18-20]. Oak acorns are particularly vulnerable to damages by drying, intense sunlight or temperature[21]. Thus burial also increases seed germination through providing protection and improving moisture. However, because of differences of acorn foraging behavior of rodent, spatial and temporal heterogeneity of habitat as well as rodent density, the success of burial could vary greatly[6,8].

The natural regeneration of the Liaodong oak is extraordinary low in the study area (Ma Keping, personal communication). We speculated that rodents might have destroyed large amount of acorns of the oak. This study aims to investigate three questions: (1) which rodent species attribute acorn disappearance of Liaodong oak? (2) can burial reduce acorn predation by rodents and improve seedling recruitment of Liaodong oak? (3) how ground vegetation affect seedling recruitment?

1 STUDY AREA AND METHODS

1.1 Study area

The study was carried out nearby the Beijing Forest Ecosystem Research Station of Chinese Academy of Sciences. The station is located in the Xiaolongmen Forest Farm, Mentougou District, Beijing, China. The station lies about 114 km northwest of downtown Beijing, at a latitude and longitude of 40°03′ N and 115°26′E. The elevation of the study area ranges from 800 m to 1 600 m. It is a typical area of warm-temperate zone. Apart from oak, birch (*Betula* spp.), poplar (*Populus davidiana*) and walnut (*Juglans mandshurica*) are commonly found in the region. The Chinese pine (*Pinus tabulaeformis*) and larch (*Larix principis-rupprechtii*) are planted forests by local forest farms. Filbert (*Corylus* spp.), les-

pedeza (*Lespedeza bicolor*) and spiraea (*Spiraea trilobata*) are dominant shrub species in this area.

1.2 Key rodent species

Wooden snare traps baited with fresh and ripe oak acorns were used for identifying rodent species of removing oak acorns. A total of 226 traps were placed in different habitats in the study area in October of 1996. For comparing the food preference of rodents to oak acorns, another 774 wooden traps baited with fresh peanuts (the routine bait for snare trapping) were used to trap rodents.

1.3 Acorn disappearance and predation by rodents

The fresh ripe and intact acorns of Liaodong oak were collected on September 20 to 22, 1996 for seed placement test. A total of five sites which represent different habitats were selected, and a transect line was located in each site. For three sites, five plots were located with an interval of 10 m apart along each transect line. For the other two sites, ten and twelve sites were located respectively in same way. At each plot, ten oak acorns were placed on soil surface. The test began on September 24, 1996, and acorns on the soil surface were checked 1 day, 10 days and 20 days later.

1.4 Effect of burial on acorn predation and seedling recruitment

Six sites in a north-facing slope were located for acorn burial test. Fifty acorns were buried 5 cm deep in soil evenly in an area of one square meter at each site on October 25－26, 1997, with minimum disturbance to soil and grasses. The seedling numbers and seedling height were measured on May 20, 1998. The ground grass cover and height were also measured.

1.5 Statistics

SPSS for Window was employed for statistic analysis. Pearson correlation was used for analyzing correlation between seedling numbers or height and grass cover or height. Non-parametric Chi-square and Bionomial Tests were used for identifying the difference of rodent abundance obtained by two methods.

2 RESULTS

2.1 Key animal species affecting acorn disappearance

In October of 1996, a total of 98 rodents were captured by using 774 wooden traps baited with peanuts, among them *Apodemus speciosus* making up 63.3%, *Rattus confucian* making up 8.2%, *A. agrarius* making up 21.4%, *Cricetulus triton* making up 7.1%. A total of 16 rodents were captured by using 226 wooden traps baited with fresh acorns of *Liaodong oak*, among them *Apodemus speciosus* making up 62.5%, *Rattus confucian* making up 12.5%, *A. agrarius* making up 25%. This result indicates that three rodent species (i.e. *Apodemus speciosus*, *Rattus confucian* and *A. agrarius*) attributed to the most acorn disappearance, and abundance of these three species obtained by using traps baited with peanuts was not significantly different from that obtained by using traps baited with

acorns ($P = 0.920$, $df = 2$) (Fig.1). The abundance of *C. triton* between these two methods was also not significant ($P = 0.308$, Binomial test). Therefore, acorn disappearance in this study is assumed to be due to predation by rodents.

