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The decline of *Austrocedrus chilensis* forests in Patagonia, Argentina: soil features as predisposing factors

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Abstract

The forests of *Austrocedrus chilensis* in southern Argentina suffer mortality from ‘‘mal del ciprés’’, whose causes remain unknown. The purpose of this work was to establish the relation of soil features with the occurrence of the disease. In Río Grande Valley, Chubut Province, Argentina, 14 areas with ‘‘mal del ciprés’’ were selected for study. The spatial pattern of the decline varied among the different areas and was classified as aggregated and disaggregated. In each area, symptomatic and asymptomatic plots were established and characterized by 11 edaphic and topographic variables. Three forest areas where the disease was totally absent were also included. Site features were related to the occurrence of the decline using principal component analysis and cluster analysis. Results indicated that soil properties related to poor internal drainage, such as the proximity to water streams, non-allophanized soils of fine textures, and redoximorphic features, act as predisposing factors to the development of ‘‘mal del ciprés’’. Poor soil drainage was strongly associated not only with the occurrence of the disease, but also with its spatial pattern. Symptomatic and asymptomatic plots presented similar edaphic features in areas with a disaggregated distribution of the decline and were grouped together in the multivariate analysis. This result suggests that large areas with such a pattern are prone to develop the decline.

Keywords: Cordilleran cypress; Drainage; Forest decline; Topography

1. Introduction

Cordilleran cypress (*Austrocedrus chilensis* (D. Don) Pic. Sern. et Bizzarri) is an endemic member of Cupressaceae of southern Argentina and Chile, distributed throughout the Patagonian Andes and its foothills. In Argentina, it is discontinuously distributed between 36°30′S and 39°30′S latitude and, more continuously, between 39°30′S and 43°35’S latitude, along a 60–80 km wide strip (Hueck, 1978; Dezzoti and Sancholuz, 1991). It forms pure or mixed stands with *Nothofagus* species along a precipitation gradient from 1700 mm in the west to 500 mm in the east including the fringes of the Patagonian steppe. Of the few gymnosperms inhabiting southern Argentina, all in the families Cupressaceae and Araucariaceae, it has the largest range, covering ca. 160,000 ha.

With its high quality and straight stems, the wood is used for construction and woodworking. Most of the Cordilleran cypress importance leans on its environmental and landscape roles, as their forests surround most of the cities and villages in the area. The distribution, vegetation types, autoecology, structure and

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stand dynamics of this species have been reported by Seibert (1982), Veblen et al. (1995), Donoso (1993) and Dezzoti and Sancholuz (1991). Disturbances and conservation of Cordilleran cypress forests have been reviewed by Veblen et al. (1995, 1996, 1999). Loguercio (1997) and Loguercio et al. (1999) developed forest management criteria for this species in Argentina.

1.1. The decline of Cordilleran cypress forests

Mortality of Cordilleran cypress was detected about 50 years ago throughout its range in Argentina. This decline is known locally as "mal del ciprés" and its extension and importance has increased in the past few decades (Hranilovic, 1988). The symptomatology of this disease is manifested as progressive withering and defoliation, decline in radial growth, and the decay of main roots lending to a brown rot in the sapwood and the final death of the tree. The cause of the decline is unknown. Filip and Rosso (1999) summarized the characteristics of the disease and discussed several hypotheses on its origin. Biotic causes have been suggested and screening of soil phytopathogenic fungi such as *Phytophthora* and *Pythium* has been carried (Rajchenberg et al., 1998), as well as screening for wood-rotting basidiomycetes responsible for brown root-rots in decaying trees (Barroetaveña and Rajchenberg, 1996). The importance of *Phytophthora* needs further re-evaluation (Hansen, 2000). Wood-rotting fungi appear to play a secondary role, as they are well known saprophytic species that colonize a wide range of substrates in this area. The lack of vesicular–arbuscular mycorrhizae on fine roots was also investigated, but did not appear to contribute to the disease (Fontenla et al., 1991).

Abiotic factors related to "mal del ciprés" have also been evaluated. Using dendrochronological techniques, Calí (1996) suggested that the decline was related to triggering factors such as a sequence of several cold and humid springs and summers or earthquakes. He also showed that the disease develops slowly in individual trees (approximately 75 years), which suggests that "mal del ciprés" is a type of decline disease (Manion, 1991; Manion and Lachance, 1992). In a study carried out in Nahuel Huapi National Park (Río Negro Province, Argentina), Baccalá et al. (1998) showed that forests prone to develop symptoms grew on sites with relatively high precipitation and moderate altitudes.

