Site index estimation in Scots pine (*Pinus sylvestris* L.) stands in the High Ebro Basin (northern Spain) using soil attributes

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SUMMARY

Site index curves and an edaphic discriminant rule for Scots pine stands in High Ebro basin (Northern Spain) are presented to estimate site index under different silvicultural situations. High-grading practices strongly modify the forestry structure by the means of bias in the dominant height and stand density. In order to achieve the silvicultural and site variability of Scots pine stands in the studied area, 75 plots from the National Forest Inventory of Spain (NFI) were selected. In these plots 46 dominant trees were cut down and 104 trees were bored at stump and at breast height (1.3 m). In each plot a soil sample from the first ten centimeters of soil was taken and signs of dimensional cutting were recorded. Site index curves and the edaphic discriminant rule were developed. The Site index curve model used is an extension of the Richard's model. The site factors selected in the discrimant rule represent the most important edaphic parameters for forest productivity (texture and the asimilability of the nutrients). Site quality of studied stands was medium-low as compared with other site index curves for Scots pine around the world. The edaphic discriminant rule presented is useful to estimate site index classes in stands exposed to dimensional cutting and in young stands of Scots pine in the High Ebro basin (Northern Spain). Site index curves fitted to allow an estimate of the site index of undisturbed and stands which were not high-graded .

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INTRODUCTION

Site index, defined as top height (average height of the 100 trees/ha of largest diameter) at a base age, is normally applied in forestry for site quality characterization and potential productivity estimation. On the other hand, it is an important parameter in forest growth and yield modeling. Site index can be estimated through site data, stand data, or both combined. When dimensional cutting biases the top height (by harvesting dominant trees), the site index is underestimated if stand data is used. In order to estimate site index, site variables are useful when site trees are not suitable. Systems for evaluating site quality and predicting forest yield based upon the site-growth relationship have been developed in the last half-century. The most important approach is based on the soil-growth relationship and it is called soil-site method. Although these kind of relationship have been studied for a wide range of species elsewhere (e.g., Harding *et al*, 1985, Jokela *et al*, 1988, Moserud *et al*, 1990, Pacheco, 1991 and Wang, 1995), very few soil-site studies have been reported for Scots pine (Tamminen, 1993, Holmgren, 1994) and none in the southern area of its distribution.

In soil-site studies topographic and edaphic factors are utilized to estimate site index in these situations. The topographic factor commonly used is altitude (Jokela *et al*, 1988; Pacheco, 1991; Holmgren, 1994) because it is closely related with regional climate. In addition, slope and aspect (Jokela *et al*, 1988; Pacheco, 1991; Holmgren, 1994) and geographic position (Pacheco, 1991) have been used. Topographic factors are usually utilized in combination with edaphic factors. Physical properties of soils related with soil moisture and nutrients levels are commonly analyzed (Baker & Broadfoof, 1979; Jokela *et al*, 1988; Turner *et al*, 1990; Pacheco, 1991). The wide range of nutrients used to estimate site index and the variable analytical methods obstruct the comparison of results. On the other hand, the nutrients explain a low percentage of height increment (Baker & Broadfoof, 1979). So, it is not strange that some authors avoid the use of nutrients in site index estimation (Steinbrenner, 1976). Soil and horizon depths also are included in the soil characterization by some authors (Jokela *et al*, 1988; Turner *et al*, 1990). Linear regression has been used to relate soil properties and site index (Steinbrenner, 1976; Bara & Toval, 1983; Pacheco, 1991, Tamminen, 1993, Holmgren, 1994 and Wang 1995). However, multicollinearity among soil properties in relation to site index may also cause problems in regression analysis (McQuilkin, 1976 and Verbyla, 1986). To avoid this problem, classification systems such as tree classification

(Verbyla and Fisher, 1988) or discriminant analysis (Harding *et al*, 1985) have been used previously.