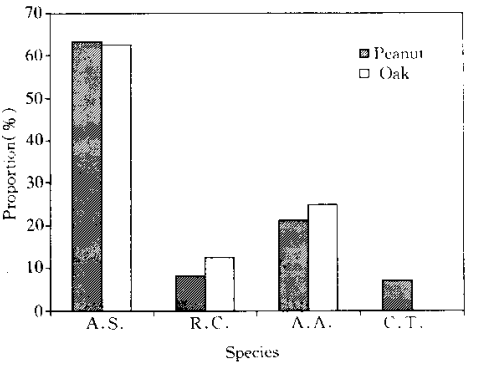

Fig.1 Proportion of rodent species captured by using wooden snare traps baited with peanuts (shadow bar) and oak acorns (open bar)

A.S. denotes *Apodemus speciosus*; R.C. denotes *Rattus confucian*; A.A. denotes *Apodemus agrarius*; C.T. denotes *Cricetulus triton*

2.2 Acorn disappearance on soil surface

A total of 370 acorns were placed on soil surface in five plots, and 15.1% disappeared next day, 78.1% disappeared 10 days later and all of them disappeared 20 days later (Fig.2). This result indicated that seed removal by rodents was very great after acorns fallen on the ground.

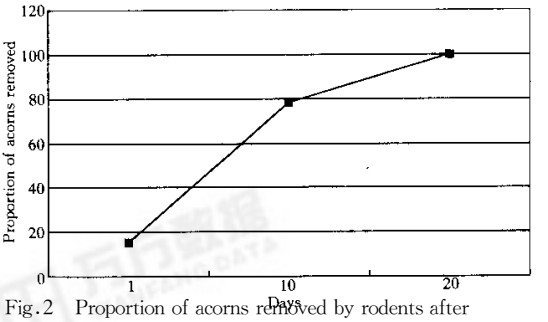

Fig.2 Proportion of acorns removed by rodents after acorns were placed on soil surface.

2.3 Impact of burial on acorn predation and seedling recruitment

The mean seedling recruitment rate (seedlings/acorns × 100%) in five sites was 11.2% after acorns were buried in soil (Table 1). This result clearly indicated that burial could effectively reduce acorn predation by rodents, and thus improved seedling recruitment rate. The burrowing activities of rodent at sites where acorns were buried were commonly observed. Nearly all sites showed traces of burrowing activities of rodents. This implied that rodents were much able to locate the buried acorns.

Table 1 Seedling numbers and height when checked on May 20, 1997 after fifty acorns were buried at 5 cm deep in each site on October of 1996

Site	1	2	3	4	5	Mean ± SD
Seedling recruitment rate (%)*	14	24	2	6	10	11.2 ± 8.4 ($n = 5$)
Seedling height (cm)	6.4 ± 1.7 ($n = 7$)	8.0 ± 2.7 ($n = 12$)	7.5 ($n = 1$)	7.0 ± 1.7 ($n = 3$)	9.5 ± 1.8 ($n = 5$)	7.7 ± 1.2 ($n = 5$)
Grass height (cm)	14	22	35	30	35	27.2 ± 9.1 ($n = 5$)
Grass cover (%)	80	70	80	95	90	83.0 ± 9.7 ($n = 5$)

* The seedling recruitment rate is seedlings/acorns × 100%

2.4 Impact of environmental factors

The variation of seedling recruitment rates within the 5 sites was somehow associated with grass vegetation cover and height (Table 1). Though not significant, the seedling re-

cruitment rates tended to negatively correlate with grass cover ($r=-0.663$, $P=0.223$, $n=5$) and height ($r=-0.649$, $P=0.236$, $n=5$).

3 DISCUSSION

3.1 Species affecting acorn disappearance and recruitment

In this study, only four rodent species were identified as major agents for acorn disappearance on surface by using snare traps baited with oak acorns. There are several other rodent species (including *Crecetulus triton*) which were not captured by using this method in this region. Those species are house mouse (*Mus musculus*), Norway rat (*Rattus norvegicus*), brown-backed vole (*Clethrionomys rufocanus*), gray squirrels (*Sciurotamias davidianus*) and chipmunks (*Eutamias sibiricus*). The major reason would be because of the small probability of being captured due to their small abundance and small extensive trapping effort. Some rodent species such as brown-backed vole, gray squirrels, chipmunks have been observed to eat oak acorns in some previous studies[5,22-25]. Except for rodents, several other large animals like birds, deer, wild pigs, cattle also attributed to acorn removal of oak[6,16,26]. In this region, some birds such as *Garrulus glandariu pekingensis*, *Phasianus colchicus karpowi*, and wild pig (*Sus scrofa*) were observed to eat oak acorns by local residents.

