Towards optimizing acorn use as animal feed in Tunisia: evaluation and impact on natural regeneration

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Photo 1.
Germinated acorns of *Quercus suber* L.
Photo B. Stiti.

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RÉSUMÉ

Optimiser l'usage de glands pour l'alimentation du bétail en Tunisie : évaluation et impact sur la régénération naturelle

Dans les forêts méditerranéennes, outre les conflits d'usages entre gestionnaires et populations locales souvent pauvres et dépendantes de leur bétail pour vivre, le coût des matières premières fourragères est de moins en moins supportable pour les paysans. Il est de plus en plus admis que l'utilisation raisonnée de glands permet de réduire les coûts de l'alimentation animale tout en favorisant une gouvernance participative et durable des peuplements. La présente étude vise à réaliser une évaluation quantitative, qualitative et économique du potentiel des glands dans une suberaie du nord-ouest de la Tunisie et à étudier leur impact post-dispersion sur la régénération naturelle. Les quantités ont été estimées en novembre et en février, respectivement, pour les glands récoltés sur les arbres et ramassés au sol. Un suivi dans le temps a également été mené entre l'automne 2014 et le printemps 2015. Les résultats montrent une baisse significative de la quantité des glands, qui passe de 5,28 ± 4,61 t/ha en novembre à 0,684 ± 0,1 t/ha en février. Toutefois, cette baisse ne compromet pas les premiers stades de la régénération naturelle des chênes-lièges, puisque le pourcentage de glands inaptes à la germination a été estimé à 37 % seulement fin février et le nombre moyen à 40 000 plantules par hectare en avril. Un modèle ajusté a permis d'établir une estimation prévisionnelle de la production de glands et d'identifier le système agroforestier le mieux adapté pour optimiser l'usage des glands. Les données sur la quantité et la qualité indiquent que les glands d'automne seraient à affecter aux pépinières et au bétail et les glands plus tardifs à la faune sauvage et la régénération naturelle.

Mots-clés : gland de chêne-liège, fourrage, régénération naturelle, prédation, sylvopastoralisme, amélioration des revenus, pérennité, Tunisie.

ABSTRACT

Towards optimizing acorn use as animal feed in Tunisia: evaluation and impact on natural regeneration

In Mediterranean forests, besides the conflict between forest managers and local populations who are often poor and dependent on livestock for survival, the cost of raw materials used in animal feed is increasingly a burden for farmers. There is growing recognition that wise use of acorns can reduce feed costs and enhance sustainable participatory governance of these woodlands. This paper aimed to carry out a quantitative, qualitative and economic evaluation of acorn potential in a cork oak forest in north-western Tunisia and to investigate the impact of their post-dispersal on natural regeneration. Quantities were estimated in November and February, respectively for acorns collected directly from trees and from the ground. Time-dependent monitoring of acorn quality and numbers of new seedlings was also conducted from autumn 2014 to spring 2015. The results show a significant decrease in acorn quantity from 5.28 ± 4.61 t/ha in November to 0.684 ± 0.1 t/ha in February. However, this loss did not put the early stages of natural cork oak regeneration at risk since the percentage of acorns not able to germinate was estimated at only 37% in late February. Furthermore, the average number of new seedlings was estimated in April at 40,000 seedlings/ha. A model was fitted to predict tree acorn production and to establish the best agroforestry system to optimize acorn use. Based on acorn quantity and quality data, earlier acorns should be directed to nursery and livestock production and the later acorns to wildlife and natural regeneration.

Keywords: cork oak acorn, animal feed, natural regeneration, predation, silvopastoralism, income improvement, sustainability, Tunisia.

RESUMEN

Hacia la optimización del uso de la bellota como alimento para animales en Túnez: evaluación e impacto en la regeneración natural

En los bosques mediterráneos, además del conflicto entre los gestores forestales y las poblaciones locales, que a menudo son pobres y dependen del ganado para sobrevivir, el coste de las materias primas utilizadas en la alimentación animal es una carga cada vez mayor para los agricultores. Se está reconociendo que un uso inteligente de las bellotas puede reducir los costes en alimentación y mejorar la gobernanza participativa sostenible de estos bosques. El objetivo de este trabajo es realizar una evaluación cuantitativa, cualitativa y económica del potencial de las bellotas en un bosque de alcornoques del noroeste de Túnez e investigar el impacto de su dispersión posterior en la regeneración natural. Las cantidades se estimaron en noviembre y febrero, respectivamente, para las bellotas recogidas directamente de los árboles y del suelo. También se realizó un seguimiento temporal de la calidad de las bellotas y del número de nuevas plántulas desde el otoño de 2014 hasta la primavera de 2015. Los resultados muestran una disminución significativa de la cantidad de bellota desde 5,28 ± 4,61 t/ha en noviembre hasta 0,684 ± 0,1 t/ha en febrero. Sin embargo, esta pérdida no representó un riesgo para las primeras etapas de la regeneración natural del alcornoque, ya que el porcentaje de bellotas que no pudieron germinar se estimó en solo un 37 % a finales de febrero. Además, el número medio de plántulas nuevas se estimó en abril en 40 000 por hectárea. Se adaptó un modelo para predecir la producción de bellotas y establecer el mejor sistema agroforestal para optimizar el uso de las bellotas. Basándose en los datos de cantidad y calidad de las bellotas, las más tempranas deberían destinarse a la producción en viveros y al ganado, y las más tardías a la fauna silvestre y a la regeneración natural.

