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Influence of vegetation management and fertilization on *Pinus pinaster* growth and on understory biomass and composition

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Abstract

To study the influence of understory vegetation management and fertilization, on pine growth and competing vegetation, a field trial was established in a 6-year old pine forest. Treatments included: control (C), vegetation cutting and removal, with and without fertilization (CRF and CR treatments), vegetation chipping, with and without fertilization (CDF and CD treatments). Treatments were replicate three times and arranged in completely randomized blocks. Pine volume was determined between 2002 and 2007 and understory was surveyed, quantified and analysed for macronutrients in 2002 and 2003.

Vegetation chipping plus fertilization lead to the largest ($p < 0.05$) increase in pine volume (9.6 m^3 ha^{-1} $year^{-1}$) while removal of understory resulted in the lowest ($p < 0.05$), 5.1 m^3 ha^{-1} $year^{-1}$. In the other treatments, the average increase in volume was similar (6.4 m^3 ha^{-1} $year^{-1}$).

When understory was removed nutrient output was rather large, especially the N output since *Ulex minor* was in 2002 the dominant species (65%). CD treatment was the most effective in reducing understory biomass (–76%), followed by CR (–65%), CDF (–57%) and CRF (–46%) treatments. In Control, vegetation biomass increased 48%.

These results indicate that removal of understory without fertilizer addition is not a suitable practice. Chipping of vegetation besides avoiding nutrient output, decreased the amount of fuel, hence decreases fire risk, and if used with fertilizers leads to a significant increase in pine growth.

Key words: understory removal; understory chipping; understory biomass; pine growth.

Resumen

Influencia del manejo de la vegetación y la fertilización en el crecimiento y sobre la biomasa y composición del subpiso

Para estudiar la influencia del manejo de la vegetación del subpiso y de la fertilización en el crecimiento y la vegetación competidora, se realizó un ensayo en un pinar de 6 años de edad. Los tratamientos incluyeron: Control (C), corta y extracción de la vegetación, con y sin fertilización (tratamientos CRF y CR), astillado de la vegetación, con y sin fertilización (tratamientos CDF y CD). Los tratamientos se repitieron tres veces y se distribuyeron en bloques completos al azar. El volumen de los pinos se determinó entre 2002 y 2007, y los macronutrientes del subpiso se evaluaron, cuantificaron y analizaron en 2002 y 2003.

El astillado de la vegetación junto con la fertilización condujeron al mayor ($p < 0,05$) incremento en el volumen de los pinos (9,6 m^3 ha^{-1} $año^{-1}$), mientras que la extracción del subpiso produjo el menor crecimiento ($p < 0,05$), 5,1 m^3 ha^{-1} $año^{-1}$. En los otros tratamientos, el incremento medio en volumen fue similar (6,4 m^3 ha^{-1} $año^{-1}$).

Cuando se extrajo el subpiso la salida de nutrientes fue bastante grande, especialmente en N, puesto que Ulex minor era en 2002 la especie dominante (65%). El tratamiento CD fue el mas efectivo en reducir la biomasa del subpiso (–76%), seguido por CD (–65%), CDF (–57%) y CRF (–46%). En el control, la biomasa de la vegetación se incrementó en un 48%.

Estos resultados indican que la extracción del subpiso sin fertilización no es una práctica adecuada. El astillado de la vegetación además de evitar la extracción de nutrientes disminuye la cantidad de combustible y por tanto disminuye el riesgo de incendio, y si se usa con fertilizantes produce un incremento significativo en el crecimiento de los pinos.

Palabras clave: extracción del subpiso; astillado del subpiso; biomasa del subpiso; crecimiento de pinos.

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Introduction

Maritime pine (*Pinus pinaster* Ait.) is the second dominant species in Portugal, occupying 23% of the national forestry area (DGRF, 2007). Usually, pine stands have dense understories which compete for soil available moisture, sunlight and nutrients. As such, control of competing vegetation in plantations is important not only because it generally increases tree growth, due to a decreased competition (Cain, 1991; Powers and Reynolds, 1999; Rose and Ketchum, 2002; Albaugh *et al*., 2003; Borders *et al.,* 2004), but also because it decreases the wildfire risk (Savill *et al*., 1997; Fernandes *et al*., 2004). Vegetation management, however, will have to be done through techniques which sustain the productive capacity of forest soils. Due to the increased demand of vegetation for biomass centrals, removal of all understory vegetation in pine stands is becoming a usual practice in Portugal. This practice, however, may modify nutrient capital and rate of supply to trees. Removal of understory biomass, besides being a major pathway for loss of nutrients (Pritchett and Fisher, 1987), can also lead to a reduction in forest floor carbon due to an increased soil temperature (Burgess *et al*., 1995; Marsushima and Chang, 2005). Chipping of vegetation may be a more suitable management practice. Besides avoiding nutrient outputs, it may increase the amount of nutrients available to plants depending on the composition and quantity of the plant residues (Tisdale *et al*., 1998).