Various studies have related forest declines with site features. The decline and mortality of *Chamaecyparis nootkatensis* (D. Don) Spach in Alaska, which has important similarities with "mal del ciprés" (Filip and Rosso, 1999), has been associated with boggy and semi-boggy sites (Hennon et al., 1990). In Poland, oak decline develops on soils with lower water uptake compared to healthy sites (Maciaszek, 1996). In northeastern USA, stands of sugar maple (*Acer saccharum* Marsh.) suffer moderate to severe decline on unglaciated ridges, shoulders or upper backslopes, while stands located on glaciated sites and unglaciated lower topographic positions were not in decline (Horsley et al., 2000).

It is not still clear what role site features may play in the development of "mal del ciprés". Field observations suggest that it appears to be associated with wet soils (Rajchenberg and Cwielong, 1993; Filip and Rosso, 1999), but this hypothesis has not been thoroughly tested. The objective of this work was to evaluate what soil features are associated with the occurrence of the disease.

2. Materials and methods

2.1. Study sites

The study was carried out along an east–west (E–W) transect of the Río Grande Valley, Chubut Province, Argentina, located at 43°12′S latitude, between 71°28′W and 71°43′W longitude. This area is characterized by a marked precipitation gradient, from approximately 1500 mm at the border with Chile to nearly 600 mm at the eastern limit of Cordilleran cypress distribution. During 2000–2001, 14 areas of pure Cordilleran cypress forests with "mal del ciprés" were selected along the transect at varying points along the precipitation range. All the sampled areas corresponded to dense forests, originated after fires, with regular structure, with no history of salvage or exploitation cuttings. Areas were numbered according to their longitudinal position with increasing precipitation along the E–W transect (Fig. 1).

In each sampled area, a pair of representative 200 m^2 plots were established that differed in decline

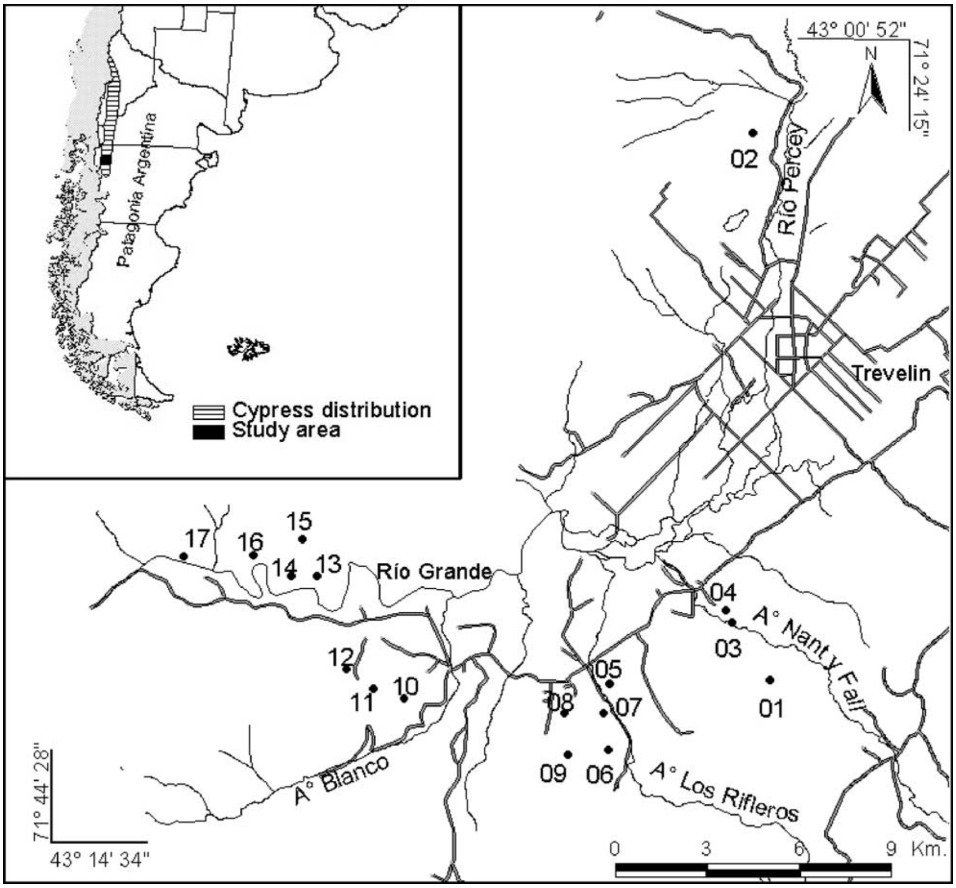

Fig. 1. Distribution area of *A. chilensis* in Patagonia, Argentina (dashed) and location of sampling areas along Río Grande Valley.

symptoms. Each pair included a plot with an advanced degree of decline (symptomatic plot) and another that did not exhibit symptoms (asymptomatic plot). Both plots within a pair had similar forest structure and were 50–100 m apart. Declining plots had approximately 90% dead trees, which included dominant, codominant, intermediate and overtopped crown classes. Asymptomatic plots could contain up to 20% of trees with symptoms of defoliation, but corresponded to overtopped crown trees. Symptoms of overtopped trees were related with high densities. Three control areas along the transect where the disease was totally absent were included (areas 1, 2 and 15) (Fig. 1). A total of 31 plots along the transect were established.