Scots pine (*Pinus sylvestris* L.) is one of the most important species in Europe. Together with other species it dominates the forest landscape from the boreal region in northern and eastern Europe to the Mediterranean mountains in southern Europe. Intelligent management of this vast forest resource requires accurate assessment of forest productivity both at local and regional levels. In the wide area occupied by Scots pine, accurate information on growth site relationships is needed, especially where site trees are not suitable (e.g., young and high-graded stands).

The aim of this study was to evaluate site index estimators in Scots pine stands in mountain areas of northern Spain. To accomplish this objective, site index curves and an edaphic discriminant rule for Scots pine stands in Northern Spain were developed. A minor objective was to uncover soil-productivity relationships in Scots pine stands in the Mediterranean mountains distribution area. These objectives were accomplished by analyzing soil and dendrometric data from 75 pure Scots pine stands in High Ebro basin in northern Spain.

MATERIALS AND METHODS

Site description

High Ebro Basin is a transitional area for Scots pine in northern Spain situated between 700 and 900 m above sea level. The climate ranges from Mediterranean to the Atlantic types, with an annual rainfall of 787 mm (123 mm in summer), an annual average temperature of 11.2 ºC, and no pronounced drought or severe frost. The annual variation of temperature and rainfall of the Mediterranean climate is moderated by the Atlantic Ocean influence. Soils are mostly calcaric cambisols, with luvisols in humid sites. *Pinus sylvestris* L. dominates the vegetation community with a mixture of *Quercus faginea* Lamk, *Fagus sylvatica* L., *Quercus ilex* L., *Calluna vulgaris* (L.) Hull, *Erica* sp, *Ulex* sp and *Pteridium aquilinum* (L.) Kuch in the understory.

Data

To represent the silvicultural variability of the area studied, 75 plots of the Second National Forest Inventory of Spain (NFIS2) were randomly selected. These plots cover a wide range of silvicultural situations (Table 1) in pure natural Scots pine stands (between 72 and 100 percent of Scots pine in basal area) in the High Ebro Basin (northern Spain). The NFIS2 plots selected were visited to complete the data base. In 23 of these plots, chosen randomly among the plots with highest basal area (> 20 m^2/ha) and top height (> 10 m) and with no dimensional cut signs, two dominant, straight, un-broken and non-forked trees were cut and in the other 52 plots, cores from two dominant, straight, un-broken and non-forked trees, at stump (10 cm length from the top soil) and at breast height (1.3 m), were taken. Signs of dimensional cutting (high-grading) based upon the presence of big stumps and the presence of 'released' trees were recorded. Twelve plots were removed from the data set because they had signs of high grading practices and they are not further described.

Table 1.- Characteristics of Scots pine plots used to study site index estimation in the High Ebro Basin (northern Spain).

	Basal area (m^2/ha)	Volume (m^3/ha)	N (trees/ha)	Dg (cm)	H_0 (m)
Mean	26.64	159.97	690.28	24.1	13.42
Maximun	60.16	375.55	1743.75	37.98	23.74
Minimum	15.28	86.91	142.71	12.71	6.28
Standard deviation	9.42	62.62	407.10	6.14	3.65

A soil pit extending down to the first 10 cm layer was used to describe forest soil condition according to Jokela *et al* (1988). Soil samples were analyzed to determine percentage of sand, silt and clay (using ISSS method); percentage of carbonate and organic matter; concentrations of phosphorus using the Olsen method, potassium, calcium, magnesium and sodium following extraction with 1N ammonium acetate; cation exchange capacity (CEC), defined as the equivalent amount of cations from the first salt that are retained on the exchanges sites, in meq/100 g, pH and electrical conductivity (mmhos/cm). Soil laboratory analyses followed the standard procedures in agricultural soil research. Soil characteristics are summarized in Table 2. Only soil data from old stands (over 85 years old) without dimensional cut signs were used in developing soil-site relationship (28 plots).

