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Designing acorn protection for direct seeding of quercus species in high predation areas

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Abstract

Aim of the study: a) To present the trial-and-error approach followed in the design and patent of a manufactured seed and seedling protector effective against mice and voles, rabbits, wild boar and deer (http://bopiweb.com/elemento/829172/). b) To assess the viability of direct oak seeding with and without protection in the complex acorn predation reality of post fire restoration and underplanting in existing pine afforestations.

Study area: Northern Plateau of Spain, in an area of extreme acorn predation.

Material and methods: We followed a classical trial-and-error approach for problem solving. Different modifications to a wire mesh screen cylinder were tested in subsequent trials aiming to evaluate the effects on acorn predation and early emerging plant survival and growth. The final protector is based on a thin wire mesh cylinder with three innovations: a truncated cone, a circular crown and a sphere compartment. Further we assessed the viability of direct oak seeding with and without protection in the complex acorn predation reality of post fire restoration and underplanting in existing pine afforestations.

Main results: The manufactured seed protector was found to be effective against synergic attacks of mice, rodents, wild boars and herbivores. Survival of protected oak was 77% under canopies and 32% in open light conditions two years after sowing.

Research highlights: Our results confirm the viability of direct oak seeding for woodland restoration if seed predation is controlled.

Keywords: sowing; underplanting; trial-and-error; seed protector; afforestation; oak.

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Introduction

Direct seeding of acorns has been the traditional reforestation method for Mediterranean oaks until the second half of the 20th century. Seed predation and browsing have been recognized as major limiting factors for *Quercus* sowing since the classical antiquity. Interest in direct seeding of Mediterranean oaks decreased in the 20th Century when planting container seedlings became the dominant technique to regenerate most species, including oaks. However, more recently, the advantages of direct acorn seeding over planting (e.g., lower costs, better taproot development and drought resistance, diseases spread risk through infected nursery stock (i.e. *Phythopthora*)) have renewed interest in the technique (Sánchez *et al*., 2005; González-Rodríguez *et al*., 2011; Prévosto *et al*., 2011a).

Direct seeding of oaks under canopy or in small gaps may be an efficient mean of achieving a more diverse forest mixture. However, substantial rodent and ungulate damage to acorns and seedlings occurs in underplanting (Madsen & Löf, 2005; Dey *et al*., 2012). Tree protectors and shelters have been frequently shown to be ineffective under such conditions, where damage is created indistinctly by micro-mammals (mice and moles), lagomorphs (rabbits and hares), squirrels or large herbivores. In addition, protection of seeds and emerging seedlings against synergic attacks of rodents and wild boar (*Sus scrofa*) is extremely difficult. In broad areas of Spain, with the rural exodus during the last decades of the 20th Century, population increases for rabbits (*Oryctolagus cuniculus*), wild boars (*Sus scrofa*) and roe deers (*Capreolus capreolus*) have created recurrent agricultural pest management issues. Due to extreme acorn predation, direct acorn seeding is no longer considered in either afforestation or woodland restoration.

The objective of this paper is to present a specific seed protector for direct seeding in afforestation and to summarize the inventive process that led to a specific patent. Subsequently we report the assessment of its effectiveness on protecting acorns in a Mediterranean environment characterized by very high seed predation.

Protector description

The protector is based on a wire mesh (wire diameter of 0.6 mm on 6 mm spacing) wrapped into a simple cylinder (height ~ 35 cm, diameter ~ 6 cm) (Figure 1). To prevent micromammals from digging vertical passageways and to improve the physical stability of the protector against wild boar and rabbits, longitudinal strands at the basal part of the cylinder are separated by cutting transversal strands. Longitudinal strands are then alternately 1) pinched together forming a conical seed deposit at the end of the cylinder, and 2) bent outwards moving away from the cylinder axis at a right angle. These latter wires are crimped together forming a circular mesh flange/collar located under the soil surface at 5 cm depth. With the goal of preventing micromam-