Palabras clave: bellota de alcornoque, alimentación animal, regeneración natural, depredación, silvopastoreo, mejora en los ingresos, sostenibilidad, Túnez.

Introduction

The last three centuries of cork oak forests commercial management have resulted in decline and deforestation in Mediterranean forest of the cork oak, *Quercus suber*. Long dry seasons (climate change), forest fires and overgrazing are considered to be the main factors of these problems as well as management practices (Palahí, 2004; Nsibi, 2006; Boussaidi and Rebai, 2017). Although experiments favouring natural regeneration have shown good results in southern Mediterranean forests, it seems illusory to imagine prolonged defences against human pressure on large surfaces, in territories where local populations are affected by poverty (Boudy, 1950; Marion, 1955; Stiti *et al.*, 2014). Actually, recent researches on cork oak forest services (Khalfaoui *et al.*, 2020) showed that in north-western Tunisia, grazing (including acorns consumption) provided a high Economic Value of 0.16 M€/year in 2016. This value ranged from 33% to 48% of the Total Economic Value (TEV), depending on the stand density. Tunisian Cork oak forests are publicly owned allowing free usage to the local population. In fact, the TEV was shared between the local users (58%) and the government (42%) (Daly-Hassen *et al.*, 2009). However, the farmers are not involved in management and conservation issues exclusively fulfilled by Forest Administration which led to a critical and a conflictual situation. These conflicts could be perceived through illegal practices such as forest fires, trees cutting and even violence against the forest administration agents.

In addition, despite the high coefficient of overgrazing, the forage deficit is significant (Boussaidi and Rebai, 2017). Considered as highly dependent on the forest resources, 91% of the local population's income is partially provided by animal breeding. A rural household owns in average 1.8 cattle, 6.3 sheep and 4.5 goats, based on self-production and grazing for their living. The average grazing time is 5 hour-day in the forest and 2 hours in the shrubs, enhanced by acorns collection and stocking for the low production periods (Khalfaoui and Daly-Hassen *et al.*, 2017). This behaviour is often justified by the expensive prices of raw materials used in animal feed, mostly imported, thereby increasing the cost of producing meat and dairy products. Hence the importance to find a local feed source which reduces the food cost and respect nutritional constraints linked to growth performance and meat and milk quality.

Acorns were used primarily for human consumption, mainly during food shortages and because of the high abundance and distribution of *Quercus* tree species, especially across the Iberian Peninsula (García-Gómez, 2017). They are edible in at least 27 countries as an alternative food source because they are rich in starch, proteins and lipids and the flour is gluten free (Vinha *et al.*, 2016) and can be used for up to 20% of the diet of chickens and other animals without difficulty and are nutritionally comparable to many cereal grains (Zarroug *et al.*, 2020). Consequently, interest in acorns for farmers is increasing in North Africa (Kayouli and Buldgen, 2001; Moujahed *et al.*, 2005; Keddam *et al.*, 2010) taking as a model the experience of Spain with Iberian ham (Extremadura) and the land-use systems in Spain and Portugal.

This study aimed to point the importance of the acorn potential in cork oak forests in north-western Tunisia in terms of natural production and income improvement of local population. The objectives were to: (1) quantify and model annual production of cork oak acorns; (2) investigate the impact of quantity and quality of acorns on natural regeneration; (3) enhance the economic value of acorns to promote their integration into forest management decisions. Overall, we expected that the balance between the restoration of cork oak stands and the use of acorns by animals and especially by livestock, within an agroforestry system in the southern Mediterranean cork oak forests is feasible.

Photo 2.
Natural regeneration in Tunisian cork oak forest: acorns and seedlings.
Photo B. Stiti.

Material and methods

Study zone

This study was carried out in the extensive cork oak forests of Kroumirie, a mountainous region located in north-western Tunisia and north-eastern Algeria. Within this vast North African area, the investigation was conducted in the area of Ain Snoussi, (figure 1) located at the crossroads between Ain Draham (altitude region: 739 m), Tabarka (coastal region: 12 m) and Amdoun (448 m). According to the bioclimatic map of northern Tunisia, the entire study area is included within the 4.5 °C isotherm for the minimum average for the coldest month (GDF, 2012).