In each felled tree, sections for stem analyses were made every meter from the stump to 5.3 m height and every two meters from 5.3 m height to the tip. In each section two radii were analyzed by an optical scanner and WinDendro v 6.2 software (Régent Instrument Inc, 1997[a] and 1997b). Cores were also analyzed by WinDendro software. As stated before, data from high-graded plots were removed so a total number of

554 data (height/age pair values) from 116 trees in 63 plots without dimensional cut signs were used. The data used from stem analysis to develop site index curves are shown in Figure 1. According to previous works (Lembcke *et al*, 1975; Schober, 1987; Persson, 1992; Rojo and Montero, 1996) site index is defined as top height at a base age of 100 years. The site index was estimated using stem analysis when the felled trees were older than 85 years. Otherwise, the site index was predicted from soil attributes using the discriminant rule previously developed. Table 3 shows the distribution and origin of the height/age data set.

Table 2.- Characteristics of the soil samples used to develop the discriminant rule to estimate the site index class in Scots pine stands in the High Ebro Basin (northern Spain). ppm means part per million.

VARIABLE	Mean	Standard deviation	Maximum	Minimum
Sand (%)	62.08	14.06	85.23	37.05
Silt (%)	20.06	9.13	37.40	6.75
Clay (%)	16.80	8.67	34.85	5.35
P (ppm)	3.50	4.48	23.00	1.00
K (ppm)	140.32	97.59	445.00	19.00
Ca (meq/100g)	16.91	13.69	49.40	0.20
Mg (meq/100g)	0.19	0.21	0.60	0.00
Na (meq/100g)	0.84	1.08	4.95	0.05
Carbonates (%)	3.37	5.49	18.00	0.00
Organic matter (%)	4.89	2.06	10.30	1.10
CEC (meq/100g)	19.16	8.56	34.40	5.50
pH	6.26	1.57	8.30	3.60
Conductivity (mmhos/cm)	0.19	0.11	0.41	0.02

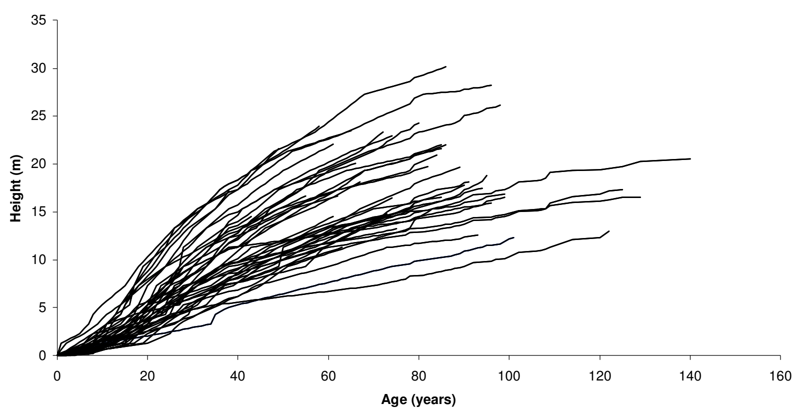

Figure 1.- Stem analysis data set used to develop site index curves for Scots pine in High Ebro Basin (northern Spain).

Table 3.- Origin of height/age data set used to fit the site index curve model.

SITE INDEX	CORES plots (trees)	STEM ANALYSIS plots (trees)	TOTAL plots (trees)
14	19 (34)	8 (16)	27 (50)
17	8 (15)	1 (2)	9 (17)
20	7 (12)	5 (10)	12 (22)
23	6 (9)	9 (18)	15 (27)
TOTAL	40 (70)	23 (46)	63 (116)