In each area, geographical location, altitude, aspect and precipitation were recorded. The spatial pattern of the disease in each area was visually classified as aggregated or disaggregated (Rosso et al., 1994) (Table 1). An aggregated pattern refers to the decline presenting hot spots clearly differentiated from the surrounding asymptomatic forest areas (Shurtleff and Averre, 1997). On the contrary, the spatial pattern was classified as disaggregated when declining trees were fairly uniform over the area (Shurtleff and Averre, 1997). Geographical location was recorded with a Garmin GPS75 global positioning system unit, the altitude with a digital altimeter and the aspect with a compass. Precipitation was recorded from the nearest meteorological station. Since it is a mountainous area and the variation in precipitation is very marked in short distances, these values were approximated. Precipitations are concentrated in autumn and winter (i.e. Mediterranean climate).

Table 1
Orientation, altitude, precipitation and spatial pattern of the decline in the sampled areas

Area	Aspect	Altitude (m.a.s.l.)	Precipitation (mm per year)	Spatial pattern of decline
01[a]	NO	546	689.9	None
02[a]	NE	546	689.9	None
03	NE	442	689.9	Disaggregated
04	S	450	689.9	Disaggregated
05	SW	398	887.5	Disaggregated
06	E	519	887.5	Aggregated
07	NE	478	887.5	Disaggregated
08	N	456	887.5	Aggregated
09	N	506	887.5	Aggregated
10	N	452	1105	Aggregated
11	NE	524	1105	Aggregated
12	E	384	1105	Aggregated
13	W	322	1105	Aggregated
14	W	318	1105	Aggregated
15[a]	S	424	1105	None
16	SW	346	1500	Aggregated
17	S	310	1500	Aggregated

[a] Control areas.

2.2. Plots characterization

Diameter at breast height (DBH), crown class and vitality class were recorded for all cypress trees ≥ 5 cm in DBH. Vitality class was classified visually following the scale of Rajchenberg and Cwielong (1993) that establishes six categories from 0 (healthy) to 5 (dead) (Table 2). In order to characterize the decline condition of each plot, the percent of cypress basal area in decline was used. It was calculated as the proportion of cypress basal area in classes 2–3 (diseased) and 4–5 (dead) (Table 2) compared with the total stand basal area of cypress.

In each plot the slope was measured and a pit was dug in order to study soil features. Eleven edaphic and topographic variables were used to characterize the sites: slope, horizon A thickness, textural classes of A and C horizons, bulk density of A horizon, pH in sodium fluoride (NaF) of A horizon, percentage of rock fragments in the soil profile, abundance of redoximorphic features, rooting depth of the soil, moisture at the end of summer and basic infiltration. The variables, their abbreviation and measurement unit are indicated in Table 3.

SLOPE was recorded with a clinometer. THICKA and DEPTH were measured in the soil profile with a tape measure. TEXTA and TEXTC were determined in the field according to methods described by Brady (1974). Traditional laboratory methods for particle-size analysis were not employed because Cordilleran soils usually present andic properties (Colmet Dâage et al., 1993, 1995; López et al., 1993; Lanciotti and Cremona, 1999) which make particles-size determinations difficult (Warkentin and Maeda, 1980). The term ‘‘andic properties’’ refers to soils developed from volcanic parent materials having distinguishing properties such as high content of amorphous clay (allophane, imogolite, poorly crystalline halloysite), low bulk density and irreversible changes in physical and mechanical properties on drying (Warkentin and Maeda, 1980). In order to determine DENSA, an undisturbed clod was collected from horizon A with a 100 cm^3 container, and oven-dry weight was determined. To determine NAFA, a soil sample of horizon A was collected, air-dried and passed through a 2 mm sieve. The pH was measured in 1 N sodium fluoride (1:50) at 2 and 60 min (Fieldes and Perrot, 1966). NAFA allows the detection of amorphous clays

Table 2
Vitality classes according to Rajchenberg and Cwielong (1993)