The study area is a transition zone between intense forest and wooded area, with 3,787 ha comprising 50% cork oak (*Q. suber*), 24% shrubs, 13% cropland and olive trees and 10% of bare land (Khalfaoui *et al.*, 2020). Small and medium timber (diameter between 7.5 and 22.5 cm and between 22.5 and 42.5 cm, respectively) were the most represented in the study forest (Stiti, 2017). The cork production cycle is 12 years in Tunisia, starting with "virgin cork" (cork bark harvested at the first bark stripping at age 30) then harvesting "reproductive cork" in the following cycles. 1,700 inhabitants live inside this forest (NIST, 2014). The zone is publicly owned but the local households benefit from free usage rights and are the main beneficiary from the forest economic value (Khalfaoui *et al.*, 2020). The study site provides a multitude of goods and services (Campos *et al.*, 2007; Daly-Hassen, 2009; Stiti *et al.*, 2016; Stiti, 2017).

To meet the objectives of this study, we selected 17 circular plots of 400 m^2 installed within the study area. The slope and the elevation inside these plots varied from 5 to 23% and from 324 to 611 m, respectively. The density ranged from 275 to 1,225 trees/ha and for 85% of inventoried trees, diameter (diameter at 1.30 m) varied from 11.1 to 36.6 cm.

Quantitative estimation of acorn production

A first lot composed of 50 trees, considered healthy and upright and inventoried in terms of circumference and height, formed a representative sample of cork oaks in the 17 selected plots. For each tree, another one close as possible in the same plot and belonging to the same diameter and height classes was picked in such a way as to set out a second lot of 50 trees. Actually, the first lot of trees was used for the quantitative estimation of acorn production carried out at the optimal period of their ripeness, in mid-November 2014.

Directly harvested on these trees, all acorns reaching the ground either naturally or man induced by using sticks, were collected on two traps placed beneath the crown to avoid seed contact with the soil. The mass of collected acorns was determined per tree and then extrapolated per hectare using the density of the plots. The second lot of 50 trees was used to quantify the acorns remaining on the forest ground in the end of February and to estimate the seedlings number derived from them in the spring. Therefore, four quadrats