Data analysis

Site index model. A great variety of height growth models has been used in forest research. Two main groups of growth models have been used: deterministic (continuous and time-discrete) and stochastic models. The most classical and wide spread approach is the deterministic using continuous models such as Schumacher (1939), Von Betarlanffy (1949 & 1957), Richards (1959) and its variants. Zeide (1993) carefully described and analyzed this kind of models. Wang and Payandeh (1994) using a time-discrete model found it useful to construct a base-age invariant site index model for *Picea mariana* (Mill.) B.S.P. The stochastic models have been explored by several authors. García (1983) used a stochastic differential equation approach including the Richards model as deterministic part of the equation. The diffusion approach has been used by Rennols and Little (1993) to develop a stochastic growth model. Although there is a great variety in approach, and models in height growth studies, Richard's (1959) model has been extensively used in forestry because its differential form includes the basic components of biological growth: anabolism and catabolism. Models with a biological basis, like Richard's model, extrapolate consistently out of the original data range. On the other hand, in its original form, Richard's model needs to be fitted independently for each site index class. To fit site index curves Payandeh (1977) used an extension of Richard's model, previously reported by Ek (1971) [1]. This extension has the ability to generate polymorphic curves and allows a fit of all site index classes simultaneously.

[1] $$H_0 = a * S^b * \left[1 - e^{c*t}\right]^{d*S^e}$$

where H0 is the dominant height, t is the total age, S is the site index and a, b, c, d and e are the parameters.

The model [1] does not fit the definition of site index (H_0 predicted at the base age is not the SI), so Newnham (1988) and Payandeh & Wang (1994) proposed a modified site index model [2]:

$$[2] \quad H_0 = a * S^b * \left[1 - e^{-c*t}\right]^{f(a,b,c,t_i,S)}$$

where:

$$f(a,b,c,t_i,S) = \frac{\ln\left[\dfrac{S^{(1-b)}}{a}\right]}{\ln\left[1 - e^{(c*t_i)}\right]}$$

and t_i is the base age.

Nonlinear regression using the Marquardt algorithm has been utilized to fit site index curves. Seed values of parameters to start non-linear fitting process were obtained from site index curves for Scots pine in the Central range of Spain (Rojo & Montero, 1996). PROC NLIN of SAS® was used.

Edaphic Discriminant models. Discriminant functions studied include edaphic variables related with nutrients, assimilability and soil structure. Fifteen discriminant models were studied in order to achieve site index class. In addition a variable number of site index classes were tested, (three, four or five). The central points for each one of these site classes were 14, 17, 20, 23 and 26 m (five classes), 14, 17, 20 and 23 m (four classes) and 14, 20 and 26 m (three classes), so forty-five combinations (fifteen discriminant rules for each number of site index classes) were tested The variables considered for discriminant analysis are normally distributed (Table 4) and they are not strongly correlated (Table 5). No correlation between silt fraction and CEC was found by Ilvesniemi (1991) in Scots pine forest soils. Edaphic variables showing lack of normality (Table 5) were not further used in the analysis. The discriminant rules studied were as follow:

[3] constant + sand + √(K) + organic matter + CEC

[4] constant + silt + √(K) + organic matter + CEC

[5] constant + silt + √(K) + organic matter +conductivity

[6] constant + silt + organic matter +conductivity

[7] constant + sand + √(K) + organic matter +conductivity

[8] constant + √(clay) + √(K) + organic matter +conductivity

[9] constant + √(clay) + organic matter +conductivity

[10] constant + √(clay) + organic matter + CEC

[11] constant + √(clay) + organic matter

[12] constant + √(clay) + CEC

[13] constant + silt + √(clay) + organic matter +conductivity

[14] constant + silt + √(clay) + organic matter + CEC

[15] constant + silt + √(clay) + organic matter

[16] constant + silt + √(clay) + CEC

[17] constant + silt + √(clay) + conductivity

Table 4.- Normal probabilities of Shapiro-Wilk test of edaphic variables. Symbol + means values not valid for the transformation. In bold, the normal variables selected.