Vitality classes		Characteristics	Defoliation (%)
Healthy	0	Crown dense; leaves strong green	0–10
	1	Crown almost dense; leaves strong green	10–25
Diseased	2	Crown moderately thinned, with little foliage or foliage absent towards the bole. Leaves green, yellowing or withered	25–60
	3	Crown intensely thinned, with foliage only present at the branches tips. Leaves green, yellowing or withered	60–99
Dead	4	Leaves lacking. Standing, recently dead tree; bark unaltered	100
	5	Leaves lacking. Standing, tree dead 2–3 years ago or more; bark splitted	100

Table 3
Variables used to characterize the site

Variable	Abbreviation	Units/classification
Slope	SLOPE	°
Horizon A thickness	THICKA	cm
Textural class of horizon A	TEXTA	Clay: 1; silty clay: 2; sandy clay: 3; silty clay loam: 4; clay loam: 5; sandy clay loam: 6; silt: 7; silt loam: 8; loam: 9; sandy loam: 10; loamy sand: 11; sand: 12
Bulk density of horizon A	DENSA	g/cm^3
pH in 1 N NaF of horizon A at 60 min	NAFA	
Textural class of horizon C	TEXTC	clay: 1; silty clay: 2; sandy clay: 3; silty clay loam: 4; clay loam: 5; sandy clay loam: 6; silt: 7; silt loam: 8; loam: 9; sandy loam: 10; loamy sand: 11; sand: 12
Rock fragments in the profile	ROCK	vol.%
Abundance of redoximorphic features	REDOX	None: 0; few: 1; common: 2; many: 3
Rooting depth of the soil	DEPTH	cm
Moisture at the end of summer	MOISTURE	vol.%
Basic infiltration	BI	cm/h

derived from ash alteration. When NAFA is higher than 10, it indicates the presence of allophane (Fieldes and Perrot, 1966). Soils with imogolite present NAFA greater than 9.2 and soils with poorly crystalline halloysite present NAFA lower than 9.2. Non-volcanic soils and volcanic soils without amorphous clays present values near to 8 (Irissari, 2000). ROCK and REDOX were estimated in the soil profile according to Schoeneberger et al. (1998). Redoximorphic features originate from oxidation/reduction of iron and/or manganese and are usually present in conditions of poor drainage. REDOX was detected visually and/or with $\propto,\propto'$-dipiridil solution (Schoeneberger et al., 1998). MOISTURE was determined using Time Domain Reflectrometry at a depth of 60–80 cm at the end of the dry season in 2001. An average of two measurements were taken at two points separated by 8 m. BI is defined as the velocity of water entering into the soil, once the variation of that velocity has stabilized (Criddle et al., 1956). It was measured with a double ring infiltrometer until obtaining three equal infiltration rates, with a minimum of 10 readings (Fernández et al., 1971).

2.3. Statistical analysis

A principal component analysis (PCA) was conducted with the 11 variables mentioned above. Altitude, aspect and precipitation were not considered, since the declining plots and their respective asymptomatic pairs were sampled in neighboring areas with similar values. A matrix was built with the values of the variables (11 variables) in each plot (31 plots). PCA was conducted using a correlation matrix to avoid variation due to differences in measurement units (Escofier and Pagès, 1992). A cluster analysis was carried out, using the components of the PCA as variables. Ward's method was used which is based on the square of the distance among the points (Gauch, 1982). Multivariate analysis were carried out with PC ORD for Windows Version 3.0 (MjM Software, Gleneden Beach, Oregon, USA), a program developed for multivariate analysis of ecological data.

3. Results

The variables that characterized the sampled sites varied widely (Table 4). Cordilleran cypress stands grew on nearly flat sites but also on steep slopes that surpassed 40°. Soils varied from very shallow to deep; from clayey (TEXTC = 1) to sandy (TEXTC = 12), with no rock fragments along the profile to horizons with 90% rock fragments, with no redoximorphic features in the profile to many of such features. Allophanized volcanic soils occurred with NAFA greater than 10, but there were also non-volcanic soils with NAFA lower than 8. BI, which quantifies the soil capacity to accept water, varied from low to very high. Horizon A bulk densities were generally low, varying

Table 4
Average, standard error and value range of variables used to characterize the sites (for units, see Table 3)

Variable	Average	Standard error	Value range
SLOPE	13.18	9.49	1–41
THICKA	24.10	11.91	5–60
TEXTA	8.68	1.51	5–11
DENSA	0.77	0.19	0.42–1.20
NAFA	9.36	1.09	7.6–11.1
TEXTC	5.48	3.64	1–12
ROCK	21.90	31.80	0–90
REDOX	1.16	1.27	0–3
DEPTH	84.74	34.05	26–140
MOISTURE	30.12	8.86	17.1–50.8
BI	48.87	41.99	0.6–140.3

between 0.42 and 1.20 g/cm^3. Thickness of the A horizon varied widely.