3.2 Impact of burial on acorn predation and seedling recruitment

This study clearly indicated that burial effectively reduced acorn predation and improved seedling recruitment rate of the Liaodong oak. This observation is very similar to many previous studies[3,5,15-17]. Ovington and MacRae found 1% germination of *Q. petraea* on the surface compared to 80% in the soil (seed predation excluded)[15]. Shaw recorded the following percentages of germination: (a) on surface, 48% acorns germinated, (b) beneath a layer of litter, 59%, and (c) a few centimeters into soil, 63%[3].

Burial could reduce acorn predation by rodents, which much depend on odour when locating seeds[18]. However, the capacity of burial in reducing acorn predation may vary depending on the species and environments. According to our observation, rodents are quite capable of locating acorns in soil because burrowing holes were commonly seen at sites where acorns are buried. Burial may also eliminate competition from deer and other large animals[16], and effectively eliminates avian competition for acorns, because birds have a poor sense of smell[26].

Burial in the soil also benefits emerging seedlings since buried seed often produce more vigorous seedlings due to the improved moisture[21]. Griffin observed that in the absence of predator, surface-sown acorns are more susceptible to overheating and desiccation, failure of the radicle to penetrate the soil surface, and mold[27]. Acorns are particularly vulnerable to damage by drying, intense sunlight, or low temperature[21]. Therefore, burial by animals is very important for the regeneration of oak, especially for some oak like the central California

oaks which is poorly adapted to surface germination[21].

The natural regeneration of oak in 1996 - 1997 was estimated at 0.1% - 1% (Zhang Zhibin, Unpublished data). The proportion of seedling recruitment through burying acorns in soil was very larger than the natural regeneration rate through rodent dispersal. Therefore, it is concluded that most of the acorns was consumed by rodents although few of them can escape their predation.

3.3 Impact of vegetation on seedling recruitment

There are two possible explanations on how ground vegetation affects seedling recruitment rate. One explanation is that dense ground vegetation competes for water and nutrition with oak seedlings. This explanation was supported by some studies, which suggested that much seedling mortality resulted from competition with existing plants[28,29]. The other explanation is that acorns buried at habitats with dense vegetation suffer more predation because dense vegetation has more visits of rodents by providing safer shelter for them. Several studies have shown a positive correlation between plant cover and seed removal by rodents, which prefer dense habitats[5,30]. Acorns of *Q. Mongolica* usually disappeared more rapidly from habitats with ground cover than those without ground cover[5]. Kondo suggested that the ground cover is an important factor favoring the activities of mice[31]. Kollmann and Schill reported that acorn predation and harding by mice were highest under scrub and in unmown grassland[26]. However, Herrera reported the predation rate is zero under dense heath scrub, but 52% under open scrub[6]. Dense scrub is a good deterrent to predation by large animals like ungulate. Observation that seed predation differs among micro-habitats as a function of predator behaviour, e.g. hiding from their own predators, are frequently reported[30,32,33]. The main reason for higher abundance of mice in unmown abandoned grass is probably better protection against avian predators[26]. Therefore, the role of ground cover in reducing acorn predation much depends on the predators and their foraging behaviors. In a previous study, we found there was not much relation between rodent occurrence and habitats[34]. Rodents are very capable of finding acorns on soil surface.

3.4 Implication for oak reforestation and management

Many studies have shown worries about natural regeneration of oak forests because of its low recruitment rate and high acorn predation by rodents. Herrera concluded that the prospect for natural establishment of cork oak seedlings are slim because of the low population density of tree, the lack of effective dispersers, and a superabundance of predators like ungulates[6]. Such conditions definitely have a harmful effect on the regeneration of this once abundant species. Santos and Telleria reported that predation by mice was apparently responsible for the failure of sexual reproduction in the small fragmented stands [13].

Directing seeding and planting seedling are two major ways for reforestation. Direct seeding has obvious advantage over planting seedlings in terms of cost and easiness of handling. Many experimental seeding projects conducted by US Federal and State agencies and

private companies showed that successful seeding is impossible without effective control of seed-eating mammal[35]. Sowing seeds in soil was proven effective in increasing seedling establishment in other forest trees. Radvanyi found when seeds were covered by snow or litter, only 16 percent of the white spruce seeds were destroyed by mice and shrews, while 46 percent of them were destroyed when tagged white spruce seed were just put out on the ground surface[36]. Forget and Milleron concluded that seed artificially buried have more chance to escape seed predation than unburied seeds under natural condition[37].

As demonstrated in some previous study as well as in this study, many factors affect the result of burial. For reforestation of Liaodong oak forests in the study region, we suggest to sow acorns at 5 cm deep in soil. In areas with dense grasses, site preparation of clearing grasses is recommended before sowing acorns.