The best results of controlling vegetation are usually obtained if fertilizers are also applied (Burgess *et al*., 1995; Albaugh *et al*., 2003; Borders *et al.,* 2004). Although maritime pine is, in general, well adapted to low fertility soils, in Portugal, some studies demonstrated that nutrients such as nitrogen (N), phosphorus (P) and potassium (K), have positive effect on its growth (Oliveira, 1959; Marques, 1987; Alves, 1998).

Given the scarcity of experimental data to determine the interest of fertilisation along with mechanical vegetation control on the growth of maritime pine, in 2002, a field trial was established in a 6-year old pine forest in order to evaluate (1) the effect of vegetation management (cutting with removal or chipping) and fertilization on pine volume increment and (2) on understory biomass and composition.

Material and Methods

The study took place between July 2002 and February 2007, in a pine stand established in northern Portugal (Seia - 38° 48' N, 23° 20' O; altitude - 450 m). The climate is of the Mediterranean type, with mean annual temperature of 10°C and mean annual rainfall of 1,100 mm. The soils, classified as Humic Cambissols, are sandy loam derived from schist. Some soil properties, at the beginning of the study, are shown in Table 1.

The pine stand, which occupies an area of 126 ha, was planted in 1996, at 3.0 m × 2.5 m spacing (1,333 trees/ha). The pine seedlings were 1-year old and they were produced at a nursery near Coimbra, central Portugal. The origin of the population is unknown since, at the time, in Portugal it was not mandatory to certify the seeds.

The experimental design consisted of five treatments replicated three times and arranged in completely randomized blocks (Fig. 1): control (C); vegetation cutting and removal (CR) – the most used practice in the region; vegetation cutting, removal and addition of N, P and K (CRF); vegetation cutting and chipping (CD); vegetation cutting, chipping and addition of N, P and K (CDF). The average plot size was 782 m^2 and the average tree per plot was 115.

The understory vegetation management was done in July 2002. All the vegetation present in each plot was cut at ground level, and removed or chipped depending on the treatment. The fertilizers were added in September, to all trees in CDF and CRF plots. It was applied 20 g of N per tree, as ammonium nitrate with lime 20,5%N (130 kg ha^{-1} of fertilizer), 88 kg of P ha^{-1} and 166 kg K ha^{-1} as a compound fertilizer (0:20:20-1,000 kg ha^{-1}). Nitrogen was not broadcast as P and K

Table 1. Soill properties determined before treatments (April, 2002)

Deph	OM (%)	pH (H_2O)	P_2O_5 (mg kg^{-1})	Ca^{2+} (cmol$_c$ kg^{-1})	Mg^{2+} (cmol$_c$ kg^{-1})	K^+ (cmol$_c$ kg^{-1})	Al^{3+} (cmol$_c$ kg^{-1})	CEC (cmol$_c$ kg^{-1})
0-20 cm	7.84	5.0	5	0.16	0.11	0.07	1.31	1.80
20-40 cm	1.12	4.9	1	0.08	0.05	0.04	0.77	0.98

OM (organic matter): modified Walkly-Black method. pH: 1:2.5soil solution ratio. P_2O_5: Egner-Riehm method. Exchangeable bases: 1N ammonium acetate pH 7. Exchangeable Al: KCl method. CEC (cation exchange capacity): sum of exchangeable bases and exchangeable acidity.