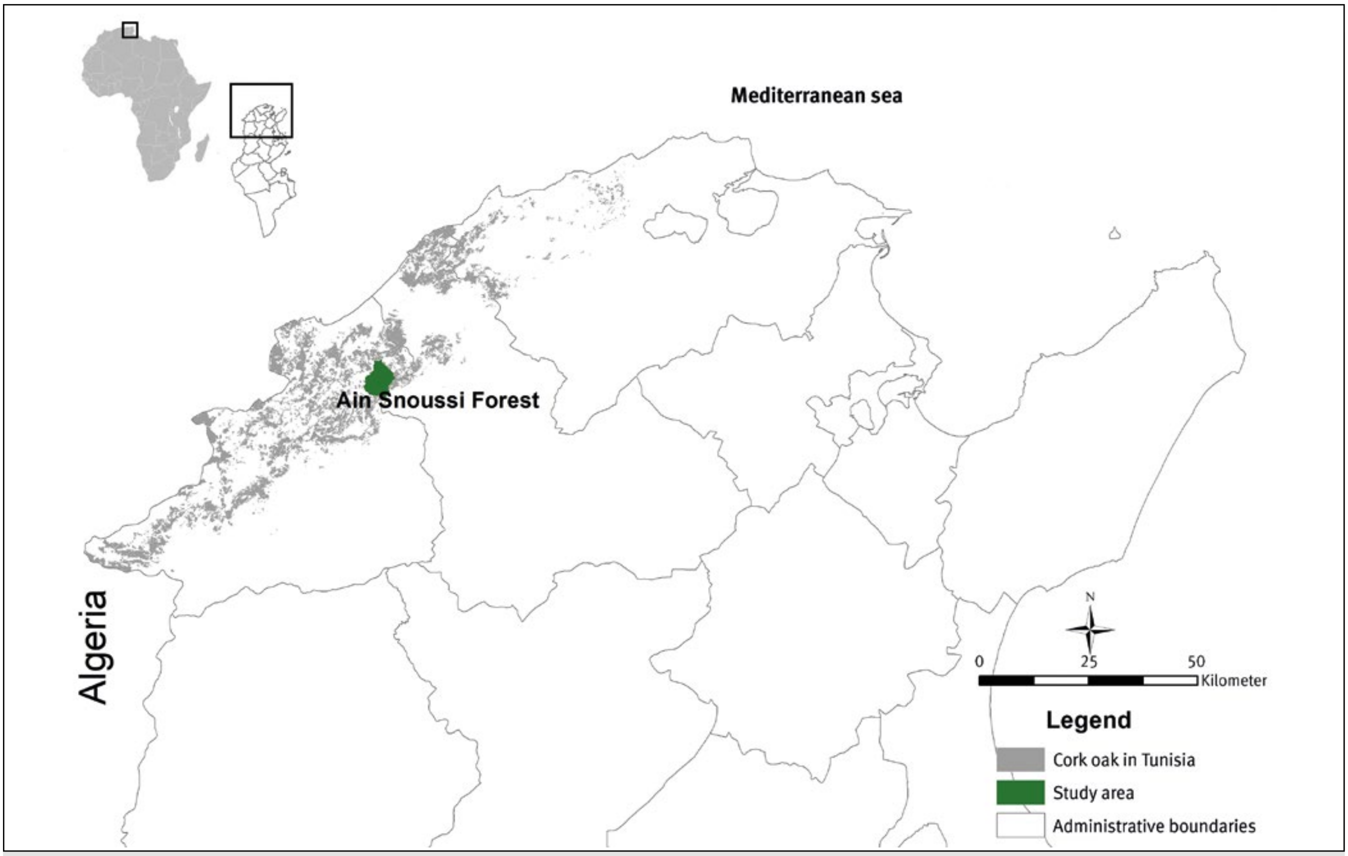

Figure 1.
Location of the study area within Tunisian cork oak forest.

of 1 m^2 were positioned under the canopy of each tree, 3 m to the stem in the four cardinal directions. In the last week of February 2015, a collection of acorns was conducted, by picking them up from the ground, in the quadrats. The mass and the number of the collected acorns were determined per square metre and then extrapolated to the hectare.

Furthermore, in order to detect the impact of acorn lost on the early stages of natural regeneration, we estimated the percentage of seeds that evolved to seedlings among those remained on the ground. The approach was to count the number of cork oak seedlings before the season harvest in autumn 2014 (November) and then in spring 2015 (April), period of the pick seedling emergence (Arosa *et al.*, 2015).

Moreover, a model of the mass of acorns (W in kg) produced per tree was fitted using the data of seeds gathered in the beginning of the harvest season on the first lot of the 50 sampled trees. The choice of the prediction model was based on biological sense, simplicity, literature and statistical means. In a first step, the independent variables were measured by considering all the parameters that characterize the vigor of the trees.

In fact, for each of the 50 trees, six variables were recorded, namely the circumferences (C) at 0.30 m (C0.3) and 1.30 m (C1.3) from the ground (m), the total height (Ht), the radius of projection of the crown on the ground (Rcr) as well as the crown height (Hcr). The distances to the four individuals closest to the tree in the four cardinal directions (m) were also measured (D). The characteristics of these variables are summarized in table I.

Then, a step-by-step regression analysis was performed using SPSS 20 software to examine and explore the relationships between the mass of acorns per tree and the measured variables and to fit the best model. The model that most met the following requirements was the best choice; a low standard error or RMSE (Root Mean Squared Error), a high coefficient of determination, significant parameters and well distributed residues with no particular tendency.

Qualitative estimation of acorn production

The qualitative estimation was carried out on the acorns collected at three different dates, in mid-November directly on the 50 trees (first lot), in mid-January and in the end of February 2015 on the ground in the squares installed beneath the 50 crown trees (second lot) as described above. Firstly, we monitored the evolution of the status of the acorns in the three dates, especially, the seed categories composed of germinated (G), not sound (NO S), rotten (R) and insect-infested (I-I). Then, for a better understanding of the effect of entomological and pathological attacks on the quality which could influence the subsequent use of acorns for regeneration or feeding, another analysis was made on the acorns collected in November and on those picked up on the ground in February. We investigated initially the location of the infestation and whether it affected the embryo and/or the cotyledons by a longitudinal section of the seeds (Suszka *et al.*, 1994). We inspected also the magnitude of the insect infestation using as indicators the size and the number of the holes.

Economic valuation of acorns

In cork oak forests, acorns are considered as secondary products, consumed by livestock and wild animals by grazing. Moreover, 20% of the total production is gathered by the local population as a supplementary feed creating an exchange market (Chebil *et al.*, 2009). Several methods were applied to determine the value of acorns. Because Tunisian forests are publicly owned and allowing access rights to local populations, the Forest Code (decree of January 17, 1995) defined the prices of forest products including acorns at 0.035 TND/kg (TND, Tunisian dinar money). However, this price was never revised and is no longer applied. More commonly, acorns are valued either as fodder, valued on the basis of consumed forage units (FU) and the market price of barley, considered as equivalent product (Hanley, 2008; Daly-Hassen *et al.*, 2009) or as market price value at farm gate (Campos *et al.*, 2007; Chebil *et al.*, 2009; GDF, 2012). Recently, a trade has been established and acorns have been locally acquired in local markets. The acorn market price of 2016 estimated at 0.042 €/kg (equivalent to 0.100 TND in 2016) and considered as farm gate price was applied in the present study.

Statistical analysis

Data processing and model adjustment were carried out using SPSS 20 software. Pearson's correlation coefficients were used to interpret relationships between acorn production and parameters of the sampled trees and plots by means of the SPSS 20 software. The former enabled us also by way of the GLM procedure (General Linear Models) to test the significance difference between the seed categories percent and among the dates of their collection. Results are presented as mean ± standard deviation.