VARIABLE	X	√(X)	√(X+0,5)	Ln(X+1)	Log(X)
Sand (%)	**0.3115**	0.2853	0.2857	0.1976	0.1945
Silt (%)	**0.1909**	0.3064	0.3098	0.1664	0.1468
Clay (%)	0.0436	**0.3055**	0.2903	0.4644	0.4637
P (ppm)	0.0001	0.0001	0.0001	0.0003	0.0011
K (ppm)	0.0058	**0.7296**	0.7232	0.5243	0.4860
Ca (meq/100g)	0.0038	0.0488	0.0385	0.0043	0.0012
Mg (meq/100g)	0.0001	0.0001	0.0002	0.0002	+
Na (meq/100g)	0.0001	0.0040	0.0003	0.0011	0.0455
Carbonates (%)	0.0001	0.0001	0.0001	0.0001	+
Organic matter (%)	**0.5217**	0.5211	0.6148	0.1610	0.0291
CEC	**0.1117**	0.0354	0.0366	0.0068	0.0055
pH	0.0048	0.0028	0.0029	0.0018	0.0055
Conductivity (mmhos/cm)	**0.2831**	0.4260	0.3377	0.3382	0.0297

Table 5.- Correlation between edaphic variables using the Pearson coefficient.

Variables	Sand	Silt	√(Clay)	√(K)	MO	CEC	Conductivity.
Sand	1.00000	-0.77622	-0.75655	-0.63352	-0.07854	-0.28235	-0.65050
Silt		1.00000	0.41586	0.67842	0.32249	0.48531	0.72451
√(Clay)			1.00000	0.53364	0.00948	0.11875	0.48101
√(K)				1.00000	0.33484	0.39082	0.53741
MO					1.00000	0.49158	0.54512
CEC						1.00000	0.37980
Conductivity.							1.00000

Classificatory discriminant analysis has been applied to obtain site index groups from soil variables. The original data set has been used both to define and to evaluate the classification criteria. The resulting error-count estimate has an optimistic bias and is called an apparent error rate. In order to reduce this bias, cross-validation has been used (see Johnson, 1998, pp 217 to 285 for further details). For all independent variables, normality, using the Shapiro-Wilk test, and correlation, using the Pearson coefficient, were studied. Different transformations of original variables were tested to eliminate non-normality. The procedures CORR, DISCRIM and UNIVARIATE of SAS® were used.

RESULTS

All the parameters of site curves model were significant at a probability level of 95 per cent (Table 6). The mean squared of the error and the mean squared of the model are equal to 0.0753 and to 219.9708, respectively. The use of site index as independent variable allows the generation of polymorphic site index curves. The model fitted is:

$$H = 1.0852 * S^{1.0006} * \left[1 - e^{-0.3137*t}\right]^{\left[\frac{Ln\left(\frac{S^{0.0006}}{1.0852}\right)}{Ln\left(1-e^{-0.3137*ti}\right)}\right]}$$

The cross-validation of the fitted model is shown in Table 7. The correct classification of site index is over 68 % in classes 14, 17 and 23. In class 20 the classification using this model is poor (8.33 %). The miss-classifications are usually concentrated in a contiguous site index class. The performance of the model fitted is adequate with a 61.11 % overall correct classification.

Table 6.- Site index curves parameters estimates by non-linear regression in Scots pine stands in the High Ebro Basin (northern Spain).

Parameters	Estimate	Standard Deviation	Confidence interval (95 %)	
a	1.0852	0.0102	1.0652	1.1051
b	1.0006	0.0108	0.9794	1.0219
c	-0.3137	0.0127	-0.3386	-0.2888

Table 7.- Cross-validation of the site index model using stem analysis data from trees older that 85 years in Scots pine stands in the High Ebro Basin (northern Spain). The height-age values over 20 years and the site index curves fitted have been used to predict the site index classes.