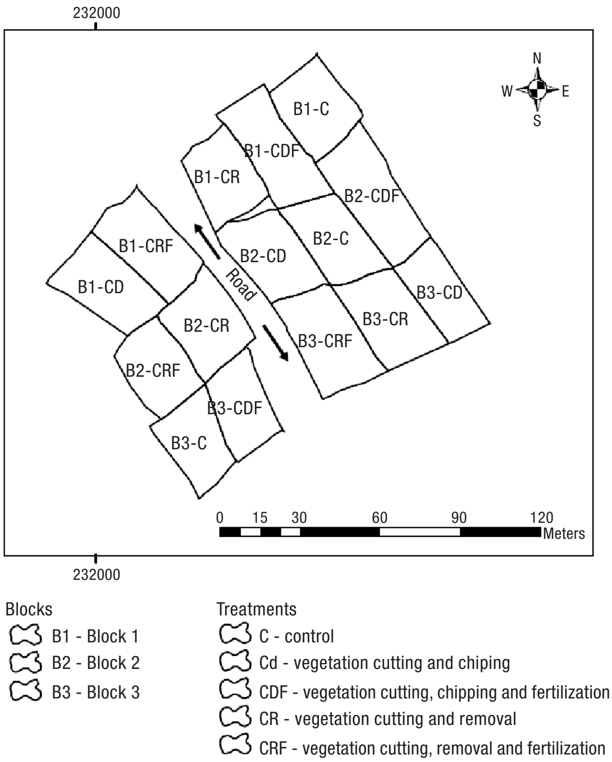

Figure 1. Experimental design layout.

in order to minimize the understory growth since wildfire risk in the area where the stand was located was very high.

In July of 2002 and 2003, the quadrat method (Kent and Coker, 1992) was used to survey the understory vegetation and to assess their biomass. Since the vegetation was relatively uniform in distribution, cover, height and species through experimental plots, a 1 m × 1 m frame was randomly applied only three times in each plot. All the plants inside the frame were harvested close to the ground, sorted by species and weighted. After, a sample of each species was dried at 60°C for at least 48 h, weighed for dry matter determination and ground to pass a 1-mm screen for determination of N, P, K, Ca, and Mg concentrations. For K, Ca and Mg determinations the ground tissue was digested with nitric-perchloric acids, being Ca and Mg determined by atomic absorption spectrophotometry and K by flame photometry. For N and P analysis, the digestion was with sulphuric acid and their concentration was determined by an autoanalyzer.

In these two years the species identified in all plots were: *Ulex minor* Roth (dwarf gorse), *Calluna vulgaris* (L.) Hull (scotch heather), *Pterospartum tridentatum* (L.) Willk, *Agrostis castellana* Boiss. & Reut. (bentgrass), *Cytisus striatus* (yellow broom), *Pteridium aquilinum* (L.) Kuhn (bracken fern), *Pseudoarrhenatherum longifolium* (Thore) Rouy and *Halimium alyssoides* (Lam) C. Koch (sargasso).

In each plot, immediately after vegetation management (July 2002), all pines were measured for determination of height (h) and breast height diameter (DBH, 1.3 m). After, all pine trees in the plots were measured four more times in the dormant season (March 2003, January 2004 and in February of 2006 and 2007). With height and breast height diameter tree volume (v) was calculated. Until February 2006 tree height was measured with a telescoping measuring rod and, on later phases, with a Vertex hypsometer.

Since the initial tree height and breast height diameter was not uniform, the statistical analysis was performed on the volume increments by using the JMP5 program (SAS Institute). It was performed a Oneway ANOVA and the Tukey HSD test was conducted as mean comparison test. The significance level of 0.05 was used in all statistical analysis. Normality tests, the Skewness and Kurtosis tests, on data set showed that transformations of data were not required. Although all trees in the plots were measured, the statistical analysis was performed, on average, on data collected on 60 trees per plot since two tree rows between each plot were left as border.

Results

In the year following the application of treatments, the biggest ($p < 0.05$) increase in volume occurred in treatment CDF, followed by treatment CD (Table 2). No significant differences were found among the other treatments. After the third year, the biggest ($p < 0.05$) increases in volume took place still in the CDF treatment but the lowest ($p < 0.05$) increases occurred in the CR treatment. Thus, the cumulative increases (2002/2007) in volume occurring in this treatment were significantly lower than those of other treatments. In this treatment, the mean annual volume increase was 5.1 m^3 ha^{-1}, followed by the CRF treatment (6.1 m^3 ha^{-1}), Control and CD treatment (6.4 m^3 ha^{-1}) and CDF treatment (9.6 m^3 ha^{-1}).

As expected, from 2002 to 2003, understory vegetation increased in Control (48%) and decreased in the other treatments (Table 3). The biggest biomass reduction occurred in CD treatment (76%), followed by the CR treatment (65%). When fertilizers were applied,

Table 2. Initial pine volume (m^3 ha^{-1}), mean and cumulative volume increaments (m^3 ha^{-1}) of *Pinus pinaster* trees with different vegetation management and fertilization along a sequence of five years (mean ± SE). Within each column, means followed by the same letter are not different ($p < 0.05$)