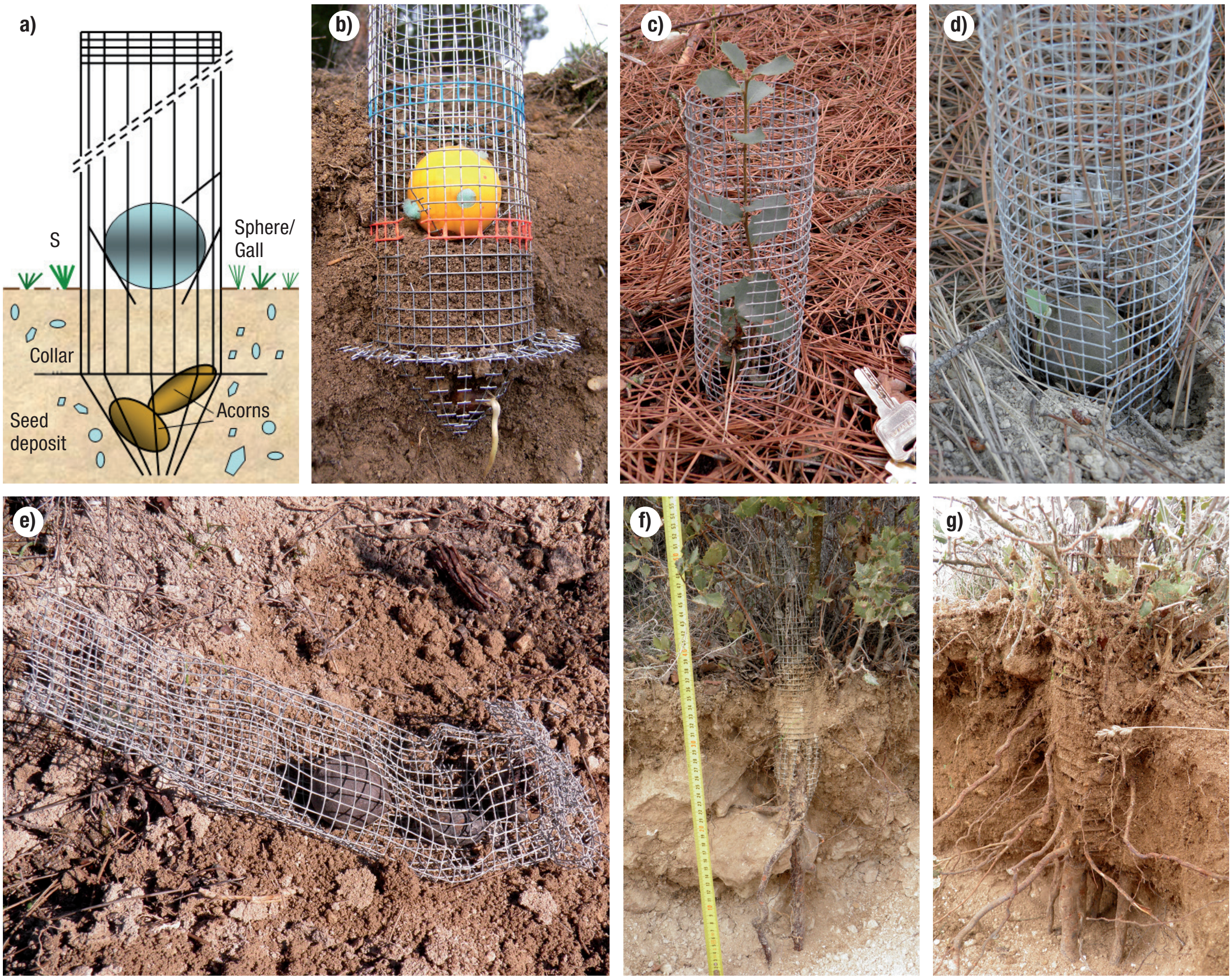

Figure 1. ***a)*** Side view of the protector. ***b)*** Partially unburied protector with roots emerging in the month of February. In this case the sphere is a ping-pong ball instead of an oak gall. ***c)*** Twenty-two month old direct seeded *Quercus ilex* growing inside the protector (prototype P4). ***d)*** Emerging protected underplanted oak and mice gallery. The ring (collar) prevented the access to the acorn. ***e)*** Wild boar attack. The attack was destructive but the suid could not obtain the encapsulated acorn inside the protector. ***f, g)*** Unburied seven year old holm oak seedlings grown in the P2 prototype seed protector. The seedlings present optimum taproot development, and the thinner wire mesh starts to break apart as the plant grows.

mals that climb into the protector (and wild boars) from easily obtaining the acorns, a biodegradable sphere, in example an oak gall, is placed aboveground inside each cylinder. The sphere is restrained by three wire strands previously separated by shearing transverse strands (at the level S in Figure 1). Prior to this step, however, one to three acorns are placed in the seed deposit cone whose strands were pinched together at its bottom and tied with cotton thread. For sowing, protectors are placed 10 cm deep in holes dug into the ground. Acorns placed inside the protector at a depth of 5 cm are finally covered with coarse sand. A more detailed description can be found in: http://www.oepm.es/pdf/ES/0000/000/02/38/34/ES-2383420_B1.pdf.

No interference with taproot growth occurs and seedlings develop one or two free growing taproots. In addition, the thin wires start breaking apart as branches and roots grow (Figure 1). Wild boars may knock protectors down, but acorns will stay retained by the sphere and collapsed protector (Figure 1). After several attempts, wild boars will give up in their attacks as they are not able to access to the acorns.