3.1. Multivariate analysis

The first four PCA axes explained more than 75% of the total variation. Axis 4 had an eigenvalue near 1, whereas the subsequent axes had eigenvalues less than 1 and, therefore, were not considered (Pla, 1986) (Table 5).

The first axis explained 33% of the variance and was correlated with a gradient of soil drainage. It was negatively related with TEXTC, ROCK, NAFA and TEXTA and positively related with REDOX and MOISTURE (Table 6). In the ordination, declining plots tended to be together along axes 1 (Fig. 2). Asymptomatic plots tended to be placed towards negative values along axis 1, as did the three control plots (Fig. 2). The percent cypress basal area in decline tended to be placed towards positive values along axis 1, and plots with no or low declining basal area (i.e. asymptomatic and control plots) tended to group toward negative values along this axis (Fig. 3). However, some exceptions are distinguishable (Fig. 3). Although plots 11D, 12D and 16D were negatively related with axis 1, two of them (12D and 16D) were located only a few meters from a stream and bog, respectively. Plots 03A, 04A, 05A, 07A and 13A were positively related with axis 1. The first four of these plots corresponded to areas where the disease had a disaggregated spatial pattern (Table 1).

Table 5
Eigenvalues, explained variance and cumulative percent of variance for the four first components of PCA

Axis	Eigenvalue	Variance explained (%)	Cumulative variance (%)
1	3.638	33.07	33.07
2	2.114	19.22	52.29
3	1.416	12.87	65.17
4	1.127	10.24	75.41

Table 6
Eigenvectors of PCA

Variable	Axis 1	Axis 2	Axis 3
SLOPE	−0.2394	−0.4728	−0.0209
THICKA	−0.2077	0.2953	−0.2312
TEXTA	−0.2771	0.3263	0.0886
DENSA	0.1736	−0.2227	0.6310
NAFA	−0.3275	0.2142	−0.2570
TEXTC	−0.3470	−0.0793	0.4778
ROCK	−0.3376	−0.2922	−0.2315
REDOX	0.4351	−0.1275	−0.2458
DEPTH	−0.2437	0.4279	0.2079
MOISTURE	0.3741	0.2316	−0.1200
BI	−0.2498	−0.3777	−0.2721

Axis 2 explained 19% of the variance and was positively related with DEPTH, TEXTA and THICKA, and negatively with SLOPE, BI and ROCK (Table 6). There was no separation of declining plots from asymptomatic ones along axis 2 (Fig. 2).

Axis 3 explained 13% of the variance and was positively related with DENSA and TEXTC, and negatively with BI (Table 6). Plots with allophanized and rocky soils, with low bulk density of horizon A, and high basic infiltration, were placed in the third quadrant of the ordination according to axes 1 and 3. The three control plots were also placed in that quadrant (Fig. 4).

PCA showed that declining plots tended to be grouped together and separated from asymptomatic and control ones, with some exceptions. In order to test tendencies observed in the PCA, a cluster analysis was carried out using the coordinates of the first three axes of PCA as variables. A 50% value of remaining information was used to distinguish plot groupings, which were divided into three clusters (Fig. 5).

Most of the declining plots were grouped in Cluster I (10D, 04D, 07D, 05D, 03D, 17D, 06D, 08D, 14D, 09D and 13D). Four asymptomatic plots were also

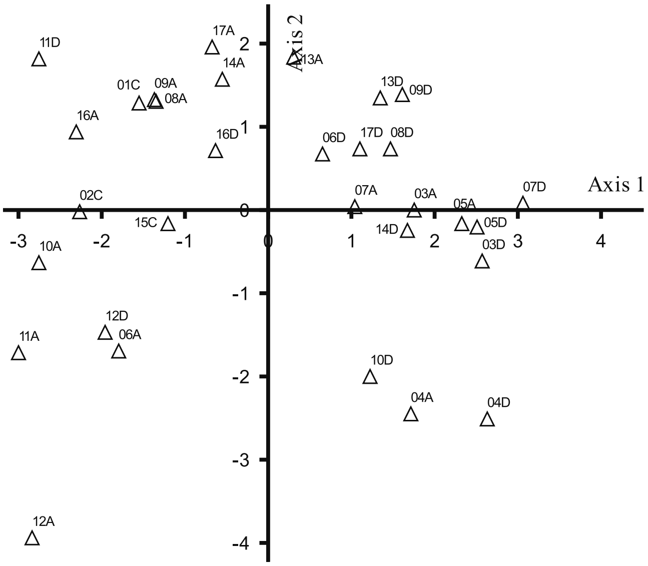

Fig. 2. Plot ordination according to the first and the second components of principal components analysis (PCA). Each plot is identified with the corresponding area number and a letter—“D”: declining plot; “A”: asymptomatic plot; “C”: control plot.

