Distribution of chestnut (*Castanea sativa* Mill.) forests in Spain: possible ecological criteria for quality and management (focusing on timber coppices)

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Abstract
The literature dealing with Spanish chestnut coppices from 1990 till 2001 is reviewed. Assuming that the basal area and Hart's indexes are the best parameters to identify the optimal environmental conditions for chestnut trees, the best ecological conditions for sweet chestnuts are given according to Spanish districts.

It is concluded that it is possible to increase the surface of chestnut forests in western Spain. In northern districts, however, mean annual temperature and soil permeability are important limiting factors for chestnut reforestation. Evapotranspiration in summer and soil moisture storage are the limiting factors in southern Spain.
Keywords: coppices, chestnut, ecological parameters, quality, Spain

1 Introduction

Being able to predict the best sites for replanting with chestnut trees is important when considering the possible reforestation of marginal districts in Europe. This paper seeks to define the ecological criteria best suited for chestnut timber production and to find out how they are influenced by chestnut coppice management. The relationship between ecological characteristics and the production of chestnut coppice forests need to be understood so as to promote better sustainable management of these forests.

2 Methodology

Papers dealing with sweet chestnut coppices and orchards in different districts in Spain were reviewed. As a rule, basal area (G, m^2 ha^{-1}) or Hart's indices (Iq, ha stool$^{-1/2}$; Schütz 1990) were selected for defining the optimum quality of these coppices, and hence to find the relationships between these and the environmental and soil characteristics. Correlations between these proposed chestnut-quality indices and environmental and edaphic variables of the Spanish chestnut forests were made when selecting the values that correlated with best chestnut production. In most cases, more than 20 chestnut-forest sites were selected from each district. Regressions and Tukey test were used to find significant differences.

3 Results and discussion

Data were taken from the Spanish literature: Rubio (1993), Rubio and Gandullo (1993), Rubio and Gandullo (1994a, 1994b), Blanco *et al*. (1997), Rubio (1997), Rubio *et al*. (1997), Moreno *et al*. (1998), Rubio *et al*. (1999), Blanco *et al*. (2000). The best ecological parameters in each district (based on G and Iq parameters) that provided the best growing conditions for sweet chestnut were then sought. Tables 1 and 2 show the information obtained from these papers about both the environmental and edaphic characteristics of the Spanish sweet-chestnut forests. Other statistical methods used are described by the authors referred to above.

The review of these papers shows that many types of soils are suitable for chestnut, including humic and district Cambisols, haplic and district Luvisols and haplic Alisols (soil types according to the F.A.O.'s soil system). Nevertheless, in some districts, such as Asturias, Catalunya, and Extremadura, the dominant soils with chestnut coppices are humic Cambisols. This indicates that the best soil conditions for producting chestnut forests vary according to the different Spanish districts. Even these differ from the recommended criteria for France, which mainly refer to soil texture and water balance (BOURGEOIS 1992). In all districts, however, soil suitable for chestnut should: 1. have fair to high pluviometry with no soil dryness during summer; 2. be deep with not too high a content of stones and/or clays; 3. have good soil permeability; 4. be acid, but not too acid; and 5. contain a fair amount of soil organic matter (BERROCAL *et al*. 1998),

Table 1 shows that the mean values of both environmental and soil characteristics of sweet-chestnut sites (forests, coppices or orchards) are different in different regions, in some cases significantly. The characteristics of sites from Extremadura differ markedly from those of the chestnut sites from northern Spain. With respect to: altitude, complexity index, annual and summer rainfall, mean annual and July temperatures, potential and actual evapotranspirations, winter water drainage, length of drought (in Navarra this period is almost null), soil moisture storage, soil organic matter content, and C/N ratio.