		PREDICTED SITE INDEX CLASS			
		14	17	20	23
ACTUAL SITE INDEX CLASS	14	71.74 %	21.74 %	6.52 %	0.00 %
	17	25.00 %	68.75 %	6.25 %	0.00 %
	20	50.00 %	41.67 %	8.33 %	0.00 %
	23	2.78 %	4.17 %	20.83 %	72.22 %

The error rates of the discriminant rules ranged from 0.6967 to 0.3278. The error rate decreased when the number of site index classes decreased, so a compromise between a low error rate and an adequate number of site index classes was needed. In addition, a low error rate is more important in the highest site index classes. Error in the site index estimation in a high productivity stand involves a higher bias in the growth and yield prediction than in a low productivity stand. Error distributions with the best discriminant rule for each number of site index classes are presented in Table 8. Model [16], with four site index classes had no error in classes 23 and 17, in addition the misclassifications in class 20 (error rate equal to 80 percent) were distributed between adjacent classes 23 and 17. Therefore model [16] and four site index classes were selected and parameters of this model are shown in Table 9. When dimensional cutting is not used in a given stand, the site index curves may be utilized to determine site index. Otherwise, and in young stands, the edaphic discriminant rule may be applied.

Table 8.- Error rates by site index class and overall for the selected edaphic discriminant rules using five, four and three site index class in Scots pine stands in the High Ebro Basin (northern Spain).

	SI					
Model	14	17	20	23	26	Total
18	0.6667	0.0000	0.7500	1.0000	0.2500	0.5333
18	0.6667	0.0000	0.8000	0.0000		0.3667
9	0.4000		0.3333		0.2500	0.3278

Table 9.- Edaphic discriminant rule to estimate site index class for Scots pine in northern Spain.

	Site index			
Variables	14	17	20	23
Constant	-14.87014	-11.45326	-13.60515	-5.82951
Silt	0.03833	0.05722	-0.07621	-0.02714
$\sqrt{(clay)}$	5.37847	3.59074	5.72787	3.62204
CCC	0.26128	0.38393	0.22954	0.16047

DISCUSSION AND CONCLUSIONS

The site quality of Scots pine stands in the studied area is medium-low comparing with other site index curves for natural stands and plantations around Europe and eastern United States (Decourt, 1965, Hannah, 1971 *in* Carmean, *et al*, 1989, Hamilton and Christie, 1971, Lembcke *et al*, 1975, Garcia Abejon, 1981, Garcia Abejon and Gomez Loranca, 1984, Garcia Abejon and Tella Ferreiro, 1986, Schober, 1987, Persson, 1992, Jansen *et al,* 1996 and Rojo and Montero, 1996). Usually the highest class of our system corresponds with the medium class of the other systems. The maximum SI in the other classes is over 29 m. If one compares the site index curves presented in this paper with the Rojo & Montero (1996) site index curves for Central

Spain, those estimate a superior site class in the young stands, but at 70 years of age the estimation tends to stabilize in the actual site class. This effect is analogous to the density-dependent behavior of site index curves developed in natural stands when they are used in plantations. Elfving and Kiviste (1997) tested 13 different functions to develop site index equations for Scots pine but not the modified Ek-Payandeh model was used. They advise the use of the Hossfeld equation in 10-80 years old stands but not in older stands. This is correct because as the Hossfeld equation no have a clear asymptote overestimate the site index in older ages. In the previous Spanish site index curves for Scots pine (García Abejon, 1981, García Abejon and Gómez Loranca, 1984, García Abejon and Tella Ferreiro, 1986) the Hossfeld equation was used so this curves may not be used for site index estimation. The use of the Richard model or its modification avoids this problem. The new site index curves sets for Spain, Rojo y Montero (1996) for Central Spain and the curves we show here for northern Spain, avoid this problem using the Richard model or it extensions.