grouped in this cluster (04A, 05A, 03A, and 07A); they corresponded to areas where the disease presented a disaggregated spatial pattern (Table 1). All plots grouped in Cluster I were positively related with the first component of the PCA (Fig. 2). They were characterized by low TEXTA and TEXC (i.e. fine textures), low NAFA, and high REDOX and MOISTURE. Most of these plots presented low slope levels, clayey horizon C, and lacked rock fragments (Table 7). Soils that did not present amorphous clay were included in this cluster. All the plots grouped in Cluster I presented redoximorphic

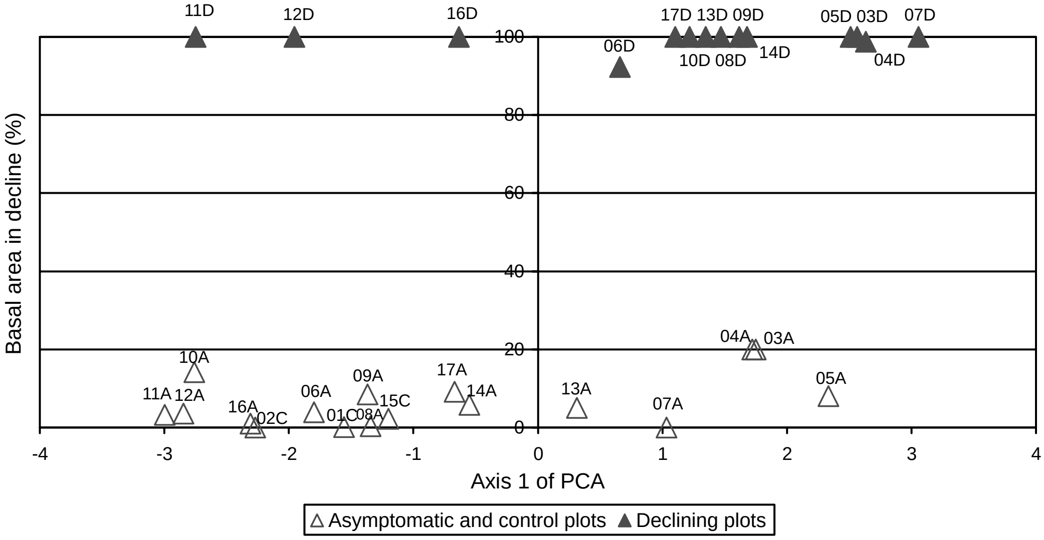

Fig. 3. Relationship between percent diseased and dead cypress basal area of each plot and its corresponding coordinates in the first component of PCA.

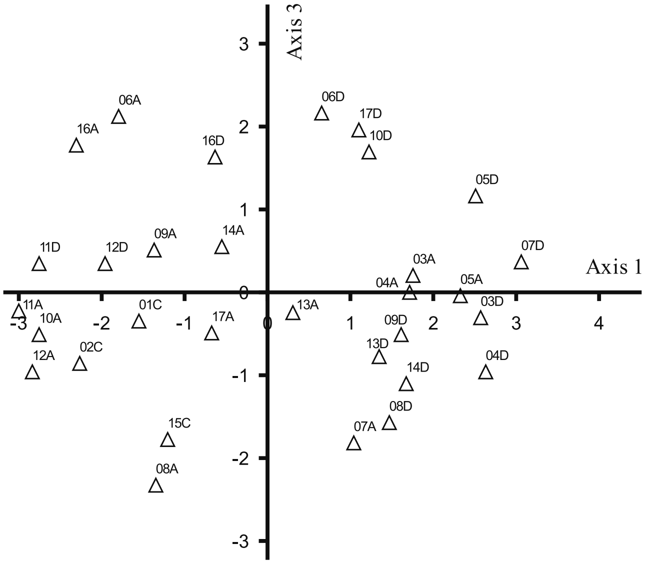

Fig. 4. Plot ordination according to the first and the third components of principal components analysis (PCA). Each plot is identified with the corresponding area number and a letter—"D": declining plot; "A": asymptomatic plot; "C": control plot.

features, which were found between 7 and 60 cm depth, and co-occurring with roots. Redoximorphic features were related with the presence of the clayey horizon, excepting the two plots that had coarser textures and rock fragments (6D and 10D), which were in riverine systems.