Problem description and inventive process

The design of the seed protector started in 1996 and followed a classic trial-and-error strategy for dealing with a complex problem: a) establish a basic approach strategy or prototype, b) design a first prototype, c) observe the effects, d) correct for undesired effects, e) observe the effects of the corrections, and f) progressively correct and observe (Popper, 1935; Poyla, 1945).

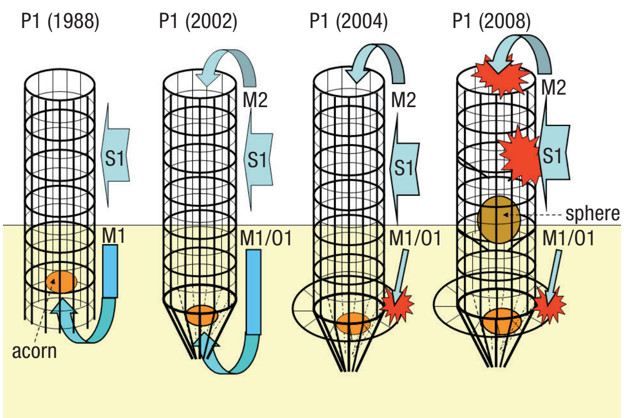

Figure 2. Prototypes (P_i) and innovations tested for acorn and seedling protection against rodents and herbivores. Design based on wire mesh cylinder modifications (6 mm commercial mesh screen). Where: M1 represent mircomammals (mice and voles) galleries; O1 rabbit (*Oryctolagus cuniculus*) digging; M2 micromammals climbing; S1 Wild boar (*Sus scrofa*) bracking protector down.

Different modifications to a wire mesh screen cylinder were tested in subsequent trails aiming to evaluate the effects on acorn predation and early emerging plant survival and growth (Figure 2). Seed predation trials were conducted in the Northern Castilian Plateau (Palencia, Spain). The region has a continental Mediterranean climate (altitude: 750–900 m). Soil type was dominantly a Haplic Regosol (RGha).

The main problem in this situation was the array of acorn predators, well known for damage despite tree shelters and protectors used in afforestation:

- Micromamals: Voles (*Microtus duodecimcostatus, M. arvalis)* and mice (*Apodemus sylvaticus, Mus spretus)*. Both dig underground passageway that allow them contact with the seeds, climb into protector, and gnaw protectors
- Rabbit: *Oryctolagus cuniculus*. Rabbits dig soil around the protector and reach acorns, browse emerging plant, and gnaw protectors
- Wild boar: *Sus scrofa*. Boars knock protectors down and reach acorns or emerging plants
- Roe dear: *Capreolus capreolus*. Dears browse young plants

Damages from the different predators occur simultaneously in a complex interaction. The use of commercial protective tubes made of biodegradable polyethylene was rejected considering the well documented damages caused by the gnawing of rodents in the region and that severe damages in the study area are caused by wild boar. Alternatively, single acorn protection against wild boar could be achieved using heavy wire mesh protectors (wire diameter 5 ≥ mm), but the spacing throughout the body of such mesh cloths often permits rodents to pass through. The calibre of this wire also would lead to very slow breakdown and require removal after several years. We ultimately started trials using thinner, flexible wire mesh, known as commercial hardware cloth (wire diameter < 1 mm). It was assumed that the attacks of wild boars would destroy these protectors, but the flexibility of the device would encapsulate the seed making the acorn inaccessible to predators. It was also expected that the use of thinner wire would promote fracture as it oxidizes and the plant grows.

Seed predation experiment

The experiment was established on slopes of the calcareous plateaus afforested with *Pinus halepensis* and *P. pinea* in the early 1960s (41º59’24.03”N, 4º28’57.62”W). In 2002, a wildfire burned this area and several stands suffered severe damage; all deadwood was removed post-fire. Some stands were not affected by the wildfire and were low thinned in 2006 to a basal area of 20m^2/ha in 2005; understory vegetation was sparse and consisted mainly of herbaceous plants. An adjacent 16-ha fenced military area with restricted access for the last 75 years acts as a wildlife refuge.

In this experiment we compared seed survival and seedling establishment in direct acorn seeding with three seed protection treatments: no seed protector (*C:* control), a simple wire mesh plate (*MP:* mesh plate), and the P4 seed protector (*SP:* seed protector). Two sowing environments were tested: *underplanting* (beneath a forest canopy) and *open light* in adjacent unforested slopes. In the wire mesh plate treatment (*MP*), a 20x20 cm square of wire mesh (12 mm grid spacing) was horizontally placed over the acorns. These experimental treatments were replicated in a split-plot design across six units (blocks) (Table 1). Four units were established along the contour without tree cover (open light) following the systematic distribution of the site preparation during afforestation in 2003 (2 x 3 m). The other two units were laid out along the contour under the pine canopy, with the three treatments systematically distributed at the vertices of a 25 x 25 m grid. At each vertex, three sowing points (one per treatment) were established separated by one meter. Each of the six units contained 45 sowing points (15 for each treatment).