Table I.
The variables measured on the trees sampled in the forest study: mean, minimum and maximum. Ht (m): total height, C1.3 (m): circumference at 1.30 m, C0.3 (m): circumference at 0.3 m, Hcr (m): crown height, Rcr: radius means of projecting the crown on the ground (m), D (m): the average of the distances of the four individuals closest to the tree in the four cardinal directions (m), Mass (kg): the mass of acorns per tree (Wa, kg).

Variable	Ht (m)	C1,3 (m)	Co,3 (m)	Hcr (m)	D (m)	Rcr (m)	Mass (kg)
Mean	7.98	0.93	1.04	5.09	5.2	2.8	8.85
Minimum	3.5	0.35	0.48	2	1.93	1.35	0.72
Maximum	13.5	2.65	2.67	9.3	9.92	6.6	39.6

Table II.
Pearson correlation coefficients among acorn production (kg/tree). Ht (m): total height, C1.3 (m): circumference at 1.30 m, C0.3 (m): circumference at 0.3 m, Hcr (m): crown height, Rcr: radius means of projecting the crown on the ground (m), D (m): the average of the distances of the four individuals closest to the tree in the four cardinal directions (m), E(m): elevation inside the plots, Pearson: Pearson coefficient.

Variable	C1.3	Co.3	Rcr	Hcr	Ht	D	Density	E
Pearson	0.736**	0.704**	0.718**	0.473**	0.573**	0.307*	−0.380*	−0.284*

* Significant at the 0.05 probability level.
** Significant at the 0.01 probability level. N = 50.

Results

Quantitative estimation of acorns

At the beginning of the season (November 2014), acorn production was estimated at 8.85 ± 8.23 kg/tree ranging widely between 0.72 and 39.6 kg. As a consequence, this production was evaluated at 5.28 ± 4.61 t/ha varying between 0.63 and 21.4 t/ha. Moreover, acorn production showed a significant difference between trees ($P < 0.05$) but no significant difference was noted between plots ($P < 0.158$). Pearson correlation analysis revealed that acorn production (kg/tree) was significantly and positively influenced ($P < 0.01$) by C1.3, C0.3, Rcr, Hcr and Ht but was positively affected to a lesser extent ($P < 0.05$) by distance (D). However, it was negatively affected by density ($P < 0.01$) and elevation ($P < 0.05$) whereas no significant correlation was noted with slope (table II). At the end of winter (February 2015), the mass of acorns was evaluated at 68.495 ± 102.27 g/m². Therefore, acorn production was equivalent to 0.684 ± 0.1 t/ha ranging between plots from 0 to 4.58 t/ha. This quantity of acorns collected tardily is much less than that harvested at the start of the acorn season (November), which indicates an important use and predation of acorns.

On the other hand, the number of acorns recorded (February 2015) in the quadrats was estimated at 27 ± 41 acorns/m² ranging from 0 to 160 acorns/m² (270,000 acorns/ha). Then in April, we recorded 4 ± 6 seedlings per m² (min=0 and max=34) and emergence was estimated at 17 ± 31% with a large variation between 0 and 163 %. As shown in figure 2, for some quadrats, the number of new seedlings appeared higher than that recorded for acorns in February and new seedlings emerged even in quadrats having previously no acorns. Previously in November 2014, we recorded 1 ± 2 seedlings/m² as a result of regeneration of the preceding year (2013) ranging between 0 and 16 seedlings/m².

Acorn mass modelling

A linear model, without constant, and with two variables (C0.30 and C1.30) was selected; it is written in the form:

Wacorns=(-0.235×C0.30)+(36.202×C1.30) (1)

Wacorns: mass of acorns (in kg), C0.30: circumference at 0.30 m height (in m), C1.30: circumference at 1.30 m height (in m).

This adjusted linear model explained 85% ($R^2 = 0.853$, adjusted $R^2 = 0.847$) of the variation in acorn mass values with a standard error (or RMSE) of 0.9784 kg. The latter actually represents the standard error of the predicted value; it gives the extent of the confidence interval (CI) at the significance level of 5% of the predicted value (CI ~ 2XRMSE). The step-by-step regression technique used excluded most of the measured parameters and included the circumferences at 0.30 m and 1.30 m. These parameters are easy to measure for the forester, which simplifies the use of this model and consolidates its choice. The parameters of the adjusted model are found in table III. In addition, the model's predicted acorn mass values were in agreement with those measured (figure 3). Thus, the proposed linear model seems to correctly adjust the data for the mass of acorns produced per tree.