Acknowledgements: We are grateful to Mr. Zhibin Meng and Mr. Shoushen Hao for their help in field for this study.

REFERENCES:

[1] Chen L Z. The importance of Dongling Mountain region of warm temperate deciduous broad-leaved forest [A]. In: Chen L Z, Huang J H eds. Structure and Function of Warm Temperate Forest Ecosystem [C]. Beijing: Science Press, 1997. 1－9. (in Chinese).

[2] Shaw M W. Factors affecting the natural regeneration of sessile oak (*Quercus petraea*) in North Wales. Ⅱ. A preliminary study of acorn production [J]. *Journal of Ecology*, 1968, 56: 565－585.

[3] Shaw M W. Factors affecting the natural regeneration of sessile oak (*Quercus petraea*) in North Wales. Ⅱ. Acorn losses and germination under field conditions [J]. *Journal of Ecology*, 1968, 56: 647－660.

[4] Kanazawa Y, Nishikata S. Disappearance of acorns from the floor in *Quercus crispula* forests [J]. *Journal of Japanese Forestry Society*, 1976, 58: 52－56.

[5] Kikuzawa K. Dispersal of *Quercus mongolica* acorns in a broad-leaved deciduous forest. 1. Disappearance [J]. *Forest Ecology and Management*, 1988, 25: 1－8.

[6] Herrera J. Acorn predation and seedling production in a low-density population of cork oak (*Quercus suber* L.) [J]. *Forest Ecology and Management*, 1955, 76: 197－201.

[7] Sork V L. Examination of seed dispersal and survival in red oak, *Quercus rubra* (Fagaceae), using metal-tagged acorns [J]. *Ecology*, 1984, **65** (3): 1020－1023.

[8] Miyaki M, Kikuzawa K. Dispersal of *Quercus mongolica* acorns in a broad-leaved deciduous forest. 2. Scatterhoarding by mice [J]. *Forest Ecology and Management*, 1988, 25: 9－16.

[9] Jensen T S. Seed predation by animals [J]. *Ann Rev Ecol Syst*, 1971, 2: 465－492.

[10] Jensen T S. Seed production and outbreaks of non-cyclic rodent populations in deciduous forests [J]. *Oecologia*, 1982, 54: 184－189.

[11] Jensen T S. Seed predator interactions of European beech (*Fagus silvatica* L) and forest rodents, *Clethrionomys glareolus* and *Apodemus flavicollis* [J]. *Oikos*, 1985, 44: 149－156.

[12] Silvertown J W. The evolutionary ecology of mast seeding in trees [J]. *Biol J Linn Soc*, 1981, 14: 235－250.

[13] Santos T Telleria J L. Vertebrate predation on Holm Oak, *Quercus ilex*, acorns in a fragmented habitat: effects on seedling recruitment [J]. *Forest Ecology and Management*, 1997, 98: 181－187.

[14] Jensen T S, Nielsen O F. Rodents as seed dispersers in a heath-oak wood succession [J]. *Oecologia*, 1986, 70: 214－221.

[15] Ovington J D, MacRae C. The growth of seedlings of *Quercus petraea* [J]. *Journal of Ecology*, 1960, 48: 549

－555.

[16] Stapanian M A, Smith C C. Density-dependent survival of scatterhoarded nuts：an experimental approach [J]. *Ecology*, 1984, **65** (5)：1387－1396.

[17] Borchert M I, Davis F W, Michaelsen J, Oyler L D. Interactions of factors affecting seedling recruitment of blue oak (*Quercus douglasii*) in California [J]. *Ecology*, 1989, **70** (2)：389－404.

[18] Reichman O J, Oberstein D. Selection of seed distribution types by Dipodomys merriami and Perognathus amplus [J]. *Ecology*, 1977, 58：636－643.

[19] Reichman O J. Factors influencing foraging in desert rodents [A]. In：Kamil A C, Sagent T D eds. Foraging behavior：ecological, ethological, and psychological approaches [C]. New York：Garland Press, 1981. 195－213.

[20] Vander Wall S B. Foraging success of granivorous rodents：effects of variation in seed and soil water on olfaction [J]. *Ecology*, 1998, **79** (1)：233－241.

[21] Vander Wall S B. Food Hoarding in Animals [M]. Chicago：University of Chicago Press, 1990. 1－10.

[22] Thompson D C, Thompson P S. Food habits and caching behavior of urban grey squirrels [J]. *Can J Zool*, 1980, 58：701－710.