Cluster II contained mainly asymptomatic and one control plot (10A, 02C, 11A, 06A and 12A). These plots tended to be negatively related with axes 1 and 2 of PCA (Fig. 2). They corresponded to sites with high SLOPE, NAFA, ROCK and BI and low THICKA, REDOX and DEPTH (Table 7). Only one plot (10A) presented few redoximorphic features which were at a depth of 90 cm, deeper than rooting depth. A declining plot, i.e. 12D, also grouped in this cluster and presented the same characteristics mentioned above. This plot was also located near a water stream.

Cluster III contained asymptomatic and control plots (16A, 09A, 14A, 01C, 13A, 17A, 08A and 15C), but also two declining plots (11D and 16D).

Table 7
Average, standard error and value range for the variables for each of the three clusters produced by the cluster analysis (for units, see Table 3)

	SLOPE	THICKA	TEXTA	DENSA	NAFA	TEXTC	ROCK	REDOX	DEPTH	MOISTURE	BI
Cluster I											
Average	9.83	18.60	7.93	0.84	8.77	3.47	4.93	2.33	66.93	35.34	34.43
Standard error	6.47	7.88	1.71	0.20	1.11	2.70	11.05	0.72	24.32	7.83	35.85
Value range	1–19	5–32	5–11	0.57–1.20	7.6–10.4	1–9	0–40	1–3	26–120	19.9–50.8	0.6–105.2
Cluster II											
Average	24.33	21.67	9.67	0.75	9.78	9.00	66.67	0.17	76.00	20.17	103.58
Standard error	12.44	9.18	1.03	0.18	0.71	2.68	30.11	0.41	36.85	1.33	35.31
Value range	8–41	10–33	8–11	0.48–1.01	8.8–10.6	4–12	20–90	0–1	36–140	18.2–21.9	52.6–140.3
Cluster III											
Average	11.50	33.80	9.20	0.65	9.97	6.40	20.50	0.10	116.70	28.25	37.70
Standard error	6.64	13.05	0.79	0.13	0.78	3.60	29.29	0.32	21.81	7.09	26.52
Value range	3–25	15–60	8–10	0.42–0.83	8.7–11.1	2–12	0–75	0–1	80–140	17.1–36.8	9.7–94.7

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                         Distance (Objective Function)
          .073          55.608         111.143         166.678         222.214
          |-------+-------+-------+-------+-------+-------+-------+-------+
                         Information remaining (%)
     100.000          75.000          50.000          25.000            .000
          |-------+-------+-------+-------+-------+-------+-------+-------+
10D       -----|--------------|
04D       |----|              |
04A       |                   |
07D       ||                  |----|
05D       ||-----------|      |    |
03D       ||           |      |    |
05A       ||           |------|    | ClusterI
03A       |            |           |------------------------------------|
17D       |------------|           |                                    |
06D       |                        |                                    |
07A       |                        |                                    |
08D       |--|                     |                                    |
14D       |  |---------------------|                                    |
09D       |--|                                                          |
13D       |                                                             |
10A       |--|                                                          |
02C       |  |---|                                                      |
11A       |--|   |---|               Cluster II                         |
12D       |      |   |------------------------|                         |
06A       -------|   |                        |                         |
12A       -----------|                        |                         |
11D       ----|----|                          |                         |
16D       -|--|    |                          |-------------------------|
16A       -|       |-------|                  |
09A       |        |       |                  |
14A       |-|      |       |      Cluster III |
01C       | |------|       |------------------|
13A       |-|              |
17A       |                |
08A       -|---------------|
15C       -|
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Fig. 5. Dendrogram of cluster analysis, carried out using coordinates of the first three components of PCA.

They were negatively related with axis 1 of PCA, and positively related with axis 2 (Fig. 2). They corresponded to sites with high THICKA, NAFA, TEXTC and DEPTH and low SLOPE and REDOX (Table 7). Only one plot (08A) presented few redoximorphic features which were at a depth of 100 cm, deeper than rooting depth. Plot 16D was located approximately 5 m from a boggy area. Plots grouped in Cluster III differed from those grouped in Cluster II mainly in soil depth, the abundance of rock fragments and slope (Table 7).

4. Discussion

Cordilleran cypress develops in different environmental conditions, from very wet sites to rocky sites in the Patagonian steppe (Veblen et al., 1996). The sampled forests also presented a great variability of site features. Cypress forests developed in a wide range of soil conditions inhabiting deep and volcanic soils, but also shallow and clayey ones.

Results showed that declining plots differed from asymptomatic and control ones, mainly by their texture classes, allophanization degree, available moisture at the end of the dry season and abundance of redoximorphic features in the soil profile. In most of the sites, a relationship between decline occurrence and the variables that characterize poor drainage was evident. Most of the plots with evidence of decline had redoximorphic features not far below the surface. These features are a soil morphological property indicative that the soil is saturated with water during some portion of the year. Declining plots tended to have also a low allophanization degree. On the contrary, asymptomatic and control plots tended to have amorphous clays, which allows good water retention, as well as a good aeration and permeability. These soil properties are more marked in soils with allophane and less marked in soils with poorly crystalline halloysite (Warkentin and Maeda, 1980).