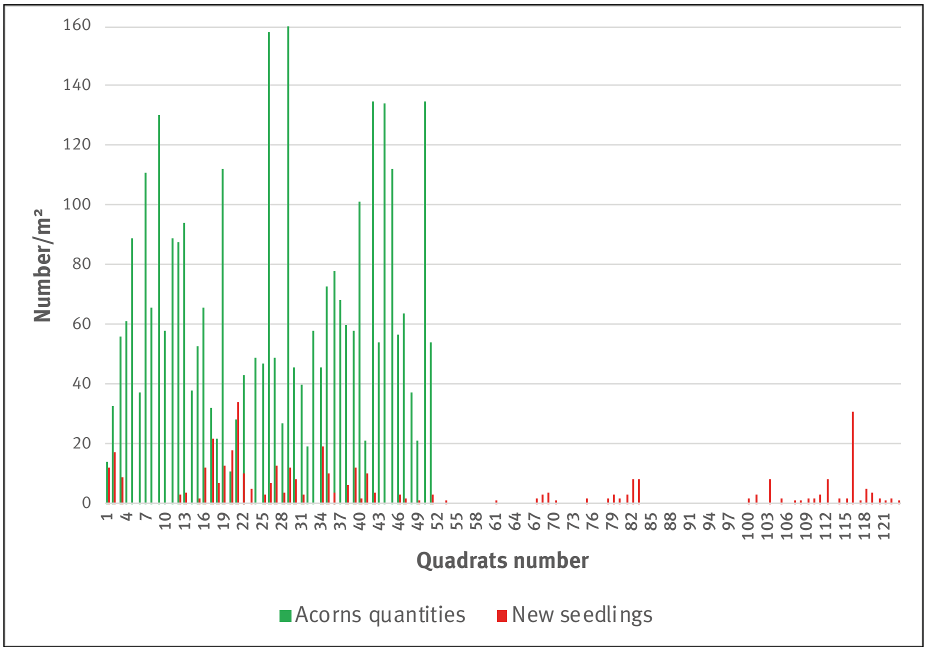

Figure 2.
Number of acorns collected in February and number of new seedlings recorded in April in the same quadrats.

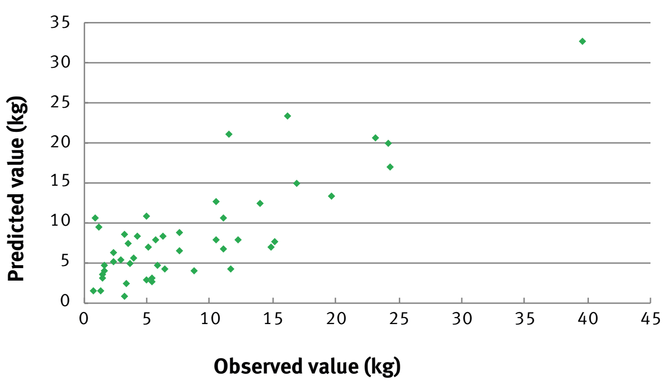

Figure 3.
Distribution of values predicted by the model as a function of measured values.

Table III.
Parameters of the linear model adjusted to the weight of the acorns: Estimated value, Standard error (ES), value of the t statistic, approximate value of Pr › | t |.

Parameter	Estimated value	ES	Value of t	Approximate value Pr › |t|
C1.30	36.202	7.964	4.523	0.000
C0.30	−0.235	0.073	−3.233	0.002

Quality of acorns

As illustrated in table IV, statistical analysis showed that the percentages of rotten and insect-infested (I-I) acorns were significantly different at the three collection dates and increased progressively during the season. As well, the percentage of germinated acorns varied significantly over time although it increased from 7% to 78.67% and then decreased to 40.11%. In contrast, the percentages of no sound acorns (very dry and embryo-free) did not differ significantly during the study period and were less than 7% even at the end of the season. The cutting test of insect-infested acorns showed that, overall, the insect damage frequently affects the cotyledons (table V). Regarding the degree of infestation, expressed by the number of holes on the acorns, the results for the beginning of the season revealed a non-significant difference between the percent of seeds having 1 and 2 holes (P = 0.356). However, after 13 weeks, 86.83% of the acorns presented one hole. Moreover, the big hole appeared more often (74%) on the acorns (table V). Based on previous studies in North Africa, the big and small holes are exit holes of the weevil *Curculio* sp. (= *Balaninus* sp.) (Coleoptera, Curculionidae) and the moths: *Cydia fagiglandana* and/or *C. splendana* (Lepidoptera, Tortricidae), respectively (El-Hassani *et al.*, 1994; Bouchaour-Djabeur *et al.*, 2011; Adjami *et al.*, 2013).

Economic valuation of acorns

Besides the economic value of acorns consumption as a part of grazing, at least 20% of the total production is picked by self-employment families to be stocked for livestock as supplementary feed and to be sold for other zones. As result, 1.06 ± 0.92 t/ha is estimated to be available for the market. Considering the farm gate price at 0.042 €/kg (equivalent to 0.100 TND in 2016), the value of acorns is estimated at 44.35 ± 38.72 €/ha.

Discussion

The global objective was to discuss the conflict between natural regeneration as an ecological issue and the acorn loss, especially, acorns' current traditional use as a local animal feed resource for small-scale livestock producers, on one hand, and the possibility of promoting the agroforestry system in the southern Mediterranean cork oak forests on the other.