[23] Kawamichi M. Food, food hoarding and seasonal changes of Siberian chipmanks [J]. *Jap J Ecol*, 1980, 30：211－220.

[24] Fox J F. Adaptation of gray squirrel behavior to autumn germination by white oak acorns [J]. *Evolution*, 1982, 36：800－809.

[25] Hutchins H E, Hutchins S A, Liu B W. The role of birds and mammals in Korean pine (*Pinus koraiensis*) regeneration dynamics [J]. *Oecologia*, 1996, 107：120－130.

[26] Kollmann J, Schill H P. Saptial patterns of dispersal, seed predation and germination during colonization of abandoned grassland by *Quercus petraea* and *Corylus avellana* [J]. *Vegetatio*, 1996, 125：193－205.

[27] Griffin J R. Oak regeneration in the upper Carmel Valley, California [J]. *Ecology*, 1971, 52：862－868.

[28] Curtis J T. The vegetation of Wisconsin [M]. Madison：University of Wisconsin Press, 1959.

[29] Potter G L. The effect of small mammals on forest ecosystem structure and function [A]. In：Snyder D P ed. Population of Small Mammals under Natural Conditions [C]. Pymaturing Laboratory of Ecology, 1976, Special Publication No.5.181－186.

[30] Wada N. Dwaef bamboos affect the regeneration of zoochorous trees by providing habitats to acorn-feeding rodents [J]. *Oecologia*, 1993, 94：403－407.

[31] Kondo N. Seasonal fluctuation of population size, activity area of *Apodemus speciosus* (Thomas) in a small stand [J]. *J Mamm Soc Jap*, 1980, 8：129－138.

[32] Gill D S, Marks P L. Tree and shrub seedling colonization of old fields in central New York [J]. *Ecol Monog*, 1991, 61：183－205.

[33] Schupp E W. Seed-seeding conflicts, habitat choice, and patterns of plant recruitment [J]. *Amer J Bot*, 1995, 82：399－409.

[34] Meng Z B, Zhang Z B. The habitat characteristics of birds and mammals in the mountain areas of Beijing [A]. In：Chen L Z, Huang J H eds. Structure and Function of Warm Temperate Forest Ecosystem [C]. Beijing：Science Press, 1997. 76－87. (in Chinese)

[35] Black H C, Lawrence W H. Animal damage management in pacific northwest forests：1901－90 [A]. In：Black H C ed. Sivicultural Approaches to Animal Damage Management in Pacific Northwest Forests [C]. USDA, FSPNRS, General Technical Report PNW－GTR－287.1992. 23－50.

[36] Radivanyi A. Small mammals and regeneration of white spruce forests in west Alberta [J]. *Ecology*, 1970, 51：1120－1105.

[37] Forget P－M, Milleron T. Evidence for secondary dispersal by rodents in Panama [J]. *Oecologia*, 1991, 87：596－599.

中 文 摘 要

人工埋藏植物种子对鼠类采食下辽东栎坚果存活及萌发率的影响

张知彬　王福生

（中国科学院动物研究所，农业害虫害鼠综合治理研究国家重点实验室，北京，100080）

辽东栎林（*Q. liaotungensis*）是北京东灵山地区典型地带植被。过去研究表明，鼠类对辽东栎更新有很大影响。本研究主要调查 3 个问题：(1) 采食辽东栎坚果的鼠类种类；(2) 将坚果埋藏于土中能否减少鼠类对坚果的采食，并提高出苗率？(3) 地表植被是否影响辽东栎的出苗率？1996 年 9 月在北京东灵山地区山地选取 5 个类型的样地 37 块，每样地在地表放置 10 粒坚果，检查地表种子消失率。使用木板夹来调查采食坚果的鼠类种类，诱饵分别为坚果和花生米。于 1997 年 10 月，选取 5 块样地，间隔 25 m，每样地在 1 m^2 范围内埋 50 粒坚果，深度 5 cm，次年 5 月调查出苗情况。研究结果表明，大林姬鼠、社鼠和黑线姬鼠为取食坚果的主要种类，取食比例与其丰富度有关。370 粒坚果放在地表后，1 d、10 d、20 d 的消失率分别达 15.1%、78.1%、和 100%。250 粒坚果埋入土层后，出苗率达 11.2%，苗平均高度为 7.8 cm，出苗率与地表植被盖度有一定负相关。本研究认为，人工埋藏植物种子可以减少鼠类捕食坚果，并能增加其出苗率。

关键词：辽东栎；更新；鼠类；埋藏；种子采食；出苗