Results of the experiment

Twenty-two months after sowing, acorns and emerging seedlings protected with the seed protector showed the highest survival rates observed to date (77% in underplanting, 32% in open light; Table 1). Oak survival was strongly affected by protection treatment in both years after trial establishment (p=0.0006) as well as by the interaction between sowing conditions and protection treatment (p=0.0033). The dramatic effect of predators on acorns sown without protection (Control) or protected with the wire mesh plate was extreme in all the blocks (<15% survival) with 100% losses during the first winter after sowing in underplanting conditions (Table 1). Wild boar damage to P4 seed protectors only occurred during the first month after trial establishment. 8.7% of the P4 seed protectors were unburied and collapsed by the boar, but they could not access acorns and apparently gave up with all further attempts (Figure 1e, Table 1). Germination extended during the whole month of June (8 months after sowing). The number of living seedlings assessed improved slightly between measurement in the control and mesh plate treatments (Table 1), although all the emerging plants in both treatments showed heavy browsing damage and were <2 cm in height.. Underplanted oak had 100% survival during the second, extremely dry summer in contrast to heavy mortality that occurred in the open light sowing conditions.

Discussion and conclusions

Our procedure for designing and assessing an acorn protection solution followed a classic trial-and-error approach for problem solving (Poyla, 1945). The critical description of what Newell & Simon (1972) call the “mechanism of generate and test” is characteristic of this approach, in which the internal parameters may be modified or altered when needed through feedback and an exhaustive search is impractical (Popper, 1935).

The cost of the seed protector here presented is equivalent to the one of commercial polyethylene 40 cm tree protectors. Manufacturing is currently manual and requires five minutes of handcraft per unit. Sowing costs require the same time and effort as manual planting of

Table 1. Percentage of living holm oak seedlings and mean plant height (standard deviation in brackets) eight months (post first summer), eighteen months (post second spring) and twenty-two months (post second summer) after direct seeding in two sowing conditions: *underplanting* (Forest, two blocks) and in *open light conditions* (Open, four blocks), with three seedling protection treatments (seed protector, mesh plate, control). Summer survival rate shows the percentage of plants that survived after the second, extreme dry, summer.

CONDITION	Treatment	n	8 months (September)	18 months (June)		22 months (September)		Second summer survival (%)
			Living seedlings (%)	Living seedlings %)	Height (cm)	Living seedlings %)	Height (cm)	
Forest	Seed protector	102	76,47	76,47	12,61 (4,02)	76,47	12,61 (3,78)	100
	Mesh		0	0,00	–	–	–	–
	Control		0	0,00	–	–	–	–
Open	Seed protector	174	48,27	44,82	6,65 (2,46)	31,03	7,82 (1,74)	69,23
	Mesh		0	11,36	<2	0	–	0
	Control		4,54	18,18	<2	13,63	<2	74,97

2+2 container plants without tree protectors. In addition, due to the fracture and breakdown of the protector, no future removal costs have to be considered here (Figures 1f and 1g). Protection against predators also allows autumn sowing that avoids seed storage and permits free, early emergence of taproots (Figure 1b).

The results confirm the viability of *Quercus ilex* direct seeding in forest restoration and document predation as a major current limitation in Mediterranean environments in the absence of protection. Partial shading/shelter appears to have a major influence on acorn early survival and growth (Pausas *et al.,* 2004; Rodríguez-Calcerrada *et al*., 2008; Prévosto *et al*., 2011b). Micromammal and rabbit activity was evident and dramatic all over the study site. In addition, two weeks after sowing, wild boars had already scoured the entire site. Attacks on acorns protected with the seed protector were destructive but reduced in extent (only 10% of the tubes). In all the cases the acorns were found intact encapsulated inside the collapsed tube and, after the first months, no further boar attacks were reported as a clear example of selective learning. Plant emergence occurred four to eight weeks later as it does in forest nurseries in the region, indicating a different growth pattern as a result of distinct taproot development. In fact, the slight increase in the number of living seedlings assessed in the control and mesh treatments assessed between the first and second inventory can be explained due to late emergence or resprouting after browsing.

Our work spams almost two decades and led to the concession of a patent (http://bopiweb.com/elemento/829172/). Future work will focus on improvements to the manufacture process of the protector, which currently is manual, as well as on the assessment of different sowing/growth conditions and rate of oxidation and break down.

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