Treatments	Initial pine volume	Mean volume increament				Cumulative volume increament		
		2002/03	2003/04	2004/06	2006/07	2002/04	2002/06	2002/07
C	6.9	1.5 ± 0.2[c]	5.5 ± 0.4[b]	15.9 ± 0.9[b]	9.0 ± 0.5[b]	7.0 ± 0.5[b]	22.9 ± 1.2[bc]	31.9 ± 1.6[b]
CR	6.1	1.8 ± 0.2[c]	6.4 ± 0.4[b]	11.4 ± 0.9[c]	5.7 ± 0.5[c]	8.2 ± 0.5[b]	19.6 ± 1.2[c]	25.3 ± 1.6[c]
CRF	4.9	1.9 ± 0.2[c]	6.6 ± 0.4[b]	15.4 ± 0.9[b]	6.8 ± 0.5[c]	8.5 ± 0.5[b]	23.9 ± 1.2[bc]	30.7 ± 1.7[bc]
CD	6.3	2.6 ± 0.2[b]	6.2 ± 0.4[b]	15.6 ± 0.9[b]	7.2 ± 0.6[bc]	8.9 ± 0.5[b]	24.6 ± 1.3[b]	31.8 ± 1.7[b]
CDF	9.0	4.3 ± 0.1[a]	9.2 ± 0.3[a]	22.9 ± 0.7[a]	11.5 ± 0.4[a]	13.5 ± 0.4[a]	36.4 ± 0.91[a]	47.8 ± 1.2[a]

C: control. CR: vegetation cutting and removal. CRF: vegetation cutting, removal and fertilization. CD: vegetation cutting and chipping. CDF: vegetation cutting, chipping and fertilization.

Table 3. Understory dry matter (DM) before (2002) and after (2003) applying the treatments

Treatment	DM in 2002 (kg ha^{-1})	DM in 2003 (kg ha^{-1})	Variation (%)
C	8,988	13,360	+48
CR	15,139	5,230	–65
CRF	8,249	4,519	–46
CD	10,620	2,584	–76
CDF	12,403	5,292	–57

C: control. CR: vegetation cutting and removal. CRF: vegetation cutting, removal and fertilization. CD: vegetation cutting and chipping. CDF: vegetation cutting, chipping and fertilization.

the reduction of vegetation was not as accentuated as without fertilizers and, in treatment CDF the decrease in understory biomass was greater than in the CRF, 57 and 46% respectively.

From 2002 to 2003 the composition of the understory vegetation also changed, either by loss of species or appearance of new ones (Table 4). In 2003, and in all treatments, *Calluna vulgaris* has become the dominant species at the expense of *Ulex minor*. This species had even disappeared in treatments CRF and CD. When vegetation was cut and removed, treatment CR, in addition to the sharp decline of *Ulex minor* (76 to 6%), *Pterospartum tridentatum* disappeared. The development of *Agostis castellana* increased and a new grass (*Pseudoarrhenatherum longifolium*) appeared. When vegetation was only cut and chipped, treatment CD, appeared *Pseudoarrhenatherum longifolium* and also *Halimium alyssoides*. *Ulex minor*, as already mentioned, disappeared in this treatment. When fertilizers were also added, treatments CRF and CDF, besides increasing *Agrostis castellana* growth, *Pseudoarrhenatherum longifolium*, *Pteridium aquilinum* and *Halimium alyssoides* appeared. *Cytisus striatus*, which was present only in one of the three plots where treatment CDF was tested, disappeared in 2003. In Control, *Agrostis castellana* was no longer present in 2003, perhaps as a result of being shaded out by the shrubs.

Table 4. Percentage of each species to total dry matter (DM) biomass, in 2002 and 2003

	C		CR		CRF		CD		CDF	
	2002	2003	2002	2003	2002	2003	2002	2003	2002	2003
Ulex minor	60	43	76	6	66	0	70	0	54	2
Calluna vulgaris	23	55	12	78	15	48	23	38	22	51
Pterospartum tridentatum	6	1	3	0	16	9	0	0	10	11
Agrostis castellana	9	0	5	9	2	31	3	17	5	25
Cytisus striatus	0	0	0	0	0	0	0	0	7	0
Pteridium aquilinum	2	2	3	4	0	2	4	7	1	5
Pseudoarrhenatheum longifiliumr	0	0	0	3	0	3	0	27	0	3
Halimium alyssoides	0	0	0	0	0	7	0	11	0	4

C: control. CR: vegetation cutting and removal. CRF: vegetation cutting, removal and fertilization. CD: vegetation cutting and chipping. CDF: vegetation cutting, chipping and fertilization.