Acorn production was highly variable, with a mean production estimated at 8.85 kg acorns/ tree (0.72–39.6 kg) scaling up to an estimated 5,280 (630–21,400 kg) acorns/ha. This variability was as well recorded in Tunisian and Spanish sites, with a productivity ranging, respectively, from 1,303–4,089 kg acorns/ha (Boussaidi and Rebai, 2017) and from 0.5–135 kg/tree (Koenig *et al.*, 2013). Several studies have also indicated that acorn production is erratic and has shown that the age of the tree or its vigour, the density of the stand and climatic events such as late spring frosts or heavy

Table IV.
Percentage of acorns by state for the 3 collection dates (mean ± standard error of the mean. Anova (D1, D2, D3): Anova between the values for the three dates and Anova* (D1, D3): Anova for the two dates. The difference between the percentages, analysed by ANOVA, is indicated by S when it is significant (Ns: not significant) at the significance level 0.05. The probability P is given in parentheses. D1: November 2014, D2: January 2015, D3: February 2015. I-I: insect-infested acorns, R: rotten acorns, No S: no sound acorns, G: germinated acorns.

Acorn collection date	Acorn classes			
	I-I (%)	R (%)	No S (%)	G (%)
D1	4,6 ± 2,06	0,2 ± 0,09	0,2 ± 0,09	7 ± 3,13
D2	6,67 ± 2,1	4 ± 1,26	0,33 ± 0,1	78,67 ± 24,88
D3	40,81 ± 5,66	21,02 ± 2,91	6,3 ± 0,87	40,11 ± 5,56
Anova (D1, D2, D3)	S (0 ‹ 0.05)	S (0,001 ‹ 0.05)	Ns (0,056 › 0.05)	S (0 ‹ 0.05)
Anova*(D1, D3)	S (0 ‹ 0.05)	S (0,014 ‹ 0.05)	Ns (0,140 › 0.05)	S (0.001 ‹ 0.05)

rainfall which interfere with pollination or flowering as well as soil and orographic conditions are factors that can affect the production of acorns (Rose *et al.*, 2012; Boussaidi and Rebai, 2017). Our results highlight particularly the positive significance of tree circumference and crown radius and the negative influence of stand density and elevation of the site on acorn production and emphasize only on the significant individual level (tree) of its variability. Thereby this could be helpful in sampling trees for acorn collection and in reaching a management pattern decision. Actually, the present study provides a useful model as a tool to predict tree acorn production. It enables to estimate this resource upstream and even to improve it by playing on the best silvicultural practices giving the optimal circumference or even the ideal crown.

Table V.
Percentages of acorns ranked by location of infestation, number and size of holes. Anova (date): Anova for the two dates. Anova*: Anova for the state of the acorns in the same date. The probability P is given in parentheses. Ns: not significant at the level 0.05, S: significant at the level 0.05. D1: November 2014, D3: February 2015, E: embryo, C: cotyledons E+C: embryo + cotyledon.

		D1	D3	Anova (date)	Anova*
Location	**E**	2.5 ± 1.25	0	Ns (0.437)	S (0)^{D1} S (0)^{D3}
	C	72.5 ± 36.25	78.57 ± 45.3	Ns (0.416)	
	E+C	25 ± 12.5	21.43 ± 12.37	Ns (0.518)	
Hole number	**One**	40 ± 20	86.83 ± 27.46	S (0)	Ns (0.356)^{D1} S (0)^{D3}
	Two	50 ± 25	10.61 ± 3.35	S (0)	
	Three	10 ± 5	2.56 ± 0.81	S (0.022)	
Hole size	**Small**	36.67 ± 21.1	21.83 ± 6.9	S (0.009)	S (0)^{D1}
	Big	63.33 ± 36.5	78.16 ± 24.7	S (0.009)	S (0)^{D3}

The results showed a wide predation and post-dispersal of acorns (88%) between November and February. This great loss of cork oak acorns stock is due to multiple predators such as wild boars, deer, rodents, birds, insects as well as man and his animals which are very active and act both in terms of seeds and young seedlings (Nsibi, 2006). Livestock of local population consume large quantities of acorns and have a special preference for mature acorns (Hasnaoui, 1992). However, our study proved that this shortage does not put the early stages of cork oak natural regeneration at risk. In fact, the average number of new seedlings coming from the acorns of the year was estimated in April at 40,000 seedlings/ha and could reach 340,000 seedlings/ha. Seedling appeared also in sampled quadrats with no previous acorns which indicate a short-distance dispersal done, especially, by birds. The main dispersal agent of most European oaks, including cork oak, is the European jay (*Garrulus glandarius*), which is a forest bird occurring not only in Europe but also in North Africa and Asia (Pons and Pausas, 2007ab, 2008). It is worth noting that both squirrels and mice also move and sometimes disperse acorns, though over shorter distances than jays (Pons and Pausas, 2007abc). In autumn, jays harvest healthy acorns from the tree crowns. They bury these acorns for later consumption, preferen-