In areas with high silvicultural, environmental or both of these variabilities, models that predict site class rather than exact site index may be more appropriate. Therefore developing a classification or discriminant rule is more useful in these situations than using a linear model. Verbyla and Fisher (1989) showed the advantages of using a classification instead of a linear regression. In addition, under these circumstances it is easier to determine site class than an exact site index. These stands in northern Spain show a high silvicultural variability including high graded areas so the discriminant analysis is the correct way to estimate SI. The discriminant rule should be used when the estimation by means of dominant height and age are not secure, for instance, in young stands or in dimensionally cut stands. The discriminant rule estimates the distance between the observation and the different groups so the observation must be classified in the closer group. Site factors representing the most important edaphic parameters for forest productivity, e.g., texture (represented by the percentage of silt and the root squared of percentage of clay) and the assimilability of the nutrients (represented by the cation exchange capacity) made the greatest contribution in discriminating between site index classes. Wang (1995) found that in White Spruce (*Picea glauca* (moensch) Voss) soil physical properties explained more variance (54 per cent) than soil chemical properties (29 per cent). However, the same author found that the combination of soil chemical and physical properties explained up to 60 % of the total site index variance. In Scots pine stands in Sweden soil texture and element ratios have a strong importance to the estimation of site index (Holmgren, 1994). Jokela *et al* (1988) found that soil drainage conditions (percent of silt) and fertility (CEC) were important in estimating forest productivity. Failure of soil nutrients alone to explain a large proportion of the total variance of site index in different species such as White Spruce (Payandeh, 1986, Wang, 1995), Douglas-fir (Monserud *et al*, 1990), Ponderosa pine (Verbyla & Fisher, 1989) or Scots pine in this case, does not suggest that soil nutrients are not tree growth limiting. As Wang (1995) stated (1) there are many nutrients affecting tree growth and the limiting nutrient(s) may vary with site, (2) there are complex interactions between nutrients not described by linear relationships, (3) soil nutrients from chemical analysis may not be perfect measures of nutrient availability to tree growth and finally, (4) normally the internal nutrient cycling is not considered. The discriminant rule fitted shows that as the CEC is lower the texture is more important (Figure 2) to determine the site index (SI) class. Sandy soils usually have a lower SI while clay soils tend to have a higher SI. Studying the regeneration process in the Scots pine stands in the High Ebro Basin (northern Spain), González-Martínez and Bravo (in press) found that in sandy sites the Scots pine showed a higher density of viable seedling (related to a faster heigh growth) than in non sandy sites however, the authors had no statistical conclusive results in sandy sites due to interaction with other variables (competition and site preparation) and the lack of a strong sample. The site index in silty soils depends strongly on clay percentage and the CEC. Tamminen (1993) found that texture was weakly correlated with site index in southern Finland. However, our study shows that texture is a key variable in determining site index in Mediterranean sites, where the soil capacity to retain water is very important to forest growth. The different decomposition rates in boreal and mountain Mediterranean forest soils complicate the interpretation of this finding, but in general the nutrient supply has a lower impact than water supply in tree growth in the studied forest stands. Berg et al (1995) supported this idea because they found that the annual actual evotransporation were positively related with mineral (N, P, S and K) decomposition so when the cycling rate was high (warm sites) an adequate supply and retention of water has the highest importance for tree growth.

In conclusion, the site index curves fitted allow estimation of site index classes in pure Scots pine stands in northern Spain. An overall 61.11 per cent correct classification has been found using the site index curves developed. Additionally, an edaphic discriminant rule was developed and is useful for high-graded and young stands of Scots pine in the High Ebro basin (Northern Spain). The edaphic model selected tends to classify plots into the correct site index group with an error rate of 64 per cent, which is a normal value for these kinds of studies.