Table 2 compares characteristics between coppices from Asturias (northern Spain) and Extremadura (central Spain), because in both regions coppices are dominant (in Galicia orchards are predominant). Significant differences in altitude, slope, both winter and summer rainfalls, mean annual and July temperatures, thermal amplitude, potential and actual evapotranspiration, summer water deficit, dryness (both length and intensity), soil texture, water-holding capacity of soil, permeability, annual moisture deficit, and soil pH were found. Obviously, these resulted in different production values, ranging from 5 to 18 m^3 ha^{-1} a^{-1} depending on the coppice management implemented (CABRERA and OCHOA 1997, GALLARDO *et al*. 2000, GALLARDO, submitted).

Lastly, as regards the distribution of chestnut forests, it should be pointed out that coppices are maintained in Asturias, Catalunya, and Extremadura (GALLARDO 2001), but are disappearing in Navarra because, unless there is no summer water deficit, some pine species grow faster and earn more money than chestnut. On the other hand, there continues to be a decrease in the production of chestnut fruit in orchards from Galicia (Gallardo, submitted), where nut production is concentrated, and contributions of nuts from Asturias and the provinces of Leon and Salamanca are also decreasing.

From the existing data, it seems it could be possible to increase the surface of chestnut forests because they can occupy mostly the climax areas where *Quercus pyrenaica* Willd., *Q. robur* L., and *Q. suber* L. grow. One limiting factor, however, is the increasing mean age of the people living in rural, mountainous areas (MORENO *et al*. 1998). Only some developing districts, close to the Portuguese border (western Spain) that still have a small young population (e.g. in the Aliste district, province of Zamora), are making efforts to improve the remaining chestnut orchards and to reforest the area with chestnut forests. They are seeking financial support for this from the European Union. Nevertheless, the current situation is that chestnut forests are disappearing from the best timber areas (e.g. in Navarra and Galicia) in favour of other tree species. The orchards are tending to be abandoned in areas where the Spanish economy has improved as a result of tourism, becoming peri-urban areas with industrial zones, or modern, intensive agriculture has been implemented. Some of the old orchards are being converted to coppices and, in this way, the surface of chestnut coppices has been almost maintained in Spain.

Forests have nowadays increased their importance as a sink for sequestering atmospheric CO_2 (Kyoto agreement). Therefore areas with chestnut may be extended if they are managed as coppice. Because chestnut orchards have a limited economical yield in post-industrial societies, a decrease in nut production in the European Union is foreseeable.

Table 1. Environmental characteristics of the Spanish chestnut forests. PET: Potencial evapotranspiration; v: Volume; N.d.: No data available; Best: Optimal value for that parameter; Yes: significantly different from other districts.