Photo 3.
Range of cork oak seedlings in Tunisian cork oak forest.
Photo B. Stiti.

tially in open stands. As a result, cork oak dispersal ranges from a few meters to a few kilometres (Pons and Pausas, 2007a). A few months later, during the breeding season, jays collect the acorns they have stored in advance. By that time (April and thereafter), most of the acorns have already germinated, but the resulting seedlings do not necessarily die when the acorn, which is still attached to the seedling, is removed by the jay (Sonesson, 1994). Acorns are also predated by insects, and it is very common to find small exit holes made by larvae of the acorn moth (*Cydia* spp., Lepidoptera) or larger holes made by the acorn weevil (*Curculio* spp., Coleoptera) with a highly variable infestation proportion (Pausas *et al.*, 2009). During the study period (November to February), the proportion of acorns predated by these insects varied significantly between 4.6 and 40.81%. Despite these damage rates, acorns maintain their germination ability and could develop into new seedlings and produce regeneration if adequate conditions are sustained. In line with this assumption, the mean number of seedlings resulting from the previous year's emergence was estimated at 160,000 seedlings/ha. Considering these results, we presume that these seedlings are sufficient to lead natural regeneration. Several studies corroborate the fact that damaged acorns of *Q. suber* germinate and produce viable seedlings (Branco *et al.* 2002; Pausas *et al.*, 2009; Bouchaour-Djabeur *et al.*, 2011; Adjami *et al.*, 2013; Jdaidi *et al.*, 2018) since damage mainly affect the cotyledons and the embryos remain intact. These results corroborate those found for *Q. suber* (Branco *et al.*, 2002) and for *Q. variabilis* (Guo *et al.*, 2009) but are different from those found for the species *Q. alba* and *Q. rubra* which show a remarkable decrease in germination even for a slight loss of endosperm (Weckerly *et al.*, 1989). Although these attacks would not have a direct influence on germination but they could decrease the nutritive reserves and may show reduced vigour and a lower probability of surviving drought stress (Pausas *et al.*, 2009) and could, thus, reach the resulting pastoral and nutritive value of acorns. Considered as useless, rotten and no sound acorns, were estimated at 0.4% and 27% of the collected seeds, respectively, in November and then in February. However, they contribute to the total fallout of litter which is an important input in the maintaining of soil fertility and tree growth. This contribution was estimated in the study zone between 3.5% and 15.3% (Ben Yahia, 2017). Therefore, by adopting a clear management plan based on agreement between forest services and local population, acorn production has to be estimated during September and October using field investigation and the predicted model (fit in this study), then acorns are recommended to be harvested in November and not after January by both stakeholders in pre-indicated sites. Afterward, acorns sanitary state and their size are among the major considerations when deciding to use them in reforestation or in feeding. Earlier acorns (before January) should be directed for nursery and livestock production while the later should be intended for wildlife and natural regeneration. Sound acorns could be used in the short term for nursery production and animal feeding or stored for later use whereas insect-infested seeds should be used in the short time and medium terms provided that they are stored in cold to maintain their viability.

Conclusion

This study is specifically important in the context of the optimization of the sustainable forest management development under climate warming and food security challenge and in accordance with the recommendations of FAO (Food & Agriculture Organization) in which it is registered to carry out enterprising agroforestry activities and ensure coordination between all the activities that contribute to the formation of landscapes and it is noted that the best way to save a forest is to manage it sustainably, taking advantage of the products and services it provides (FAO, 2012).

Photo 4.
Sapling of cork oak in Kroumirie forest.
Photo B. Stiti.

The objective was to check the profitability of cork oak acorns as local resource and a forest provisioning service. At this level, the economic valuation of acorns showed a relatively high average value per hectare compared to other provisioning services valued in the same area, naming cork with 31 €/ha and grazing (including acorn consumption) with 89 €/ha (Khalfaoui *et al.*, 2020). Historically, acorns have been always considered as secondary products for cork oak forests, while management strategies were oriented toward the optimization of cork production. The results of this study estimated an average of 44 €/ha for acorn economic value and this is besides their value in grazing which should enhance decision-makers interest in this production. Moreover, this study proved that there is no impact of loss in acorn quality and quantity on the early stages of regeneration and on their possible extensive use in animal feed. An adequate management strategy based on a wise sharing of acorn stock involving both forest administration and local households can be a considerable step toward socio-economic development, leading to an optimum exploitation of the resource in terms of regeneration, soil fertility, and livestock feeding; in addition to an increase of local households' income. As acorn production is correlated to stand density and to climatic traits, pruning could be recommended in dense stands in response to climate change. A research dealing with the relation between cork oak phenology and site characteristics is ongoing. Furthermore, more research is required to improve the sustainable management strategy and the adaptive patterns, using part of the seed production from all three periods and all stands in order to keep and investigate a wider range of genetic variation that probably affect the future generation structure and the quality of oak populations.

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