Table 5. Average nutrient output, 2002, in the plots where treatments CR and CRF were established

	N	P	K	Ca	Mg
	(kg ha^{-1})				
Ulex minor	132.7	3.9	18.5	20.7	17.2
Calluna vulgaris	14.0	1.2	5.7	4.4	2.7
Pteridium aquilinum	2.6	0.2	1.6	0.8	0.5
Pterospartum tridentatum	9.2	0.3	1.0	1.2	1.4
Agrostis castellana	3.9	0.3	1.9	0.7	0.4
Total output	162.4	5.9	28.7	27.8	22.2

CR: vegetation cutting and removal. CRF: vegetation cutting, removal and fertilization.

Ulex minor, the dominant species in 2002 (65% of dry matter understory biomass-average of all treatments), was the species responsible for increased output of nutrients, being N the nutrient exported in larger quantities (Table 5). From the 162 kg of N ha^{-1} exported, 133 kg (82%) were contained in this species. This was expected since this *Ulex minor* is a legume and, as such, have high concentrations of N, 15.4 g kg^{-1} MS (Xavier, 2008).

Discussion

Chipping of understory combined with fertilization, CDF treatment, resulted in significant increases in pine growth. The effect of increasing pine volume was still significant at the end of this study, four years after vegetation management (Table 2). Albaugh *et al*. (2003), also indicated that the best growth in volume of *Pinus taeda* was obtained in the combined treatment, control vegetation and fertilisation, followed by fertilization and after by control of vegetation. Similar results were reported in other studies (Burgess *et al*., 1995; Martin and Jokela, 2004; Borders *et al*., 2004). If the effects of fertilisation and vegetation management were examined separately, the effect of fertilisation in growth only exceeded the effect of vegetation control when the water content of the soil was not limiting, even in soils with low fertility. When water was not a limiting factor, any one of the treatments gave good results, although greater increases in volume were obtained when the two treatments were applied jointly (Powers and Reynolds, 1999; Rose and Ketchum, 2002; Albaugh *et al*., 2003; Borders *et al*., 2004).

Removal of understory, with or without fertilizers did not improve growth and three years after removing the vegetation, in the CR treatment the increaments in pine volume were even lower ($p < 0.05$) than in Control, suggesting that in this treatment light was no longer a major factor limiting growth.

Plant species change after competition control is consistent with other vegetation management studies (Miller *et al.,* 1995; Carneiro *et al*., 2007). Usually, the disappearance of large plants tends to favour the appearance of grass or grass like vegetation, besides increasing the growth of the herbaceous already present (Miller *et. al*., 1995). These plants are effective competitors for nutrients and water (Cain, 1991). The increased amount of grasses in CR treatment may have contributed to the reduced increase in pine volume. Several other factors may explain this reduced pine growth. One could be related to the lack of soil cover after vegetation management, which may affect the soil available water content. Removal of all vegetation can result in higher soil temperature (Marsushima and Chang, 2005), hence decreasing soil water, while the operation of chipping creates on the soil a layer of residues which decreases the solar radiation that comes directly to the ground and, consequently, may decrease water evaporation. The decrease in nutrients due to nutrient output through removal of vegetation may also be related. Chipping of vegetation, besides avoiding nutrient output, depending on the rate of mineralization of the residues, may increase the amount of nutrients available to the plants. In this study, however, that was not yet verified. In January 2006, where soil samples were collected again, the eventual increase in nutrient availability had not yet reflected in the results of the soil analysis (Xavier, 2008). That could be attributed to the fact that the dominant species of the understory of this the pine stand were woody, *Ulex minor* and *Calluna vulgaris*. Hence, their mineralization should be less rapid than mineralization of herbaceous vegetation (Tisdale *et al*., 1998).

Despite the increases in pine growth being the largest in CDF treatment, the cost of fertilization may make this practice economically unviable. As such, chipping of understory (CD treatment) should be considered since the operation of chipping leaves on the soil a layer of residues which decreases the solar radiation that comes directly to the ground and, consequently, leads to a decrease in plant regeneration (Table 3), decreasing the wildfire risk.

Conclusions

Removal of understory, which is the vegetation management practice most used in the area of study (Seia), led to lowest ($p < 0.05$) increases in pine volume. Therefore, these results point out that removal of understory vegetation, for instance to be used in biomass centrals, should be considered only if fertilizers were applied in order to avoid negative effects on pine growth. Chipping of vegetation plus fertilization led to a significant increase in volume and it was an effective method in decreasing the amount of fuel, hence in decreasing pine forest flammability. Vegetation management changed understory composition. Shrub removal, besides allowing the appearance of new herbaceous species, increased the growth of herbaceous already present.

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