Districts	Extremadura				Catalunya				Navarra			Galicia			
Parameter values	Mean	Lowest	Highest	Best	Mean	Lowest	Highest	Best	Mean	Lowest	Highest	Mean	Lowest	Highest	Best
Topography															
Altitude (m a.s.l.)	783	500	1 200	950	582	330	870	750	593	330	740	578	400	750	
Slope (%)	30	3	64	25	48	30	68		38	18	62	32	15	55	
Erosion (index)	N.d.	N.d.	N.d.		N.d.	N.d.	N.d.		1.4	1	2	N.d.	N.d.	N.d.	
Insolation (º)	0.9	0.5	1.2		0.7	0.4	1.0		0.9	0.5	1.3	0.8	0.5	1.1	0.7
Complexity (index)	79	0	164	25	N.d.	N.d.	N.d.		65	43	84	N.d.	N.d.	N.d.	
Climate															
Annual rainfall (mm/a)	1 176	N.d.	N.d.	1 000	850	761	929		1 771	1 455	2 054	1 262	1 143	1 420	
Spring rainfall (mm)	330	192	521		229	205	252	240	505	410	579	315	283	354	
Summer rainfall (mm)	57	32	95	Yes	196	152	226		249	192	322	130	115	141	Yes
Autumn rainfall (mm)	335	202	561	275	250	232	270		453	387	511	335	310	380	
Winter rainfall (mm)	454	N.d.	N.d.		175	156	192		564	464	633	482	442	546	480
Mean annual temperature (ºC)	13.2	10.9	14.9		12.7	11	15	11.5	10.9	10.1	12.5	11.5	10.6	12.2	
Mean t January (ºC)	4.9	N.d.	N.d.	2,0	5.4	4.0	6.8	Yes	0.7	(-0.6)	2.8	5.4	4.4	6.3	
Mean t July (ºC)	31.5	27	36	27,5	21.1	19	23	20	24.3	24	25	18.4	17.7	19.1	
Thermal amplitude (ºC)	19	N.d.	N.d.	30	16	15	16		24	21	25	13	12	14	Yes
Last frost (Julian day)	120	76	153	100	N.d.	N.d.	N.d.		N.d.	N.d.	N.d.	N.d.	N.d.	N.d.	
PET (mm/a)	739	666	816	Yes	716	658	772	Yes	655	636	693	670	647	690	
PET January (mm)	N.d.	N.d.	N.d.		N.d.	N.d.	N.d.		147	132	170	N.d.	N.d.	N.d.	
PTE July (mm)	603	538	692		N.d.	N.d.	N.d.		508	499	523	N.d.	N.d.	N.d.	
Winter water drainage (mm)	701	179	1 292	650	296	217	380		1185	939	1368	776	683	909	750
Summer water deficit (mm)	264	91	409		162	103	227		70	10	130	183	157	214	Yes
Water regime (index)	81	N.d.	N.d.	60	29	12	48		174	137	208	100	79	119	
Length of drought (month)	2.7	N.d.	N.d.		0.3	0	0.6	Yes	N.d.	N.d.	N.d.	0.4	1.0	1.5	
Intensity of drought (index)	0.11	0.05	0.2	0.12	0.01	0	0.01		0	0	0	0.01	0	0.02	
Physical soil properties															
Fine earth fraction (%)	41	10	78	50	52	39	68		58	35	85	44	25	74	40
Sand (%)	40	24	71		60	36	74	Yes	26	7.1	42	47	27	69	
Silt (%)	43	24	57		28	15	48		47	38	53	40	23	56	
Clay (%)	17	11	22	12.5	12	7	17	15	28	21	40	14	9	18	
Water holding capacity (% v/v)	26	18	32		18	14	25		30	26	37	24	17	29	
Moisture storage (mm/m)	116	31	249	175	79	37	123	100	195	41	360	113	59	169	
Permeability (index)	3.9	2.9	5.0	3.7	4.2	2.9	5.0	Yes	2.2	1.3	3.4	3.9	3.0	5.0	
AET (mm/a)	474	391	563	525	610	572	651		632	579	685	571	521	615	
Annual moisture deficit (mm/summer)	264	165	359		106	27	182		23	0.1	65	99	67	141	
Annual moisture surplus (mm/winter)	701	247	1041	250	239	159	322		1 139	843	1 358	691	598	838	
Physico-chemical soil properties															
pH (KCl)	3.7	3.5	3.9		3.8	3.3	4.2		4.2	3.9	4.3	4.0	3.6	4.2	
pH (H2O)	4.6	4.2	5.2		4.8	4.4	5.4		5.2	4.7	5.4	4.8	4.5	5.1	
Chemical soil properties															
Organic matter (%)	2.9	1.2	4.7	3.5	2.9	1.7	4.1	2.5	2.9	1.8	4.2	5.1	1.8	8.0	Yes
Total N (mg/g)	1.5	0.6	2.9		1.4	0.8	2.2		1.5	0.6	2.7	2.6	1.0	4.3	Yes
C/N	15	7.8	23	15	12	9.5	17		14	5.3	19	12	8.8	15	13
Available P (mg/kg)	1.5	0.4	3.1		N.d.	N.d.	N.d.		1.4	0.8	1.9	N.d.	N.d.	N.d.	
Available K (mg/kg)	116	37	201	100	N.d.	N.d.	N.d.		77	47	134	N.d.	N.d.	N.d.	