Cordilleran cypress is a pioneer species that establishes very rapidly after fire (Veblen et al., 1995, 1996). Colmet Dâage (1992) hypothesized that “mal del ciprés” appears when Cordilleran cypress colonizes inappropriate sites, where a higher risk of becoming diseased exists. Our results support this view. Declining stands developed on poorly drained soils that are saturated with water during some period of the year, creating O_2 deficiency (Black, 1975). The lack of aeration seriously affects respiration and the active absorption of nutrients that depend on the energy liberated by respiration (Kozlowski et al., 1991). Poor soil aeration is externally manifested by crown discoloration and death of the leaves, reduction in stem growth, and on occasions, the death of the trees (Donoso, 1981). This symptomatology is coincident with that observed in declining Cordilleran cypress forests (Havrylenko et al., 1989; Filip and Rosso, 1999).

Three declining plots had similar soil features as asymptomatic and control plots. However, two of these plots were located near water. Only one declining plot had well-drained soil far from water. It was a single case and an evidence that other factors associated with the disease may exist, independent from drainage.

Asymptomatic plots of areas where the disease exhibited a disaggregated pattern were grouped with declining plots. These asymptomatic plots and their respective declining pairs, had clayey and shallow soils. The presence of fine materials at a shallow depth results in lack of aeration and hinders the penetration of roots as well as water infiltration (Donoso, 1981; Narro Farías, 1994; Lanciotti and Cremona, 1999; Conti, 2000). On these areas, asymptomatic plots did not constitute a large or well-defined area of healthy trees; on the contrary, they were surrounded by declining trees and the spatial pattern of the decline was classified as disaggregated. This is an indication that the whole stand may be susceptible to develop the decline. Previous works suggested that “mal del ciprés” presents a disaggregated pattern of distribution only at high level of incidence (Rosso et al., 1994).

Although a distinct relationship existed between the drainage and the disease, this study could not clarify if this relationship is direct or if the deficient drainage acts as a predisposing factor for the disease, perhaps favoring the proliferation of certain pathogens, such as *Phytophthora* spp. (Rajchenberg et al., 1998; Filip and Rosso, 1999; Hansen, 2000). The high moisture content of the soil associated with limited drainage, produces appropriate conditions for the proliferation and infection by these organisms (Sinclair et al., 1987). A disaggregated pattern of distribution of the disease, though, is not a strong indication of the existence of a biotic cause. Diseases caused by soilborne pathogens are rarely uniformly present over an entire stand (Shurtleff and Averre, 1997).

While Calí (1996) related the onset of the decline with previous climatic or geologic events that were postulated as triggering factors of the decline, our results show that stand vulnerability to the disease is strongly associated with microsite factors. It is interesting to point out that in the stands studied by Calí (1996), the declining condition increased with increasing proximity of trees to water.

Numerous fungal species were associated with the decline but none of them could be demonstrated to act as a primary pathogen (Rajchenberg et al., 1998). An association was also detected between the decline and topographic and climatic factors (Baccalá et al., 1998; Calí, 1996) and, in this study, a narrow relationship was found between the decline and several edaphic features associated to drainage. These results suggest that ‘‘mal del ciprés’’ can effectively be considered a decline disease (Manion, 1991; Innes, 1993).

This study is a first step towards understanding how soil features are related with the decline. Future studies should focus in detailed measurements of the time that soils remain saturated with water during the year and the depth of saturation. Two aspects that also need future evaluation are the influence of mineral nutrition and human activity on the development of the disease. Several studies have shown the important influence of tree nutrition and soil mineral concentrations on tree vigor in forest diseases (Horsley et al., 2000; Innes, 1993).

The comprehension of how edaphic variables are involved to *A. chilensis* decline may also be used in the development of site indexes for forest management.

5. Conclusion

In the area of Río Grande Valley an edaphic pattern associated to the decline and mortality of Cordilleran cypress exists. Declining stands developed on soils of fine textures, not allophanized, with presence of redoximorphic features not far below the soil surface, and/or near to water streams. These variables might be considered the most relevant features associated to the occurrence of the disease. Thus, site conditions that favor poor internal drainage act as predisposing factors that enhance the development of ‘‘mal del ciprés’’. Site conditions would dictate where, and with what spatial pattern the disease develops. According to site features, asymptomatic trees in areas with a disaggregated pattern of distribution of the disease, should also be considered as prone to develop the disease.

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