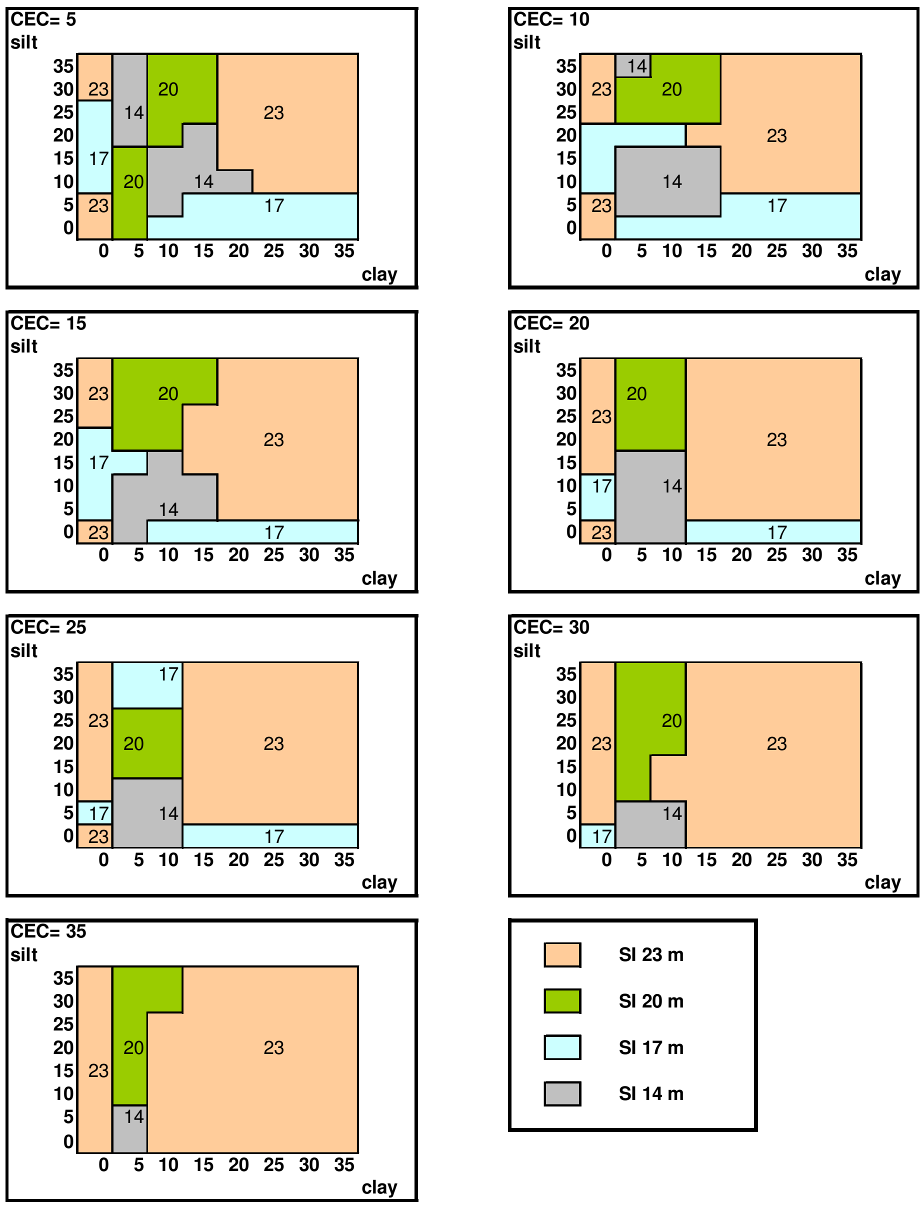

Figure 2.- Site index classification using CEC, clay and silt as classificatory variables for Scots pine stands in the High Ebro Basin (northern Spain).

Soil analysis is expensive in money and time, so foresters must balance the model's reliability prediction and alternative systems to estimate site index with the expense of collecting the necessary data. The edaphic rule must be used in high graded and in young stands while the site index curves must be the general tool in predicting site index in Scots pine stands in the High Ebro Basin (northern Spain). On the other hand, in developing new stands by plantation in the studied area, priority must be given to non sandy sites. Further analysis is needed to study the influence of texture upon tree growth and its importance on successful forest regeneration.

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