Table 2. Environmental characteristics of the chestnut coppices from Extremadura and Asturias. (N.d.: No data available; significance: No: No significant difference; * p < 0.05; ** p < 0.01; *** p < 0.001).

Districts	Extremadura & Asturias			Extremadura		Asturias		Significant
Parameter values	Mean	Lowest	Highest	Mean	Standard error (±)	Mean	Standard error (±)	differ-ences
Topography								
Altitude (m a.s.l.)	688	530	920	783	33	571	48	***
Slope (%)	35	10	75	28	2.6	47	5.1	***
Insolation (°)	0.9	N.d.	N.d.	0.93	0	0.8	0.1	No
Climate								
Annual rainfall (mm/a)	1 198	870	1 573	1 176	55	1 226	36	No
Spring rainfall (mm)	324	216	415	330	18	318	11	No
Summer rainfall (mm)	106	40	169	58	2.9	165	3.2	***
Autumn rainfall (mm)	342	237	429	335	17	351	10	No
Winter rainfall (mm)	425	314	577	454	22	391	16	*
Mean annual temperature (ºC)	12.0	9.6	14.4	13.2	0.2	10.6	0.4	***
Mean t January (ºC)	5.0	3.3	6.4	4.9	0.2	5.2	0.4	No
Mean t July (ºC)	20.3	16	24	23.4	0.3	16.5	0.4	***
Thermal amplitude (ºC)	15.3	11	20	18.5	0.3	11.3	0.1	***
PET (mm/a)	696	619	778	739	8	646	11	***
Winter water drainage (mm)	757	487	1 059	803	51	702	35	No
Summer water deficit (mm)	255	102	440	366	13	123	7	***
Water regime (index)	89	35	154	81	8	99	7	No
Length of drought (month)	1.5	0	3.5	2.7	0.1	0.08	0.04	***
Intensity of drought (index)	0.06	0	0.18	0.11	0.01	0.0004	0.0004	***
Physical soil properties								
Fine earth fraction (%)	47	12	76	41	4	54	3	*
Sand (%)	35	17	62	40	3	29	3	**
Silt (%)	44	25	58	42	3	46	2	No
Clay (%)	21	11	31	17	0.9	25	2	***
Water holding capacity (% v/v)	27	18	33	28	1.1	29	1	**
Moisture storage (mm/m)	126	31	237	116	14	138	16	No
Permeability (index)	3.3	1.9	4.5	3.9	0.1	2.5	0.2	***
AET (mm/a)	530	404	609	475	13	596	9	***
Annual moisture deficit (mm/summer)	167	23	328	264	14	50	5	***
Annual moisture surplus (mm/winter)	669	376	1000	701	54	630	37	No
Physico-chemical soil properties								
pH (H_2O)	4.8	4.3	5.2	4.7	0.1	4.9	0.1	*
Chemical soil properties								
Organic matter (%)	3.0	1.1	5.1	2.9	0.3	3.1	0.4	No
Total N (mg/g)	N.d.	N.d.	N.d.	4.7	0.1	4.6	0.1	No
Available P (mg/kg)	N.d.	N.d.	N.d.	2.9	0.3	3.1	0.4	No
Available K (mg/kg)	N.d.	N.d.	N.d.	1.6	0.3	1.3	0.2	No

4 Conclusions

In spite of the limited number of parameters that can be useful as criteria for characterising the best chestnut area (see Tables 1 and 2), every district has optimum values, which are correlated with the more productive chestnut coppices. In northern Spain, mean annual temperature, last frost, and soil permeability can be good criteria for chestnut reforestation, but in the southern districts these criteria can be dramatically changed by such factors as altitude, summer evapotranspiration, length of drought, and soil moisture storage. If the results are to be extrapolated to Central Europe, only the selected criteria for Galicia and Asturias (perhaps also those for Navarra) should be included.

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Accepted 26.2.02